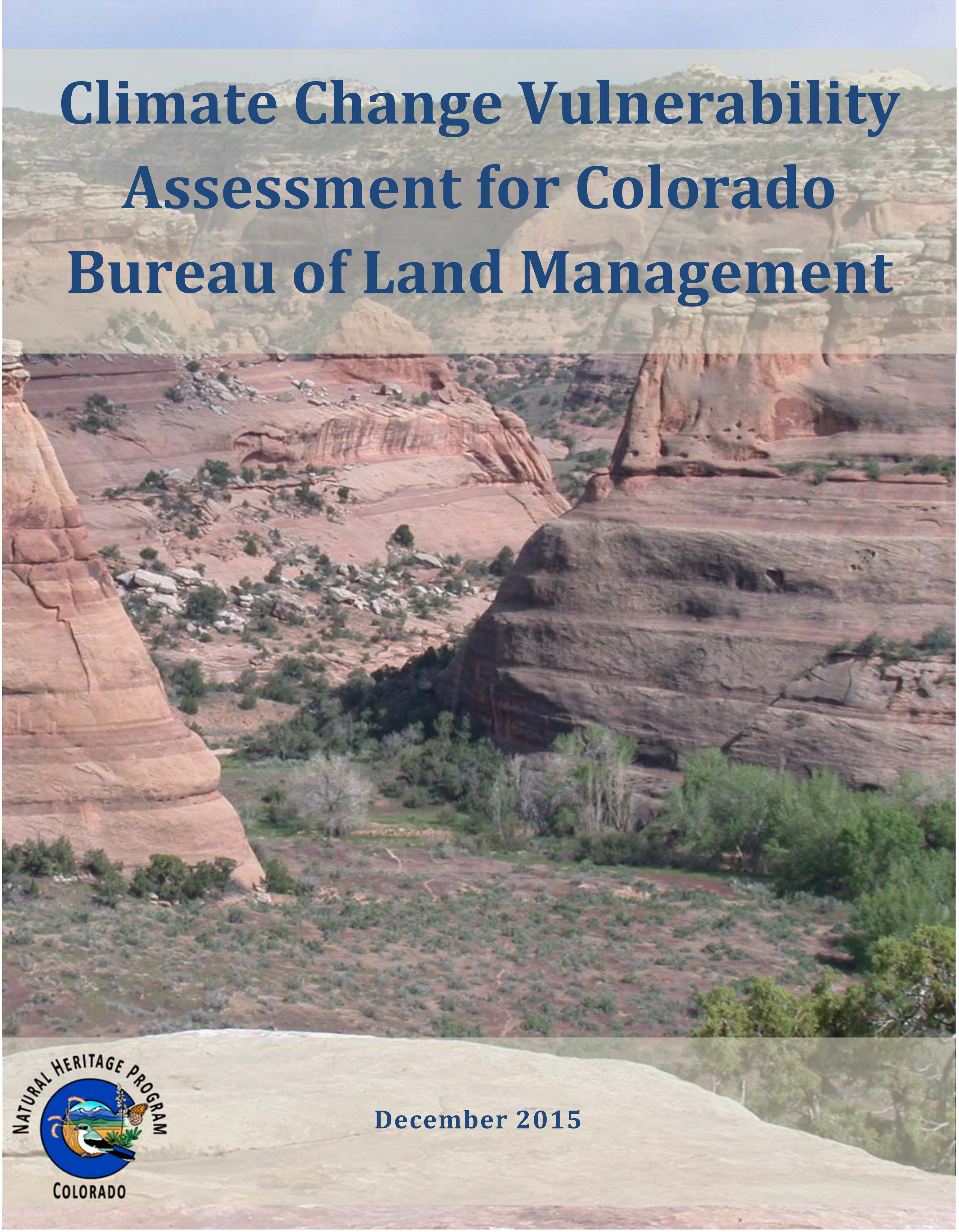
# Climate Change Vulnerability Assessment for Colorado Bureau of Land Management



NATURAL HERITAGE PROGRAM
COLORADO

December 2015

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Front cover: Knowles Canyon, photo © Peggy Lyon.

# Climate Change Vulnerability Assessment for Colorado Bureau of Land Management

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# EXECUTIVE SUMMARY

The Colorado office of the Bureau of Land Management (BLM), which administers 8.4 million acres of Colorado's surface acres, and more than 29 million acres of sub-surface mineral estate, has been charged with developing a climate adaptation strategy for BLM lands within the state. The assessments presented herein present a statewide perspective on the potential future influences of a changing climate on species and ecosystems of particular importance to the BLM, with the goal of facilitating development of the best possible climate adaptation strategies to meet future conditions.

The Colorado Natural Heritage Program conducted climate change vulnerability assessments of plant and animal species, and terrestrial and freshwater ecosystems ("targets") within a time frame of mid-21st century. Our assessments 1) evaluate the potential impact of future climate conditions on both species and ecosystems by identifying the degree of change expected between current and future climate conditions within the Colorado range of the target, and 2) address the potential impact of non-climate factors that can affect the resilience of the target to climate change, or which are likely to have a greater impact due to climate change. Climate change vulnerability assessments are not an end unto themselves, but are intended to help BLM managers identify areas where action may mitigate the effects of climate change, recognize potential novel conditions that may require additional analysis, and characterize uncertainties inherent in the process.

## Ecosystems

Sixteen terrestrial ecosystem types and six freshwater ecosystem groups were assessed under a high radiative forcing scenario (RCP8.5) for their relative vulnerability by mid-century. Terrestrial types included six forest or woodland types, four shrubland types, four herbaceous or grassland types, and riparian and wetland areas. Four terrestrial types (pinyon-juniper woodland, shortgrass prairie, and riparian and wetland areas of the eastern plains) were ranked with high vulnerability, and a single type (riparian woodland and shrubland of lower elevation west slope areas) was ranked with very high vulnerability. Most terrestrial ecosystems were ranked with low or moderate vulnerability to the effects of climate change by mid-century.

The majority of terrestrial ecosystems were evaluated as currently having low to moderate resilience to climate impacts. Actions that increase ecosystem resilience and enhance the adaptive capacity of these targets will cushion their vulnerability to changing climate conditions, and should be a primary focus of management efforts. For forest and woodland ecosystems, adaptation actions are likely to focus on disturbance factors such as fire and insect outbreak, while for shrubland and herbaceous ecosystems, reducing the impacts of anthropogenic fragmentation and disturbance is central to adaptation management.

Freshwater ecosystems (streams, rivers, lakes, and reservoirs) were evaluated in relation to a modeled transition zone between warm and cool- to cold-water habitats that compared current

reach extent in each zone to what could be expected under warmer future conditions. Results were summarized by three regions (eastern plains, mountain, and western valleys). Overall vulnerability of freshwater ecosystems was noticeably higher than for terrestrial types. Four of the evaluated freshwater ecosystems, primarily those of lower elevations, had vulnerability ranks of high or very high. Only streams of higher elevations were considered to have low vulnerability.

Nearly all freshwater ecosystems have moderate to high exposure to potential impacts from climate change, and generally moderate levels of resilience or adaptive capacity. As a result, most of these types will remain moderately vulnerable at best, even under conditions of improved resilience. Actions that maintain or increase hydrologic connectivity and reduce non-climate impacts are the primary means by which adaptive capacity in freshwater ecosystems can be maintained or increased.

## Species

Ninety-eight species (36 animals and 62 plants) were evaluated for vulnerability by mid-century using the NatureServe Climate Change Vulnerability Index, under a high cumulative carbon emission scenario (SRES A2).

Animal species included four amphibians, thirteen birds, nine fish, one insect, six mammals, and three reptiles. Five species were ranked as extremely vulnerable to climate change. Overall, 42% of the evaluated animal species were ranked with high to extreme vulnerability to climate change by mid-century. Fish, in particular, were ranked on the high to extremely vulnerable end of the range; other taxonomic groups were generally more evenly distributed between presumed stable to highly vulnerable.

Nearly all of the vascular plant species (59 of 62) evaluated were ranked with extremely high vulnerability to climate change by mid-century, generally due to their highly restricted distributions, natural barriers to movement and relatively limited dispersal ability and/or pollinator specificity. Restriction to a particular physiological hydrological niche, or to uncommon geologic features and substrates also tend to increase the vulnerability of most of Colorado's rare plants.

## Conclusions

The climate change vulnerability assessments presented herein provide a basic foundation for the development of adaptation strategies going forward. Together with clearly articulated goals and objectives for the conservation of important BLM-managed resources, the information included in these assessments highlighting the potential impacts of climate change and species- or ecosystem-specific key vulnerabilities can be linked to specific management actions that are intended to address changing climate conditions.

It is important to recognize that species assemblages are very likely to change from what has been seen in the historic past, so that the investigation of shifting distributions, altered ecological functions, and critical thresholds that are tied to a warming climate will provide essential tools for adaptation strategies.

Because earlier action allows for greater impact and influence on management challenges both now and in the future, we suggest:

- Use of structured decision making techniques to focus and clarify BLM goals and objectives for climate change adaptation targets
- Moving ahead with the development of adaptation strategies for key species and ecosystems
- Prioritizing adaptation efforts for species and ecosystems, taking into consideration both the vulnerability level of the target, practical criteria of time and resource availability, and trade-offs or constraints that may be present
- Developing and implementing methods for monitoring or measuring the results of adaptation actions
- Potentially revisiting climate change vulnerability rankings as new information becomes available or additional concerns become apparent.

# ACKNOWLEDGEMENTS

The authors would like to acknowledge the generous support of the Bureau of Land Management Colorado Office, who provided funding for this effort. We thank the BLM staff who shared their extensive professional experience and knowledge throughout the process. Bruce Rittenhouse (Branch Chief, Natural Resources), Jay Thompson (Fishery Biologist), and Carol Dawson (Botanist) acted as coordinating liaisons for the project. Additional BLM personnel who participated in the review process include Robin Sell (Wildlife Biologist), and BLM interns Phil Krening and Colleen Sullivan.

Megan Friggens (Research Ecologist) with the USDA Forest Service Grassland, Shrubland and Desert Ecosystems Program of the Rocky Mountain Research Station provided valuable review and input regarding the resilience rankings of forest and woodland ecosystems, as well as review of the document as a whole.

We continue to appreciate the help of Jeff Morisette and the North Central Climate Science Center staff, especially Colin and Marian Talbert, who provided us with essential technical tools for accessing and using climate projections. Shannon McNeely of the NCCSC also provided feedback on the preliminary results of the assessment.

Finally, at CNHP, Joanna Lemly provided critical review and information about wetland and riparian habitats, and Renée Rondeau provided advice and review throughout the project. Thank you all.

# Table of Contents

# 1 INTRODUCTION

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## List of Figures and Tables

# BACKGROUND

The Colorado office of the Bureau of Land Management (BLM) has been charged with developing a climate adaptation strategy for BLM lands within the state. In order to ensure the best possible adaptation strategies, a statewide perspective on the potential future influences of a changing climate on species and habitats is needed. To assist the BLM in this effort, the Colorado Natural Heritage Program (CNHP) conducted a climate change vulnerability assessment for priority species and ecosystems within a time frame of mid-21st century.

The vulnerability assessment is intended to be part of a dynamic, iterative, multi-scale process that will focus management actions on strategies that are effective under both current and future climates. The components of vulnerability were described by Glick et al. (2011) and consist of projected exposure to climate change, sensitivity of the species or ecosystem to expected changes, and the adaptive capacity of the species or ecosystem to respond to changes (Figure 1.1). Although this diagram is straightforward and conceptually simple, the individual components of exposure, sensitivity, and adaptive capacity can be difficult to calculate with any precision. Uncertainty comes from both the degree of variation in the many climate projection models, and from the gaps in our knowledge of the target species or habitat. In addressing these components, we hope to identify which ecosystems are most or least vulnerable to climate change as well as the type and spatial pattern of the most significant impacts. This information is expected to help land managers identify areas where action may mitigate the effects of climate change, recognize potential novel conditions that may require additional analysis, and characterize uncertainties inherent in the process.

Our assessment is aligned with existing and ongoing vulnerability assessments for Colorado species and habitats to maximize the efficiency and effectiveness of our work, leverage data development, share lessons learned, and coordinate expert input and interpretation. These include the Gunnison Basin Climate Working Group, San Juan Climate Initiative, the State Wildlife Action Plan revision and climate change vulnerability assessment, and the Colorado Rare Plant Conservation Initiative. This analysis is based on a relatively short temporal scale (i.e., suited to agency planning horizons and attentive to uncertainty levels in projected climate models) and the use of a limited but representative set of potential change scenarios.

Our objectives were to:

1. Identify plant and animal species, and terrestrial and freshwater ecosystems of importance to BLM management as targets of our analysis.
2. Evaluate the potential impact of future climate conditions on both species and ecosystems by identifying the degree of climate change expected between current and future conditions within the Colorado range of the target, and incorporating scientifically documented information on species or ecosystems response to climatic factors.
3. Evaluate the potential impact of non-climate factors particular to each target that can affect the resilience of the target to climate change, or which are likely to have a greater impact due to climate change.
4. Produce summary vulnerability rankings for priority species and ecosystems.

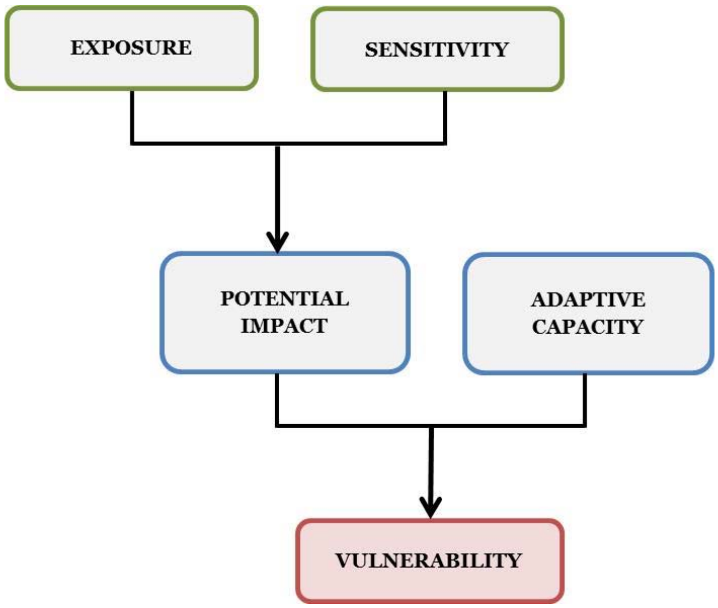


**Figure 1.1**. Components of vulnerability (Glick et al. 2011).

## Study area

### Overview

Colorado's boundaries encompass some 66.6 million acres, or over 104,000 square miles. Within this area, the type and extent of natural vegetation is determined by many factors, including elevation, climate, soils, disturbance patterns, and the ecological history of the landscape. Colorado spans the continental divide amid the highest peaks of the Southern Rocky Mountains. As a result, the state's topology is complex. To the east of the continental divide, the eastern plains rise gently at the rate of about 10 feet per mile from elevations of 3,350-3,650 feet at the state's eastern edge. Although they appear comparatively flat, Colorado's eastern plains boast little-known dramatic river canyons, shale outcrops forming buttes and scarps, sandy stabilized dune fields, and basalt-capped mesas that are local landmarks in the eastern counties. At elevations of 5,500 to 6,000 feet near the mountain front, the plains transition fairly abruptly to foothills and mesas that, in turn, quickly rise to montane elevations. The central portion of the state is dominated by the peaks and ranges of the Southern Rocky Mountains. Here, a series of mountain ranges trending generally north-south bound a string of high mountain valleys or parks, and include more than fifty peaks reaching elevations of 14,000 feet or more. To the west, more mountains and extensive plateaus, heavily dissected by ravines and canyons, form the characteristic valley and plateau western slope landscape. Near the western border of the state elevations decrease again, reaching a low of about 4,325 feet where the Colorado River crosses the border with Utah.

## General climate

Colorado's position at the high point of the continent means that several different weather patterns influence the climate of the state, and hence its vegetation. In general, higher elevations have cooler temperatures and receive more precipitation, although local topography has a significant effect on air movements controlling these factors. Moisture may reach the state from either the Pacific Ocean or the Gulf of Mexico, depending on current air circulation. Storms originating to the west of the state drop much of their moisture as rain or snow on the mountains and western-facing slopes; a rain-shadow effect prevents most of this precipitation from reaching the eastern plains. The western part of Colorado receives most of its yearly precipitation during winter months. Moisture from the Gulf of Mexico can produce heavy precipitation on the eastern slope of the divide, especially in spring and summer, and the plains receive the majority of their annual precipitation during the growing season. Southern portions of the state generally receive mid- to late-summer precipitation as the margin of the North American Monsoon moves north.

## Geology and soils

The landscape we see today is the product of both past and ongoing geologic processes. The effects of continental drift, geologic uplifts, volcanic eruption, and erosion have resulted in a highly complex arrangement of rock and soil types that provide a substrate for Colorado's native vegetation. Colorado's eastern plains are dominated by soils derived from Tertiary (2-65 mya) and Cretaceous (65-140 mya) sedimentary formations, shaped by the action of flowing water and wind. In the central portion of the state, the Colorado Rocky Mountains are formed of igneous and metamorphic rock that is thrust up through the sedimentary layers to the east and west. Here soils are generally less well developed, except in low-lying areas, where erosion has deposited substantial soil material. The western plateaus and valleys are also primarily formed in Tertiary and Cretaceous substrates, and many soils have high concentrations of salts and minerals that inhibit plant growth. In combination with climate factors, soils are a good indicator of which type of vegetation will dominate the landscape in a particular area.

## Land ownership

Ownership patterns reflect the land use history of the state, and, together with management practices are an important factor in determining the conservation status of Colorado's landscape. Arable lands, especially on the eastern plains and along river drainages, are primarily in private ownership. Colorado's mining history has left a legacy of private inholdings within extensive tracts of public land. Lower elevation lands on the west slope used primarily for grazing, mining, oil and gas extraction, and recreation are generally administered by the Bureau of Land Management. Higher elevation (mostly forested) parts of the state are largely under the administration of the U.S. Forest Service, while National Grasslands administered by the U.S. Forest Service in eastern Colorado were formed from farmland reclaimed from the ravages of the Dust Bowl days. The distribution of state-owned land still reflects the school land grant included in the 1875 Enabling Act for the Territory of Colorado, which provided that two sections of every township (usually sections 16 and 36) be granted for the support of public schools.

About 57% of the state's surface acres are privately owned, with the remainder in federal, state, local government, or tribal ownership. Federal public lands account for a little over 36% of Colorado acreage. The BLM administers 8.4 million acres (13%) of Colorado's surface acres, as well as over 29 million acres of sub-surface mineral estate. Other federal lands in Colorado are administered U.S. Forest Service (22% of state acreage), National Park Service (1%), and other federal agencies including the U.S. Fish and Wildlife Service, Bureau of Reclamation, and Department of Defense (<1%). The State of Colorado owns nearly 5% of the acreage, and also holds about a million acres of sub-surface mineral estate on lands in other ownership. Tribal lands account for about 1% of Colorado's acreage, and the remainder is owned by governments at the county and city level.

## Human influence on the landscape

In addition to natural disturbance processes such as fire, wind, and flooding, the effects of human activities have also changed patterns of disturbance in Colorado. The settlement history of Colorado has resulted in a pattern of land ownership where public lands are a significant part of the landscape.

### *Development*

Although industrial, urban, suburban, and exurban development in Colorado are generally not occurring on public lands, these activities are a source of potential disturbance to adjacent areas. Colorado's total population of over 5 million is largely concentrated in the Front Range corridor from Pueblo north to Fort Collins where 11 counties account for 83% of the state's population. Larger cities outside this area include Grand Junction, Montrose, and Durango. A network of highways, roads, and other transportation corridors, together with utility right-of-ways of various types connects populated places large and small throughout the state. In spite of the state's increasing population, and patchwork of private and public lands, more than 75% of Colorado's landscape remains covered by natural vegetation, especially in higher elevation areas.

### *Resource Extraction and Energy Development*

Mining for coal, gold, gypsum, limestone, silver, molybdenum, soda ash, sodium bicarbonate, sand, gravel, and crushed stone, as well as the extraction of petroleum and natural gas, have had a significant role in shaping Colorado's landscape. Energy development is a significant and expanding activity in Colorado, especially in the natural gas and oil-rich areas of the northern Front Range and western slope. Beginning in the 1860s, coal and petroleum were the first energy resources to be developed in Colorado. Together with natural gas and oil shale, these fossil fuels have historically constituted the majority of energy development in the state. The BLM administers mineral leasing for all federal lands in Colorado where such rights have not been withdrawn, as well as for split-estate federal mineral rights under non-Federal lands. As part of its trust responsibility, the BLM also oversees mineral operations on tribal lands.

Renewable energy facilities have not been developed on BLM lands. Colorado currently has over 1,500 wind turbines in operation, primarily on the eastern plains. Concentrated solar energy facilities are also being developed in several areas of the state. However, with the projected future growth of these industries, Colorado can expect to see an increase in transmission line construction that may involve BLM administered lands.

### *Agriculture*

The original grasslands of Colorado's eastern plains were home to large numbers of grazing animals including deer, pronghorn, elk and bison. With European settlement, these native grazers were largely replaced by domestic livestock. Large-scale grazing began in the 1860s, and quickly expanded as railroads provided access to eastern markets. Both the Bureau of Land Management and the U.S. Forest Service issue grazing permits for public lands in Colorado, and state-owned lands may also be leased for grazing. Cattle and associated products form the largest portion of Colorado's agricultural cash receipts, followed by field crops (USDA NASS 2015). Around 1900, crop farming began to expand in the state, with wheat and corn as the primary products. Although periodic droughts have repeatedly dealt hard blows to farming and ranching in Colorado, these land uses still make an important contribution to the state's economy, and have had an undeniable effect on the arrangement and condition of Colorado's natural vegetation.

BLM-administered Colorado rangeland is subject to grazing use by permitted livestock operators. About 2,500 grazing allotments are managed by permits or leases that specify the kind and number of livestock, season of use, and amount of use permitted each grazing year. Permits or leases are subject to compliance review and public scoping prior to renewal.

### *Recreation and Conservation*

In recent decades, recreation has become an increasingly important part of land use in Colorado. From National Parks to local open space lands, increasing numbers of residents and visitors are drawn to a variety of outdoor activities such as hiking, camping, winter sports, hunting, fishing, and off-road vehicle use. Paradoxically, recreation on Colorado's public lands can contribute to both its conservation and its degradation.

Although the BLM manages public lands for recreation, the agency is also responsible for preservation of the environment, wildlife and archaeological and paleontological resources; sustainable natural resource extraction; the visual appeal of public lands; and considering socioeconomic impacts of management decisions. The BLM's approximately one million acres of National Conservation Lands in Colorado include two national monuments, three national conservation areas, five wilderness areas, 53 wilderness study areas, as well as National Historic and Scenic Trails. The BLM also a manages a number of Areas of Critical Environmental Concern for scientific, scenic, ecological, biological, geological, historical and prehistoric values for public benefit.

# CLIMATE CHANGE VULNERABILITY ASSESSMENT

## Uncertainty in climate change vulnerability assessment

The increasing number of climate change vulnerability assessments tends to indicate that many entities regard the reality of climate change with a high level of certainty. However, there are a number of sources that introduce uncertainty of varying degree into these assessments. Frequently acknowledged sources of uncertainty or variation in projected outcomes are the modeled components of climate change analysis: the global circulation models, hydrologic models, species response models, and so on. With all projections of future climate conditions we cannot know with absolute certainty which, if any, will turn out to be true. Downscaling these models does not remove inherent uncertainty.

Uncertainty in the context of climate change is not equivalent to complete lack of knowledge. Current climate models represent the best available science, yet do not all agree. In general, climate models are understood to have higher levels of certainty about global temperature responses to forcing factors than they do for precipitation response. Both the direction of response (increase or decrease) and the magnitude (degrees, inches, etc.) of response of climate factors are variable among climate models. Currently, consensus about the direction of temperature change (increasing) is greater than for precipitation. The magnitude of expected change for both factors is uncertain.

## Comparing the vulnerability of ecosystems and species

Although we have estimated the vulnerability to climate change of both ecosystems and the species that inhabit them in the following chapters, there are differences of both method and scale between these assessments.

For ecosystems, exposure and sensitivity were combined into a single metric that was paired with a resilience-adaptive capacity metric in a scoring matrix to produce an overall vulnerability rank. Species were assessed using the NatureServe Climate Change Vulnerability Index method (Young et al. 2015), which treats exposure as a modifier of sensitivity and adaptive capacity (i.e., low exposure discounts sensitivity/adaptive capacity factors, and high exposure amplifies those factors).

Ecosystems were assessed using the representative concentration pathway (RCP8.5) emissions scenario method of the IPCC Fifth Assessment Report, while both animal and plant species were assessed under A2 scenario of the Special Report on Emissions Scenarios (SRES) standards employed in two previous IPCC reports. This difference is due to the use of the NatureServe CCVI, which is based on the earlier methodology, for species only. For the mid-century time-frame of our assessment, the SRES A2 scenario projects CO2 concentration levels and temperature increases that are slightly lower on average than those projected by the RCP8.5 scenario. However, the two scenarios are approximately equivalent in that they are based on similar underlying assumptions about future demographic and economic trends, and are generally regarded as "worst-case" scenarios. Neither scenario is considered 'better' than the other by the climate science community.

In addition, the correlation of plant and animal species with a single ecosystem is rare, especially for mobile animal species. Because of this variability, and also because of differences in scale between individual organism life-cycle factors and landscape level processes, it is possible for the vulnerability of a particular species to be different from that of its primary ecosystem.

## Previous vulnerability assessments in the Colorado region

Prior to the effort reported herein, a number of studies have evaluated vulnerability to changing climatic conditions in and around Colorado (Table 1.1). Additional reports not included in Table 1.1 have also addressed the vulnerability to climate change of a variety of socio-economic elements. The listed studies employed an assortment of qualitative and quantitative approaches; a number do not explicitly address individual habitats or species. Furthermore, spatial scales of listed assessments differ by one to three orders of magnitude. An element that is considered highly vulnerable to extinction in a small area may have significantly reduced vulnerability in other portions of its range. Consequently, a comparison of vulnerability ranking results across these efforts is problematic. Nevertheless, a few general trends are evident across vulnerability assessments. Species and habitats of higher elevations are usually considered more vulnerable than those of mid-elevation areas. Species and habitats that are extremely closely associated with water resources are generally expected to have higher vulnerability than those in more xeric conditions. Agreement about vulnerability for some dry mid-to-lower elevation habitats is poor. For instance, pinyon-juniper woodlands and sagebrush shrublands have received rankings ranging from Highly Vulnerable to Likely to Increase, depending on the scale, location, and method of assessment. This disagreement illustrates the importance of attention to scale and time-frame in the development of management goals and objectives for climate adaptation planning, and highlights areas where additional research to address well-formulated questions may be needed.

**Table 1.1**. Summary of climate change vulnerability assessments in the Colorado region that have addressed habitats or species.

| **Full Citation** | **Area** | **Habitats** | **Species** | **Target Time Frame & Emissions Scenario** | **Methodology** | **Vulnerability Ranking** (see code key below) |
|---|---|---|---|---|---|---|
| Brown et al. 2008. Climate Change in Rocky Mountain National Park. http://www.nps.gov/romo/parkmgmt/upload/climate_change_rocky_mountain2.pdf | Rocky Mtn. National Park | Wetlands, lakes & streams, montane, subalpine, alpine | ---- | None given | Qualitative (workshop narrative synthesis) | No rankings |
| Ray, A.J., J.J. Barsugli, and K.B. Averyt. 2008. Climate change in Colorado: A synthesis to support water resources management and adaptation. Report for Colorado Water Conservation Board. Western Water Assessment http://wwa.colorado.edu/publications/reports/WWA_ClimateChangeColoradoReport_2008.pdf | Statewide | Water resources, no individual habitats explicitly addressed | ---- | Mid-century. CMIP3 B1, A1B, A2 ensembles | Qualitative (narrative synthesis) | No rankings |
| Reiman, B.E. and D.J. Isaak. 2010. Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: Implications and alternatives for management. General Technical Report RMRS-GTR-250. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, CO. http://www.fs.fed.us/rm/pubs/rmrs_gtr250.pdf | Western Colorado, as part of Rocky Mtn. west | Stream environments, including riparian | Native fishes | None given | Qualitative (narrative synthesis) | No rankings - habitat loss or gain. |
| Colorado Natural Heritage Program for Rare Plant Conservation Initiative. 2011. Colorado Wildlife Action Plan: proposed rare plant addendum. Lee Grunau, Jill Handwerk, and Susan Spackman-Panjabi, eds. Colorado Natural Heritage Program, Colorado State University, Fort Collins, CO. http://www.cnhp.colostate.edu/download/documents/2011/rareplant_SWAP_final_june_30_2011_formattedv2.pdf | Statewide | ---- | 121 G1 and G2 plants | Mid-century. A2 | Quantitative (NatureServe CCVI) | EV/HV/MV/PS/IL/IE |

| Full Citation | Area | Habitats | Species | Target Time Frame & Emissions Scenario | Methodology | Vulnerability Ranking (see code key below) |
|---|---|---|---|---|---|---|
| Neely, B., R. Rondeau, J. Sanderson, C. Pague, B. Kuhn, J. Siemers, L. Grunau, J. Robertson, P. McCarthy, J. Barsugli, T. Schulz, and C. Knapp, Eds. 2011. Gunnison Basin: Vulnerability Assessment for the Gunnison Climate Working Group by The Nature Conservancy, Colorado Natural Heritage Program, Western Water Assessment, University of Colorado, Boulder, and University of Alaska, Fairbanks. Project of the Southwest Climate Change Initiative. http://wwa.colorado.edu/publications/reports/TNC-CNHP-WWA-UAF_GunnisonClimChangeVulnAssess_Report_2012.pdf | Gunnison Basin | 17 terrestrial ecosystems and 7 freshwater | 73 species of conservation concern | Mid-century. CMIP3 A2 - Barsugli and Mearns 2010 projected climate scenarios. | Qualitative (Manomet-MADFW, expert opinion), quantitative (NatureServe CCVI) | Uplands: EV/HV/MV/PS/SI. MI/GI/U Riparian: H/M/L Species: EV/HV/MV/PS/IL /IE |
| Nydick, K., Crawford, J., Bidwell, M., Livensperger, C., Rangwala, I., and Cozetto, K. 2012. Climate Change Assessment for the San Juan Mountain Regions, Southwestern Colorado, USA: A Review of Scientific Research. Prepared by Mountain Studies Institute in cooperation with USDA San Juan National Forest Service and USDOI Bureau of Land Management Tres Rios Field Office. Durango, CO. http://www.mountainstudies.org/s/ClimateResearchReview_SJMs_FINAL.pdf | Southwest Colorado | Sagebrush, oak, PJ, Ponderosa, Mixed conifer, aspen, subalpine, alpine, riparian, fens & wet meadows | 7 taxonomic groups | Mid-century. NARCCAP (CMIP3 A2) | Qualitative (narrative relates to regional climate models, and synthesizes work by others) | Decrease – no or little change - increase |
| Woodbury, M., M. Baldo, D. Yates, and L. Kaatz. 2012 Joint Front Range Climate Change Vulnerability Study. Water Research Foundation and Tailored Collaboration partners. Denver, CO. http://cwcb.state.co.us/environment/climate-change/Pages/JointFrontRangeClimateChangeVulnerabilityStudy.aspx | North Central Colorado (Headwaters of South Platte, Arkansas, Colorado rivers) | Streams | ---- | 2040 and 2070. Selected CMIP3 A2 ensembles | Quantitative (models) | No rankings |
| USDA Forest Service, Region 2. UNPUBLISHED. CCVAs for selected habitats. | | | | | | |
| Decker, K. and R. Rondeau. 2014. San Juan / Tres Rios Climate Change Ecosystem Vulnerability Assessment. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. http://www.cnhp.colostate.edu/download/documents/2014/SJRA_ecological_systems_vulnerability_analysis_FINAL.pdf | Southwest Colorado (San Juan / Tres Rios management area) | 14 upland and 3 wetland/ riparian ecosystems | ---- | Mid-century. Suite of CMIP5 RCP4.5 & 8.5 models - 3 scenarios – Rangwala 2012 | Qualitative (modified Manomet-MADFW, expert opinion and narrative synthesis) | EV/HV/MV/PS/SI /MI/GI/U |

| Full Citation | Area | Habitats | Species | Target Time Frame & Emissions Scenario | Methodology | Vulnerability Ranking (see code key below) |
|---|---|---|---|---|---|---|
| Handwerk, J., B. Kuhn, R. Rondeau, and L. Grunau. 2014. Climate Change Vulnerability Assessment for Rare Plants of the San Juan Region of Colorado. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. http://www.cnhp.colostate.edu/download/documents/2014/SanJuan_CCVI_Final_Report.pdf | Southwest Colorado (San Juan / Tres Rios management area) | ---- | 60 rare plant spp. | Mid-century. CMIP3 A2 | Quantitative (NatureServe CCVI) | EV/HV/MV/PS/IL/IE |
| Lukas, J., J. Barsugli, N. Doesken, I. Rangwala, K. Wolter. 2014. Climate change in Colorado: A synthesis to support water resources management and adaptation, 2nd edition. A report for the Colorado Water Conservation Board. Western Water Assessment, Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder. http://cwcbweblink.state.co.us/WebLink/0/doc/191995/Electronic.aspx?searchid=e3c463e8-569c-4359-8ddd-ed50e755d3b7 | Statewide, and specific subregions | Water resources, no individual habitats explicitly addressed | ---- | Mid-century. CMIP3 and CMIP5, pooled RCPs (4.5 & 8.5 discussed) | Qualitative (narrative synthesis) | No rankings |
| Decker, K. and M. Fink. 2014. Colorado Wildlife Action Plan Enhancement: Climate change Vulnerability Assessment. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. http://www.cnhp.colostate.edu/download/documents/2014/CO_SWAP_Enhancement_CCVA.pdf | Statewide | 13 terrestrial habitats | ---- | Mid-century. BCCA CMIP5 - RCP6.0 | Quantitative (models – projected range shift) | VH/H/M/L |
| Pocewicz, A., H.E. Copeland, M.B. Grenier, D.A. Keinath, and L.M. Washkoviak. 2014. Assessing the future vulnerability of Wyoming's terrestrial wildlife species and habitats. Report prepared by The Nature Conservancy, Wyoming Game and Fish Department and Wyoming Natural Diversity Database. http://www.nature.org/media/wyoming/wyoming-wildlife-vulnerability-assessment-June-2014.pdf | Adjacent to Colorado | 11 habitat types, largely analogous to Colorado types | 131 Species of greatest conservation need | Mid-century. A2 | Quantitative (models – annual mean temperature & moisture deficit, NatureServe CCVI) | VH/H/M/L |
| Gordon, E. and D. Ojima, eds. 2015. Colorado Climate Change Vulnerability Study. A report by the University of Colorado Boulder and Colorado State University to the Colorado Energy Office. http://wwa.colorado.edu/climate/co2015vulnerability/co_vulnerability_report_2015_final.pdf | Statewide | Broad categories: Alpine, Forests, and Grasslands | ---- | Mid-century? | Qualitative (narrative synthesis) | No rankings - key vulnerabilities for broad categories |

| Full Citation | Area | Habitats | Species | Target Time Frame & Emissions Scenario | Methodology | Vulnerability Ranking (see code key below) |
|---|---|---|---|---|---|---|
| Handwerk, J., L. Grunau, and S Spackman-Panjabi, eds. Colorado Wildlife Action Plan: 2015 Rare Plant Addendum. Colorado Natural Heritage Program, Colorado State University, Fort Collins, Colorado. http://www.cnhp.colostate.edu/download/reports.aspx | Statewide | ---- | 117 G1 or G2 plants | Mid-century. CMIP3 A2 | Quantitative (NatureServe CCVI) | EV/HV/MV/PS/IL/IE |
| THIS DOCUMENT (CNHP 2015) | Statewide | 16 terrestrial habitats and 6 freshwater groups | 97 species of conservation concern | Mid-century. NEX-DCP30 – CMIP5 RCP8.5 & CMIP3 A2 | Quantitative (models – out of range conditions, NatureServe CCVI) | Ecosystems: VH/H/M/L Species: EV/HV/MV/PS/IL/IE |

| Rank | Definition |
|---|---|
| NatureServe CCVI http://www.natureserve.org/conservation-tools/climate-change-vulnerability-index (in CNHP RPCI 2011, Neely et al. 2011, Handwerk et al. 2014 & 2015, CNHP 2015) | |
| EV - Extremely Vulnerable | Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050. |
| HV - Highly Vulnerable | Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050. |
| MV - Moderately Vulnerable | Abundance and/or range extent within geographical area assessed likely to decrease by 2050. |
| PS - Presumed Stable | Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change. |
| IL - Not Vulnerable/Increase Likely | Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050. |
| IE - Insufficient Evidence | Available information about a species' vulnerability is inadequate to calculate an Index score. |
| Neely et al. (2001), Decker & Rondeau (2014) | |
| EV - Extremely Vulnerable | Ecosystem at risk of being eliminated from the area as a result of climate change. |
| HV - Highly Vulnerable | Majority of ecosystem at risk of being eliminated (i.e., >50% loss) as a result of climate change, but unlikely to be eradicated entirely. For riparian, overall loss of system is expected to be > 50% or ecological process is expected to be severely impacted, e.g., flood frequency occurs 50% less than current flooding regime. |
| MV - Moderately Vulnerable | Extent of ecosystem at risk of being moderately reduced (<50% loss) as a result of climate change. For riparian, overall loss of system is expected to be > 50% or ecological process is expected to be severely impacted, e.g., flood frequency occurs 50% less than current flooding regime. |
| LV - Low Vulnerability | For riparian only, 0 to 10% loss of area and condition of system remains stable. |
| PS - Presumed Stable | Extent of ecosystem approximately the same, but there are significant pattern or condition changes within the area. |
| SI - Slight Increase | Ecosystem may become established within the basin from areas outside. |
| MI - Moderate Increase | Extent of ecosystem may expand moderately (<50% gain) as a result of climate change. |

| Rank | Definition |
|---|---|
| GI - Greatly Increase | Ecosystem may expand greatly (>50% gain) as a result of climate change. |
| U - Unknown | Vulnerability of ecosystem under climate change is uncertain |
| Decker & Fink (2014), CNHP (2015) | |
| VH - Very High Vulnerability | Habitats/ecosystems have high vulnerability to climate change when exposure and sensitivity are high, and adaptive capacity and resilience are low. Transformation of the habitat/ecosystem is most likely to occur in upcoming decades. |
| HV - Highly Vulnerable | High vulnerability to climate change results from combining either high or moderate exposure-sensitivity with low or medium adaptive capacity-resilience. Under either combination, climate change is likely to have noticeable impact. |
| MV - Moderately Vulnerable | Moderate vulnerability to climate change results from a variety of combinations for exposure-sensitivity and adaptive capacity-resilience. The number of possible combinations indicates a degree of uncertainty in the vulnerability ranking. Under circumstances where the two factors are essentially balanced, vulnerability is thought to be reduced, but still of concern. |
| LV - Low Vulnerability | Low vulnerability to climate change occurs when a habitat combines low exposure and sensitivity with high or moderate adaptive capacity and resilience. For these habitats/ecosystems climate change stress and its effects are expected to be least severe or absent. |

## Climate change in Colorado

Annual average temperatures across Colorado have increased by 2.0°F over the past 30 years (Figure 1.2a). Warmer temperatures are evident for all seasons, and daily high and low temperatures have also increased (Lukas et al. 2014). In contrast, over the period of record, there are no comparable trends in average annual precipitation in Colorado (Figure 1.2b), although snowpack levels have been generally below average since 2000. The decrease in snowpack, along with warming spring temperatures and the effects of increased dust-on-snow have combined to shift the timing of snowmelt and peak runoff from 1-4 weeks earlier (Lukas et al. 2014). Flowering dates for some plant species are over a month earlier than they were a century ago (Munson and Sher 2015). Drought conditions as measured by the Palmer Drought Severity Index also reflect warming temperatures and the recent period of below average precipitiation (Figure 1.2c). Reconstructions of droughts in western North America show a number of droughts prior to the instrumental record that were more severe and longer lasting than the worst droughts of the past century (Woodhouse 2004, Stahle et al. 2007, Routson et al. 2011), which illustrates the relatively narrow view of variability provided by the historical record. Both historic and pre-instrumental-record droughts have had notable effects on vegetation patterns, and have severely impacted patterns of human habitation and social interaction (Woodhouse 2004, Benson et al. 2007). The possibility of future droughts that greatly exceed the most severe droughts of the past millenia can not be excluded (Cook et al. 2015).

Projections based on 17 models (NASA Earth Exchange Downscaled 30 Arc-Second CMIP5 Climate Projections dataset for the conterminous U.S., Thrasher et al. 2013), run under RCP8.5 and RCP4.5 for the 30-year period centered on 2050 indicate that all areas of Colorado will experience some degree of warming, and potentially changes in precipitation as well. Temperature change projections are regarded as more certain (Barsugli pers. comm.), and there is general agreement that conditions have already warmed to some degree (Lukas et al. 2014); uncertainty for temperature change is greater regarding the magnitude of the projected change. In combination with expected changes in temperature, however, even a wetter future may not be sufficient to maintain runoff and soil moisture conditions similar to those of the recent past. Climate projections presented here are summaries of long-term trends and do not track inter-annual variation, which will remain a source of variability, as it has been in the past. Our ecosystem analysis focused on a single representative concentration pathway (RCP 8.5) and a limited subset of available global circulation models; at this point in time we have no way of knowing if this is the scenario that will be found valid by mid-century. However, in all scenarios, changes that in the past occurred over periods of several thousand years are now projected to take place in only a hundred years.

Projected changes summarized in Figure 1.3a indicate average seasonal temperature increases of anywhere from about 3.5-5.8 °F, with mean increases of about 4.1-5.4 °F. Furthermore, minimum and maximum temperature increases are also projected for all seasons. Somewhat greater increases are projected under RCP8.5 in comparison with RCP4.5 at mid-century. Winter minimum temperatures are projected to have greater increases than winter maximum temperatures, but in all other seasons the greatest increases are projected in maximum temperatures, and the least in

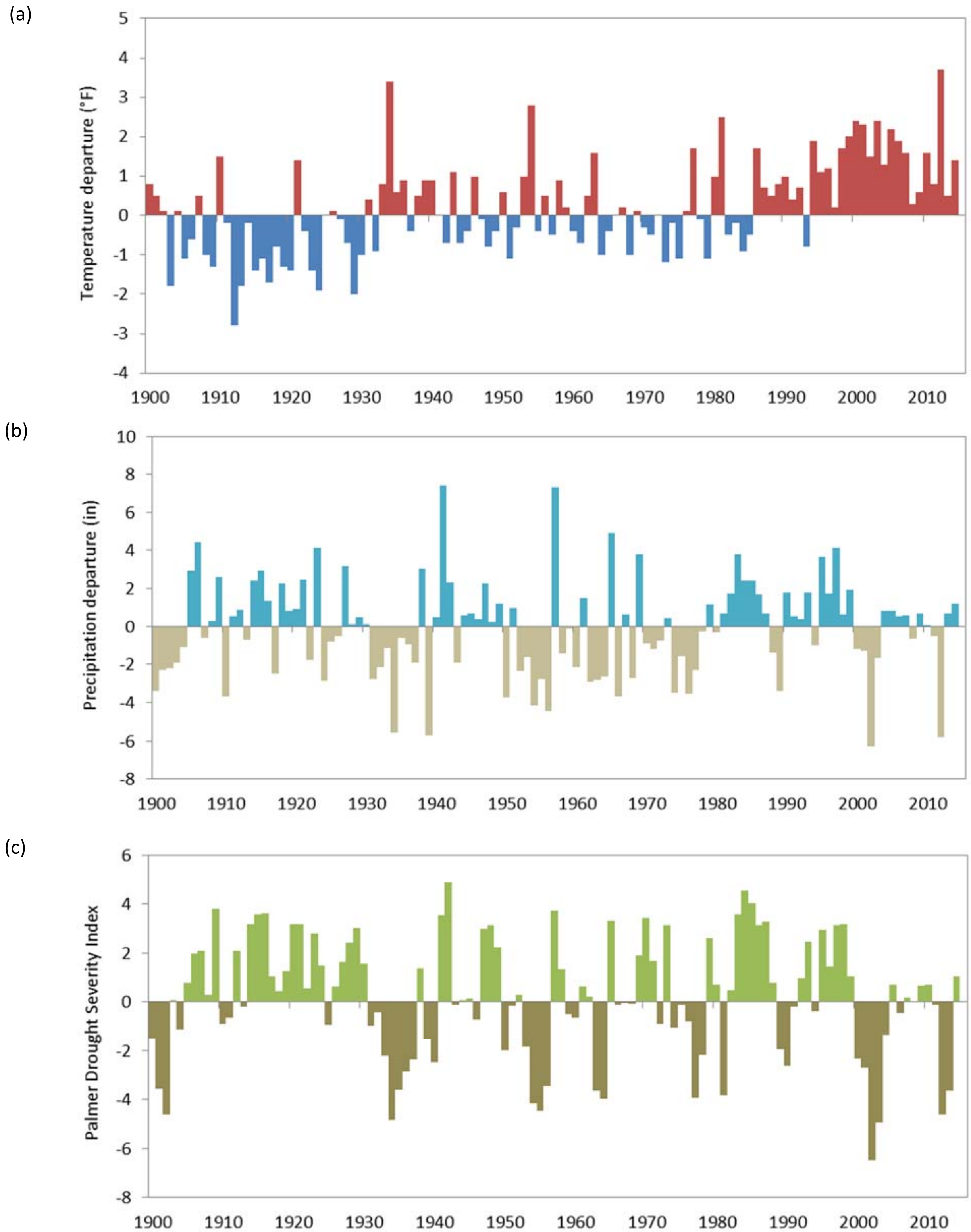


**Figure 1.2.** Historical (1990-2014) Colorado statewide trends for (a) annual mean temperature, (b) annual precipitation, and (c) Palmer Drought Severity Index. Temperature and precipitation are shown as departure from the mean of base period (1901-2000). Data are from NOAA National Centers for Environmental Information: http://www.ncdc.noaa.gov/cag/data-info.

minimum temperatures (Figure 1.3a). Ranges of projected increase for all seasons are broadly overlapping.

Mean projected precipitation changes are generally less certain than those for temperature, and may not be outside the range of historic variability, at least by mid-century. Seasonal projected percent increases in precipitation are on average greatest for winter and spring (Figure 1.3b), while summer and fall are projected to have decreased or essentially unchanged precipitation. However, ranges for growing seasons include both increased and decreased precipitation.

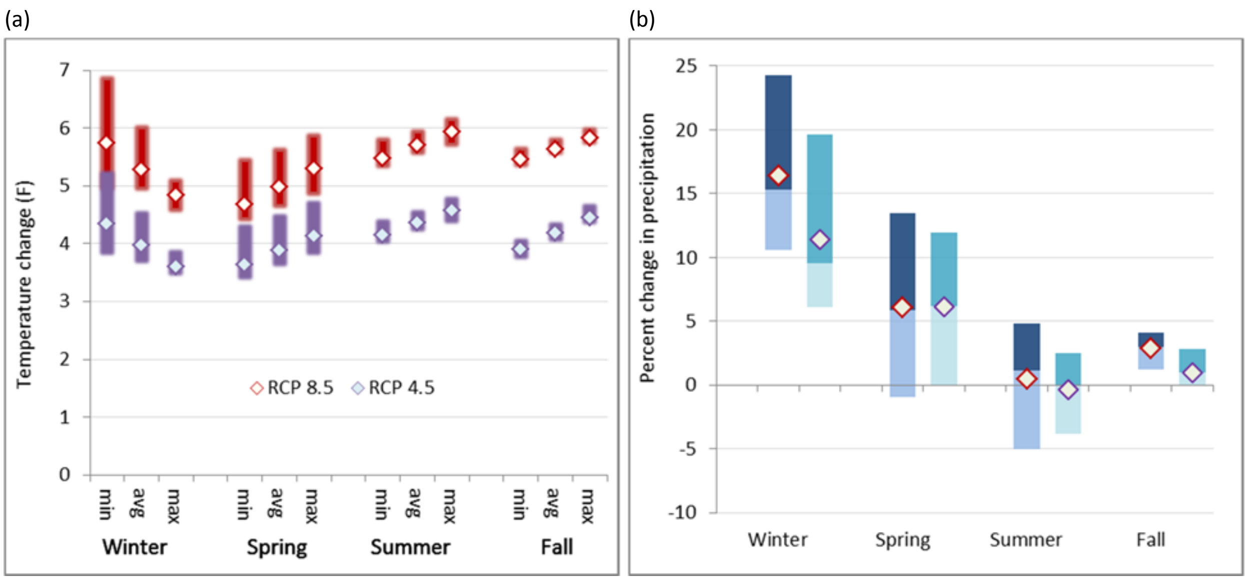


**Figure 1.3**. Seasonal projected temperature (a) and precipitation (b) changes by mid-21st century (2050; centered around 2035-2064 period) for Colorado.

For temperature (a), the bottom of each bar represents the 10th percentile, and the top of the bar is the 90th. Mean projected change is represented by open diamonds. RCP8.5 statewide projected change in average seasonal temperatures are the top (red) bars, and RCP4.5 are bottom (purple) bars. For precipitation (b), the bottom of each bar represents the 10th percentile, the middle line is the 50th, and the top of the bar is the 90th. RCP8.5 statewide projected percent change in seasonal average precipitation are the left-hand bars, and RCP4.5 are the right-hand bars. Seasons are: winter=DJF, spring=MAM, summer=JJA, and fall=SON. A temperature interval of 1°F is equal to an interval of 5⁄9 degrees Celsius. Climate scenarios used were from the NEX-DCP30 dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange, and distributed by the NASA Center for Climate Simulation (NCCS).

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# 2 ECOSYSTEMS

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# Table of Contents – 2 Ecosystems

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# TERRESTRIAL ECOSYSTEMS - METHODS

## Target selection

In consultation with BLM, CNHP identified 16 terrestrial ecosystem types or groups of interest for BLM management to be assessed (Table 2.1). Terrestrial ecosystem distribution was mapped using SWReGAP (USGS 2004) for upland ecosystems, and National Wetland Inventory mapping for riparian and wetland ecosystems (USFWS 1975-2013). The vulnerability of ecosystems was assessed under two primary headings: exposure-sensitivity, and resilience-adaptive capacity. Scores for these two factors were combined to obtain an overall vulnerability rank.

**Table 2.1.** Ecosystems assessed for vulnerability to climate change.

| Terrestrial | |
|---|---|
| **Forest and Woodland** | **Grassland or herbaceous** |
| Aspen forest | Alpine |
| Lodgepole pine forest | Montane grassland |
| Mixed conifer forest | Semi-desert grassland |
| Pinyon-Juniper woodland | Shortgrass prairie |
| Ponderosa pine forest | |
| Spruce-Fir forest | **Riparian & Wetland** |
| | Riparian woodland & shrubland - Eastern |
| **Shrubland** | Riparian woodland & shrubland - Mountain |
| Desert shrubland | Riparian woodland & shrubland - Western |
| Oak & mixed mountain shrubland | Wetlands - Eastern |
| Sagebrush shrubland | Wetlands - Mountain |
| Sandsage shrubland | Wetlands - Western |

## Terrestrial ecosystem responses to climate change

The prediction of potential plant distribution under future climate conditions is based on the ecological principle that the presence of a species on the landscape is controlled by a variety of biotic and abiotic factors, in the context of biogeographic and evolutionary history. Biotic interactions (e.g., competition, predation, parasitism, etc.) together with climate and other abiotic components act to influence the spatial arrangement of species at local, regional, and continental scales. Abiotic factors that influence ecosystem processes and species distributions include temperature, water, carbon dioxide, nutrients, and disturbance regimes (Prentice et al. 1992, Holling 1992). Water balance, or the difference between precipitation inputs and water loss in the form of evapotranspiration, runoff, and deep drainage, is a primary determinant of terrestrial vegetation distribution in the U.S. (Stephenson 1990, Nielson et al. 1992, Nielson 1995).

Because complete and accurate knowledge of driving factors and history is rarely, if ever, available, we rely on correlative models that relate observed species distribution with past and recent levels of climatic variables. The predictive process is further constrained by our inability to measure such variables accurately on a continuous spatial or temporal scale. As a result, modeling variables are usually an approximation of the environmental factors that control species distribution, using available data that are likely only surrogates for the actual controlling factors. Furthermore, because the rate of vegetation response to environmental shifts is likely to be lower than the rate of climate change itself, and because relic trees may remain for decades, predictive models are more useful in identifying the future location of suitable habitat for a species than in predicting the actual ground cover at a specific time in a particular location. Finally, although we can estimate the climatic requirements of a given species, and extrapolate from that estimate the eventual distribution of an ecosystem, it is more difficult to predict vegetation dynamics that are the result of disturbance events or ecological processes (e.g., drought, fire, snowmelt, herbivory, insect outbreaks, etc.). These factors are addressed narratively, and evaluated through expert elicitation. Because of these limitations, we looked at degree of change of climatic variables over an ecosystem's current range as a measure of exposure to climate change, rather than attempt to predict overall changes in distribution.

## Exposure and sensitivity assessment – terrestrial ecosystems

We used spatial analysis methods to evaluate the exposure and sensitivity to climate change for each ecosystem. We used ensemble averages of 800 m NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30) for the Continental US. These averages are based on 34 models developed for the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5). Individual models are listed in Appendix A.

There is general agreement that temperatures throughout Colorado are projected to increase. Precipitation models are much more variable, and, on average tend to show increasing precipitation for most of Colorado. However, hydrologic modeling for the Colorado River and other basins (e.g., Nash and Gleick 1991, 1993) has indicated that, as a generalized rule-of-thumb, for each 1.8°F (1°C) of warming, an approximate 5% increase in precipitation would be required for runoff levels to remain unchanged (Solid line in Figure 2.1). With projected mid-century temperatures increasing 4°F or more, no areas in Colorado are projected to receive sufficient compensatory precipitation. In order to account for the potential effects of warmer temperatures on soil moisture availability, and determine the extent to which each ecosystem may be exposed to effectively drier conditions, we made a conservative application of the above rule, to evaluate how much of an ecosystem might receive at least a partial (50%) level of compensatory precipitation (dashed line in Figure 2.1).

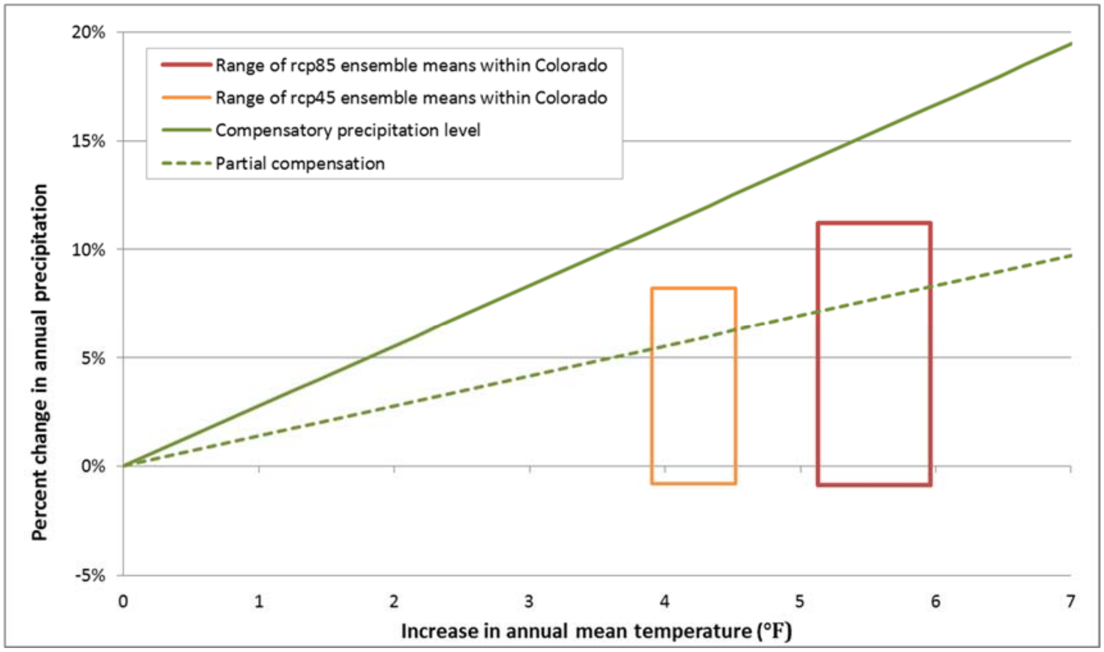


**Figure 2.1.** Statewide envelope of projected change in annual mean temperature and precipitation under two emissions scenarios (boxes), in comparison with levels of precipitation increase required to maintain the status quo.

For each ecosystem, we calculated the proportion of acreage where projected annual mean temperature for mid-century under RCP 8.5 was greater than any annual mean temperatures currently experienced by that ecosystem within Colorado, AND projected future precipitation changes were less than 5% increase over current levels. Ecosystems were scored according to the scale shown below (Table 2.2). In addition, any ecosystem whose proportion of acreage with temperatures within the normal range, but with more than 50% of that acreage having projected future precipitation changes with less than 5% increase over current levels, was bumped to the next higher exposure category.

It is important to note that the resulting scores are intended to give a relative, not an absolute indication of the potential impact of future climate conditions on an ecosystem. That is, a "Low" score does not mean that an ecosystem is not vulnerable to climate change, but that the analysis indicates that it may be less vulnerable than those ecosystems with scores of Moderate, High, or Very High. Furthermore, under the scoring system we used, "Moderate" is a broad category, and all ecosystems with a Moderate vulnerability rank are not necessarily equally vulnerable.

**Table 2.2**. Criteria for scoring exposure of terrestrial ecosystems.

| Percent Colorado acres with projected temp > max & ppt delta < 5% | 36 – 100% | | 16 – 35% | | 0 – 15% | |
|---|---|---|---|---|---|---|
| Initial Exposure-Sensitivity Score | High | | Moderate | | Low | |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | Yes | No | Yes | No | Yes | No |
| Final Exposure-Sensitivity Score | Very High | High | High | Mod. | Mod | Low |

## Resilience-adaptive capacity assessment – terrestrial ecosystems

This score summarizes indirect effects and non-climate stressors that may interact with climate change to influence the adaptive capacity and resilience of an ecosystem. Factors evaluated are adapted from the methodology used by Manomet Center for Conservation Science and Massachusetts Division of Fish and Wildlife (MCCS and MAFW 2010), combined under five headings (Table 2.3). Factors were scored on a scale of 0 (low resilience) to 1 (high resilience).

**Table 2.3.** Description of factors used to assess resilience-adaptive capacity in terrestrial ecosystems.

| Assessment factor | Description |
|---|---|
| Bioclimatic envelope and range | This factor summarizes the expected effects of limited elevational or bioclimatic ranges for an ecosystem. Suitable conditions for ecosystems at upper elevations may be eliminated. Ecosystems with narrow bioclimatic envelopes may be more vulnerable to climate change. Finally, ecosystems that are at the southern edge of their distribution in Colorado may be eliminated from the state under warming conditions. |
| Growth form and intrinsic dispersal rate | This factor summarizes the overall ability of the ecosystem's component species to shift their ranges in response to climate change relatively quickly. Characteristics of growth form, seed-dispersal capability, vegetative growth rates, and stress-tolerance are considered. |
| Vulnerability to increased impact by biological stressors | This factor summarizes whether expected future biological stressors (invasive species, grazers and browsers, pests and pathogens) have had, or are likely to have, an increased effect due to interactions with changing climate. Climate change may result in more frequent or more severe outbreaks of these stressors. Ecosystems that are currently vulnerable to these stressors may become more so under climate change. |
| Vulnerability to increased frequency or intensity of extreme events | This factor evaluates characteristics of an ecosystem that make it relatively more vulnerable to extreme events (fire, drought, floods, windstorms, dust on snow, etc.) that are projected to become more frequent and/or intense under climate change. |
| Other indirect effects of non-climate stressors – landscape condition | This factor summarizes the overall condition of the ecosystem at the landscape level across Colorado, and is derived from a landscape integrity score indexing the degree of anthropogenic disturbance (Rondeau et al. 2011, Lemly et al. 2011). |

### Bioclimatic envelope and range

Each ecosystem was scored for elevational range, southern edge of range, annual precipitation range, and growing degree days range. Ecosystems restricted to high elevations received a score of 0, other ecosystems scored 1. Likewise, ecosystems at the southern edge of their continental range in Colorado were assigned a score of 0, and other ecosystems scored 1. Annual precipitation and growing degree days range were calculated as the proportion of total variable range in Colorado in which the ecosystem had significant presence mapped. These four scores were averaged to produce a single score for this factor.

### Growth form and intrinsic dispersal rate

Scores of 0 (low resilience), 0.5 (uncertain or moderate resilience), and 1 (high resilience) were assigned to each ecosystem based on growth form of the dominant species (i.e., trees scored 0, shrubs and herbaceous scored 1), and other information derived from the literature regarding the dispersal abilities of those species.

### Vulnerability to increased attack by biological stressors

Beginning with a default score of one, we subtracted 0.2 for vulnerability to potential increased effects of grazers or browsers, and 0.3 for vulnerability to invasive species. In addition, forest types with levels of insect mortality sufficient to cause dramatic structural changes over a large area (>1 million acres in Colorado) received a score of 0, and forest types with lower levels of insect mortality received a starting score of 0.7. Forest scoring was based on cumulative damage totals from USFS Aerial Surveys (USDA Forest Service 2014).

### Vulnerability to increased frequency or intensity of extreme events

Ecosystems not especially vulnerable to increased frequency or intensity of abiotic stressors received a default score of one. Forest types not adapted to dry conditions were scored 0.5, to account for increased susceptibility to the combined effects of drought and potentially increased wildfire, while more drought tolerant forest types scored 0.7. Non-forest ecosystems vulnerable to drought were scored 0.5, and ecosystems vulnerable only to other abiotic stressors scored 0.9.

### Landscape condition

The average value across the statewide landscape integrity models (Rondeau et al. 2011, Lemly et al. 2011) for each ecosystem was calculated as a value between 0 and 1.

### Resilience-adaptive capacity ranking

Scores for the five factors are based on both spatial analysis and literature review. Rankings for this sub-score are opposite to the direction of the exposure-sensitivity ranking scheme (i.e., a higher value indicates "better" and a lower value indicates "worse.") The rounded average of the five sub-scores determines the final Resilience-Adaptive Capacity score.

| | | | |
|---|---|---|---|
| Average of Resilience-Adaptive Capacity Scores | 0 – 0.50 | 0.51 – 0.70 | 0.71 – 1.0 |
| Overall Resilience-Adaptive Capacity Score | Low | Moderate | High |

## Vulnerability assessment ranking

### Overall vulnerability ranking

The Exposure-Sensitivity score and the Resilience-Adaptive Capacity score are combined (Figure 2.2) according to the scheme presented below (Comer et al. 2012) to produce an overall vulnerability rank for each ecosystem.

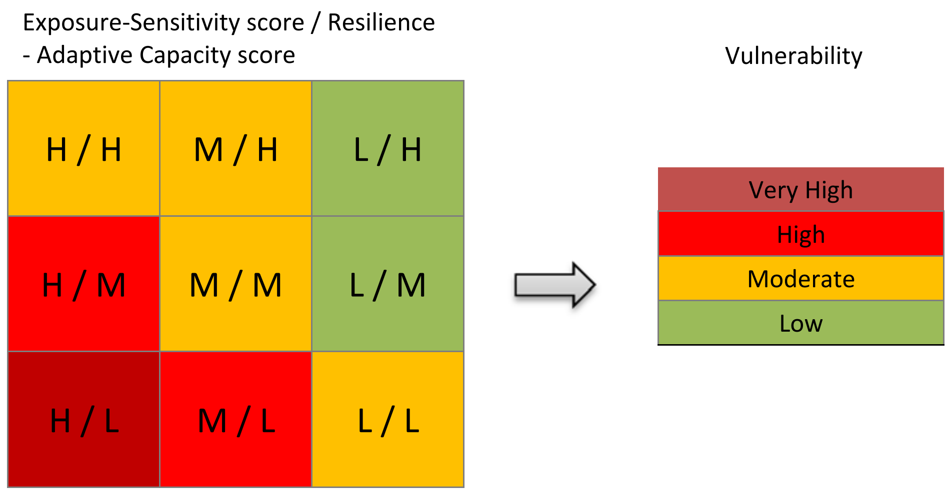


**Figure 2.2.** Vulnerability ranking matrix.

**Very High:** Ecosystems have high vulnerability to climate change when exposure and sensitivity are high, and adaptive capacity and resilience are low. Under these circumstances, transformation of the ecosystem is most likely to occur in upcoming decades.

**High:** High vulnerability to climate change results from combining either high or moderate exposure-sensitivity with low or medium adaptive capacity-resilience. Under either combination, climate change is likely to have noticeable impact.

**Moderate:** Moderate vulnerability to climate change results from a variety of combinations for exposure-sensitivity and adaptive capacity-resilience. The scoring matrix is slightly weighted toward increased vulnerability in the number of possible combinations which produce a moderate vulnerability ranking. Under circumstances where the two factors are essentially balanced, vulnerability is thought to be reduced, but still of concern.

**Low**: Low vulnerability to climate change occurs when an ecosystem is expected to experience low exposure and sensitivity in combination with high or moderate adaptive capacity and resilience. For these ecosystems climate change stress and its effects are expected to be least severe or absent.

# Terrestrial Ecosystems - Results

## Overview of terrestrial ecosystems

### Change in temperature and precipitation by mid-century

Under the most severe scenario ecosystems evaluated herein are projected to experience annual mean temperatures that are 5-6°F warmer than in the recent past; at the same time future precipitation levels are not projected to increase sufficiently to compensate even partially for increased moisture loss due to warmer temperatures (dashed line in Figure 2.3).

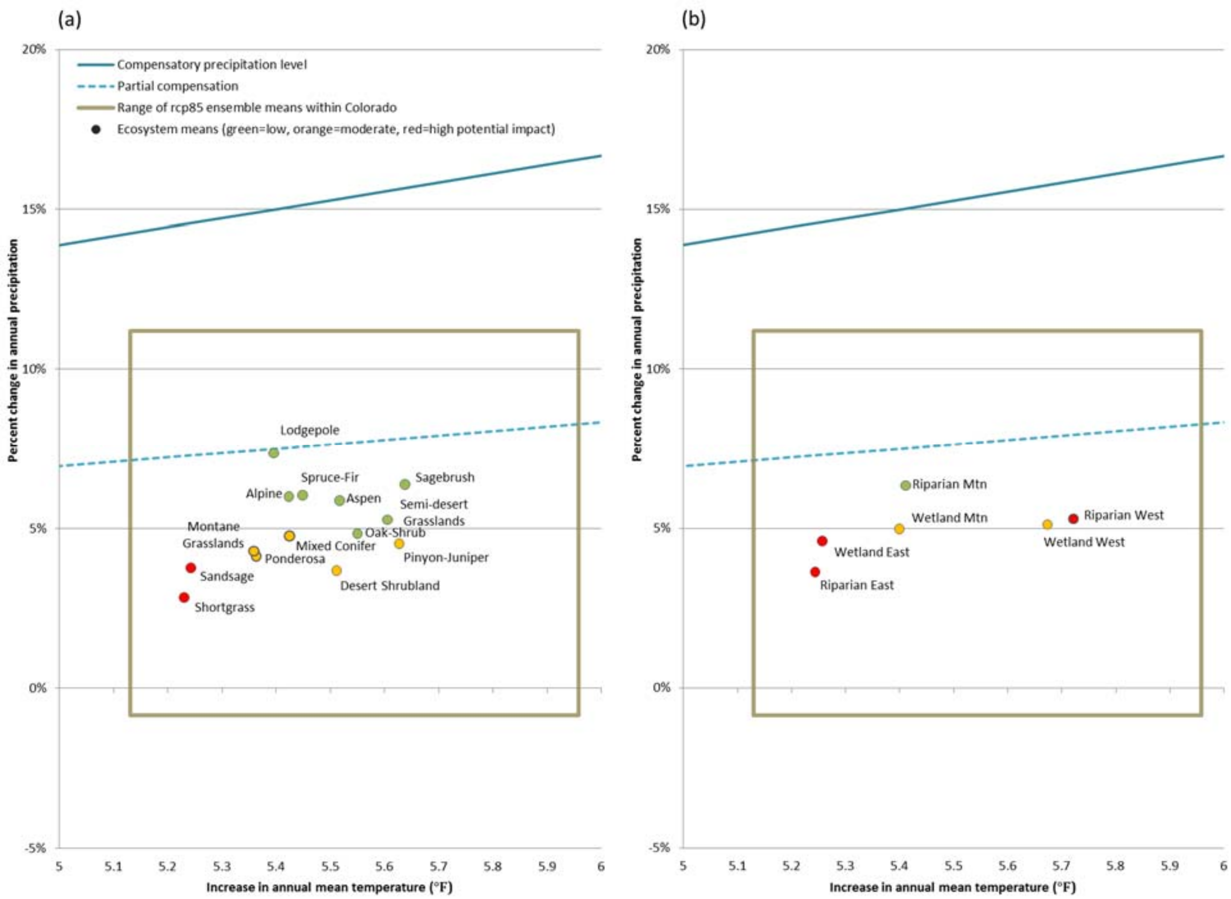


**Figure 2.3.** Projected annual change in Colorado for (a) upland ecosystems, and (b) wetland and riparian ecosystems. Ecosystem means are colored to indicate the degree to which the ecosystem is projected to experience conditions that are out of range of those in its current statewide distribution.

### Resilience factors

Results for individual resilience factors are shown in Figure 2.4 and discussed in detail below.

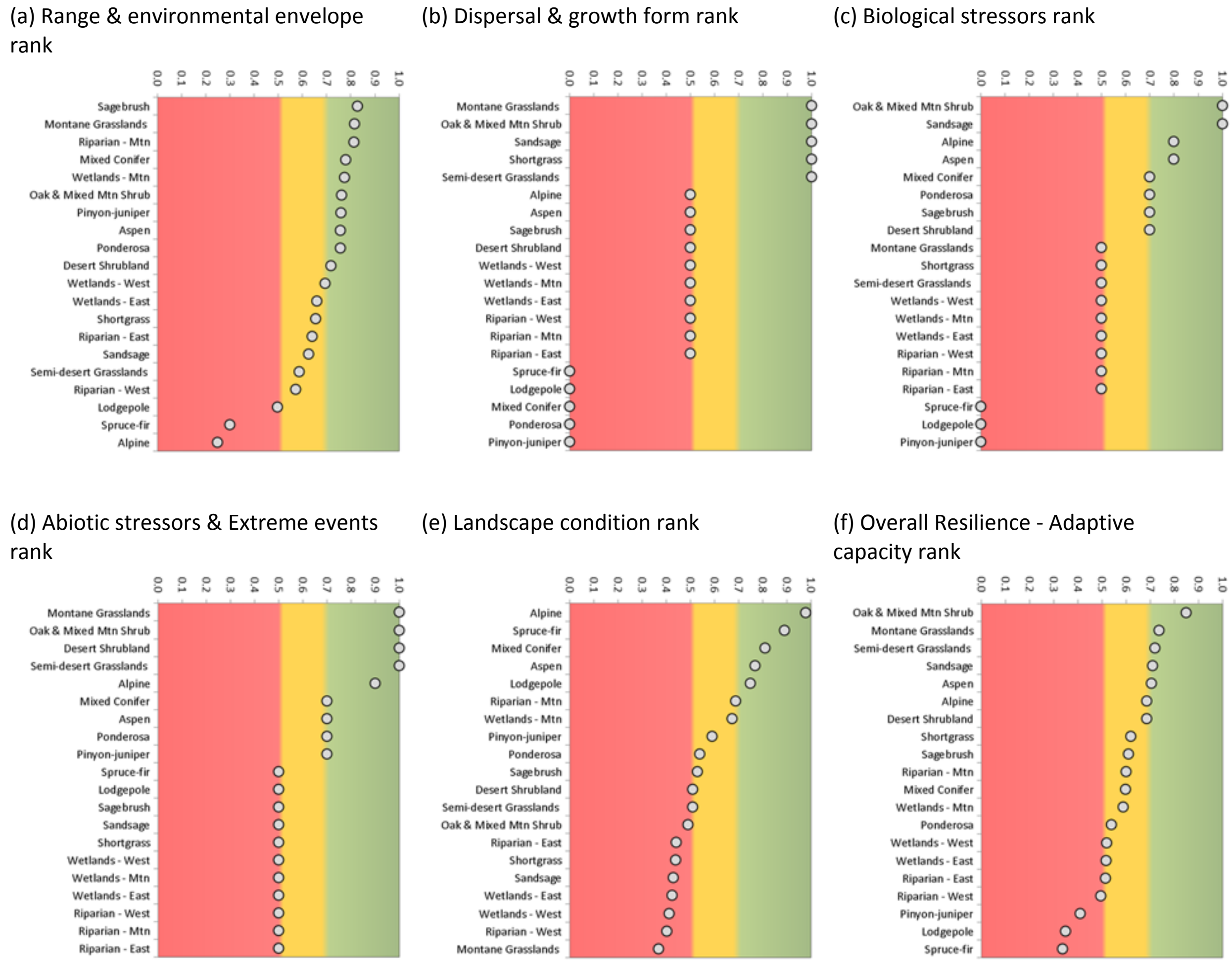


**Figure 2.4.** Comparison of scores by ecosystem for (a-e) individual resilience factors, and (f) overall resilience – adaptive capacity score. Background colors reflect the low (red), moderate (orange), and high (green) resilience categories.

## Elevation range and relative abundance

Together with range extent and bioclimate envelope (below), we considered elevation as a factor that might detract from the resilience of an ecosystem. Ecosystem elevations in Colorado range from about 3,500 ft to nearly 14,000 ft (Figure 2.5). The extreme highest elevations are non-vegetated. Low elevations are occupied by grassland, shrubland, and woodland ecosystems dominated by species adapted to lower precipitation and warm conditions. A number of montane to sub-alpine ecosystems are clustered together at middle elevations from about 7,000-10,000 ft. At higher elevations, subalpine forest and alpine vegetation occupy fairly distinct elevational zones.

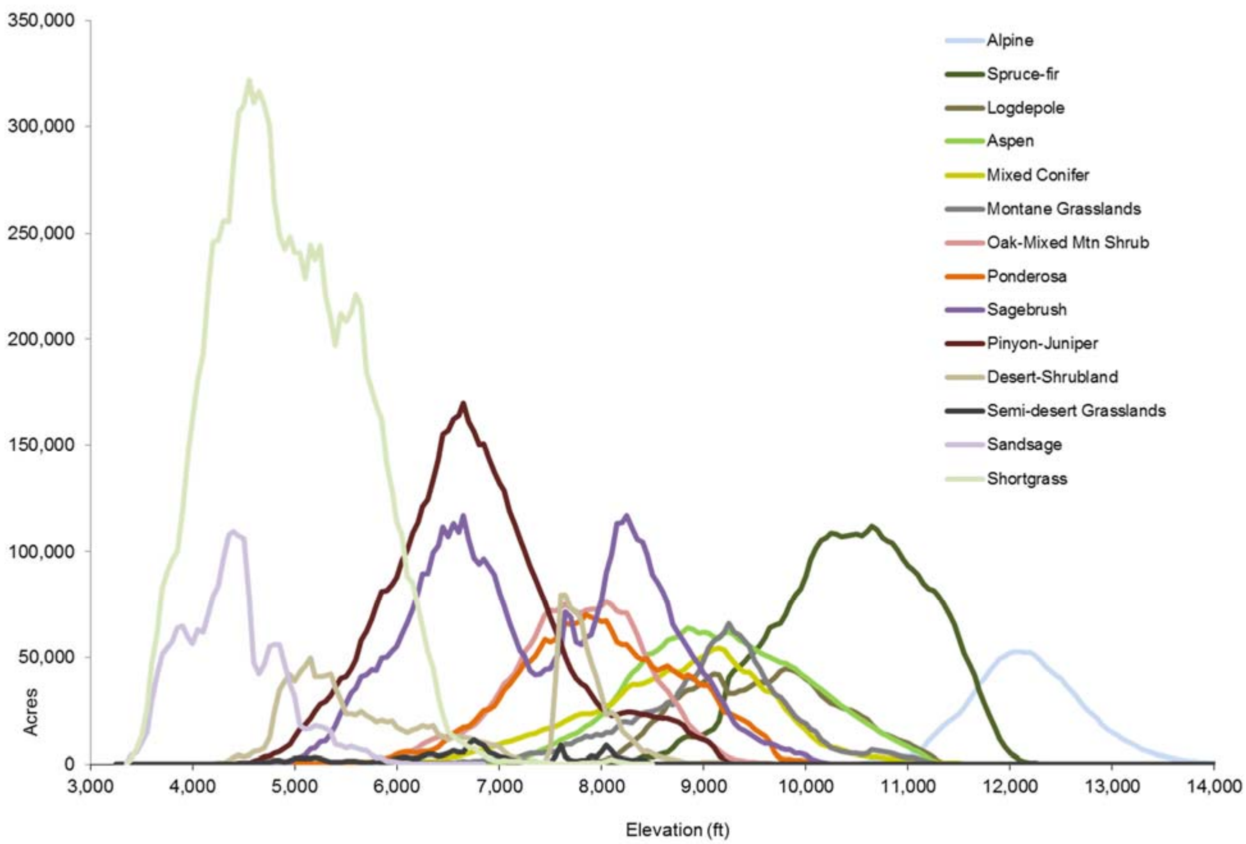


**Figure 2.5.** Area of ecosystems mapped at various elevations in Colorado.

## Bioclimatic envelope

Temperature and precipitation variables were used to characterize the current bioclimatic envelope for each terrestrial ecosystem. A combined precipitation and temperature space is shown for each of the 14 upland ecosystems in Figure 2.6. Because precipitation and temperature are highly correlated with elevation, patterns are similar to those shown under elevation range above. Desert shrubland occupies the driest bioclimatic envelope, while sandsage and shortgrass prairie are the warmest. Statewide, ponderosa, oak-shrub and sagebrush shrubland are closely related in bioclimatic space, and show substantial overlap with the warmer and drier pinyon-juniper and semi-desert grassland. Above these warmer and drier ecosystems, mixed conifer, aspen, and lodgepole forest share a mid-elevation envelope with montane grasslands. The coldest, wettest environments are occupied by alpine types, with spruce-fir forest intermediate between the middle group and these habitats.

Historic temperature ranges for winter minimums and summer maximums for each upland ecosystem are shown in Figure 2.7, and illustrate the same relationship to elevation as do the other climate variables. The geographic area currently occupied by each ecosystem in Colorado is likely to experience a shift toward warmer temperatures, with the result that bioclimatic envelopes will shift toward higher elevations. The acreage that falls within a particular temperature range will be reduced for cooler temperatures and increased for warmer temperatures.

The overall elevation, range, and bioclimate envelope results are shown in Figure 2.4a.

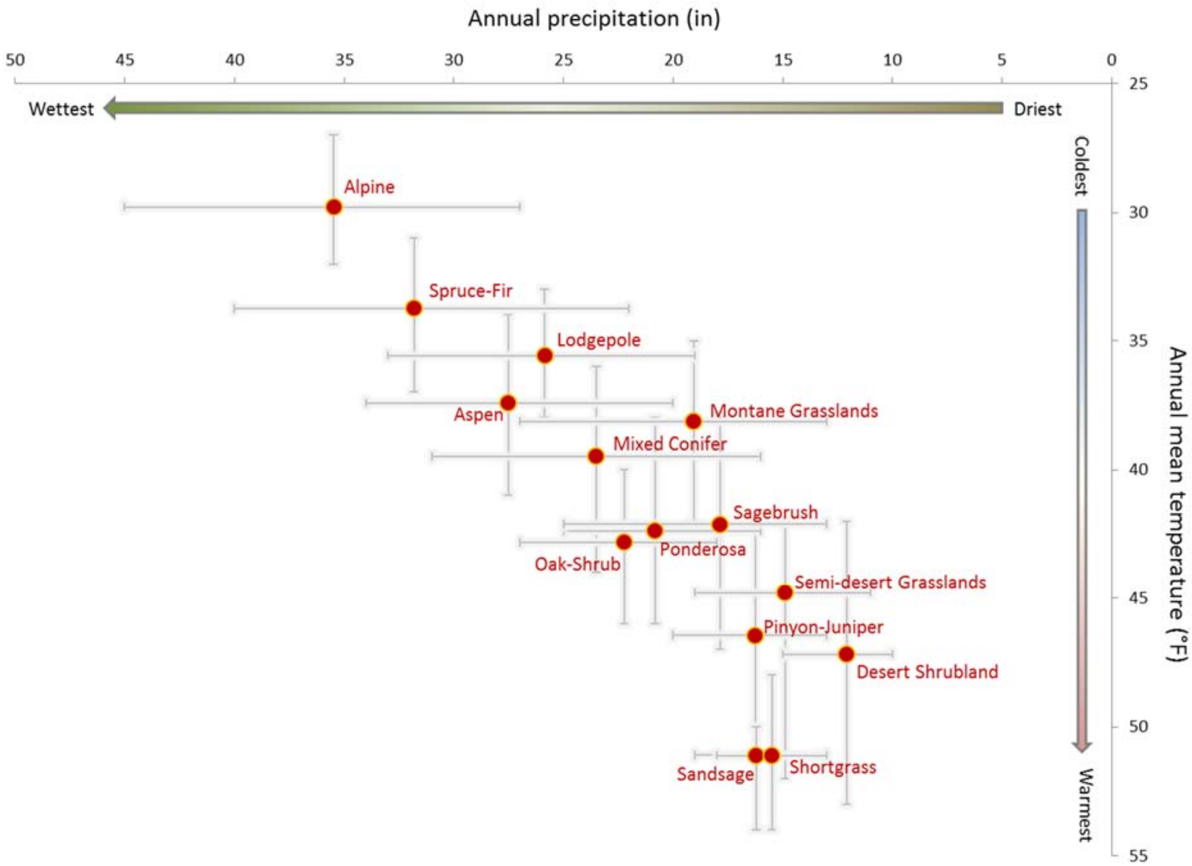


**Figure 2.6.** Bioclimatic envelope as represented by annual precipitation and mean temperature for ecosystems in Colorado. Error bars represent the 10-90% range around the mean.

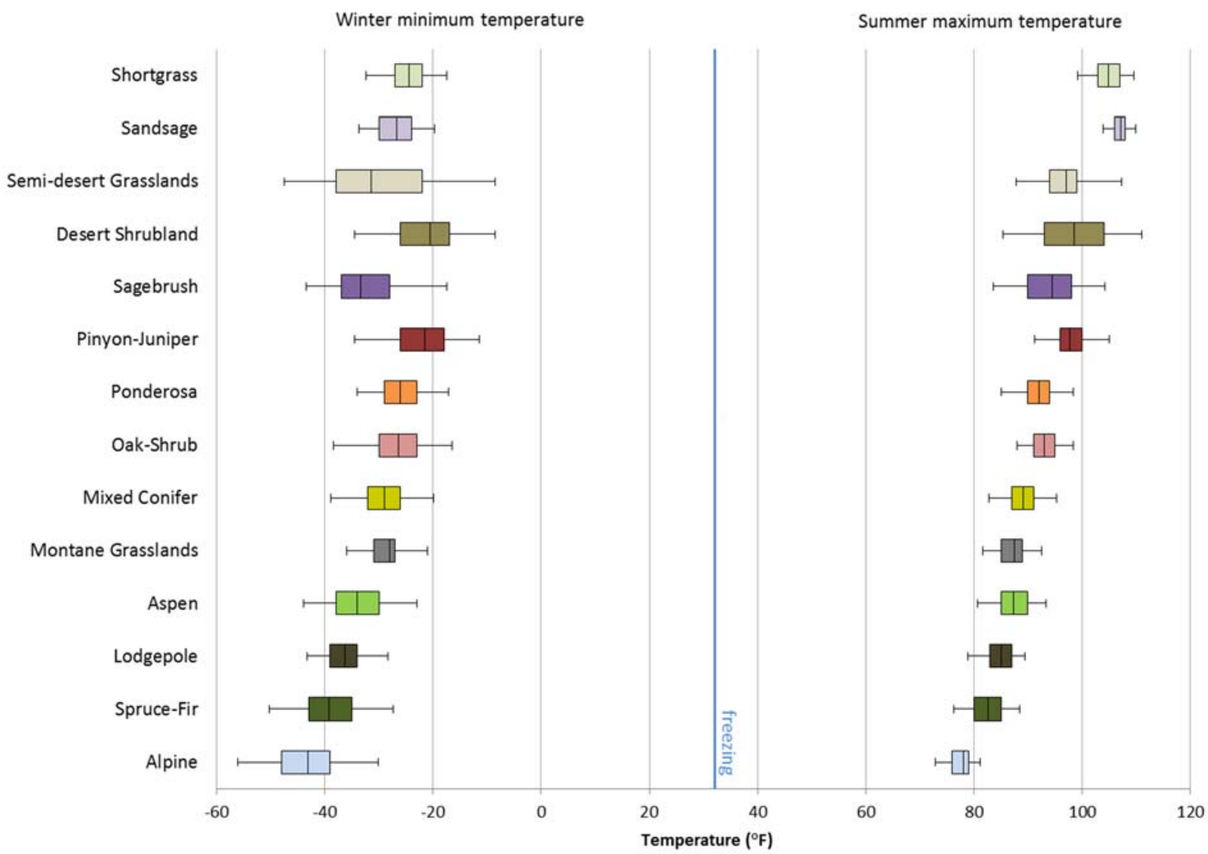


**Figure 2.7.** Minimum winter and maximum summer temperature ranges for ecosystems in Colorado. Boxes represent the middle quartiles, while whiskers show the 10-90% range.

## Intrinsic dispersal rate

Most characteristic species of forest or woodland ecosystems do not produce large numbers of seedlings or spread quickly via vegetative growth. With the exception of aspen and Gambel oak, forest and woodland tree species are typically slow growing, with limited dispersal ability. Past migration rates for North American tree species in the current interglacial have been estimated at tens to several hundreds of meters per year. Although the currently observed distribution of a species is likely to lag behind current climate conditions, future conditions are predicted to require migration rates one to five *kilometers* per year in order for species to keep up with suitable habitat conditions (Roberts 2013). Shrub and grass-dominated ecosystems are somewhat better adapted to spread into available habitat through relatively rapid vegetative growth. Barriers to ecosystem movement in Colorado are primarily those due to elevational gradients or habitat fragmentation, although soil type is likely to influence dispersal and establishment patterns through variable water-holding capacity. Ecosystem ranks for this factor are shown in Figure 2.4b.

### Biological stressors

Biological stressors for ecosystems in Colorado include forest pests and pathogens, invasive species, incompatible domestic livestock grazing, and changes in patterns of native ungulate herbivory. Ecosystem ranks for this factor are shown in Figure 2.4c.

Native insects that cause tree damage and mortality include bark beetles (*Dendroctonus* spp., *Ips* spp.), western spruce budworm (*Choristoneura occidentalis*), and tent caterpillars (*Malacosoma* spp.). Armillaria root disease is a significant cause of mortality in conifer species. Pinyon are susceptible to the fungal pathogen *Leptographium wageneri* var. *wageneri*, which causes black stain root disease. Five-needle pines, including limber and bristlecone, are threatened by white pine blister rust (WPBR) infection caused by the introduced fungus *Cronartium ribicola.*

Exotic invasive plant species with the potential to alter ecosystem functioning that are regionally widespread in Colorado include cheatgrass (*Bromus tectorum*), knapweed (*Acroptilon* and *Centaurea* spp.) Russian olive (*Elaeagnus angustifolia*) leafy spurge (*Euphorbia esula*), and tamarisk (*Tamarix ramosissima*). Canada thistle (*Cirsium arvense*) and musk thistle (*Carduus natans*) are also widespread, and other, less prevalent problem species include oxeye daisy (*Leucanthemum vulgare)* and yellow toadflax (*Linaria vulgaris*). Mountain grasslands, low elevation shrubland, and riparian/wetland ecosystems are most affected.

Together with livestock grazing, overabundance of native ungulates (e.g., deer and elk) and feral burros or horses can alter vegetation, soils, hydrology, and wildlife species composition and abundances in ways that intensify the effects of climate change on these resources (Beschta et al. 2013). For terrestrial ecosystems, the projected combination of increasing drought, higher temperatures, earlier snowmelt, and precipitation variability interacting with the effects of ungulate use can result in decreased biodiversity, reduced soil moisture, accelerated soil and nutrient loss, and increased sedimentation (Beschta et al. 2013).

### Extreme events

Extreme events that may increase in frequency and/or severity under changing climatic conditions include drought, wildfire, flooding/erosion, and windstorms. Ecosystem ranks for this factor are shown in Figure 2.4d.

Prolonged drought has been a periodic influence in the western United States, including Colorado (Woodhouse 2004). Ecosystems of lower elevations are generally drought tolerant, although species composition within an ecosystem is likely to shift with changing climate patterns. Although we scored vulnerability to abiotic events as distinct from biological stressors, the interaction of wildfire and drought with the effects of these factors, especially forest mortality agents like bark beetles, blurs the distinction somewhat. The species that characterize Colorado's ecosystems have varying tolerance to drought, however, it is likely that all species are less resistant to the effects of herbivory, pests, and pathogens when under drought stress. Widespread prevalence of drought-stressed trees may provide enhanced conditions for stand-replacing events such as fire or insect outbreak (DeRose and Long 2012). Ecosystems of higher, wetter elevations have generally been "climate-limited," with high fuel loads, but rarely having dry climate conditions suitable for fire spread. Lower, more mesic ecosystems have been characterized as "fuel-limited," with conditions frequently suitable for fire, but low fuel loads unless prior years have been wet (Whitlock et al. 2010). With warmer temperatures and more frequent drought, higher elevation forests with abundant fuels may have increased fire frequency, while lower elevation grassland and shrubland ecosystems become more fuel-limited with reduced biomass production (Arnold et al. 2014).

Although there are no overall precipitation increase trends associated with recent warming, there is evidence that extreme precipitation events have increased in frequency over the past several decades (Walsh et al. 2014). Warmer air and ocean temperatures allow the atmosphere to hold more moisture, which can result in heavy precipitation, causing more extreme flooding and erosion events, even if annual precipitation totals decline. Although future trends in storm occurrence are uncertain, an increase in frequency of severe storms could increase the frequency of windthrow events in forested areas.

### Non-climate abiotic stressors

The combined effects of human actions that fragment landscapes, alter natural processes, reduce biodiversity, and degrade environmental quality are likely to reduce the resilience of complex adaptive ecosystems to regime shifts under changing climate conditions (Folke et al. 2004). The cumulative effects of anthropogenic disturbance in Colorado are due to habitat fragmentation and conversion due to agricultural use as well as industrial, residential, resource, and recreational development activities. Our scoring assumes that ecosystems with higher levels of anthropogenic disturbance are likely to be less resilient to disturbance of any kind under future climate conditions. Ecosystems of the highest elevations, which are generally in public ownership, had the highest resilience rating for this factor, while ecosystems of valley bottoms, or those otherwise fragmented by land use had poor resilience ratings (Figure 2.4e).

## Ecosystem vulnerability ranks

Four of the 20 ecosystems or regional ecosystem subgroups assessed have an overall vulnerability rank of High, and one is ranked Very High (Table 2.4). In general, ecosystems of the eastern plains have the greatest exposure to change, and those of higher elevations have lower exposure. Under a longer time-frame, high elevation areas would be subject to increased exposure. Most ecosystems were assessed as having moderate resilience. A summary of climate change vulnerability analysis (CCVA) details for each ecosystem is provided below, beginning on page 42.

**Table 2.4.** Vulnerability rank summary for all assessed terrestrial ecosystems.

| Ecosystem Target | Exposure - Sensitivity final ranking | Resilience - Adaptive Capacity final ranking | Combined ranks | Overall vulnerability rank |
|---|---|---|---|---|
| **Forest and Woodland** | | | | |
| Aspen forest | Low | High | L/H | **Low** |
| Lodgepole pine forest | Low | Low | L/L | **Moderate** |
| Mixed conifer forest | Moderate | Moderate | M/M | **Moderate** |
| Pinyon-Juniper woodland | Moderate | Low | M/L | **High** |
| Ponderosa pine forest | Moderate | Moderate | M/M | **Moderate** |
| Spruce-Fir forest | Low | Low | L/L | **Moderate** |
| **Shrubland** | | | | |
| Desert shrubland | Moderate | Moderate | M/M | **Moderate** |
| Oak & mixed mountain shrub | Low | High | L/H | **Low** |
| Sagebrush shrubland | Low | Moderate | L/M | **Low** |
| Sandsage shrubland | High | High | H/H | **Moderate** |
| **Grassland or Herbaceous** | | | | |
| Alpine | Low | Moderate | L/M | **Low** |
| Montane grassland | Moderate | High | M/H | **Moderate** |
| Semi-desert grassland | Low | High | L/H | **Low** |
| Shortgrass prairie | High | Moderate | H/M | **High** |
| **Riparian & Wetland** | | | | |
| Riparian woodland & shrubland - east | High | Moderate | H/M | **High** |
| Riparian woodland & shrubland - mountain | Low | Moderate | L/M | **Low** |
| Riparian woodland & shrubland - west | High | Low | H/L | **Very High** |
| Wetlands - east | High | Moderate | H/M | **High** |
| Wetlands - mountain | Moderate | Moderate | M/M | **Moderate** |
| Wetlands - west | Moderate | Moderate | M/M | **Moderate** |

## Conclusions

All ecosystems are likely to be affected to some extent by climate change. Ecosystems with low exposure and high resilience could be the beneficiaries of future conditions, while those with high exposure and low resilience are likely to experience range contractions and/or significant changes in species composition and overall condition. The majority of habitat types were ranked with low or moderate vulnerability in our analysis, however, the gradations of moderately vulnerable, and the transition to highly vulnerable are less clear than the separation between low and moderate vulnerability. The methods used to combine estimated exposure and resilience scores leave a large middle ground which can be affected by uncertainty in climate projections, current knowledge, and ongoing management actions.

By mid-century, under both moderate and high radiative forcing scenarios (RCP4.5 and RCP8.5), we can expect to see warmer temperatures statewide, especially on the eastern plains. Warmer temperatures are likely to include more heat waves, fewer cold snaps, and generally extended frost-free periods. Although these conditions could benefit many species if precipitation remains adequate, the warming trend is likely to be accompanied by effectively drier conditions in many areas. Even if precipitation levels at higher elevations are essentially unchanged, warmer conditions will lead to more precipitation falling as rain instead of snow, a decreased snowpack, earlier runoff, and earlier dry conditions in late summer (Lukas et al. 2014). All of these factors may interact with stressors such as fire, forest pests and diseases, drought, and anthropogenic disturbance to alter the future trajectory of a particular ecosystem.

Comparison of the recent historical values of climate variables with projected values within the current Colorado distribution of the terrestrial ecosystems (Figures 2.8 and 2.9) indicates seasonal differences in degree and direction of projected changes in temperature and precipitation. For instance, ecosystems of higher elevations are projected to experience a greater increase in winter precipitation than those of lower elevations, although the amount of warming is similar for all elevations. Projected changes in summer precipitation are generally less than for winter, with some ecosystems seeing a slight increase and others a slight decrease.

The interaction of climatic conditions with other environmental factors and biogeographic history shapes the distribution of ecosystems that we currently observe. Furthermore, the time lag between when climate conditions become suitable or unsuitable for a species and the eventual colonization or elimination of that species in an area adds another level of uncertainty to projections of future distribution. Climate changes over the past few decades are probably already facilitating a gradual shift of ecosystems that will become more apparent by mid-century.

Our analysis of the range of future uncertainty focused on “worst case” (RCP 8.5) outcomes in order to provide a vulnerability prioritization of key ecosystems that will facilitate a pragmatic “no-regrets” planning strategy for BLM staff dealing with the ongoing effects of climate change in Colorado.

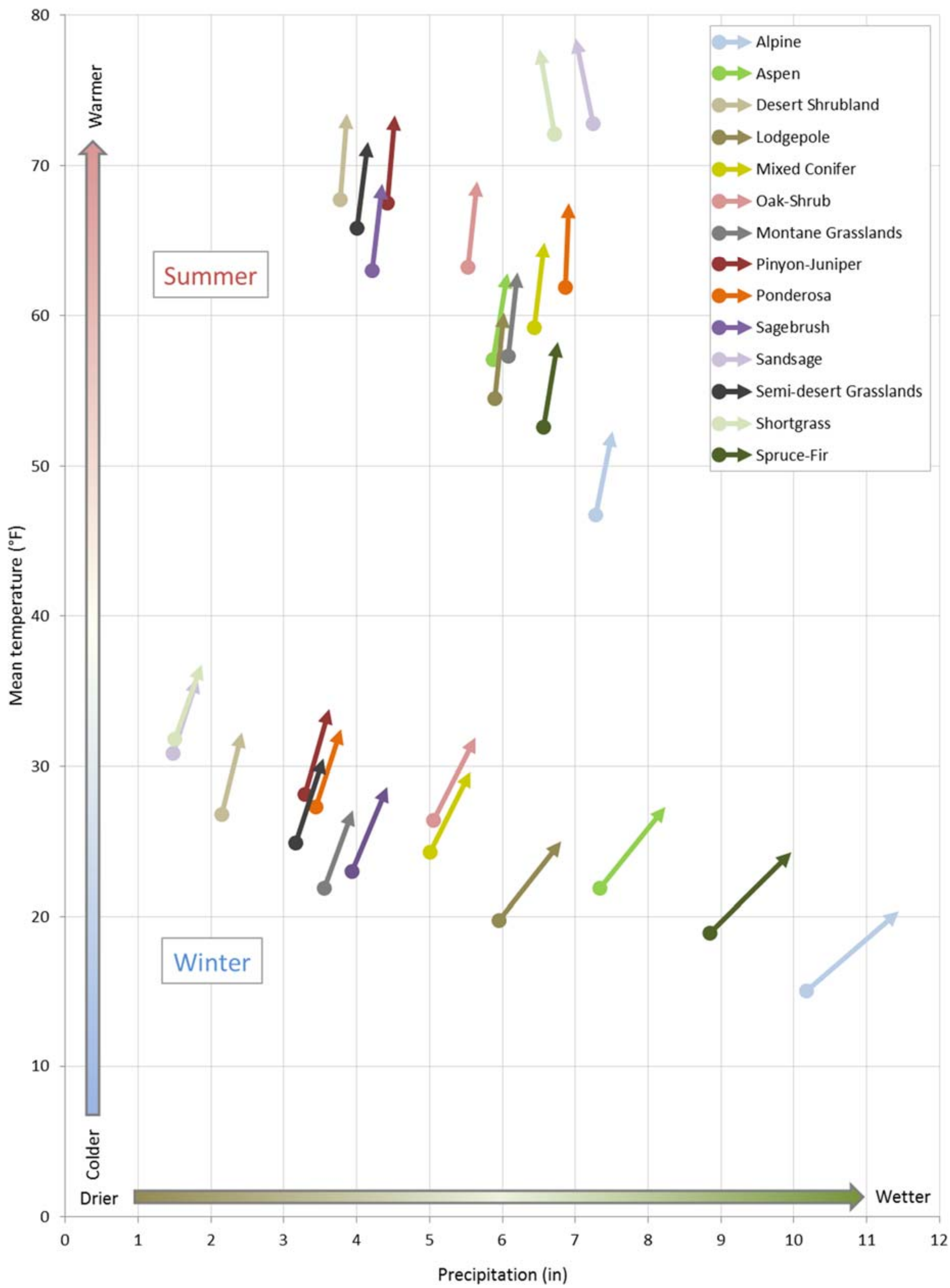


**Figure 2.8**. Projected seasonal average precipitation and mean temperature trajectories for current upland ecosystem ranges in Colorado by mid-century under a high radiative forcing scenario (RCP8.5). Circles represent current conditions.

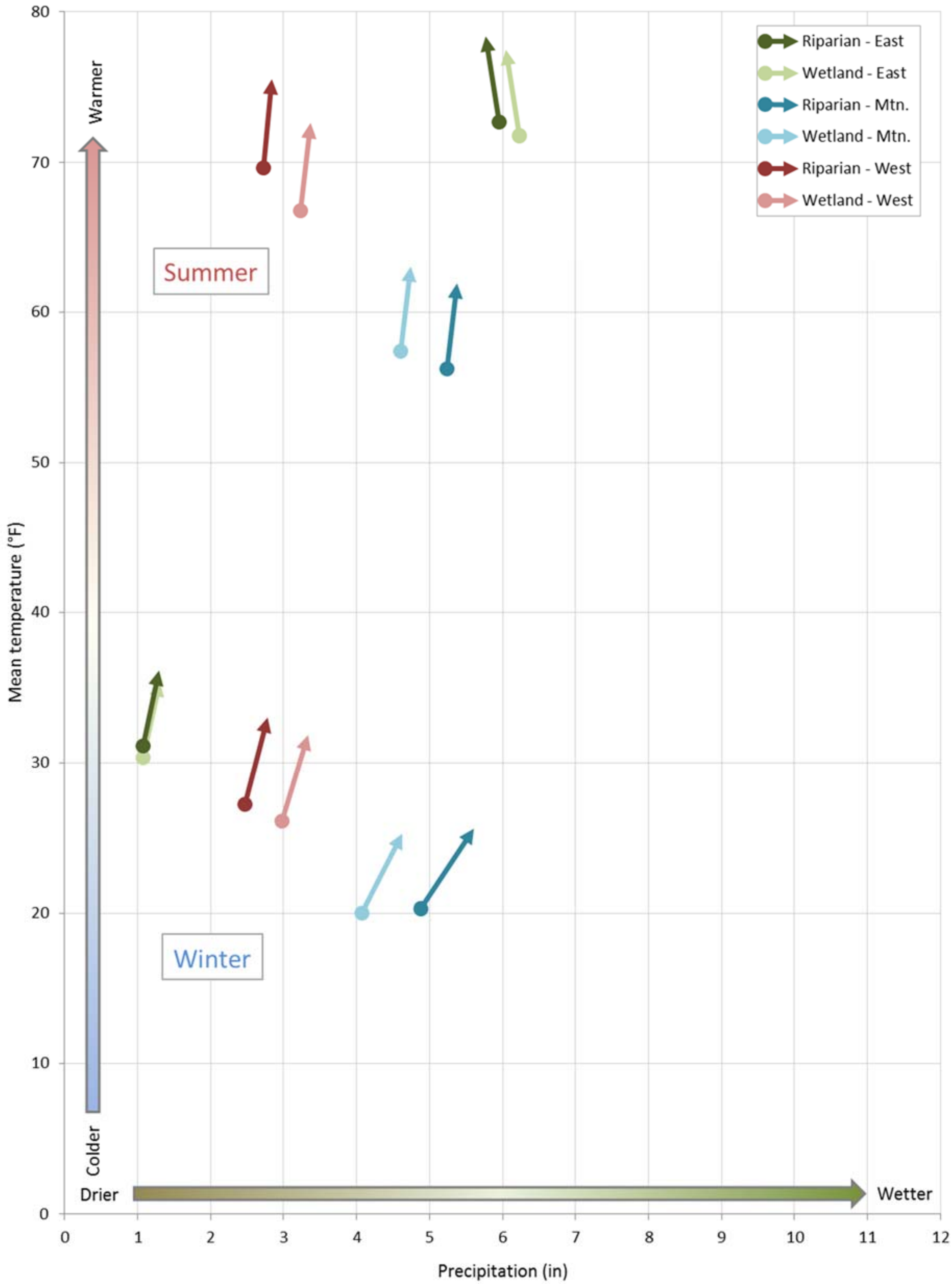


**Figure 2.9**. Projected seasonal average precipitation and mean temperature trajectories for current wetland and riparian ecosystem ranges in Colorado by mid-century under a high radiative forcing scenario (RCP8.5). Circles represent current conditions.

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# Terrestrial Ecosystem CCVA Summaries

## Forest and Woodland

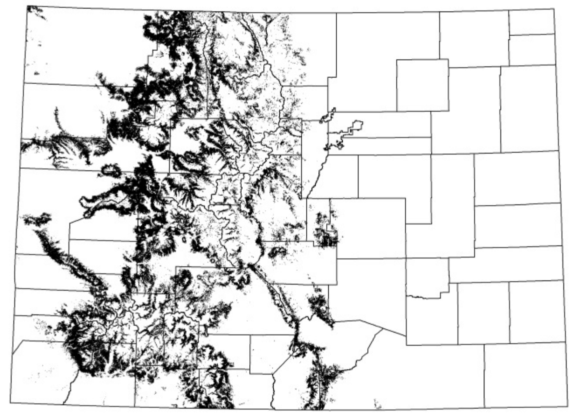
**Table 2.5**. Key vulnerabilities, forest and woodland ecosystems.

| Habitat | Climate factor(s) | Consequences | Other considerations |
|---|---|---|---|
| Aspen | Warmer and dry conditions | Aspen decline, especially at lower elevations | May benefit from fire increase, small patches in conifer forest may expand after conifer mortality |
| Lodgepole | Drought, warmer temperatures | Fire and insect outbreak; range contraction | |
| Mixed Conifer | Warmer and dry conditions | Change in relative species abundance or conversion to other type | Diverse species composition makes it likely that some species will thrive |
| Pinyon-juniper | Warmer and dry conditions | Change in relative species abundance favoring juniper; fire and insect outbreak; reduced pinyon pine cone production | Soil types affect distribution |
| Ponderosa | Drought | Fire and insect outbreak | Wildland-Urban Interface complicated management |
| Spruce-fir | Drought | Fire and insect outbreak | Slow dispersal, short growing season increases vulnerability over time |

# ASPEN

Forests and woodlands dominated by quaking aspen

R. Rondeau



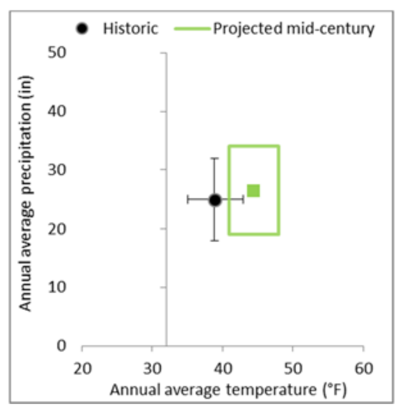
extent exaggerated for display

## Climate Vulnerability Rank: Low

### Vulnerability summary

**Key Vulnerabilities:** Hot and dry conditions are likely to lead to aspen decline and mortality at the lowest elevations. However, small aspen patches in conifer forest may benefit from fire increase and expand following conifer mortality.

Overall exposure to warmer and effectively drier conditions is low for this ecosystem in Colorado; stands at lower elevations are most at risk. These forests are moderately resilient, and in generally good condition. Aspen dynamics are variable across the west, depending on both spatial and temporal scales (Kulakowski, Kaye, and Kashian 2013); as a result there is much uncertainty about the future distribution of this species. Low elevation stands impacted by drought are likely to experience dieback, but in other areas the interaction of changing climate and disturbance regimes may favor aspen (Kulakowski, Matthews, Jarvis, and Veblen 2013).




### Distribution

Quaking aspen (*Populus tremuloides*) has the largest distribution of any tree native to North America (Little 1971). The range of this species has expanded dramatically since the end of the last glacial maximum, during which the greater part of its range was covered by the Cordilleran and Laurentide ice sheets. This widespread ecosystem occurs throughout much of the western U.S. and north into Canada, although it is more common in the montane and subalpine zones of the southern and central Rocky Mountains. These are upland forests and woodlands dominated by quaking aspen, or forests of mixed aspen and conifer, occurring as a mosaic of varying plant associations and adjacent to a diverse array of other ecosystems, including montane grasslands and shrublands, wetlands, and coniferous forests. In Colorado this system ranges in elevation from about 7,500 to 10,500 feet, and is quite common on the west slope, with smaller stands represented on the east slope.

### Characteristic species

These forests have a somewhat closed canopy of trees of 15-65 ft (5-20 m) tall, dominated by quaking aspen. A few conifers may be present including white fir (*Abies concolor*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), blue spruce (*Picea pungens*), ponderosa pine (*Pinus ponderosa*, ) and Douglas-fir (*Pseudotsuga menziesii*). If conifers make up more than 15% of the tree canopy the occurrence is generally considere a mixed conifer stand.

The aspen canopy typically allows sufficient light penetration for the development of a lush understory. Understories are highly variable and may be dominated by shrubs, graminoids, or forbs. Common shrubs include Rocky Mountain maple (*Acer glabrum*), Saskatoon serviceberry (*Amelanchier alnifolia*), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*),common juniper (*Juniperus communis*), chokecherry (*Prunus virginiana*), Wood's rose (*Rosa woodsii*), russet buffaloberry (*Shepherdia canadensis*),mountain snowberry (*Symphoricarpos oreophilus*), and the dwarf-shrubs creeping barberry (*Mahonia repens*) and whortleberry (*Vaccinium* spp.). Common graminoids include pinegrass (*Calamagrostis rubescens*), dryspike sedge (*Carex siccata*), Geyer's sedge (*Carex geyeri*), Ross' sedge (*Carex rossii*), blue wildrye (*Elymus glaucus*), slender wheatgrass (*Elymus trachycaulus*), Thurber fescue (*Festuca thurberi*), and needle-and-thread (*Hesperostipa comata*). Exotic grasses such as the perennials Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) and the annual cheatgrass (*Bromus tectorum*) are often common in occurrences disturbed by grazing. Associated forbs may include common yarrow (*Achillea millefolium*), Engelmann's aster (*Eucephalus engelmannii*), larkspur (*Delphinium* spp.), Richardson's geranium (*Geranium richardsonii*), common cowparsnip (*Heracleum maximum*), Porter's licorice-root (*Ligusticum porteri*), silvery lupine (*Lupinus argenteus*), sweetcicely (*Osmorhiza berteroi*), western brackenfern (*Pteridium aquilinum*), Fendler's meadow-rue (*Thalictrum fendleri*), western valerian (*Valeriana occidentalis*), American vetch (*Vicia americana*), mule-ears *(Wyethia amplexicaulis*), and many others.

### Environment

Rangewide elevations generally range from 5,000-10,000 feet (1,525 to 3,050 m), but can be lower in some regions. Topography is variable, sites range from level to steep slopes. Occurrences at high elevations are restricted by cold temperatures and are found on warmer southern aspects. At lower elevations occurrences are restricted by lack of moisture and are found on cooler north aspects and mesic microsites. The soils are typically deep and well developed with rock often absent, and texture ranges from sandy loam to clay loams. Parent materials are variable and may include sedimentary, metamorphic or igneous rocks, but this type appears to grow best on limestone, basalt, and calcareous or neutral shales (Mueggler 1988).

Distribution of aspen forest is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand, and secondarily is limited by the length of the growing season or low temperatures. Climate is temperate with a relatively long growing season, typically cold winters and deep snow. Mean annual precipitation is greater than 15 in (38 cm) and typically greater than 20 in (50 cm), except in semi-arid environments where occurrences are restricted to mesic microsites such as seeps or areas that accumulate large snow drifts.

### Dynamics

Aspen is extremely shade intolerant, and able to establish quickly over a disturbed open area due to its ability to reproduce by vegetative sprouting (Howard 1996). The tufted seed capsules produced by mature aspen trees are amenable to wind dispersal over a considerable distance. Although quaking aspen establishment from seed is common in Alaska, northern Canada and eastern North America, this is less true in the western US, probably because germinated seedlings do not receive sufficient moisture for survival (Kay 1993). There is conflicting evidence for the frequency of seedling establishment in the western US, however, and quaking aspen may establish from seed more frequently than previously thought (Howard 1996, Romme et al. 1997).

There is some evidence for synchronous aspen stand establishment events over a large area of the intermountain west. Kaye (2011) identified two peak periods of establishment via sexual reproduction, the first in the period 1870-1890, and the other in 1970-1980. She speculates that the earlier establishment event may be the legacy of the last large fire events before widespread fire suppression in the intermountain west. The second establishment peak corresponds with improved moisture conditions due to a shift in the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation. Elliot and Baker (2004) found that aspen stands in the San Juan Mountains are regenerating and increasing in density. Furthermore, they believe that aspen increase at treeline is occurring as a result of establishment from seed. Although quaking aspen produces abundant seeds, seedling survival is rare because the long moist conditions required to establish them are rare in these habitats. Superficial soil drying will kill seedlings (Knight 1994).

Aspen forests and woodlands often originate from, and are likely maintained by, stand-replacing disturbances such as crown fire, disease and windthrow, or clearcutting by man or beaver. The stems of these thin-barked, clonal trees are easily killed by ground fires, but they can quickly and vigorously resprout in densities of up to 30,000 stems per hectare (Knight 1994). The stems are relatively short-lived (100-150 years), and the occurrence will succeed to longer-lived conifer forest if undisturbed. Occurrences are favored by fire in the conifer zone (Mueggler 1988). With adequate disturbance a clone may live many centuries.

Although aspen is not fire tolerant, it is highly competitive in burned areas if other conditions are suitable. Aspen clones survive in the understory of cool, moist mixed conifer and low elevation spruce-fir, and can respond quickly to disturbances. In stands affected by multiple disturbance types (e.g. fire, blow down, beetle-kill), aspen regeneration may be favored over that of conifers (Kulakowski, Matthews, Jarvis, and Veblen 2013).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0.2% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (36.0%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, less than 1% of the current range of aspen forest in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 36% of aspen forest ecosystem in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Quaking aspen is able to grow on a wide variety of sites, both dry and mesic (Mueggler 1988). Climatic conditions, in particular minimum winter temperatures and annual precipitation amounts are variable over the range of the species (Howard 1996). In general, quaking aspen is found where annual precipitation exceeds evapotranspiration, and the lower limit of its range coincides with a mean annual temperature of 45°F (Perala 1990). In the central Rocky Mountains, quaking aspen distribution is highly correlated with elevation, due to its influence on temperature and precipitation patterns. In the Rocky Mountains stands generally occur where annual precipitation is greater than 14.9 in (38 cm) per year (Morelli and Carr 2011) and summer temperatures are moderate.

### Resilience and Adaptive Capacity Rank

| | | | |
|---|---|---|---|
| Overall Score: | 0.71 | Rank: | **High** |

***Bioclimatic envelope and range***

Averaged category score: 0.76

Aspen forests are not found at alpine elevations, but stands are common throughout central and western Colorado at montane to subalpine elevations. Aspen forests have significant presence in 63% of Colorado’s overall precipitation range, and in 40% of the state’s growing degree days range. Quaking aspen is very widely distributed in North America, and the southern limit of its range is currently well to the south of Colorado.

***Growth form and intrinsic dispersal rate***

Score: 0.50

Quaking aspen is a relatively fast growing species, and able to quickly colonize disturbed areas by vegetative reproduction. However, due to its tree growth form, and uncertainty about seed dispersal rates, this ecosystem was scored as having intermediate resilience in this category.

***Vulnerability to increased attack by biological stressors***
Score: 0.8

Vulnerability of aspen to pathogens and herbivores, and subsequent aspen mortality may be increased by climate change if drought and warmer conditions increase environmental stress (Morelli and Carr 2011). Heavy grazing by elk in combination with drought appears to be leading to decline in some areas (Morelli and Carr 2011). Stress from grazing could be mitigated by management actions. Canker infections, gypsy moth, and forest tent caterpillar outbreaks are tightly associated with drier and warmer conditions (Cryer and Murray 1992, Johnston 2001, Logan 2008, Hogg et al. 2001).

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.7

Aspens have increased susceptibility to episodic decline at lower elevations, under warm and dry conditions (Worrall et al. 2008). This aspen dieback (sometimes called Sudden Aspen Decline) appears to be related to drought stress, and is typically greatest on the hotter and drier slopes, which are usually at the lowest elevations of a stand (Rehfeldt et al. 2009). Stands may undergo thinning, but then recover. Increasing drought with climate change is believed to be the primary vulnerability of this ecosystem (Worrall et al. 2013), and substantial loss of this type can be expected. The effects of drought are likely to interact with other stressors such as outbreaks of pests and disease, snowmelt timing, and ungulate herbivory.

The interaction of climate change with natural disturbance may also affect the future distribution of aspen. Although aspen is not fire tolerant, it is likely to establish in adjacent forests that have burned, if other conditions are suitable.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.77

Aspen forests in Colorado are in good condition and not highly threatened. Much of Colorado's aspen forest is on federal lands managed by the U.S. Forest Service. Primary human activities in this ecosystem include cattle and sheep grazing, recreation, and hunting. Some aspen stands are cut for timber products. Threats to the aspen forests and woodlands are comparatively low.

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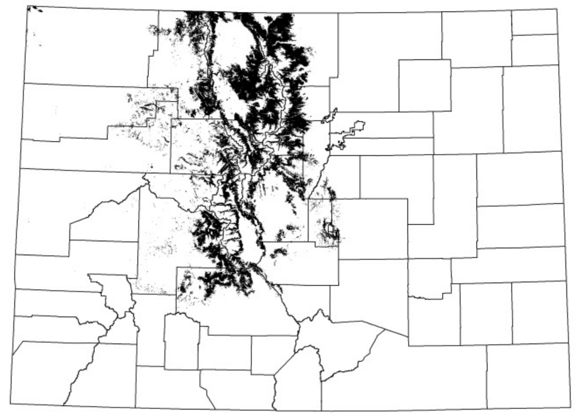
# LODGEPOLE

Forests dominated by lodgepole pine

R. Rondeau



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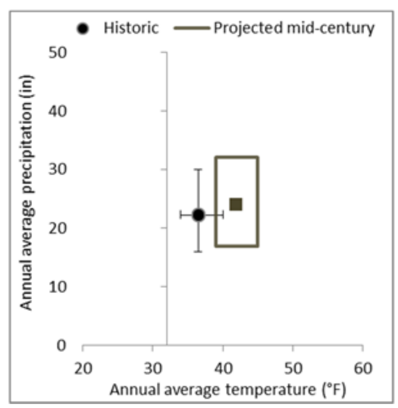
## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Warmer and drier conditions are likely to increase the impact of fire and insect outbreaks in lodgepole forests. Lodgepole stands near the southern end of the range may be lost.

Lodgepole pine forest is ranked moderately vulnerable to the effects of climate change by mid-century. Primary factors contributing to this ranking are its vulnerability to forest disturbances that may increase in the future, and the fact that it is at the southern edge of its distribution in Colorado. Lodgepole forests in Colorado have experienced significant mortality due to the mountain pine beetle, and the interaction of this factor with increased fire and drought frequency and intensity could lead to conspicuous changes in the future extent and form of these forests.




### Distribution

This matrix forming system is widespread in upper montane to subalpine elevations of the Rocky Mountains, Intermountain region, and north into the Canadian Rockies. Lodgepole pine reaches the southern extent of its range at about the middle of the upper Gunnison Basin (Johnston 1997), so this ecosystem is not found in southern Colorado.

### Characteristic species

These forests are dominated by Rocky Mountain lodgepole pine (*Pinus contorta* var. *latifolia*) with shrub, grass, or barren understories. Many stands consist of only lodgepole pine, but others are intermingled with mixed conifer or quaking aspen stands (the latter occurring with inclusions of deeper, typically fine-textured soils). Shrub and herbaceous layers are often poorly developed in lodgepole pine forests, and plant species diversity is low. Some common understory shrubs include kinnikinnick (*Arctostaphylos uva-ursi*), snowbrush ceanothus (*Ceanothus velutinus*), twinflower (*Linnaea borealis*), creeping barberry (*Mahonia repens*), antelope bitterbrush (*Purshia tridentata*), dwarf bilberry (*Vaccinium caespitosum*), whortleberry (*Vaccinium myrtillus*), grouse whortleberry (*Vaccinium scoparium*), and currant (*Ribes* spp.).

### Environment

Soils supporting these forests are typically well-drained, gravelly, have coarse textures, are acidic, and rarely formed from calcareous parent materials. In Colorado, lodgepole pine forests generally occur between 8,000-10,000 feet on gentle to steep slopes on all aspects. Some lodgepole forests persist on sites that are too extreme for other conifers to establish. These include excessively well-drained pumice deposits, glacial till and alluvium on valley floors where there is cold air accumulation, warm and droughty shallow soils over fractured quartzite bedrock, and shallow moisture-deficient soils with a significant component of volcanic ash.

### Dynamics

Lodgepole pine is an aggressively colonizing, shade-intolerant conifer. Establishment is episodic and linked to stand-replacing disturbances, primarily fire. The frequency of natural fires in Rocky Mountain lodgepole pine stands ranges from a few years to 200 or more years (Davis et al. 1980). Low to moderate serverity surface fires are likely to have a return interval on the order of a few decades, while stand-replacing fires are generally less frequent (Crane 1982).

Lodgepole pines produce both open and closed, serotinous cones, and can reproduce quickly after a fire. Following stand-replacing fires, lodgepole pine rapidly colonizes and develops into dense, even-aged stands (sometimes referred to as “dog hair” stands). This fire-adapted species has the potential to move into areas where spruce-fir forests burn. The production of serotinous cones is a highly heritable trait among Rocky Mountain lodgepole pine populations (Parchman et al. 2012). Serotinous cones appear to be strongly favored by fire, and allow rapid colonization of fire-cleared substrates (Burns and Honkala 1990), but serotiny is also selected against by continuous removal of the canopy seed-bank by active seed predators (Benkman and Siepielski 2004). Trees with serotinous cones are favored under conditions of high fire frequency and low predation, but nonserotiny has an advantage under very high seed predation, regardless of fire frequency (Talluto and Benkman 2014).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (7.3%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, less than 1% of the current range of lodgepole pine forest in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 7% of lodgepole forest ecosystem in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Lodgepole pine is tolerant of very low winter temperatures, and in many lodgepole forests summer temperatures can fall below freezing, so there is no true frost-free season (Lotan and Perry 1983). Lodgepole pine is also able to take advantage of warm growing season temperatures, and a longer growing season due to warmer fall temperatures could favor the growth of lodgepole pine (Villalba et al. 1994, Chhin et al. 2008). In southern Colorado, white fir (*Abies concolor*) appears to take the place of lodgepole pine in coniferous forests of similar elevations. White fir appears to tolerate warmer temperatures than lodgepole pine (Thompson et al. 2000); under warmer conditions it may be able to move into areas currently occupied by lodgepole forest.

Lodgepole pine is a northern species that does exceptionally well in very cold climates and can tolerate a wide range of annual precipitation patterns, from fairly dry to fairly wet, but generally grows only where annual precipitation is at least 18-20 inches (Mason 1915, Lotan and Perry 1983). Lodgepole pine forests are found on drier sites than spruce-fir forest, although snowfall is typically heavy in these forests. Summers are often quite dry, and lodgepole pine is dependent on snowmelt moisture for most of the growing season. In low snowpack years, growth is reduced (Hu et al. 2010).

### Resilience and Adaptive Capacity Rank

| | | | |
|---|---|---|---|
| Overall Score: | 0.35 | Rank: | **Low** |

***Bioclimatic envelope and range***

Averaged category score: 0.50

Lodgepole pine subspecies are widely distributed in North America, but Rocky Mountain lodgepole reaches the southern edge of its distribution in south-central Colorado. Lodgepole forests are not found at the highest elevations, but range from montane to subalpine. Statewide, the annual average precipitation range for lodgepole forest covers about 64% of Colorado's overall precipitation range. Growing season length for lodgepole broadly overlaps that of the warmer end of the spruce-fir distribution, and covers about 35% of the statewide range of growing degree days.

***Growth form and intrinsic dispersal rate***
Score: 0

The tree growth form and slow dispersal rate of lodgepole pine give this ecosystem a low resilience score in this category.

***Vulnerability to increased attack by biological stressors***
Score: 0

Although invasive species are generally not a threat, lodgepole forests are vulnerable to the pest outbreaks that appear to increase with warmer, drier, drought-prone climates. Biological stressors that interact with fire dynamics of lodgepole forest include infestations of lodgepole pine dwarf-mistletoe and mountain pine beetle (Anderson 2003). Dwarf mistletoe reduces tree growth and cone production, and generally leads to earlier mortality (Hawksworth and Johnson 1989). Although lodgepole forests are still common across Colorado, most have experienced widespread damage from a severe outbreak of mountain pine beetle. The pine beetle is a native species, and periodic outbreaks of this insect are part of the natural cycle that maintains Colorado's mountain forests. Lodgepole forests are expected to persist in Colorado (Kaufmann et al. 2008), although forest structure may differ from what has been present historically.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.5

Warming temperatures and effectively drier conditions are expected to have an effect on fire frequency and severity. Fire suppression effects in lodgepole pine forests are evident at a landscape level in an overall lack of variety in successional stages. Individual lodgepole stands may not be outside the natural range of variation, but at a landscape level fire suppression has probably led to larger, denser, more homogenous patches that are more favorable for large fire and heavy infestations of mountain pine beetle (Keane et al. 2002). The current outbreak of mountain pine beetle appears to be subsiding, leaving the potential for large fires with extreme behavior to occur in the killed forests (Kaufmann et al. 2008).

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.75

Lodgepole forest landscapes in Colorado are generally in good condition. Although large, intact patches of lodgepole forest persist in Colorado, this may change as the effects of extensive mountain pine beetle mortality and increased fire extent and frequency reshape the lodgepole matrix.

Development of exurban or recreational areas is a minor sources of disturbance and fragmentation in lodgepole forests, as are the associated roads and utility corridors. Timber harvest in Colorado's lodgepole forests has declined significantly since the late 19th century, but a recent increase in the use of beetle-kill wood had maintained a small market for this species. Wood harvest activities are a minor source of disturbance in this habitat type, but extensive salvage logging and thinning may have locally severe impacts.

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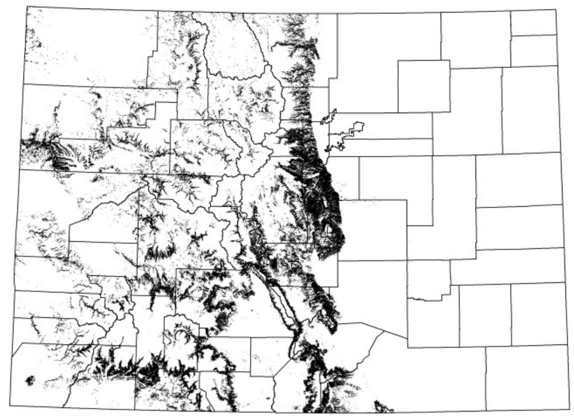
# MIXED CONIFER

Dry-mesic and mesic forests or woodlands of Douglas fir, white fir, other conifer species, and occasional aspen stands

R. Rondeau



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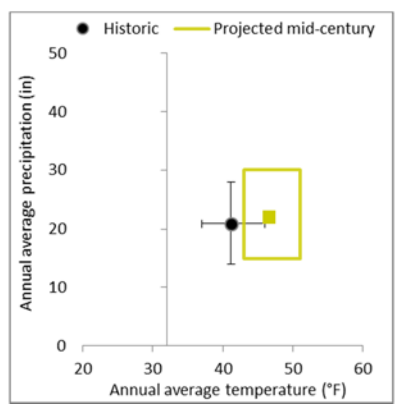
## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Warmer and drier conditions can be expected to change the relative tree species abundance in mixed conifer forests. Although some stands may convert to other types, the diverse species composition of these forests increases the likelihood that some species will benefit under future conditions. Novel mixed conifer types may appear.




The ecotonal nature of mixed conifer stands increases the difficulty of interpreting their vulnerability to climate change, and their capacity to move into new areas. The diversity of species within mixed conifer forest may increase its flexibility in the face of climate change. Changing climate conditions are likely to alter the relative dominance of overstory species, overall species composition and relative cover, primarily through the action of fire, insect outbreak, and drought. Drought and disturbance tolerant species will be favored over drought vulnerable species. Species such as blue spruce that are infrequent and have a narrow bioclimatic envelope are likely to decline or move up in elevation. Abundant species that have a wide bioclimatic envelope such as Gambel oak and aspen are likely to increase. Outcomes for particular stands will depend on current composition and location. Current stands of warm, dry mixed conifer below 8,500 ft may be at higher risk or may convert to pure ponderosa pine stands as future precipitation scenarios favor rain rather than snow. Upward migration into new areas may be possible.

### Distribution
In Colorado these mixed-conifer forests occur on all aspects at elevations ranging from 4,000 to 10,800 ft (1,200-3,300 m). The composition and structure of overstory is dependent upon the temperature and moisture relationships of the site, and the successional status of the occurrence. These complex forest and woodland communities are often intermingled with other forest types, including ponderosa pine, aspen, lodgepole, and spruce-fir, depending on elevation, and may be adjacent to shrubland and riparian types as well.

The similar environmental tolerances of mixed-conifer and aspen forest means that the two forest types are somewhat intermixed in many areas. These forests appear to represent a biophysical space where a number of different overstory species can become established and grow together. Local conditions, biogeographic history, and competitive interactions over many decades are prime determinants of stand composition.

### Characteristic species
Several sub-types or phases, representing a continuum from warm-dry to cold-wet have been described for these forests (Romme et al. 2009), and species composition, stand structure, and site characteristics vary accordingly.

These mixed-species forests may include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), quaking aspen (*Populus tremuloides*), blue spruce (*Picea pungens*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and limber pine (*Pinus flexilis*), which reaches the southern limit of its distribution in the San Juan mountains. Warm-dry sites are characterized by Douglas-fir, often with ponderosa pine and Gambel oak (*Quercus gambelii*). Cool-moist stands are likely to be dominated by Douglas fir, white fir, blue spruce and some quaking aspen. Typical understory shrub species include Rocky Mountain maple (*Acer glabrum*), Saskatoon serviceberry (*Amelanchier alnifolia*), *kinnikinnick* (*Arctostaphylos uva-ursi*), rockspirea (*Holodiscus dumosus*), fivepetal cliffbush (*Jamesia americana*), common juniper (*Juniperus communis*), creeping barberry (*Mahonia repens*), Oregon boxleaf (*Paxistima myrsinites*), mountain ninebark (*Physocarpus monogynus*), mountain snowberry (*Symphoricarpos oreophilus*), thimbleberry (*Rubus parviflorus*), and whortleberry (*Vaccinium myrtillus*). Where soil moisture is favorable, the herbaceous layer may be quite diverse.

Characteristic animal species in mixed conifer forest include Ruby-crowned kinglet, Hermit thrush, Hammond's flycatcher, Williamson's sapsucker, Yellow-rumped warbler, Pine siskin, Red-breasted nuthatch, Townsend's solitaire, Western tanager, Brown creeper, Cassin's finch, Red crossbill, Olive-sided flycatcher, Mountain chickadee, Junco, Snowshoe hare, Lynx, and Pine marten.

### Environment
The composition and structure of overstory is dependent upon the temperature and moisture relationships of the site, and the successional status of the occurrence (DeVelice et al. 1986, Muldavin et al. 1996). Drier sites, often on southerly aspects, may be similar to ponderosa pine forest, but with Douglas-fir and white fir as important canopy components. Historically, these stands were subject to fairly frequent low to moderate intensity fire, which helped to maintain a

relatively open structure (Romme et al. 2009). More mesic stands are found in cool ravines and on north-facing slopes, lack ponderosa pine, and are likely to be dominated by Douglas-fir and white fir with blue spruce or quaking aspen stands, and occasional inclusions of Engelmann spruce or subalpine fir. These cool-moist stands would have less frequent fires, and soil moisture conditions that allow the growth of dense stands that eventually burn in a high-intensity fire (Romme et al. 2009).

Soils of this ecosystem are variable, and may be derived from parent materials of igneous, metamorphic, or sedimentary origin. More open woodland communities are typically found on soils that are shallow, rocky, and well-drained.

### Dynamics

Long-term ecological dynamics of mixed conifer forests are relatively understudied (Romme et al. 2009). There has been considerable recent debate about historic range of variation for stand density and high-severity fire incidence in mixed conifer forests (Williams and Baker 2012, Fule et al. 2013, Williams and Baker 2014). Natural fire processes in this system are probably highly variable in both return interval and severity, depending on stand composition, site conditions, biogeographic history, and short- and long-term climate patterns. For instance, drought and high temperatures prior to fire initiation are associated with larger burned area as fine fuels become dry (Littell et al. 2009).

Although cool moist mixed-conifer forests are generally warmer and drier than spruce-fir forests, these stands are often in relatively cool-moist environments where fires were historically infrequent with mixed severity. When stands are severely burned, aspen often resprouts. Warm-dry mixed conifer forests had a historic fire-regime that was more frequent, with mixed severity. In areas with high severity burns, aspen or Gambel oak often resprouts and dominates the site for a relatively long period of time. In some locations, much of these forests have been logged or burned during European settlement, and present-day occurrences are second-growth forests dating from fire, logging, or other occurrence-replacing disturbances (Mauk and Henderson 1984, Chappell et al. 1997).

Additional disturbances in mixed conifer forests may be due to wind storms or insect-pathogen outbreaks. Spruce budworm infestations are a major source of tree mortality and can affect landscape-scale dynamics in mixed conifer forest (Romme et al. 2009).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0.1% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | Yes (61.0%) |
| Final Exposure-Sensitivity Rank | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, less than 1% of the current range of mixed conifer forest in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 61% of mixed conifer forest ecosystem in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

With the variation from warm-dry types to cool-moist types, mixed conifer forests have a broad ecological amplitude, and variation between stands is obviously influenced by both temperature and precipitation. The effects of climatic factors on the ecosystem as a whole, however, are little known, especially in Colorado. Generally warming conditions during the early Holocene allowed for the expansion of some mixed conifer forest tree species including Douglas-fir, ponderosa pine, and Gambel oak, and the development of mixed conifer forests in areas previously characterized by subalpine species (Anderson et al. 2008).

Studies from the southwestern US indicate that factors controlling the distribution and persistence of the component tree species in mixed conifer forests are complex and not easily explained at a broad climatic level. For instance, Kane and Kolb (2014) found that although drought was an important driver for aspen mortality in mixed conifer, there was no similar effect for the much slower-growing limber pine. Douglas-fir and white fir mortality during the drought was moderately associated with previous growth rate (i.e., site quality), indicating that longer-term processes such as competition and disturbance history may also play a role. Cool-moist mixed conifer forests of higher elevations may be less susceptible to drought (Adams and Kolb 2005), but are not completely protected by generally cooler, wetter conditions (Kane et al. 2014).

## Resilience and Adaptive Capacity Rank

| Overall Score: | 0.60 | Rank: | **Moderate** |
|---|---|---|---|

***Bioclimatic envelope and range***

Averaged category score: 0.78

Mixed conifer forests occur at foothill and montane elevations throughout central and western Colorado, and have a fairly wide ecological amplitude. These forests have significant presence in 60% of Colorado's overall precipitation range, and in 51% of the state's growing degree days range. The highly variable and ecotonal nature of mixed conifer forests contributes to the higher resilience score in this category.

***Growth form and intrinsic dispersal rate***

Score: 0

The tree growth form and slow dispersal rate of the dominant conifer species give this ecosystem a low resilience score in this category.

***Vulnerability to increased attack by biological stressors***
Score: 0.7

Stands in the southern part of Colorado have been impacted by the western spruce budworm and drought. Budworm outbreaks are part of a natural cycle in mixed conifer forest, but may be intensified by increasing drought frequency and the generally higher temperatures projected in coming decades.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.7

In areas adjacent to development, mixed conifer stands may be part of the wildland-urban interface, where they are most likely to be threatened by the effects of fire suppression. The absence of a natural fire regime in these forests has resulted in increased tree density and the buildup of duff and litter, which may increase the severity of fire when it does occur. As year-round temperatures increase and precipitation shifts more toward rain instead of snow, conditions favorable for increasing area burned may develop (Littell et al. 2009). However, many mixed conifer stands in Colorado are not as severely impacted by fire suppression.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.81

Mixed conifer forest landscapes in Colorado are generally in very good condition. Exurban development and recreational area development are a threat to these forests along the Front Range and I-70 corridor in mountain areas. Roads and utility corridors are a source of disturbance and fragmentation in mixed conifer forest statewide, but these stands naturally occur in smaller patches than some other forest types, so threats are minor. A number of tree species in mixed conifer are suitable for timber harvest, so logging is an ongoing source of disturbance in these forests. Threats from livestock grazing and hunting or recreational activities are minimal for mixed conifer forests. Mining and mine tailings are a small source of disturbance.

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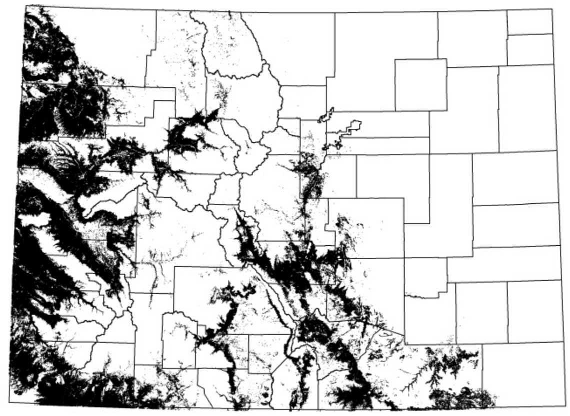
# PINYON-JUNIPER

Woodlands and shrublands dominated by pinyon pine and juniper species

S. Kettler



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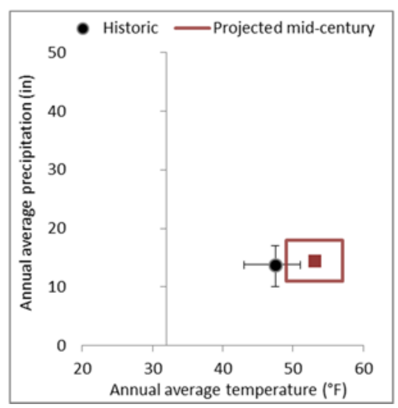
## Climate Vulnerability Rank: High

### Vulnerability summary

**Key Vulnerabilities:** Hot and dry conditions are likely to increase the impact of fire and insect outbreaks, and favor juniper over pinyon pine. Substrates play a key role in determining soil moisture availability for individual stands.




Variable disturbance and site conditions across the distribution of this ecosystem have resulted in a dynamic mosaic of interconnected communities and successional stages across the landscape. Since the last major glacial period, the distribution and relative abundance of pinyon and juniper has fluctuated with changing climatic conditions. Warming conditions during the past two centuries, together with changing fire regime, livestock grazing, and atmospheric pollution increased the ability of this ecosystem to expand into some neighboring communities, at both higher and lower elevations. However, precipitation and temperature patterns are projected to change in a direction that is less favorable for pinyon, so that juniper may become more dominant, and these habitats are unable to persist or expand in their current form. Primary factors contributing to the high ranking are the vulnerability of these woodlands to the interaction of drought, fire, and insect-caused mortality, which is likely to increase under changing climate, and the extent to which the current landscape condition of the habitat has been impacted by anthropogenic disturbance.

### Distribution

The North American distribution of this ecosystem is centered in the Colorado Plateau, generally southwest of Colorado. Pinyon-juniper forms the characteristic woodland of Colorado's western mesas and valleys, where it is typically found at lower elevations (ranging from 4,900 - 8,000 ft) on dry mountains and foothills. Pinyon and juniper may form sparse shrublands or woodlands on rocky tablelands where vegetation is largely confined to small soil pockets in exposed bedrock. Pinyon-juniper woodlands also occur on dry mountains and foothills in south-central and south-eastern Colorado, in mountains and plateaus of northern New Mexico and Arizona, and extend out onto shale breaks in the Great Plains. In the canyons and tablelands to the southeast, pinyon is absent, and juniper alone forms woodlands and savannas. Stands are often adjacent to and intermingled with oak, sagebrush, or saltbush shrubland.

### Characteristic species

Pinyon pine (*Pinus edulis*) and juniper form the canopy. In western pinyon-juniper woodlands of lower elevations, Utah juniper (*Juniperus osteosperma*) is prevalent and Rocky Mountain juniper (*J. scopulorum*) may codominate or replace it at higher elevations. In southeastern pinyon-juniper woodlands one-seed juniper (*Juniperus monosperma*) replaces Utah juniper. The understory is highly variable, and may be shrubby, grassy, sparsely vegetated, or rocky. Comer et al. (2003) separate Colorado's pinyon-juniper into four ecological systems: Colorado Plateau Pinyon-Juniper Woodland, Colorado Plateau Pinyon-Juniper Shrubland, Colorado Plateau Mixed Bedrock Canyon and Tableland, and Southern Rocky Mountain Pinyon-Juniper Woodland.

Pinyon-juniper woodland associations are characterized by stands with 25-60% canopy cover of trees that are typically 10-30 ft (3-10 m) in height. On dry rocky mesa tops and slopes these canopy dominants may be dwarfed (< 3 m tall), forming tall shrublands. On steep cliff faces, narrow canyons, and open tablelands of predominantly sedimentary sandstone, shale, and limestone, pinyon and juniper may form very sparse shrublands in cracks and pockets where soil has accumulated. Pinyon-juniper stands may be solely dominated by pinyon pine, or may be co-dominated by juniper species. Depending on substrate, the understory can range from a relatively rich mixture of evergreen and/or deciduous shrubs, to a sparse to moderately dense herbaceous layer dominated by perennial grasses (with or without shrubs), to no vegetation at all (Reid et al. 1999).

Characteristic shrubs and dwarf-shrubs include black sagebrush (*Artemisia nova*), big sagebrush (*Artemisia tridentata*), Utah serviceberry (*Amelanchier utahensis*), littleleaf mountain mahogany (*Cercocarpus intricatus*), mountain mahogany (*Cercocarpus montanus*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), mormon-tea (*Ephedra viridis*), broom snakeweed (*Gutierrezia sarothrae*), Stansbury cliffrose (*Purshia stansburiana*), antelope bitterbrush (*Purshia tridentata*), Gambel oak (*Quercus gambelii*), and mountain snowberry (*Symphoricarpos oreophilus*).

Perennial graminoids are the most abundant species in the sparse to moderately dense herbaceous layer. Characteristic species include Indian ricegrass (*Achnatherum hymenoides*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), threeawn (*Aristida* spp.), Arizona fescue (*Festuca arizonica*), needle-and-thread (*Hesperostipa comata*), bluebunch wheatgrass

(*Pseudoroegneria spicata*), muttongrass (*Poa fendleriana*), James' galleta (*Pleuraphis jamesii*), and western wheatgrass (*Pascopyrum smithii*). The forb layer may be diverse (and may include a number of rare species), but contributes little cover.

Pinyon jay, Plumbeous vireo, Juniper titmouse, Gray flycatcher, Black-throated gray warbler, and Bushtit are good indicators for the ecosystem.

**Environment**

Depending on substrate, pinyon-juniper stands are variable in structure and composition. Stands occur on a variety of aspects and slopes. Slope may range from nearly level to steep (up to 80%). Soils vary in texture ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. Parent materials likewise vary widely from granite, basalt, limestone, and sandstone to mixed alluvium (Springfield 1976). Soil depths may range from shallow to deep.

Mesic areas are generally pinyon-dominated, while junipers are able to dominate on drier sites (Gottfried 1992). Stands vary considerably in appearance and composition, both altitudinally and geographically. Juniper tends to be more abundant at the lower elevations, pinyon tends to be more abundant at the higher elevations, and the two species share dominance within a broad middle-elevation zone (Woodin and Lindsey 1954, Heil et al. 1993). Stands may range from even-aged to uneven-aged stands.

**Dynamics**

Pinyon-juniper woodlands are influenced by climate, fires, insect-pathogen outbreaks, and livestock grazing (West 1999, Eager 1999). Although it is clear that the structure and condition of many pinyon-juniper woodlands has been significantly altered since European settlement (Tausch 1999), in recent years there has been an emerging recognition that not all of these woodlands are dramatically changed by anthropogenic influence. Increasing density of pinyon juniper woodlands and expansion into adjacent grassland or shrubland are well documented in some areas, but is not a universal phenomenon in the western U.S. (Romme et al. 2009). Furthermore, the tree-dominated landscape characteristic of pinyon-juniper woodland today is not necessarily representative of the typical landscape of the past few millennia (Tausch 1999). Romme et al. (2009) distinguish three pinyon-juniper types (persistent woodlands, savannas, and wooded shrublands), using characteristics of based canopy structure, understory, and disturbance history. Local site conditions may result in a fine-scale mixture of type within a larger matrix of one type. The differences between these types have important implications for management actions, and efforts to maintain or restore natural processes in pinyon-juniper habitats.

Both pinyon pine and juniper are fairly slow growing, and can live for hundreds of years, a life cycle that is well adapted to xeric habitats, but is less suitable for quickly changing conditions. Although individuals of both species become reproductive after a few decades, most seed production is due to mature trees of 75 years of age or older (Gottfried 1992). Both species reproduce only from seeds, and do not resprout after fire. Cone production of mature pinyon pine takes three growing seasons, and the large seeds have a fairly short life span of 1-2 years (Ronco 1990). Juniper cones (often called berries) may require 1-2 years of ripening before they can germinate (Gottfried 1992).

The smaller seeds of juniper are generally long-lived, surviving as long as 45 years. Birds are important dispersers of both pinyon pine and juniper seed (Gottfried 1992).

The effects of fire in all types of pinyon-juniper depend in part on fuel provided by both canopy and understory, and by weather conditions during a fire (Romme et al. 2009). Sparse woodlands with little understory vegetation would typically have limited fire spread and little tree mortality. As tree density or understory cover (especially shrubs) increases fire spread is facilitated, and tree mortality becomes more likely. Romme et al. (2009) concluded that spreading, low-intensity surface fires have historically had a limited role in this ecosystem, and that instead the dominant fire effect is mortality of most trees and top-kill of most shrubs within the burned area, regardless of tree or shrub size. At Mesa Verde National Park, where pinyon-juniper woodlands have burned in five large fires since 1930, trees have not yet re-established. It is not known why trees have not been successful in these areas, which are now occupied by shrubland (Floyd et al. 2000).

For many pinyon-juniper woodlands, climate fluctuation and insect or disease outbreak are more important in shaping stand structure than fire. Insect and disease mortality is a natural ongoing process, usually at a low level, but occasionally as more severe episodic outbreaks. Weather patterns may enhance patterns of mortality or recruitment, shifting stand composition and structure on a local or regional scale (Eisenhart 2004, Breshears et al. 2005, Shaw et al. 2005).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 20.9% |
| Initial Exposure-Sensitivity Rank | Moderate |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (43.5%) |
| Final Exposure-Sensitivity Rank | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 23% of the current range of pinyon-juniper woodland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 64% of pinyon-juniper woodland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

These evergreen woodlands are adapted to cold winter minimum temperatures and low rainfall, and are often transitional between grassland or desert shrubland and montane conifer ecosystems (Brown 1994, Peet 2000). The pinyon-juniper ecosystem has large ecological amplitude; warmer conditions may allow expansion, as has already occurred in the past centuries, as long as there are periodic cooler, wetter years for recruitment. Increased drought may drive fires and insect outbreaks, from which these woodlands would be slow to recover. A 40% decline in pinyon pine cone production was associated with an average 2.3°F increase in summer temperatures in New Mexico and Oklahoma sites (Redmond et al. 2012). Warming temperatures may reduce recruitment for pinyon pine, and might increase mortality in drought-stressed trees (Adams et al. 2009).

Barger et al. (2009) found that pinyon pine growth was strongly dependent on sufficient precipitation prior to the growing season (winter through early summer), and cooler June temperatures. Both of these variables are predicted to change in a direction that is less favorable for pinyon pine. Drought can result in widespread tree die-off, especially of the more susceptible pinyon pine (Breshears et al. 2008). Clifford et al. (2013) detected a strong threshold at 23.6 in (60 cm) cumulative precipitation over a two-year drought period (i.e., essentially normal annual precipitation for pinyon pine). Sites above this threshold experienced little pinyon die-off, while sites receiving less precipitation included areas with high levels of mortality. Mortality of pinyon trees was extensive in the area during the 2002-2003 drought and bark beetle outbreak, but in areas where juniper and shrub species provide microsites for seedling establishment, pinyon may be able to persist (Redmond and Barger 2013). Patterns of precipitation and temperature (i.e., cool, wet periods) appear to be more important in recruitment events than history of livestock grazing (Barger et al. 2009).

## Resilience and Adaptive Capacity Rank

Overall Score: 0.41 Rank: **Low**

The statewide range of annual average precipitation is about 10-23 in (25-60 cm), with a mean of 16 in (40 cm), similar to sagebrush shrubland. Growing season temperatures are greater in the range of pinyon-juniper than for many other woody vegetation types in Colorado.

Extended drought can increase the frequency and intensity of insect outbreaks and wildfire. Pinyon are susceptible to the fungal pathogen *Leptographium wageneri* var. *wageneri*, which causes black stain root disease, and to infestations of the pinyon ips bark beetle (*Ips confusus*)(Kearns and Jacobi 2005). The differential susceptibility of pinyon and juniper to drought and insect outbreaks could eventually result in these woodlands being dominated by juniper.

### *Bioclimatic envelope and range*

Averaged category score: 0.76

The North American distribution of this ecosystem is centered in the Colorado Plateau, generally southwest of Colorado. Pinyon-juniper woodlands occur at foothill and lower montane elevations throughout central and western Colorado, and have a fairly wide ecological amplitude. Statewide, the annual average precipitation range for pinyon-juniper woodland includes about 44% of Colorado's overall precipitation range. Growing season length for these woodlands of warm, dry areas covers about 60% of the statewide range of growing degree days.

### *Growth form and intrinsic dispersal rate*

Score: 0

The tree growth form and slow dispersal rate of the dominant conifer species give this ecosystem a low resilience score in this category. Pinyon pine stands are slow to recover from intense fires; the species reproduces only from short-lived seeds and recovery is dependent on seed sources and/or adequate dispersal, as well as suitable microsites (e.g., under cover of trees or shrubs) for establishment (Floyd et al. 2015). Junipers are also slow-growing, and susceptible to being killed by fire.

***Vulnerability to increased attack by biological stressors***

Score: 0

Pinyon are susceptible to the fungal pathogen *Leptographium wageneri* var. *wageneri*, which causes black stain root disease (primarily on more mesic sites), and to infestations of the pinyon ips bark beetle (*Ips confusus*)(Kearns and Jacobi 2005), which has caused extensive mortality in pinyon-juniper habitats in southern Colorado. Extended drought can increase the frequency and intensity of insect outbreaks.

***Vulnerability to increased frequency or intensity of extreme events***

Score: 0.7

Pinyon pine stands are slow to recover from intense fires; the species reproduces only from seed and recovery is dependent on seed sources and/or adequate dispersal. Juniper are also slow-growing, and susceptible to being killed by fire. Extended drought can increase the frequency and intensity of both insect outbreaks and wildfire.

***Other indirect effects of non-climate stressors – landscape condition***

Score: 0.59

Pinyon-juniper habitats in Colorado have been moderately impacted by anthropogenic disturbance. Ongoing but limited threats from urban, exurban, and commercial development are primarily in the south central and southwestern portions of Colorado, where towns, roads, and utility corridors are often in close proximity to pinyon-juniper woodlands. As with other habitats in the wildland-urban interface, areas near developed areas are most likely to be threatened by the effects of fire suppression, while more remote areas are generally in good condition. Livestock grazing has degraded the understory grasses of some stands, and invasive cheatgrass (*Bromus tectorum*) has become established in some areas. Tree removal by chaining, or cutting for firewood is a minor source of disturbance within these woodlands, but may dramatically change the habitat where it has occurred. Military training activities are a source of disturbance to this habitat at Fort Carson and Pinyon Canyon Maneuver Site. Oil and gas development, with associated roads, pipeline corridors, and infrastructure, is an ongoing source of disturbance and fragmentation for most pinyon-juniper habitats.

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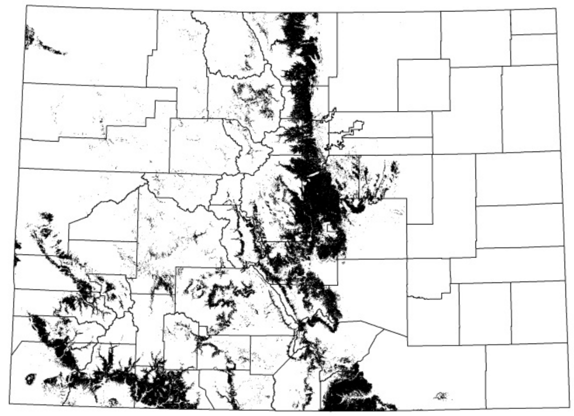
# PONDEROSA

Forests and woodlands dominated by ponderosa pine

S. Neid



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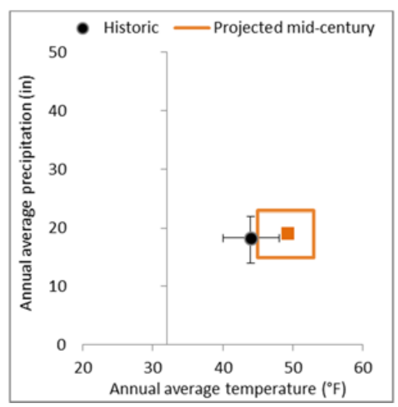
## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Increased drought intensity and/or frequency is likely to increase the impact of fire and insect outbreaks in ponderosa forests. Areas in the wildland-urban interface are most problematic.




Ponderosa pine forests and woodlands are ranked moderately vulnerable to the effects of climate change by mid-century. Primary factors contributing to this ranking are the exposure of large areas of this habitat to warmer temperatures that are likely to interact with forest stressors (mountain pine beetle, drought, and fire) that are, in turn, exacerbated by warm, dry conditions.

### Distribution

This widespread ecosystem is most common throughout the cordillera of the Rocky Mountains, but is also found in the Colorado Plateau region, west into scattered locations in the Great Basin, and north into southern British Columbia. These matrix-forming woodlands occur at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests, typically in warm, dry, exposed sites.

## Characteristic species

Ponderosa pine (*Pinus ponderosa*) is the predominant conifer; Douglas-fir (*Pseudotsuga menziesii*), pinyon pine (*Pinus edulis*), and juniper (*Juniperus* spp.) may also be present in the tree canopy. The understory is usually shrubby, with Saskatoon servicebery (*Amelanchier alnifolia*), black sagebrush (*Artemisia nova*), big sagebrush (*Artemisia tridentata*), kinnikinnick (*Arctostaphylos uva-ursi*), mountain mahogany (*Cercocarpus montanus*), chokecherry (*Prunus virginiana*), antelope bitterbrush (*Purshia tridentata*), Gambel oak (*Quercus gambelii*), and mountain snowberry (*Symphoricarpos oreophilus*) being common species. Bunchgrasses including bluebunch wheatgrass (*Pseudoroegneria spicata*) and species of needle-and-thread (*Hesperostipa*), needlegrass (*Achnatherum*), fescue (*Festuca*), muhly (*Muhlenbergia*), and grama (*Bouteloua*) are common understory grasses.

Grace's warbler, Pygmy nuthatch, and Flammulated owl are indicators of a healthy ponderosa pine woodland.

## Environment

This ecosystem occurs at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites at elevations ranging from 6,500-9,200 ft (1,980-2,800 m). It can occur on all slopes and aspects, however, it commonly occurs on moderately steep to very steep slopes or ridgetops. This ecosystem occurs on soils derived from igneous, metamorphic, and sedimentary substrates (Youngblood and Mauk 1985). Characteristic soil features include good aeration and drainage, coarse textures, circumneutral to slightly acid pH, an abundance of mineral material, and periods of drought during the growing season. Surface textures are highly variable in this ecosystem ranging from sand to loam and silt loam. Exposed rock and bare soil consistently occur to some degree in all the associations. Annual precipitation is 8-24 in (25-60 cm), mostly through winter storms and some monsoonal summer rains. Typically a seasonal drought period occurs throughout this system as well.

## Dynamics

Ponderosa pine is a drought-resistant and shade-intolerant conifer which often forms the lower treeline in the major mountain ranges of the western United States. Historically, ground fires and drought were influential in maintaining open-canopy conditions in these woodlands. With settlement and subsequent fire suppression, occurrences have become denser. Presently, many occurrences contain understories of more shade-tolerant species, such as Douglas-fir and/or white fir (*Abies concolor*) as well as younger cohorts of ponderosa pine. These structural changes have affected fuel loads and altered fire regimes. Presettlement fire regimes were primarily frequent (5-15 year return intervals), low-intensity ground fires triggered by lightning strikes or deliberately set fires by Native Americans. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature ponderosa pine (Reid et al. 1999).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0.9% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | Yes (69.4%) |
| Final Exposure-Sensitivity Rank | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 1% of the current range of ponderosa woodland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 70% of ponderosa pine woodland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Ponderosa pine occupies relatively dry, nutrient-poor sites compared to other montane conifers, but shows wide ecological amplitude throughout its distribution. Rehfeldt et al. (2012) were able to predict the distribution of ponderosa pine largely through the use of summer and winter precipitation, and summer temperatures (as growing degree days >5°C). Although periodic seasonal drought is characteristic across the range of ponderosa pine, this species is generally found where annual precipitation is at least 13 inches (Barrett et al. 1980, Thompson et al. 2000). Ponderosa stands to the south of Colorado were primarily reliant on winter precipitation (Kerhoulas et al. 2013), while growth of Front Range stands was correlated with spring and fall moisture (League and Veblen 2006), indicating some variability in the ability of ponderosa pine to take advantage of seasonal water availability, depending on site factors and stand history. Consequently, vulnerability of ponderosa forests to changes in precipitation patterns may differ according to their location in Colorado.

Ponderosa pine is able to tolerate fairly warm temperatures as long as there is enough moisture, especially in the growing season. Optimal germination and establishment conditions occur when temperatures are above 50°F and monthly precipitation is greater than 1 inch (Shepperd and Battaglia 2002). Significant recruitment events may occur on burned areas when conditions are wetter than normal after a fire year, but normal precipitation may also be sufficient for seedling establishment in such cases (Mast et al. 1998). In lower elevation ponderosa woodlands of the Colorado Front Range, episodic recruitment of ponderosa pine was associated with high spring and fall moisture availability during El Niño events (League and Veblen 2006). A correlation between drought and low rates of ponderosa seedling recruitment has also been identified throughout the western Great Plains (Kaye et al. 2010). Drought in combination with future projected higher temperatures is likely to reduce ponderosa pine regeneration, especially in drier, lower elevation areas. The work of Brown and Wu (2005) suggests that coincident conditions of sufficient moisture and fewer fires are important for widespread recruitment episodes of ponderosa pine; such conditions may become less likely under future climate scenarios.

Increased drought may drive fires and insect outbreaks. Relative proportions of associated species (e.g., other conifers, aspen, understory shrubs and grasses) in ponderosa stands may change. This ecosystem is well adapted to warm, dry conditions if precipitation is not too much reduced, and may be able to expand into higher elevations.

Although climate change may alter fire regimes slightly by affecting the community structure, fire is not expected to have a severe impact in the future for these stands, and may actually be beneficial in some areas if it restores some pre-settlement conditions (Covington and Moore 1994). These forests are susceptible to outbreaks of the mountain pine beetle and mistletoe infestations, both of which may be exacerbated by increased drought. Impacts of native grazers or domestic livestock could also alter understory structure and composition, and have the potential to negatively impact soil stability (Allen et al. 2002). While ponderosa pine forests may be able to expand upwards in elevation or remain in the same vicinity if precipitation doesn't drastically change, the density of some stands may decrease due to a reduction in available soil moisture. Stands of lower elevations and southwestern-facing slopes are most likely to experience reduced extent of ponderosa pine forests, with the potential for replacement by grassland, shrubland or pinyon-juniper woodland.

### Resilience and Adaptive Capacity Rank

| Overall Score: | 0.54 | Rank: | **Moderate** |
|---|---|---|---|

***Bioclimatic envelope and range***

Averaged category score: 0.76

Ponderosa woodlands are not found at high elevations, but instead form a broad zone of coniferous forest along the southern flank of the San Juan Mountains, as well as along the eastern mountain front, generally at elevations between 6,000 and 9,000 ft. These woodlands are in within the central portion of their North American distribution in Colorado. Annual precipitation is similar to that for oak shrubland, and ponderosa forests are found in 50% of Colorado's overall precipitation range. Ponderosa occurs in 50% of growing season lengths across the state.

***Growth form and intrinsic dispersal rate***

Score: 0

The tree growth form and slow dispersal rate of ponderosa pine give this ecosystem a low resilience score in this category. Although seeds are typically not dispersed very far, ponderosa pine is often present in mixed conifer stands; these areas may provide a seed bank for regeneration or a shift to ponderosa pine. Recruitment is episodic, depending on precipitation and disturbance patterns.

***Vulnerability to increased attack by biological stressors***

Score: 0.7

These forests are susceptible to outbreaks of the mountain pine beetle (*Dendroctonus ponderosae*) and mistletoe infestations, both of which may be exacerbated by increased drought. Mountain pine beetle has caused extensive mortality in ponderosa pine habitats throughout Colorado, although the current outbreak appears to be subsiding. Impacts of native grazers or domestic livestock, and the spread of invasive grasses could also alter understory structure and composition, with the potential to negatively impact soil stability (Allen et al. 2002).

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.7

Ponderosa pine is well adapted to survive frequent surface fires, and mixed-severity fires are characteristic in these communities (Arno 2000). Although climate change may alter fire regimes slightly by affecting the community structure, fire is not expected to have a severe impact in the future for these stands, and may actually be beneficial in some areas if it restores some pre-settlement conditions (Covington and Moore 1994). A projected increase in the frequency of drought conditions is likely to exacerbate both fire and insect outbreaks, and change the structure and composition of ponderosa woodlands.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.54

Ponderosa pine landscapes in Colorado have been moderately impacted by anthropogenic activities. Urban and exurban development are a primary threat to ponderosa pine habitat, especially along the Front Range, but also in other parts of the state. Increasing development has led to an extensive wildland-urban interface in ponderosa habitat, as well as fragmentation of stands in exurban areas due to housing, roads, and utility corridors; this trend is likely to continue (Theobald 2005). Oil and gas development, mining, and logging are minor sources of disturbance and fragmentation in ponderosa habitat.

Ponderosa forest and woodland historically experienced relatively frequent low intensity fires that controlled the density, age, and structure of stands. With fire suppression, ponderosa has increased into foothills grassland, stands have greatly increased in density, and open ponderosa savanna habitat has decreased. Increased tree density and fuel accumulation has resulted in more severe fires in this habitat, as well as increased occurrence of mountain pine beetle and dwarf mistletoe infestation. The alteration of natural fire regimes through fire suppression is an ongoing threat for ponderosa habitat where it is near developed areas.

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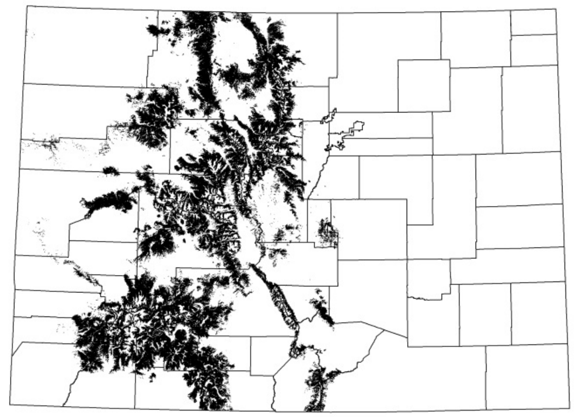
# SPRUCE-FIR

Dry-mesic and mesic forests dominated by Engelmann spruce and subalpine fir

R. Rondeau

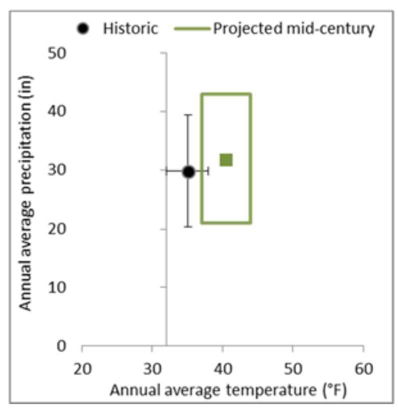


extent exaggerated for display

## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Increased drought intensity and/or frequency is likely to increase the impact of fire and insect outbreaks in subalpine forests. These forests recover slowly due to slow dispersal and a short growing season.




Climate change projections indicate an increase in droughts and faster snowmelt, which could increase forest fire frequency and extent, as well as insect outbreaks within this ecosystem. It is not known if spruce-fir forests will be able to regenerate under such conditions, especially in lower elevation stands, and there is a potential for a reduction or conversion to other forest types, depending on local site conditions.

The vulnerability of these forests to warmer temperatures, drought, and increased mortality from insect outbreaks are primary factors contributing to vulnerability. The restriction of this habitat to higher elevations and its relatively narrow biophysical envelope, slow-growth, and position near the southern end of its distribution in Colorado are additional factors. However, there may be a lag time before the effects of changing climate are evident.

The lag time of the current treeline position behind climate change is estimated to be 50-100+ years, due to the rarity of recruitment events, the slow growth and frequent setbacks for trees in the ecotone, and competition with already established alpine vegetation (Körner 2012). However, on the basis of historic evidence, treeline can be expected to migrate to higher elevations as temperatures warm, as permitted by local microsite conditions (Smith et al. 2003, Richardson and Friedland 2009, Grafius et al. 2012). The gradual advance of treeline is also likely to depend on precipitation patterns, particularly the balance of snow accumulation and snowmelt (Rochefort et al. 1994). Our analysis indicated that spruce-fir forests in Colorado have moderate vulnerability to the effects of climate change by mid-century.

### Distribution

Spruce-fir dry-mesic and moist-mesic forest ecosystems form the primary matrix systems of the montane and subalpine zones of the Southern Rocky Mountains ecoregion, and account for a substantial part of the subalpine forests of the Cascades and Rocky Mountains from southern British Columbia east into Alberta, south into New Mexico and the Intermountain region. Spruce-fir forest also shows changes with latitude including treeline elevation, species composition, and dominance. Subalpine fir (*Abies lasiocarpa*) decreases in importance relative to Engelmann spruce (*Picea engelmannii*) with increasing distance from the region of Montana and Idaho where maritime air masses influence the climate. Fir increases in importance with increasing latitude, and shares dominance with spruce at tree line over the northern half of the Southern Rocky Mountains ecoregion. Treeline occurs at over 12,450 ft (3800 m) at the southern end of the Southern Rocky Mountain ecoregion, but does not exceed 11,150 ft (3400 m) at the northern end (Peet 1978).

Individual community types may be matrix or large patch in character, though most typically occur as a mosaic of large patches across the landscape. Spruce-fir dominated stands occur on all but the most xeric sites above 10,000 ft (3,100 m), and in cool, sheltered valleys at elevations as low as 8,200 ft (2,500 m). The relative dominance of the two canopy tree species and the understory composition vary substantially over a gradient from excessively moist to xeric sites (Peet 1981). The mesic spruce-fir type occurs on cool, sheltered, but well-drained sites above 8,850 ft (2,700 m). Open slopes above 9,850 ft (3,000 m) are typically characterized by a more xeric spruce-fir type, with varying amounts of lodgepole and limber pine.

### Characteristic species

Engelmann spruce and subalpine fir dominate the canopy, either together or alone. Lodgepole pine (*Pinus contorta*) is common in many occurrences as are mixed conifer/quaking aspen (*Populus tremuloides*) stands. Understory species may include Geyer's sedge (*Carex geyeri*), common juniper (*Juniperus communis*), creeping barberry (*Mahonia repens*), Jacob's-ladder (*Polemonium pulcherrimum*) or whortleberry (*Vaccinium* spp.). More mesic understory may include red baneberry (*Actaea rubra*), sprucefir fleabane (*Erigeron eximius*), thimbleberry (*Rubus parviflorus*), yellowdot saxifrage (*Saxifraga bronchialis*), or alpine clover (*Trifolium dasyphyllum*), among other species.

Pine martens are primarily a spruce-fir obligate species that require a healthy and sizeable occurrence of mature forest and are an indicator of a healthy and viable occurrence of the spruce-fir ecosystem

**Environment**

These are the matrix forests of the subalpine zone, with rangewide elevations ranging from 5,000-11,000 ft (1,525 to 3,355 m). Sites are cold year-round, and precipitation is predominantly in the form of snow, which may persist until late summer. Moist-mesic occurrences are typically found in locations with cold-air drainage or ponding, or where snowpacks linger late into the summer, such as north-facing slopes and high-elevation ravines. They can extend down in elevation below the subalpine zone in places where cold-air ponding occurs; northerly and easterly aspects predominate. These forests are found on gentle to very steep mountain slopes, high-elevation ridgetops and upper slopes, high plateaus, basins, alluvial terraces, well-drained benches, and inactive stream terraces.

**Dynamics**

Fire, spruce-beetle outbreaks, avalanches, and windthrow all play an important role in shaping the dynamics of spruce-fir forests. Fires in the subalpine forest are typically stand replacing, resulting in the extensive exposure of mineral soil and initiating the development of new forests. Stand replacing fires are estimated to occur at intervals of about 300 years for dry-mesic areas, and longer (350-400 years) for more mesic sites (Romme and Knight 1981). Fire return intervals, intensity, and extent naturally depend on a variety of local environmental factors. Depending on site conditions, spruce or lodgepole pine may initially dominate the post-fire site, in combination with limber pine, and quaking aspen (Donnegan and Rebertus 1999). Fir is generally the least abundant for several decades after fire, but is able to establish in low-light conditions on forest litter, and gradually increases in abundance (Veblen et al. 1991).

Spruce beetle (*Dendroctonus rufipennis*) outbreaks may be even more significant than fire in the development of spruce-fir forests (Weed et al. 2013). When larger spruce trees are killed by spruce beetle infestation, smaller diameter spruce trees and subalpine fir trees are able to increase growth and continue to dominate the stand (Veblen et al. 1991). In addition to fires and beetle kill, wind disturbance in spruce-fir forests has been well documented (Schaupp et al. 1999). Blowdowns involving multiple treefalls add to the mosaic of spruce-fir stands. Under a natural disturbance regime, subalpine forests were probably characterized by a mosaic of stands in various stages of recovery from disturbance, with old-growth just one part of the larger forest mosaic (Peet 1981).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0.2% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (40.8%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, less than 1% of the current range of spruce-fir forest in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 41% of spruce-fir forest in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Spruce-fir forest typically dominates the wettest and coolest habitats below treeline. These areas are characterized by long, cold winters, heavy snowpack, and short, cool summers where frost is common (Uchytil 1991). Both Engelmann spruce and subalpine fir are dependent on snowmelt water for most of the growing season, and in low snowpack years growth is reduced (Hu et al. 2010).

The length of the growing season is particularly important for both alpine and subalpine zones, and for the transition zone between alpine vegetation and closed forest (treeline). Treeline-controlling factors operate at different scales, ranging from the microsite to the continental (Holtmeier and Broll 2005). On a global or continental scale, there is general agreement that temperature is a primary determinant of treeline. Körner (2012) attributes the dominance of thermal factors at this scale to the relative consistency of atmospheric conditions over large areas, especially in comparison to more local influence of soil and moisture factors. Furthermore, there appears to be a critical duration of temperatures adequate for the growth of trees in particular (e.g., individuals >3m tall) that determines the location of treeline. At more local scales, soil properties, slope, aspect, topography, and their effect on moisture availability, in combination with disturbances such as avalanche, grazing, fire, pests, disease, and human impacts all contribute to the formation of treeline (Richardson and Friedland 2009, Körner 2012). Patterns of snow depth and duration, wind, insolation, vegetation cover, and the autecological tolerances of each tree species influence the establishment and survival of individuals within the treeline ecotone (Moir et al. 2003, Holtmeier and Broll 2005, Smith et al. 2009). In the Rocky Mountains, tree establishment was significantly correlated with warmer spring (Mar-May) and cool-season (Nov-Apr) minimum temperatures as well (Elliott 2012).

Spruce-fir forests currently occupy cold areas with high precipitation; warmer and drier climate conditions predicted by most models could result in an upward migration of these forests into the alpine zone. However, in Canadian spruce-fir forests, warmer than average summer temperatures led to a decrease in growth the following year (Hart and Laroque 2013). Since spruce-fir may be able to tolerate warmer summer temperatures, the lower extent of this habitat type could remain at current levels for some time, even if growth is reduced.

The current location of treeline is a result of the operation of climatic and site-specific influences over the past several hundred years, and does not exactly reflect the current climate (Körner 2012). The treeline position lag time behind climate change is estimated to be 50-100+ years, due to the rarity of recruitment events, the slow growth and frequent setbacks for trees in the ecotone, and competition with already established alpine vegetation (Körner 2012). Nevertheless, on the basis of historic evidence, treeline is generally expected to migrate to higher elevations as temperatures warm, as permitted by local microsite conditions (Smith et al. 2003, Richardson and Friedland 2009, Grafius et al. 2012). In fact, treeline advance has already been documented at sites in the San Juan Mountains (Fink et al. 2014).

Furthermore, the lag time of decades or longer for treeline to respond to warming temperatures may allow the development of novel vegetation associations (Chapin and Starfield 1997), and make it difficult to identify temperature constraints on the distribution of this habitat (Grafius et al. 2012). The gradual advance of treeline is also likely to depend on precipitation patterns. Seedling establishment and survival are greatly affected by the balance of snow accumulation and snowmelt. Soil moisture, largely provided by snowmelt, is crucial for seed germination and survival. Although snowpack insulates seedlings and shields small trees from wind desiccation, its persistence shortens the growing season and can reduce recruitment (Rochefort et al. 1994).

### Resilience and Adaptive Capacity Rank

| Overall Score: | 0.34 | Rank: | Low |
| --- | --- | --- | --- |

***Bioclimatic envelope and range***

Averaged category score: 0.30

Spruce-fir forests in Colorado have a wide elevational range, extending from about 8,900 ft up to over 12,000 ft. Although not as restricted as alpine habitats, spruce-fir forests are generally limited to higher, cooler elevations, and are also near the southern extent of their continental range in Colorado. Statewide, annual average precipitation is only slightly lower than that of alpine, and these forests have significant presence in 82% of Colorado's overall precipitation range. Spruce-fir requires a longer growing season than alpine habitat, but is successful at much cooler temperatures than most other forest types, covering only 38% of the state's growing degree range. These factors combine to produce a relatively poor resilience score in this category.

***Growth form and intrinsic dispersal rate***

Score: 0

The tree growth form and slow dispersal rate of the dominant conifer species give this ecosystem a low resilience score in this category. Subalpine fir seeds require cold-moist conditions to trigger germination (Uchytil 1991), and there is some indication that Engelmann spruce seeds germinate faster at relatively low temperatures (Smith 1985), giving it a competitive advantage over less cold-tolerant species. Under warmer conditions, however, current spruce-fir communities may be gradually replaced by a mixed-conifer forest. There are no obvious barriers to the gradual dispersal of seedlings into adjacent, newly suitable habitat, although the dominant species are generally slow-growing.

***Vulnerability to increased attack by biological stressors***

Score: 0

Although these subalpine forests are not susceptible to increased prevalence of invasive species, they are vulnerable to outbreaks of the native pest species spruce bud worm and spruce beetle. Warmer temperatures (both winter and summer) are likely to facilitate these infestations. Warmer winters are correlated with reduced beetle mortality, while higher summer temperatures allow a greater proportion of the spruce beetle population to complete a generation in a single year, with a correspondingly higher probability of population outbreak (Bentz et al. 2010). The current distribution of spruce-fir habitat is therefore likely to be at increased risk of significant mortality. Insect outbreaks are also typically associated with droughts.

***Vulnerability to increased frequency or intensity of extreme events***

Score: 0.5

Historic natural fire-return intervals in these forests have been on the order of several hundred years, and the tree species are not adapted to more frequent fires. With an increase in droughts and faster snowmelts, we can expect an increase in forest fire frequency and extent within this zone as ignition of heavy fuel loads becomes less limited by cool, wet conditions. It is not known if spruce-fir forests will be able to regenerate under such conditions, especially in lower elevation stands, and there is a potential for a reduction in spruce-fir forests, at least in the short term.

***Other indirect effects of non-climate stressors – landscape condition***

Score: 0.89

Spruce-fir forest landscapes in Colorado are generally in very good condition, well protected, and minimally impacted by anthropogenic disturbance. Because natural fire return intervals in these habitats are long, fire suppression has not had widespread effects on the condition of spruce-fir habitat. At a landscape scale, however, age structures of spruce-fir forest are probably somewhat altered from pre-settlement conditions. Spruce-fir forests are subject to disturbance by recreational use, hunting, livestock grazing, mining, and logging, but in general, threats from housing, roads, and recreational development and similar anthropogenic disturbance are minor for spruce-fir habitats.

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## Shrubland

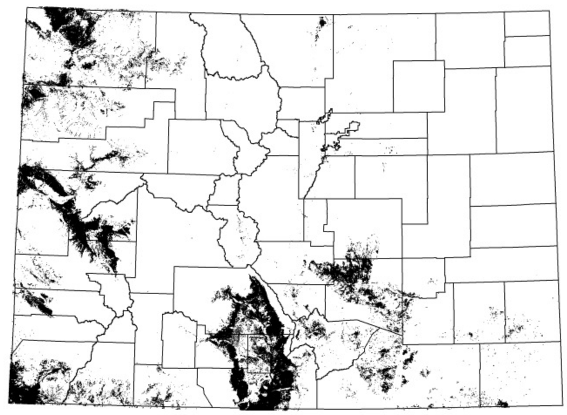
**Table 2.6.** Key vulnerabilities, shrubland ecosystems.

| Habitat | Climate factor(s) | Consequences | Other considerations |
|---|---|---|---|
| Desert shrubland | Soil moisture | Conversion to other type | Highly altered |
| Oak & mixed mtn. shrub | Drought, last frost date variability | Dieback with drought and late frost; may increase by resprouting after fire | Anthropogenic disturbance |
| Sagebrush | Drought | Increase in invasive species such as cheatgrass; fire | Variable by subspecies |
| Sandsage | Extended drought | Soil mobilization | Loss of native biodiversity |

# DESERT SHRUBLAND

Shrubland, shrub-steppe, dwarf-shrubland, and sparsely vegetated areas characterized by saltbush, rabbitbrush, winterfat, and other xeric shrub species

CNHP



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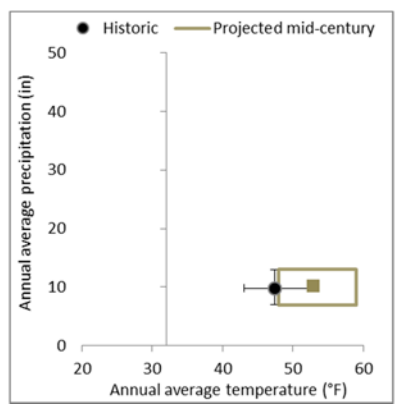
## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** The interaction of soil types and precipitation patterns largely determines the composition and extent of these shrublands, which may undergo conversion to other types under future climate conditions. The altered condition of many stands is a confounding factor.

The primary factor contributing to the moderate vulnerability ranking of desert shrublands in Colorado is the extent to which stands have been impacted by anthropogenic disturbance, with greatly altered species composition in many instances. The resilience score for this ecosystem is otherwise high, and, since these are communities of arid landscapes, they could be less vulnerable to climate change where stands are in good condition. However, changing soil moisture patterns may eventually favor semi-desert grassland in areas currently occupied by desert shrubland.




### Distribution

Desert shrubland communities occur throughout the intermountain western U.S., and are typically open-canopied shrublands dominated by saltbush species or other shrubs tolerant of saline or alkaline soils typically derived from marine shales, siltstones and clay. For this assessment, we grouped shrub-steppe, mixed salt desert shrub, mat saltbush shrublands, and sparsely vegetated shale badlands together as desert shrubland. These sparse to moderately dense low-growing shrublands are widespread at lower elevations in Colorado's western valleys, but also occur to a smaller extent on the eastern plains. Desert shrublands are found primarily between 4,500 and 7,000 feet, although shrub-steppe may extend up to 9,500 feet in some areas. Shrub-steppe does not form extensive stands in Colorado except in the San Luis Valley. Pinyon-juniper woodlands and sagebrush shrublands commonly are adjacent at the upper elevations.

### Characteristic species

Mat saltbush shrubland typically supports relatively pure stands of low-growing mat saltbush (*Atriplex corrugata*) or Gardner's saltbush (*Atriplex gardneri*). Other dwarf-shrub species that may be present include bud sagebrush (*Picrothamnus desertorum*) and shortspine horsebrush (*Tetradymia spinosa*). Scattered perennial forbs occur, such as desert princesplume (*Stanleya pinnata*), evening primrose (*Oenothera* spp. ), and phacelia (*Phacelia* spp.). Indian rice grass (*Achnatherum hymenoides*) and alkali sacaton (*Sporobolus airoides*) may be present in swales. Annuals may include desert trumpet (*Eriogonum inflatum*), and introduced species such as African mustard (*Malcolmia africana*) and cheatgrass (*Bromus tectorum*). Some areas are essentially barren, or very sparsely vegetated.

Mixed salt desert scrub is characterized by the taller saltbush species shadscale saltbush (*Atriplex confertifolia*) or fourwing saltbush (*Atriplex canescens*), and may include winterfat (*Krascheninnikovia lanata*), pale desert-thorn (*Lycium pallidum*), horsebrush (*Tetradymia canescens*), and various sagebrush (*Artemisia*) species. Grasses and forbs are sparse to moderately dense, and dominated by species tolerant of the harsh soils. Typical perennial grasses include Indian rice grass, blue grama (*Bouteloua gracilis),* thickspike wheatgrass (*Elymus lanceolatus* ssp. *lanceolatus*), western wheatgrass (*Pascopyrum smithii*), James' galleta (*Pleuraphis jamesii),* Sandberg bluegrass (*Poa secunda*), or alkali sacaton.

Colorado's shrub-steppes are grass-dominated areas with an open shrub layer. Typical grass species include blue grama, needle-and-thread (*Hesperostipa comata*), James' galleta, saltgrass (*Distichlis spicata*), Indian rice grass, and alkali sacaton. Historically, the shrub layer was dominated by winterfat, but this species has decreased under grazing pressure in many areas. Winterfat has largely been replaced by rabbitbrush (*Ericameria* and *Chrysothamnus*) species and other woody shrubs.

### Environment

Desert shrubland climate is generally arid or semi-arid with extreme temperature differences between summer and winter. For occurrences in southern Colorado, the monsoonal period of mid- to late summer normally provides most of the annual moisture; in northern areas precipitation is more evenly spread throughout the year, including during the coldest months. In these cold desert shrublands, however, the year to year variation of precipitation is likely to be greater than seasonal variablity, with resultant effects on interannual variability in growth and reproduction of shrubland species (Blaisdell and Holmgren 1984).

Desert shrubland substrates are generally shallow, typically saline or alkaline, fine-textured soils developed from shale or alluvium. Such soils are poorly developed, due to the arid climate, with very low infiltration rates (West 1983). Unvegetated substrate is common, and, if undisturbed, is often covered by a biological soil crust. Although perennial species tend to sort out along a moisture/salinity gradient according to individual species tolerances (West 1983), there do not appear to be any exceptionally narrow tolerances or requirements for a partcular soil factor present in typical desert shrubland plants (Blaisdell and Holmgren 1984).

### Dynamics

The naturally sparse plant cover makes these shrublands especially vulnerable to water and wind erosion, especially if vegetation has been impacted by grazing or disturbances including fire. Historically, salt desert shrublands had low fire frequency (Simonin 2001), and are characterized by low fuel mass and low soil moisture, which tends to mitigate fire impacts (Allen et al. 2011). However, increased extent of introduced annual grasses, especially cheatgrass, has facilitated the spread of fire by providing continuous surface fuels in many areas (West 1994, ). In the Great Basin, cheatgrass has demonstrably increased fire activity in sagebrush shrublands (Balch et al. 2013), but less is known about fire-sensitivity of saline desert types. Fire tolerance of *Atriplex* species is varied; most surviving individuals are able to resprout. Fourwing saltbush in New Mexico had severe mortality from fire (62% killed), but surviving shrubs quickly resprouted and eventually recovered prefire stature (Parmenter 2008). Shadscale is generally killed by fire and relies on seed for revegetation of burned areas (West 1994). Although their study did not include ungrazed plots for comparison, Haubensak et al. (2009) noted that, after fire, grazed desert shrublands had significantly lower vegetation cover, and were more invaded by non-native species in comparison with unburned plots.

Many of the dominant shrubs are palatable to domestic livestock, so grazing can alter species composition as well as increasing erosion potential. In combination with climatic variability, these disturbances act to change floristic composition of desert shrublands over time. For example, winterfat was historically a typical dominant in semi-desert shrub steppe. This palatable shrub is considered a decreaser under domestic livestock grazing. As a consequence of anthropogenically induced changes in grazing patterns, Greene's rabbitbrush (*Chrysothamnus greenei*) is now dominant in San Luis Valley shrub steppe, although the wetter areas still have significant amounts of winterfat.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 30.6% |
| Initial Exposure-Sensitivity Rank | Moderate |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (48.0%) |
| Final Exposure-Sensitivity Rank | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 37% of the current range of desert shrubland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 79% of desert shrubland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

The dominant desert shrubs are able to grow whenever temperatures are favorable, but only if there is sufficient soil moisture. Soil moisture accumulation is primarily in winter, and influences the amount of spring plant growth. If no additional moisture is received in spring, growth ends, and plants become dormant. Later rains during the warm season may re-induce growth (Blaisdell and Holmgren 1984). Soil saturation may cause mortality of the dominant shrubs (Ewing and Dobrowolski 1992). The characteristic interannual variability of precipitation in desert shrub areas, and the different life history strategies/phenology of the component species can produce dramatic differences in shrubland appearance from one year to the next (Blaisdell and Holmgren 1984). Munson et al. (2011) found decreased canopy cover in *Atriplex* shrublands with increasing temperature, which they attributed to increased evaporation and reduced water availability in the shale-derived soils. Thus, these shrublands may be able to tolerate higher temperatures only when precipitation is adequate. However, in some semi-arid and arid systems, temporal variation in water availability may create positive feedbacks that facilitate encroachment of $C_3$ woody plant species into areas formerly dominated by $C_4$ grasses. Other desert shrub species with deeper root systems (e.g., blackbrush, greasewood, mormon tea, sagebrush) are better adapted to expand into grassy areas than relatively shallow-rooted *Atriplex* species (Munson et al. 2011). Further differentiation between shrub species in the ability to utilize rainfall during particular seasons (Lin et al. 1996) may lead to changes in species composition in these shrublands. Shadscale saltbush (*A. confertifolia*) and other desert shrubs are typically dependent on spring soil moisture for growth, and have low metabolic activity during summer as the soil dries (Mata-González et al. 2014).

## Resilience and Adaptive Capacity Rank

Overall Score: 0.69 Rank: **Moderate**

***Bioclimatic envelope and range***

Averaged category score: 0.72

Desert shrublands are generally confined to warm, dry habitats within Colorado, occupying 31% of Colorado's overall precipitation range and 57% of the statewide range of growing degree days. These shrublands are not limited by elevational constraints, and are not at the southern edge of their range in Colorado, which gives them a good resilience score in this category.

***Growth form and intrinsic dispersal rate***

Score: 0.5

Although the dominant shrub species are likely to be fairly fast growing, lack of information about the dispersal rates of these species gives this ecosystem an intermediate resilience score for this category.

***Vulnerability to increased attack by biological stressors***
Score: 0.7

Increased invasion by non-native annual grasses and consequent increase in fire frequency is likely to depress recruitment of salt desert shrub species (Haubensak et al. 2009).

***Vulnerability to increased frequency or intensity of extreme events***
Score: 1

These shrublands are well adapted to drought, so have a high resilience score for this category. Increased fire effects are scored in the previous category as being mediated by cheatgrass invasion.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.51

Desert shrubland landscapes in Colorado have been moderately impacted by anthropogenic activities. Significant portions have been converted to agricultural use, especially in valley bottoms where irrigation is available. Remaining stands are generally in good condition, except for altered species composition in areas where grazing has reduced or eliminated some native bunch grasses. Ongoing limited threats from exurban development or conversion to agriculture are a minor source of disturbance, fragmentation, and habitat loss in the remaining extent of these shrublands. Oil and gas development, with associated roads, pipeline corridors, and infrastructure is the primary ongoing source of anthropogenic disturbance, fragmentation, and loss in this habitat. Livestock grazing has altered pre-settlement species composition, and this trend is likely to continue at a reduced rate. Roads and utility corridors, including those associated with solar energy development in the San Luis Valley are an ongoing source of disturbance, and can facilitate the spread of invasive plant species, which have become established in some areas.

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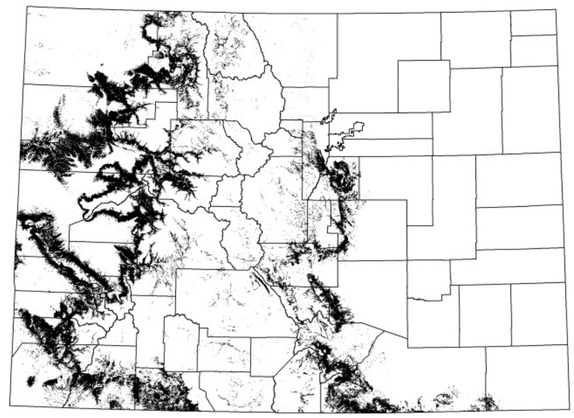
# OAK & MIXED MOUNTAIN SHRUB

Shrublands dominated by Gambel oak or serviceberry and other montane shrub species

S. Kettler



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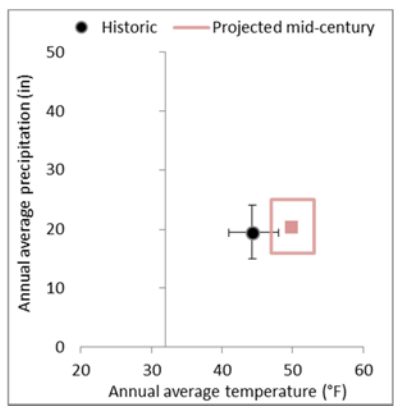
## Climate Vulnerability Rank: Low

### Vulnerability summary

**Key Vulnerabilities**: Oak shrublands are most vulnerable to drought and variability of late frosts. The vulnerability of other mountain shrub species is not well known. The ability to resprout after disturbance increases shrub resilience.

Oak and mixed mountain shrublands are ranked as having low vulnerability to the effects of climate change by mid-century. Primary factors contributing to this ranking are the wide ecological amplitude of these shrublands in Colorado, and their ability to withstand or recover from disturbance relatively quickly, which offsets the lower landscape condition score due to past anthropogenic disturbance levels.




### Distribution

This large patch ecosystem occurs in the mountains, plateaus, and foothills in the Southern Rocky Mountains and Colorado Plateau ecoregions. Oak and mixed mountain shrublands are widespread in the western half of Colorado, and along the southern stretch of the mountain front. These shrublands are most commonly found along dry foothills and lower mountain slopes from approximately 6,500 to 9,500 ft (2,000-2,900 m) in elevation, often situated above pinyon-juniper woodlands, and adjacent to ponderosa woodlands. There may be inclusions of other mesic montane shrublands with Gambel oak (*Quercus gambelii*) absent or as a relatively minor component. This ecosystem intergrades with the lower montane-foothills shrubland system and shares many of the same site characteristics.

### Characteristic species

Stands dominated by Gambel oak are common in the southern part of Colorado, but are completely interspersed with stands dominated by other shrub species, especially serviceberry (*Amelanchier* spp.) and mahogany (*Cercocarpus* spp.) at higher elevations. The vegetation is typically dominated by Gambel oak alone or codominant with Saskatoon serviceberry (*Amelanchier alnifolia*), Utah serviceberry (*Amelanchier utahensis*), big sagegrush (*Artemisia tridentata*), mountain mahogany (*Cercocarpus montanus*), chokecherry (*Prunus virginiana*), Stansbury cliffrose (*Purshia stansburiana*), antelope bitterbrush (*Purshia tridentata*), mountain snowberry (*Symphoricarpos oreophilus*), or roundleaf snowberry (*Symphoricarpos rotundifolius*). Vegetation types in this system may occur as sparse to dense shrublands composed of moderate to tall shrubs. Occurrences may be multi-layered, with some short shrubby species occurring in the understory of the dominant overstory species. Occurrences can range from dense thickets with little understory to relatively mesic mixed-shrublands with a rich understory of shrubs, grasses and forbs. These shrubs often have a patchy distribution with grass growing in between. Scattered trees are occasionally present in stands and typically include species of pine or juniper. Annual grasses and forbs are seasonally present, and weedy annuals are often present, at least seasonally.

Non-oak dominated montane shrublands are of variable species composition, depending on site conditions such as elevation, slope, aspect, soil type, moisture availability, and past history. Species present may include mountain mahogany (*Cercocarpus montanus*), skunkbush sumac (*Rhus trilobata*), cliff fendlerbush (*Fendlera rupicola*), antelope bitterbrush (*Purshia tridentata*), wild crab apple (*Peraphyllum ramosissimum*), snowberry (*Symphoricarpos* spp.), and serviceberry (*Amelanchier* spp.). Most of these species reproduce both vegetatively and by seedling recruitment, as well as resprouting easily after fire. Variable disturbance patterns may account for the local dominance of a particular species (Keeley 2000). Although fire is an obvious source of disturbance in these shrublands, snowpack movements (creep, glide, and slippage) may also provide significant disturbance in slide-prone areas (Jamieson et al. 1996).

Spotted towhee, Virginia warblers, Green-tailed towhee, Blue-gray gnatcatcher, Turkey, black bear, deer, elk, and mountain lion are characteristic of these shrublands.

### Environment

This ecosystem typically occupies the lower slope positions of the foothill and lower montane zones where it may occur on level to steep slopes, cliffs, escarpments, rimrock slopes, rocky outcrops, and scree slopes. Climate is semi-arid and characterized by mostly hot-dry summers with mild to cold winters and annual precipitation of 10-27 in (25-70 cm). Most precipitation occurs as winter snow but late summer monsoonal rain may be significant in southern stands. Substrates are variable and include soil types ranging from calcareous, heavy, fine-grained loams to sandy loams, gravelly loams, clay loams, deep alluvial sand, or coarse gravel. Soils are typically poorly developed, rocky to very rocky, and well-drained. Parent materials include alluvium, colluvium, and residuum derived from igneous, metamorphic, or sedimentary rocks such as granite, gneiss, limestone, quartz, monzonite, rhyolite, sandstone, schist, and shale.

### Dynamics

These shrublands are highly fire tolerant. Fire causes die-back of the dominant shrub species in some areas, promotes stump sprouting of the dominant shrubs in other areas, and controls the invasion of trees into the shrubland system. Density and cover of Gambel oak and serviceberry often increase after fire. Natural fires typically result in a system with a mosaic of dense shrub clusters and openings dominated by herbaceous species. Historic natural fire return intervals were on the order of 100 years in Mesa Verde (Floyd et al. 2000); under such conditions of low fire frequency, vulnerable newly sprouted stems are able to persist and form dense thickets.

Insect pests affecting Gambel oak include the wood borer (*Agrilus quercicola*) and the oak leafroller (*Archips semiferana*). The western tent caterpillar (*Malacosoma californicum*) is a common defoliator of shrub species. Large outbreaks of these insects have historically been infrequent in Colorado oak and mixed mountain shrublands (USDA Forest Service 2010).

Oak and mixed mountain shrublands are important habitat for wildlife, especially mule deer, turkey, and black bear (Jester et al. 2012). Because oak is generally unpalatable to cattle, livestock grazing can facilitate the increase of oak cover at the expense of understory grasses (Mandany and West 1983). Native mule deer, however, browse oak and mixed mountain shrub species during most seasons (Kufeld et al. 1973).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 1.8% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (47.0%) |
| Final Exposure-Sensitivity Rank | **Low** |

#### *Exposure to temperature change*

Under projected mid-century temperatures, about 2% of the current range of oak-mixed mountain shrubland in Colorado would experience annual mean temperatures above the current statewide maximum.

#### *Exposure to precipitation change*

About 49% of oak-mixed mountain shrubland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

#### *Sensitivity of ecosystem to temperature and precipitation*

In general, the upper and lower elevational limits of Gambel oak shrubland are believed to be controlled by temperature and moisture stress. Neilson and Wullstein (1983) found that seedling mortality was primarily due to spring freezing, grazing, or summer drought stress. At more northern latitudes, the zone of tolerable cold stress is found at lower elevations, but, at the same time, the areas where summer moisture stress is tolerable are at higher elevations. Neilson and Wullstein (1983) hypothesize that the northern distributional limit of Gambel oak corresponds to the point where these two opposing factors converge. Oak shrublands are typically found in areas with mean annual temperatures between 45 and 50°F (7 -10°C; Harper et al. 1985). At higher, cooler elevations, acorn production may be limited by the shortness of the growing season, and most reproduction is likely to be vegetative (Christensen 1949). Warming temperatures may increase both acorn production and seedling survival.

Although oaks are most likely to do well under climate change, droughts may reduce the frequency of establishment through seedling recruitment by reducing seedling survival (Neilson and Wullstein 1983). The larger acorn-producing stems also appear to be more vulnerable to drought induced mortality.

### Resilience and Adaptive Capacity Rank

| Overall Score: | 0.85 | Rank: | **High** |
|---|---|---|---|

***Bioclimatic envelope and range***

Averaged category score: 0.76

Oak and mixed mountain shrublands are widespread in western Colorado, and have a relatively broad ecological amplitude. These shrublands are not confined to high elevations, and are not at the southern edge of their range in Colorado. Oak and mixed mountain shrublands have significant presence in 52% of Colorado's overall precipitation range, and 53% of the state's growing degree day range, resulting in a fairly high resilience score for this category

***Growth form and intrinsic dispersal rate***

Score: 1

The shrub growth form of the dominant species, and ability to quickly colonize new areas give this ecosystem a high resilience score for this category. Gambel oak reproduces primarily by sprouting of new stems, especially after disturbances such as brush control, fire, and grazing, although recruitment from seedlings does occur (Brown 1958, Harper et al. 1985). The extensive clonal root system of Gambel oak is a primary contributor to its ability to survive during periods when seedling establishment is impossible.

***Vulnerability to increased attack by biological stressors***

Score: 1

In general oak and mixed mountain shrublands are not highly vulnerable to increased effects of biological stressors. In some areas, oak stands are vulnerable to increased prevalence of invasive species such as cheatgrass (*Bromus tectorum*) and knapweeds (*Centaurea* spp.). Livestock grazing has degraded the understory grass community of some oak stands, and cheatgrass and knapweed have become established in some areas. Mixed mountain shrublands are less impacted by invasives.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 1

These shrublands are highly fire tolerant. It is possible for this system to move up in elevation, especially if fires open up some of the adjacent forested ecosystems.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 4.9

Oak and mixed mountain shrubland landscapes in Colorado have been moderately impacted by anthropogenic activities. Ongoing but limited threats from urban, exurban, commercial, and energy development are primarily in the southern and western portions of Colorado, where towns, roads, and utility corridors are often in close proximity to oak shrublands. Mixed mountain shrublands are somewhat less impacted by developments, primarily those associated with recreation areas or exurban housing. Fire is a source of disturbance in these shrublands, and they are highly fire tolerant. As with other habitats in the wildland-urban interface, areas near developed areas are most likely to be threatened by the effects of fire suppression, while more remote areas are generally in good condition.

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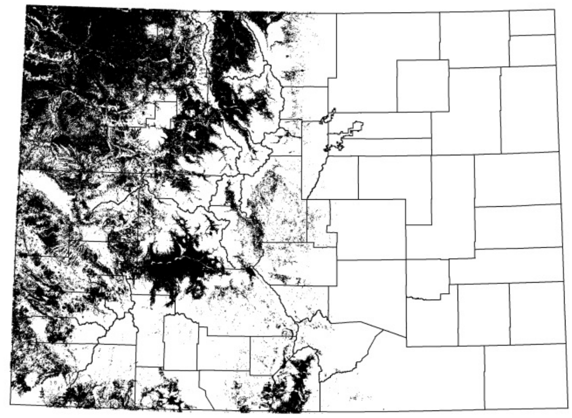
# SAGEBRUSH

Shrubland and steppe characterized by sagebrush, including three subspecies of big sagebrush, black sagebrush, Bigelow sage, and little sagebrush

R. Rondeau



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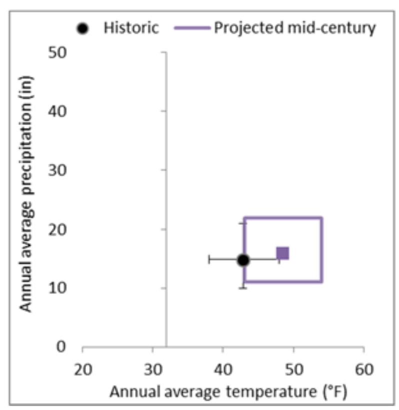
## Climate Vulnerability Rank: Low

### Vulnerability summary

**Key Vulnerabilities:** Increased drought intensity and/or frequency is likely to increase the impacts of fire in sagebrush shrublands, as well as play a role in the spread of invasive species. The vulnerability of sagebrush shrublands is expected to be variable by subspecies.




Sagebrush shrublands are ranked as having low vulnerability to the effects of climate change by mid-century. The primary factor contributing to this ranking is the comparatively low projected exposure to warmer and drier future conditions in the part of Colorado where the greater portion of this habitat is found. The combination of the three big sagebrush subspecies in our analysis collectively gives this habitat type a wide ecological amplitude. Under a longer time frame, these shrublands may have higher vulnerability, similar to the assessment of Pocewicz et al. (2014) for sagebrush habitats in Wyoming. In particular, the degraded condition of some areas, and the vulnerability of this ecosystem to potential increases in fire frequency and severity, could increase the vulnerability to climate change.

### Distribution

As evaluated herein, the three subspecies of big sagebrush (basin big sagebrush, *Artemisia tridentata* ssp. *tridentata,* mountain big sagebrush, *A. tridentata* ssp. *vaseyana,* and Wyoming big sagebrush, *A. tridentata* ssp. *wyomingensis*) are combined as the sagebrush ecosystem. In general, Wyoming big sagebrush is found in drier, warmer areas where precipitation is more likely to be in the form of rain, while mountain big sagebrush is found at higher, cooler elevations where snow is the dominant form of precipitation (Howard 1999, Johnson 2000). Changes in temperature and precipitation patterns may result in shifts in the relative abundance and distribution of the three subspecies.

This matrix forming ecosystem occurs throughout the much of western U.S. In Colorado, the largest occurrences are in the western half of the state, but this system can also be found in eastern Colorado. Northwestern Colorado, North Park, Middle Park, and the upper Gunnison Basin have large and continuous stands of sagebrush shrublands.

### Characteristic species

Sagebrush shrublands of lower, drier elevations are dominated by basin big sagebrush and/or Wyoming big sagebrush. Additional shrub species present may include silver sagebrush (*Artemisia cana*), rabbitbrush (*Chrysothamnus* or *Ericameria* spp.), winterfat (*Krascheninnikovia lanata*), and antelope bitterbrush (*Purshia tridentata*). Understories are typically grassy, and common graminoid species include Indian ricegrass (*Achnatherum hymenoides*), blue grama (*Bouteloua gracilis*), Geyer's sedge (*Carex geyeri*), thickspike wheatgrass (*Elymus lanceolatus*), Idaho fescue (*Festuca idahoensis*), Thurber fescue (*F. thurberi*), needle-and-thread (*Hesperostipa comata*), basin wildrye (*Leymus cinereus*), western wheatgrass (*Pascopyrum smithii*), James' galleta (*Pleuraphis jamesii*), Sandberg bluegrass (*Poa secunda*), or bluebunch wheatgrass (*Pseudoroegneria spicata*). Perennial forb species typically contribute less than 25% vegetative cover.

Montane sagebrush shrubland or steppe is characterized by mountain big sagebrush, and a variety of other shrubs including Saskatoon serviceberry (*Amelanchier alnifolia*), little sagebrush (*Artemisia arbuscula*), prairie sagewort (*Artemisia frigida*), rubber rabbitbrush (*Ericameria nauseosa*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), mountain snowberry (*Symphoricarpos oreophilus*), antelope bitterbrush, wax currant (*Ribes cereum*), and Woods' rose (*Rosa woodsii*), may be present. Both forbs and grasses are typically well represented in the understory. Common graminoids include Idaho fescue, Thurber fescue, timber oatgrass (*Danthonia intermedia*), Parry's oatgrass (*Danthonia parryi*), squirreltail (*Elymus elymoides*), slender wheatgrass (*Elymus trachycaulus*), spike fescue (*Leucopoa kingii*), western wheatgrass, bluebunch wheatgrass, muttongrass (*Poa fendleriana*), Sandberg bluegrass and upland sedges (*Carex* spp.). Forb species may include common yarrow (*Achillea millefolium*), rosy pussytoes (*Antennaria rosea*), white sagebrush (*Artemisia ludoviciana*), milkvetch (*Astragalus* spp.), arrowleaf balsamroot (*Balsamorhiza sagittata*), Indian paintbrush (*Castilleja* spp.), fleabane (*Erigeron* spp.), buckwheat (*Eriogonum* spp.), strawberry (*Fragaria virginiana*), avens (*Geum* spp.), owl's-claws (*Hymenoxys hoopesii*), lupine (*Lupinus*, spp.), phlox (*Phlox* spp.), and cinquefoil (*Potentilla* spp.).

Sage-grouse (*Centrocercus* spp.) is an indicator of a healthy sagebrush shrubland.

### Environment

Big sagebrush shrublands are typically found in broad basins between mountain ranges, on plains and foothills. Sites are typically flat to rolling hills with deep, well-drained sandy or loam soils between 7,000 to 10,000 feet in elevation. Most annual precipitation falls as snow in winter. Temperatures exhibit large annual and diurnal variation.

### Dynamics

Although sagebrush tolerates dry conditions and fairly cool temperatures it is not fire adapted, and is likely to be severely impacted by intense fires that enhance wind erosion and eliminate the seed bank (Schlaepfer et al. 2014). Increased fire frequency and severity in these shrublands could result increasing area dominated by exotic grasses, especially cheatgrass (*Bromus tectorum*) (D'Antonio and Vitousek 1992, Shinneman and Baker 2009). Warmer, drier sites (typically found at lower elevations) are more invasible by cheatgrass (Chambers et al. 2007). There is a moderate potential for invasion by knapweed species, oxeye daisy, leafy spurge, and yellow toadflax under changing climatic conditions, and a potential for changing fire dynamics to affect the ecosystem. There is no information on the vulnerability of this ecosystem in Colorado to insect or disease outbreak, although severe outbreaks of the sagebrush-defoliating moth *Aroga websteri* have been recorded further west in the Great Basin (Bentz et al. 2008). Grazing by large ungulates (both wildlife and domestic livestock) can change the structure and nutrient cycling of sagebrush shrublands (Manier and Hobbs 2007), but the interaction of grazing with other disturbances such as fire and invasive species under changing climatic conditions appears complex (e.g. Davies et al. 2009) and not well studied in Colorado.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 3.7% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (22.1%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 5% of the current range of sagebrush shrubland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 26% of sagebrush shrubland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Bradley (2010) points out that sagebrush shrublands in the western U.S. are currently found across a wide latitudinal gradient (from about 35 to 48 degrees north latitude), which suggests adaptation to a correspondingly wide range of temperature conditions. However, because these shrublands are apparently able to dominate a zone of precipitation between drier saltbush shrublands and higher, somewhat more mesic pinyon-juniper woodland, the distribution of sagebrush shrublands is likely to be affected by changes in precipitation patterns (Bradley 2010). Seasonal timing of precipitation is important for sagebrush habitats; summer moisture stress may be limiting if winter precipitation is low (Germino and Reinhardt 2014). Seedlings of mountain big sagebrush are more sensitive to freezing under reduced soil moisture conditions (Lambrecht et al. 2007). Winter snowpack is critical for sagebrush growth; lower elevations are probably more at risk from temperature impacts in comparison to upper elevations due to less snow, and consequently greater water stress.

Under experimental warming conditions in a high-elevation population, mountain big sagebrush had increased growth, suggesting that longer growing season length could facilitate the expansion of sagebrush habitat into areas that were formerly too cold for the shrub (Perfors et al. 2003). However, Poore et al. (2009) found that high summer temperatures resulted in lower growth rate, due to increased water stress.

Schlaepfer et al. (2012) modeled future distribution of the big sagebrush ecosystem in the western U.S. Over the entire study area, sagebrush distribution was predicted to decrease, especially under higher $CO_2$ emissions scenarios. The strongest decreases are in the southern part of the range (including southwestern Colorado), while the distribution is predicted to increase at higher elevations and in areas far to the north of Colorado.

## Resilience and Adaptive Capacity Rank

Overall Score: 0.61 Rank: **Moderate**

***Bioclimatic envelope and range***
Averaged category score: 0.83

These shrublands are primarily found in the western part of the state, at elevations from about 5,000 to 9,500 ft, and are not restricted to high elevations. The North American distribution of sagebrush habitat is largely to the west and north of Colorado. The three subspecies of big sagebrush show an elevational separation, with mountain big sagebrush in wetter, cooler conditions of higher elevations, and Wyoming big sagebrush in the warmest and driest conditions at lower elevations (Howard 1999). Due to the adaptations of the various subspecies, the range of annual average precipitation for sagebrush habitats is fairly wide, from about 8-40 in (20-100 cm), with a mean of 18 in (45 cm), covering 64% of the statewide precipitation range. Growing season heat accumulation is also highly variable across the range of the habitat, for the same reason, and covers 67% of the statewide range. This combination of factors gives sagebrush shrublands a high resilience score in this category.

***Growth form and intrinsic dispersal rate***
Score: 0.5

Sagebrush received an intermediate resilience score due to its generally slower growth rates and inability to resprout after fire. Sagebrush is generally a poor seeder, with small dispersal distances, however, there are no apparent barriers to dispersal for these shrublands. These stands may also be somewhat vulnerable to changes in phenology.

***Vulnerability to increased attack by biological stressors***
Score: 0.7

Other stressors for sagebrush shrublands are invasion by cheatgrass and expansion of pinyon-juniper woodlands. There is a moderate potential for invasion by knapweed species, oxeye daisy, leafy spurge, and yellow toadflax under changing climatic conditions, and a potential for changing fire dynamics to affect the ecosystem. There is no information on the vulnerability of this ecosystem to insect or disease outbreak.

Grazing by large ungulates (both wildlife and domestic livestock) can change the structure and nutrient cycling of sagebrush shrublands (Manier and Hobbs 2007), but the interaction of grazing with other disturbances such as fire and invasive species under changing climatic conditions appears complex (e.g. Davies et al. 2009) and not well studied in Colorado.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.5

Although sagebrush tolerates dry conditions and fairly cool temperatures it is not fire adapted, and none of the subspecies resprout after fire (Tirmenstein 1999). Sagebrush shrubland is likely to be severely impacted by intense fires that enhance wind erosion and eliminate the seed bank (Young and Evans 1989). Increased drought may increase fire frequency and severity, eliminating sagebrush in some areas, especially at drier sites of lower elevations. Increased fire frequency and severity in these shrublands may result in their conversion to grasslands dominated by exotic species.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.53

Sagebrush shrubland landscapes in Colorado have been moderately impacted by anthropogenic disturbance. Threats to sagebrush shrublands from exurban or recreational area development are limited, but ongoing at a very low level. Hunting and recreation are minor sources of disturbance in this habitat. Chaining or other shrub removal for mown hay, and to a lesser extent conversion to cropland is a substantial threat in northwestern Colorado. Large coal mining operations that completely remove this habitat prior to reclamation activity are an ongoing threat to the connectivity and quality of these shrublands. Oil and gas development, with associated roads, pipeline corridors, and infrastructure is another ongoing source of anthropogenic disturbance, fragmentation, and loss in this habitat in northwestern Colorado.

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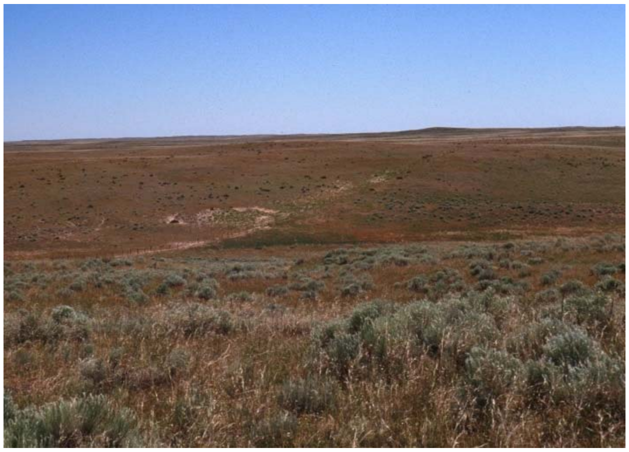
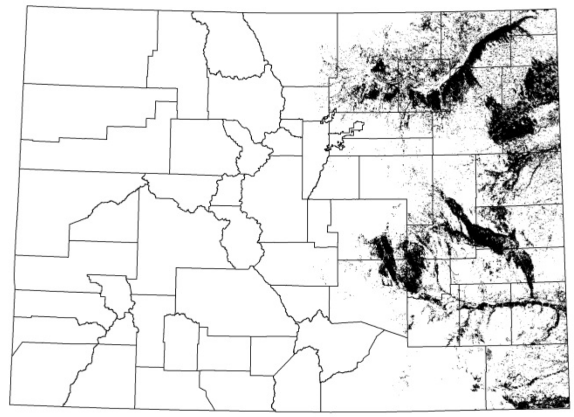
# SANDSAGE

Shrubland or steppe characterized by sand sagebrush



S. Kettler



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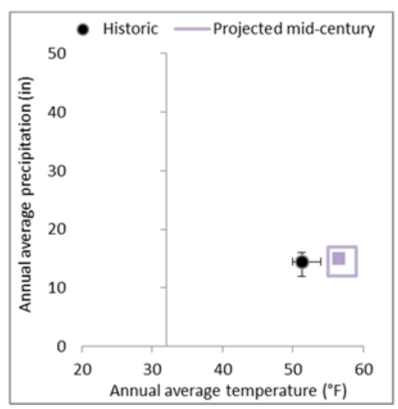
## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Extended periods of drought that decrease levels of vegetation cover would increase the likelihood that sandy substrates will be mobilized. The loss of native plant biodiversity in many stands decreases the available assemblage of drought-adapted species that can boost resilience to this vulnerability.




Sandsage shrublands are ranked moderately vulnerable to the effects of climate change by mid-century. This ranking is primarily due to the concentration of greatest exposure for all temperature variables on the eastern plains of Colorado, where this ecosystem is found. In addition, anthropogenic disturbance in these shrublands has reduced the overall landscape condition of the habitat. These shrublands are well adapted to sandy soils, and may be able to expand into adjacent areas under warmer, drier conditions, depending on disturbance interactions. Overall condition and composition of these shrublands may change with changing climate.

### Distribution

The sandsage ecosystem is found primarily in the south-central areas of the Western Great Plains. Occurrences generally range from the Nebraska Sandhill region south to central Texas, although some examples may be found as far north as the Badlands of South Dakota. The greater part of the ecosystem occurs in the Central Shortgrass Prairie ecoregion in eastern Colorado, western Kansas and southwestern Nebraska. Sandsage shrubland dominates sandy soils of Colorado's eastern plains, at elevations generally below 5,500 ft.

These shrublands have often been treated as an edaphic variant of eastern plains mixed-grass prairie (Albertson & Weaver 1944, Daley 1972), or of shortgrass prairie (Ramaley 1939, Sims and Risser 2000). Sandsage (*Artemisia filifolia*) forms extensive open shrublands in sandy soils of Colorado's eastern plains, and is of particular importance for both greater and lesser prairie chicken habitat, as well as for other grassland birds. In eastern Colorado, this system is found in extensive tracts on Quaternary eolian deposits along the South Platte, Arikaree and Republican Rivers, between Big Sandy and Rush Creeks, and along the Arkansas and Cimarron Rivers, where it is contiguous with areas in Kansas and Oklahoma (Comer et al. 2003).

### Characteristic species

Throughout its range, this system is characterized by a sparse to moderately dense woody layer dominated by sandsage. These shrubs usually do not grow as clumps but rather as individuals, and the intervening ground is most often dominated by a sparse to moderately dense layer of tall, mid- or short grasses. Associated species can vary with geography, precipitation, disturbance and soil texture. Graminoid species such as sand bluestem (*Andropogon hallii*), threeawn (*Aristida spp.*), grama (*Bouteloua* spp.), prairie sandreed (*Calamovilfa longifolia*), needle-and-thread (*Hesperostipa comata*), and sand dropseed (*Sporobolus cryptandrus*) are typical. Other shrub species may also be present including tree cholla (*Cylindropuntia imbricata*), broom snakeweed (*Gutierrezia sarothrae*), pricklypear (*Opuntia* spp.), western sandcherry (*Prunus pumila* var. *besseyi*), and soapweed yucca (*Yucca glauca*).

Greater and lesser prairie-chickens, Cassin's sparrows, and ornate box turtles are indicators of a healthy sandsage prairie system.

### Environment

Throughout its range it is closely tied to sandy soils, and this edaphic restriction is characteristic of large patch systems. Little is known about the tolerance of sandsage for soils other than well-drained sand with a low silt and clay component. Such soils are often "droughty", with reduced water-holding ability, and consequently, the potential for increased water stress to resident plants (Soil Survey Division Staff 1993). Rasmussen and Brotherson (1984) speculated that sandsage is adapted to less fertile soils than species of adjacent grassland communities.

### Dynamics

Ramaley (1939) indicated that the persistence of sandsage was facilitated by fire and long overgrazing, in the absence of which a site would transition to sand prairie. However, there is no evidence to suggest that, under certain combinations of temperature, precipitation, grazing, and other disturbance, sandsage would be unable to expand onto other soil types. Fire suppression may also contribute to an increase in shrub density in this habitat, although sandsage quickly resprouts after burning. Disturbance from grazing, fire, and drought, in combination with range improvement practices, has permitted the establishment and spread of non-native species.

Colorado's eastern plains exhibit climatic differences from north to south which may be reflected in the local expression of sandsage shrubland. Occurrences in southern Colorado experience a longer growing season, lower annual precipitation, and differences in precipitation patterns (Western Regional Climate Center 2004), and may be dominated by different species than northern stands. In the southern range of this system, Havard oak (*Quercus havardii*) may also be present and represents one succession pathway that develops over time following a disturbance. Havard oak is able to resprout following a fire and thus may persist for long periods of time once established (Wright and Bailey 1982).

During the past 10,000 years, these areas are likely to have fluctuated between active dune fields and stabilized, vegetated dunes, depending on climate and disturbance patterns (Forman et al. 2001). Extended periods of severe drought or other disturbance that results in loss of stabilizing vegetation can quickly lead to soil movement and blowouts that inhibit vegetation re-establishment, and may eventually lead to dramatically different species composition.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 44.1% |
| Initial Exposure-Sensitivity Rank | High |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (21.3%) |
| Final Exposure-Sensitivity Rank | **High** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 50% of the current range of sandsage shrubland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 65% of sandsage shrubland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Sandsage shares the dry and warm climate of shortgrass. Annual average precipitation is on the order of 10-18 inches (25-47 cm), with a mean of 16 in (40 cm). The growing season is generally long, with frequent high temperatures.

Sandsage occurrences in Colorado have historically experienced seasonal differences in precipitation patterns from north to south (Western Regional Climate Center 2004). North-south gradients in temperature and precipitation on Colorado's eastern plains appear to be reflected in the species composition of sandsage habitat, especially in midgrass species (Daley 1972), which may contribute to variable vulnerability between northern and southern stands.

## Resilience and Adaptive Capacity Rank:

| Overall Score: | 0.71 | Rank: | High |
|---|---|---|---|

***Bioclimatic envelope and range***
Averaged category score: 0.62

These shrublands are not limited to high elevations, and in Colorado are well within the range of continental distribution. The general restriction of sandsage shrublands to warm, dry areas on Colorado's eastern plains means that they display a somewhat restricted ecological envelope, covering 18% of the statewide precipitation range, and 57% of the growing degree day range. The moderate resilience score for this category may not reflect the true capacity of these shrublands to adapt to changing climate conditions if suitable substrates are available.

***Growth form and intrinsic dispersal rate***
Score: 1

Sandsage is often able to resprout quickly after fire, although it may have poor dispersal ability, with most seeds landing close to the parent plant (McWilliams 2003). The apparent ability of this species to establish quickly after disturbance gives it a high resilience score in this category.

***Vulnerability to increased attack by biological stressors***
Score: 1

Domestic livestock grazing tends to favor the increase of sandsage over associated native grasses. Long-term continuous grazing of domestic livestock has contributed to the alteration of these shrubland habitats from their pre-settlement condition, however, this factor is generally less of a threat than changes in temperature and precipitation.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.5

Drought is the most important extreme event that is likely to alter the character of these shrublands. Warmer and drier conditions, and resulting reduced vegetation cover could allow reactivation of currently stabilized sandy soils throughout eastern Colorado. Although sandsage does not reproduce vegetatively, it is able to resprout after fire. Fire extent and intensity are correlated with climate and grazing effects on fuel loads. Fire and grazing are both important disturbance processes for sandsage habitat, and may interact with drought, as well as permitting invasive exotic plant species to establish and spread.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.43

Sandsage landscapes in Colorado are significantly impacted by anthropogenic activities. In some cases this has increased the extent of sandsage shrubland if midgrass prairie is converted to shortgrass-sandsage community, due in large part to long-term continuous grazing by domestic livestock (LANDFIRE 2006). Sandsage shrublands have limited but ongoing threat of conversion to tilled agriculture or urban/exurban and commercial development. Oil and gas development, and wind turbine farms, with associated roads, utility corridors, and infrastructure is a primary ongoing source of anthropogenic disturbance, fragmentation, and loss in this habitat.

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# Grassland or Herbaceous

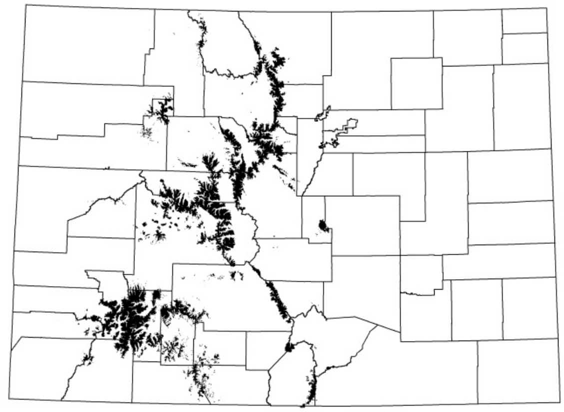
**Table 2.7**. Key vulnerabilities, grassland or other herbaceous ecosystems.

| Habitat | Climate factor(s) | Consequences | Other considerations |
|---|---|---|---|
| Alpine | Extended growing season with earlier snowmelt | Conversion to other type that includes shrubs or trees | Barriers to dispersal |
| Montane grassland | Drought, warmer temperatures | Woody species invasion, exotics; potential to expand into burned forest areas | Highly altered |
| Semi-desert grassland | ---- | May increase | Poor connectivity |
| Shortgrass | Extended drought, warmer summer nighttime temperatures | Change in relative species abundance, woody species invasion, or conversion to other type | Anthropogenic disturbance |

# ALPINE

This ecosystem includes high-elevation dry tundra turf, dwarf-shrublands, fellfield, and rock and scree communities.

R. Rondeau



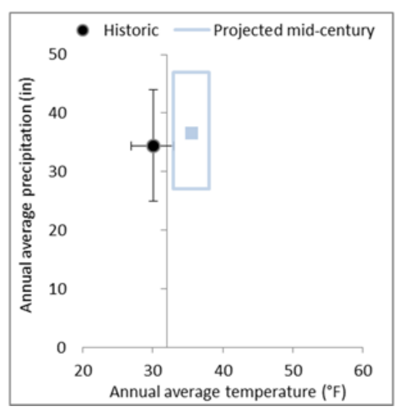
Extent exaggerated for display

## Climate Vulnerability Rank: Low

### Vulnerability summary

**Key Vulnerabilities:** Warmer conditions leading to earlier snowmelt and an extended growing season in higher elevations are expected to allow the establishment of woody species above current treeline levels, although this process is likely to be slow. Photoperiod cues (not influenced by climate change) for many species could negate the effects of a longer growing season. The ability of most alpine species to disperse across intervening lower elevation habitat is doubtful.

Alpine habitats are ranked as having low vulnerability to the effects of climate change by mid-century, due to limited exposure to warmer and drier conditions. Overall, alpine areas are in good condition, with moderate resilience. Because of the short growing season length in alpine and subalpine areas, change is expected to occur relatively slowly. Under a longer-term evaluation frame, vulnerability of this habitat is expected to be greater, since these habitats are restricted to the highest elevations of Colorado, and consequently have a narrow biophysical envelope.




### Distribution

This widespread ecosystem occurs above upper timberline throughout the Rocky Mountain cordillera. Alpine vegetation is found at the highest elevations, usually above 11,000 feet in

Colorado, where the long winters, abundant snowfall, high winds, and short summers create a harsh environment. Although alpine dry turf forms the matrix of the alpine zone, it intermingles with bedrock and scree, ice field, fellfield, alpine dwarf-shrubland, and alpine/subalpine wet meadow systems. Areas dominated by herbaceous cover may be dry tundra, cushion-plant dominated fellfield, or wet meadows. Shrub-dominated areas are characterized by ericaceous dwarf-shrubs or dwarf willows.

### Characteristic species

Alpine dry turf is formed by a dense cover of low-growing, perennial graminoids and forbs. Rhizomatous, sod-forming sedges are the dominant graminoids, and prostrate and mat-forming plants with thick rootstocks or taproots characterize the forbs. Dominant species include boreal sagebrush (*Artemisia arctica*), blackroot sedge (*Carex elynoides*), spike sedge (*Carex nardina*), northern singlespike sedge (*Carex scirpoidea*), dryspike sedge (*Carex siccata*), curly sedge (*Carex rupestris*), tufted hairgrass (*Deschampsia caespitosa*), alpine fescue (*Festuca brachyphylla*), Idaho fescue (*Festuca idahoensis*), Ross' avens (*Geum rossii*), Bellardi bog sedge (*Kobresia myosuroides*), cushion phlox (*Phlox pulvinata*), and alpine clover (*Trifolium dasyphyllum*). Dwarf- shrublands of the alpine are characterized by an intermittent layer of snow willow or ericaceous dwarf-shrubs less than 0.5 m in height, with a mixture of forbs and graminoids, especially sedges. Snow willow (*Salix nivalis*) is a typical dominant shrub. Blueberry (*Vaccinium* spp.) and alpine laurel (*Kalmia microphylla*) may also be shrub associates.

Most fellfield plants are cushioned or matted, frequently succulent, low-growing rosettes and often densely haired and thickly cutinized. Plant cover may be sparse to moderate between exposed rocks. Common fellfield species include Ross' avens, Bellardi bog sedge, twinflower sandwort (*Minuartia obtusiloba*), Asian forget-me-not (*Myosotis asiatica*), Rocky Mountain nailwort (*Paronychia pulvinata*), cushion phlox (*Phlox pulvinata*), creeping sibbaldia (*Sibbaldia procumbens*), moss campion (*Silene acaulis*), alpine clover and Parry's clover (*Trifolium parryi*). Barren and sparsely vegetated alpine substrates include both bedrock outcrop and scree slopes, with nonvascular (lichen) dominated communities. There can be sparse cover of forbs, grasses, lichens and low shrubs. Clumps of Colorado blue columbine (*Aquilegia caerulea*) and mountain thistle (*Cirsium scopulorum*) are common in scree slopes.

### Environment

The distribution of vegetation types in the alpine is controlled in part by local topography that influences snow deposition and retention, as well as soil development. Alpine turf is generally found on more gentle to moderate slopes, flat ridges, valleys, and basins, where the soil has become relatively stabilized and the water supply is more or less constant. Alpine dwarf-shrubland typically is found in areas of level or concave glacial topography, with late-lying snow and sub-irrigation from surrounding slopes. These moist but well-drained areas have developed relatively stable soils that are strongly acidic, often with substantial peat layers. Fellfields are rocky and wind-scoured areas that are free of snow in the winter, such as ridgetops and exposed saddles, where vegetation is exposed to severe environmental stress. Soils on these windy sites are shallow, stony, low in organic matter, and poorly developed; wind deflation often results in a gravelly pavement.

There is some evidence that alpine vegetation is responsive to fine-scale environmental heterogeneity, which may enhance its resilience to changing climate conditions in some topographically complex areas (Spasojevic et al. 2013).

### Dynamics

Alpine environments are generally not susceptible to outbreaks of pest species or disease, but may have some slight vulnerability to invasive plant species such as yellow toadflax (*Linaria vulgaris*), knapweed (*Centaurea* spp.), and dandelion (*Taraxacum officinale*). These treeless environments are not vulnerable to fire, but could become so if trees are able to establish.

Patterns of vegetation growth, flowering, and senescence in alpine habitats are probably dependent on both day length and temperature (Billings and Mooney 1968). The characteristic forb and graminoid dominated tundra is a result of low temperatures during the growing season that limit vegetation growth and decomposition. With longer day length and increasing solar radiation in spring, warmer air and soil temperatures, together with moisture from snowmelt enable the onset of plant growth. Although temperature appears to be the dominant control on developmental phenology (Billings and Mooney 1968), a number of alpine species are known to be sensitive to day-length (Keller and Körner 2003). The prevalence and importance of photoperiod sensitivity in Colorado's alpine flora is little known. If some alpine species are unable to quickly adapt to changing temperatures because of photoperiod constraints, this could change species interactions and relative abundances in alpine habitats, with consequences that are not well understood (Hülber et al. 2010, Ernakovich et al. 2014).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 0% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (38.9%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, less than 1% of the current range of alpine habitat in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 39% of alpine habitat in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Snowpack is a crucial component of alpine ecosystems, and depends on both precipitation amounts and winter-spring temperature (Williams et al. 2002). Vegetation in alpine areas is controlled by patterns of snow retention, wind desiccation, permafrost, and a short growing season (Greenland and Losleben 2001).

The length of the growing season is particularly important for the alpine zone, and for the transition zone between alpine and forest (treeline). Alpine areas have the fewest growing degree days and lowest potential evapotranspiration of any habitat in Colorado. Treeline-controlling factors operate at different scales, ranging from the microsite to the continental (Holtmeier and Broll 2005). On a global or continental scale, there is general agreement that cool summer temperature is a primary determinant of treeline. At this scale, the distribution of alpine ecosystems is determined by the number of days that are warm enough for alpine plant growth, but not sufficient for tree growth. Other alpine conditions that maintain treeless vegetation at high elevations include lack of soil development, persistent snowpack, steep slopes, wind, and dense turf that restricts tree seedling establishment and survival within the treeline ecotone (Moir et al. 2003, Smith et al. 2003, Holtmeier and Broll 2005). However, increased extent of tall shrub willows (e.g., *Salix planifolia* and *S. glauca*) through clonal growth has already occurred in some areas (Formica et al. 2014).

On the basis of historic evidence, treeline is generally expected to migrate to higher elevations as temperatures warm, as permitted by local microsite conditions (Smith et al. 2003, Richardson and Friedland 2009, Grafius et al. 2012). It is unlikely that alpine species would be able to move to other alpine areas. In the short-term with warmer temperatures, alpine areas may be able to persist, especially in areas where it is difficult for trees to advance upslope. The slow growth of woody species and rarity of recruitment events may delay the conversion of alpine areas to forest or tall shrub for 50-100+ after climatic conditions have become suitable for tree growth (Körner 2012). Thus, alpine ecosystems may persist for a while beyond mid-century, but are likely to eventually largely disappear from Colorado.

### Resilience and Adaptive Capacity Rank:

| Overall Score: | 0.69 | Rank: | **Moderate** |
|---|---|---|---|

***Bioclimatic envelope and range***

Averaged category score: 0.25

Elevations of alpine habitats in Colorado range from about 11,000 to over 14,000 ft., with a mean of about 12,000 ft. Alpine habitats are restricted to high elevations, and are also near the southern extent of their continental range in Colorado. Although alpine areas cover 74% of the statewide precipitation range, alpine growing seasons are the shortest of any habitat in Colorado, encompassing only 26% of the statewide range of growing degree days. These factors combine to give alpine areas a low resilience score in this category.

***Growth form and intrinsic dispersal rate***

Score: 0.50

Although alpine areas are dominated by relatively quick-growing forb and graminoid species, the short growing seasons are limiting. Furthermore, the difficulty of dispersal across intervening lower elevation habitat gives this ecosystem an intermediate resilience score in this category.

***Vulnerability to increased attack by biological stressors***
Score: 0.8

Alpine environments are generally not susceptible to outbreaks of pest species or disease, but may have some slight vulnerability to invasive plant species such as yellow toadflax under future climatic conditions. These treeless environments are not vulnerable to fire, but could become so if trees are able to establish. Xeric alpine environments are already subject to extreme conditions, but the more mesic areas are vulnerable to drought and changes in snowmelt timing. Even under increased snowpack, warmer temperatures are likely to alter patterns of snowmelt, and may reduce available moisture. These changes are likely to result in shifts in species composition, perhaps with an increase in shrubs on xeric tundra. With warming temperatures and earlier snowmelt, however, elk may be able to move into alpine areas earlier and stay longer, thereby increasing stress on alpine willow communities (Zeigenfuss et al. 2011).

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.9

Alpine habitats are also indirectly affected by both drought and land-use practices in upwind areas that lead to dust emissions. When wind-blown dust is deposited on mountain snowpack, the resulting darkening of the snow allows increased absorption of solar radiant energy, and earlier melting than under dust free conditions. Unlike warming temperatures, which advance both snowmelt timing and growing season onset for alpine vegetation, the effect of dust deposition on mountain snowpack is a source of earlier snowmelt that is not directly linked to seasonal shifting (Steltzer et al. 2009). Although dust deposition may be a significant contributor to soil development in some areas (Lawrence et al. 2011), it can increase evapotranspiration and decrease annual runoff flows (Deems et al. 2013). Changes in soil moisture levels due to earlier snowmelt may interact with other climate change effects to produce changes in species composition and structure of alpine habitats.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.98

Alpine landscapes in Colorado are generally in excellent condition, and well protected. Ongoing threats from development in alpine habitats associated with recreation areas and activities, including associated roads and infrastructure; these are generally are limited in extent. Old privately-owned mining claims are scattered throughout, but there are very few active mines operating today In southwestern Colorado, sheep grazing and isolated mining activity are minor sources of disturbance in alpine areas. Anthropogenic nitrogen deposition is an ongoing influence on alpine phenology (Smith et al. 2012) and species diversity (Farrer et al. 2015) which may interact with warming temperatures, although the long-term effects of this disturbance are not well known.

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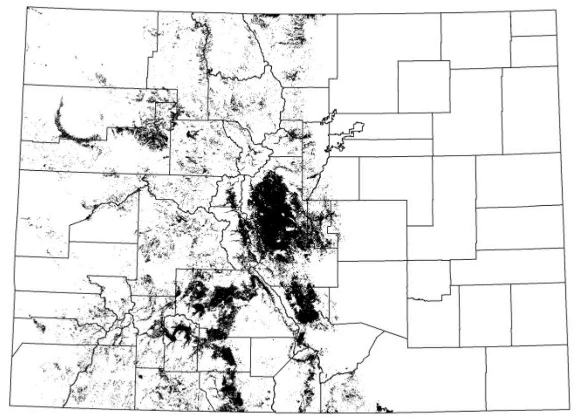
# MONTANE GRASSLANDS

Bunch-grass dominated grasslands at elevations between foothills and subalpine

D. Culver



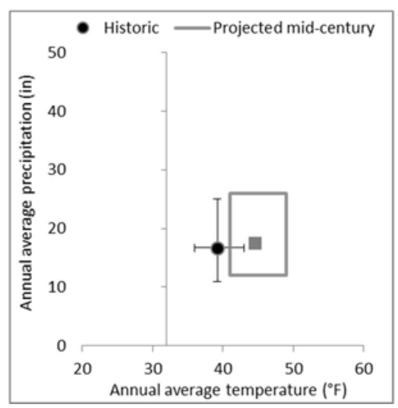
Extent exaggerated for display

## Climate Vulnerability Rank: Moderate

### Vulnerability summary

**Key Vulnerabilities:** Warmer and drier conditions are likely to facilitate the spread of invasive species, and may allow woody species to establish in grasslands. An increase in forest fire activity under future conditions may allow grassland to expand into adjacent burned areas.

Montane grasslands are ranked as moderately vulnerable to the effects of climate change by mid-century. Primary factors contributing to this ranking are vulnerability of these area to invasive species, and the generally highly disturbed condition of occurrences, both of which are likely to interact with the significant increases in temperature across much of the distribution of the habitat in Colorado to reduce resilience of these habitats.




### Distribution

Montane-subalpine grasslands in the Colorado Rockies are typically grasslands of forest openings and park-like expanses in the montane and subalpine coniferous forests at elevations of 7,200-10,000 feet (2,200-3,000 m), intermixed with stands of spruce-fir, lodgepole, ponderosa, and aspen. Although smaller montane grasslands are scattered throughout the Southern Rocky Mountains ecoregion, the largest occurrence by far (over a million acres) is on the valley floor of the large intermountain basin South Park in central Colorado. The largest occurrences are primarily within Colorado, but examples are scattered throughout the region from Wyoming to New Mexico.

### Characteristic species

These large patch grasslands are intermixed with various types of forest stands, depending on elevation. Within the subalpine zone, forbs tend to be more prominent at higher elevations, and shrubs at lower elevations (Turner and Paulsen 1976). Associations are variable depending on site factors such as slope, aspect, and precipitation, but generally lower elevation montane grasslands are more xeric and dominated by muhly (*Muhlenbergia* spp.), bluebunch wheatgrass (*Pseudoroegneria spicata*), Arizona fescue (*Festuca arizonica*), and Idaho fescue (*Festuca idahoensis*), while upper montane or subalpine grasslands are more mesic and may be dominated by Thurber fescue (*Festuca thurberi*) or timber oatgrass (*Danthonia intermedia*). Parry's oatgrass (*Danthonia parryi*) is found across most of the elevational range of this system. Montane grasslands in the Colorado Front Range are often dominated by spike fescue (*Leucopoa kingii*) or mountain muhly (*Muhlenbergia montana*)(Peet 1981). In the San Juan Mountains of southwestern Colorado, these grasslands are dominated by Thurber fescue and other large bunch grasses (Jamieson et al. 1996). Grasses of the foothills and piedmont, such as blue grama (*Bouteloua gracilis*), sideoats grama (*Bouteloua curtipendula*), needle-and-thread (*Hesperostipa comata*), prairie Junegrass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*), Sandberg bluegrass (*Poa secunda*), and little bluestem (*Schizachyrium scoparium*) may be included in lower elevation occurrences. Higher, more mesic locations may support additional graminoid species including bentgrass (*Agrostis* spp.), sedge (*Carex* spp.), alpine fescue (*Festuca brachyphylla*), Drummond's rush (*Juncus drummondii*), alpine timothy (*Phleum alpinum*), bluegrass (*Poa* spp.), or spike trisetum (*Trisetum spicatum*). Woody species are generally sparse or absent, but occasional individuals from the surrounding forest communities may occur. Scattered dwarf-shrubs may be found in some occurrences; species vary with elevation and location. Forbs are more common at higher elevations.

### Environment

This ecosystem typically occurs on gentle to steep slopes, parks, or on lower sideslopes that are dry, and may extend up to 11,000 ft (3,350 m) on warm aspects. The general climate in the range of this ecosystem is typically montane to subalpine, characterized by cold winters and relatively cool summers, although temperatures are more moderate at lower elevations. Precipitation patterns differ between the east and west sides of the Continental Divide. In general, these grasslands experience long winters, deep snow, and short growing seasons. Average annual precipitation ranges between 20 to 40 inches (51-102 cm), and the majority of this falls as snow (Turner and Paulsen 1976). Snowcover in some areas can last from October to May, and serves to insulate the plants beneath from periodic subzero temperatures. Other areas are kept free from snow by wind. Rapid spring snowmelt usually saturates the soil, and when temperatures rise plant growth is rapid. Precipitation during the growing season is highly variable, but provides less moisture than snowmelt. Growing seasons are short, typically from June through August at intermediate locations, although frost can occur at almost any time.

The geology of the Southern Rocky Mountains is extremely complex. Not surprisingly, soils are also highly variable, depending on the parent materials from which they were derived and the conditions under which they developed. Podzolic soils have developed on most high mountain areas as a result of cool to cold temperatures, relatively abundant moisture, and the dominant coniferous forest vegetation. In the intermingled parks and open treeless slopes or ridges, grassland soils have developed. Soil texture is important in explaining the existence of montane-subalpine grasslands (Peet 2000). These grasslands often occupy the fine-textured alluvial of colluvial soils of valley bottoms, in contrast to the coarse, rocky material of adjacent forested slopes (Peet 2000). Soils are often similar to prairie soils, with a dark brown A-horizon that is rich in organic matter, well drained, and slightly acidic (Turner and Paulsen 1976). Other factors that may explain the absence of trees in this system are soil moisture (too much or too little), competition from established herbaceous species, cold air drainage and frost pockets, high snow accumulation, beaver activity, slow recovery from fire, and snow slides (Daubenmire 1943, Knight 1994, Peet 2000). Where grasslands occur intermixed with forested areas, the less pronounced environmental differences mean that trees are more likely to invade (Turner and Paulsen 1976).

### Dynamics

A variety of factors, including fire, wind, cold-air drainage, climatic variation, soil properties, competition, and grazing have been proposed as mechanisms that maintain open grasslands and parks in forest surroundings. Observations and repeat photography studies in sites throughout the southern Rocky Mountains indicate that trees do invade open areas, but that the mechanisms responsible for this trend may differ from site to site. Anderson and Baker (2005) discounted fire suppression as the cause of tree invasions in Wyoming's Medicine Bow Mountains, concluding that edaphic conditions were the most likely factor limiting tree establishment. In the San Juan Mountains of southeastern Colorado, Zier and Baker (2006) also found that the probability of tree invasion varied with forest type. Climatic variation, fire exclusion, and grazing appear to interact with edaphic factors to facilitate or hinder tree invasion in these grasslands (Zier and Baker 2006). In the Gunnison Basin, Schauer et al. (1998) identified seedling mortality as the primary factor preventing invasions of Engelmann spruce, but did not determine if this was due to competition from established grassland plants, or to edaphic conditions. The work of Coop and Givnish (2007) in the Jemez Mountains of northern New Mexico suggests that both changing disturbance regimes and climatic factors are linked to tree establishment in some montane grasslands. Pocket gophers (*Thomomys* spp.) are a widespread source of disturbance in montane-subalpine grasslands. The activities of these burrowing mammals result in increased aeration, mixing of soil, and infiltration of water, and are an important component of normal soil formation and erosion (Ellison 1946). In addition, Cantor and Whitham (1989) found that below-ground herbivory of pocket gophers restricted establishment of aspen to rocky areas in Arizona mountain meadows. The interaction of multiple factors indicates that management for the maintenance of these montane and subalpine grasslands may be complex.

Grazing by domestic livestock may act to override or mask whatever natural mechanism is responsible for maintaining an occurrence. Montane-subalpine grasslands were first grazed by domestic livestock beginning in the late 1800's (Turner and Paulsen 1976). After lower-elevation, more accessible rangelands were overstocked in the 1870's and 1880's, use of montane and subalpine grasslands increased dramatically. By the turn of the century nearly all grazable land was being utilized, and much was already overgrazed (Turner and Paulsen 1976). As National Forests were established following the Organic Administration Act of 1897, regulation of grazing on these high elevation grasslands was instituted. Use levels peaked near the end of the first World War, and current use levels are substantially lower than the highest previous level (Turner and Paulsen 1976).

Floristic composition in these grasslands is influenced by both environmental factors and grazing history. Grazing is generally believed to lead to the replacement of palatable species with less palatable ones more able to withstand grazing pressure (Smith 1967, Paulsen 1975, Brown 1994, but see Stohlgren et al. 1999). In general, palatable grasses are replaced by nonpalatable forbs or shrubs under cattle grazing (Smith 1967), while palatable forbs are characteristically absent from grasslands with a long history of sheep use (Turner and Paulsen 1976). Annual species are uncommon except on heavily disturbed areas. Some occurrences are dominated by seeded pasture grasses, especially smooth brome (*Bromus inermis*), timothy (*Phleum pratense*), and Kentucky bluegrass (*Poa pratensis*).

Historically, soil disturbance was largely the result of occasional concentrations of large native herbivores, or the digging action of fossorial mammals. Domestic livestock ranching has changed the timing and intensity of grazing disturbance from that of native herbivores, with the potential to alter species composition, soil compaction, nutrient levels, and vegetation structure. In combination with grazing of domestic livestock, various "range improvement" activities (e.g. seeding, rodent control, herbicide application) have the potential to alter natural ecosystem processes and species composition. Increasing small-acreage exurban development with livestock ("ranchettes") appears to be increasing the incidence of weedy exotic species in these habitats. Exotics include Dalmatian toadflax (*Linaria dalmatica*), knapweed (*Centaurea spp.* ), cheatgrass (*Bromus tectorum*), sweetclover (*Melilotus officinalis*), and others.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 1.0% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | Yes (79.6%) |
| Final Exposure-Sensitivity Rank | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 1% of the current range of montane grassland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 81% of montane grassland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Higher elevation grasslands are characterized by cold winters and relatively cool summers, although temperatures are more moderate at lower elevations.

Soil texture has a significant effect on the distribution and persistence of montane-subalpine grasslands (Peet 2000), determining soil moisture conditions that act to exclude trees. Drought and warmer temperatures may change species composition, or allow invasion by drought-tolerant shrubs or invasive species in some areas.

### Resilience and Adaptive Capacity Rank

| Overall Score: | 0.74 | Rank: | **High** |
|---|---|---|---|

***Bioclimatic envelope and range***

Averaged category score: 0.82

These grasslands are not restricted to high elevations, and are well within the core area of their continental distribution in Colorado. The variation present in the various grassland occurrences gives this ecosystem a wide ecological amplitude, covering 79% of Colorado's overall precipitation range, and 48% of the growing degree range. These factors combine to give montane grasslands a high resilience score in this category.

***Growth form and intrinsic dispersal rate***

Score: 1

This ecosystem is dominated by relatively fast growing graminoid and herbaceous species, and is able to disperse to available habitat quickly in comparison with ecosystems dominated by woody species.

***Vulnerability to increased attack by biological stressors***

Score: 0.5

The work of Coop and Givnish (2007) in the Jemez Mountains of northern New Mexico suggests that both changing disturbance regimes and climatic factors are linked to tree establishment in some montane grasslands. Increased tree invasion into montane grasslands was apparently linked to higher summer nighttime temperatures, and less frost damage to tree seedlings; this trend could continue under projected future temperature increases. Increased disturbance may also facilitate the continued spread of introduced exotic species as climate conditions change. The interaction of multiple factors indicates that management for the maintenance of these montane and subalpine grasslands may be complex.

***Vulnerability to increased frequency or intensity of extreme events***

Score: 1

Although increased incidence or severity of drought may act to help prevent tree invasion into montane grasslands, there is some evidence that warmer, drier soil conditions could facilitate shrub growth in montane meadows or otherwise alter species composition (Perfors et al. 2003).

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.37

Montane grassland landscapes in Colorado are highly altered by anthropogenic disturbance. Higher elevation grasslands on relatively flat sites are often in private ownership, and are often vulnerable to subdivision for residential development and/or transportation corridor development. The extensive grasslands of South Park, in particular, are threatened by the subdivision of large properties, and development of transportation corridors. Recreational use (public open space use in lower elevations; hunters, packers and snow-mobilers in higher elevations) is an ongoing source of disturbance in this habitat.

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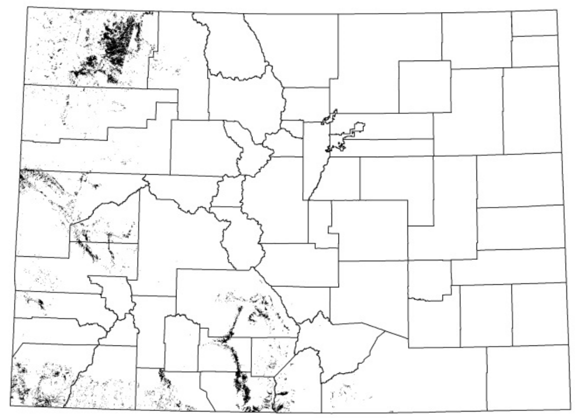
# SEMI-DESERT GRASSLAND

Dry grasslands characterized by drought-tolerant bunch grass species and scattered shrubs

P. Lyon



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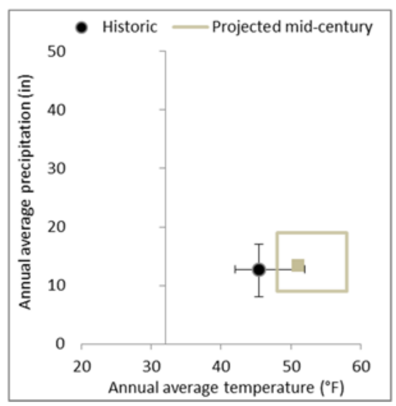
## Climate Vulnerability Rank: Low

### Vulnerability summary

**Key Vulnerabilities:** Climate related vulnerability for these grasslands is minimal, but the impacted condition of many stands may inhibit their potential for expansion.

Low exposure and sensitivity to projected conditions outside the current range experienced by these grasslands is the primary factor contributing to the low vulnerability ranking of this ecosystem. The generally fair to poor condition of many occurrences in Colorado may tend to inhibit the potential of this ecosystem to exploit and move into new areas under future climate conditions.




### Distribution

These are the driest grasslands of the intermountain western U.S., occurring in large patches in mosaics with shrubland systems dominated by sagebrush, saltbush, blackbrush, mormon-tea, and other shrub species. Climates are semi-arid to arid. Colorado's semi-desert grasslands are found primarily on dry plains and mesas of the west slope at elevations of 4,750-7,600 feet

### Characteristic species

These grasslands are typically dominated by drought-resistant perennial bunch grasses such as Indian ricegrass (*Achnatherum hymenoides*), blue grama (*Bouteloua gracilis*), needle-and-thread

(*Hesperostipa comata*), ring muhly (*Muhlenbergia torreyi*), or James' galleta (*Pleuraphis jamesii*), or bluebunch wheatgrass (*Pseudoroegneria spicata*). Scattered shrubs and sub-shrubs may be present, including sagebrush (*Artemisia* spp.), saltbush (*Atriplex* spp.), jointfir (*Ephedra* spp.), snakeweed (*Gutierrezia sarothrae*), or winterfat (*Krascheninnikovia lanata*). Blackbrush (*Coleogyne ramosissima*) is uncommon in Colorado occurrences, but typical further west.

### Environment

West Slope low-elevation grasslands occur in semi-arid to arid climates with cold temperate conditions. Hot summers and cold winters with freezing temperatures and snow are common. Grasslands of the western valleys receive a significant portion of annual precipitation in July through October during the summer monsoon storms, with the rest falling as snow during the winter and early spring months. Annual precipitation is usually from 8-16 in (20-40 cm).

These grasslands occur in xeric lowland and upland areas and may occupy swales, playas, mesa tops, plateau parks, alluvial flats, and plains. Substrates are typically well-drained sandstone- or shale-derived soils. Some sandy soil occurrences have a high cover of cryptogams on the soil. Soil salinity depends on the amount and timing of precipitation and flooding.

### Dynamics

This system is maintained by frequent fires that eliminate woody plants. A combination of precipitation, temperature, and soils limits this system to the lower elevations within the region. The dominant perennial bunch grasses and shrubs within this system are all very drought-resistant plants. Grasses that dominate semi-arid grasslands develop a dense network of roots concentrated in the upper parts of the soil where rainfall penetrates most frequently.

The semi-desert grassland system is vulnerable to invasion by exotic species, particularly cheatgrass (*Bromus tectorum*). Although frequent fires in grasslands may have been common historically, the introduction of cheatgrass has altered the dynamics of the system, increasing both fire frequency and post-fire cheatgrass dominance (Shinneman and Baker 2009, Balch et al. 2013). Cheatgrass is easily ignited, and also provides an abundance of fine fuels that carry fire (Knapp 1998).

Floristic composition in grasslands is influenced by both environmental factors and grazing history. Many grassland occurrences are already highly altered from pre-settlement condition. Grazing is generally believed to lead to the replacement of palatable species with less palatable ones more able to withstand grazing pressure (Smith 1967, Paulsen 1975, Brown 1994, but see Stohlgren et al. 1999). Grazing by domestic livestock may act to override or mask whatever natural climatic or edaphic mechanism is responsible for maintaining an occurrence. This habitat is also adapted to grazing and browsing by native herbivores including deer, elk, bison, and pronghorn, as well as burrowing and grazing by small mammals such as gophers, prairie dogs, rabbits, and ground squirrels. Activities of these animals can influence both vegetation structure and soil disturbance, potentially suppressing tree establishment. Periodic drought is common in the range of foothill and semi-desert grasslands, but may not be as great a factor in the vegetation dynamics of this system as in grasslands of the plains.

Remnant stands of desert grasslands have been highly altered by livestock grazing, and it is likely that grasslands formerly occupied some sites that are now covered by pinyon-juniper or shrubland (Dick-Peddie 1993). Grazing by domestic livestock can also influence the relative proportion of cool- vs. warm-season grasses, or favor the increase of woody shrub species.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 14.0% |
| Initial Exposure-Sensitivity Rank | Low |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (35.2%) |
| Final Exposure-Sensitivity Rank | **Low** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 19% of the current range of semi-desert grassland in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***

About 49% of semi-desert grassland in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***

Semi-desert grassland species are generally drought tolerant (Dick-Peddie 1993), and are adapted to low precipitation levels and a long growing season. Soils are typically aridisols, which are dry for most of the year, even during the growing season, and there is little infiltration of water into the soil (Sims and Risser 2000). Changes in the timing and amount of precipitation can affect the structure and persistence of grasslands. With their comparitively shallower root systems, grasses have an advantage over shrubs on shallow, poorly drained soils, whereas shrubs are favored on deeper soils where winter precipitation can penetrate deeply into the soil. Because shrubs are $C_3$ plants with higher cool-season activity (Asner and Heidebrecht 2005) they are able to utilize winter precipitation to a greater extent than are warm-season grasses. Sims and Risser (2000) report that a mean annual temperature of 50°F (10°C) is a threshold between grasslands dominated by cool-season ($C_3$) grasses and those dominated by warm-season ($C_4$) species. However, Munson et al. (2011) report a decline in perennial vegetation cover in grasslands of the Colorado Plateau with increases in temperature.

### Resilience and Adaptive Capacity Rank

| | | | |
|---|---|---|---|
| Overall Score: | 0.72 | Rank: | **High** |

***Bioclimatic envelope and range***

Averaged category score: 0.59

These grasslands are not restricted to high elevations, nor are they at the southern end of their continental distribution in Colorado. However, because they occur in the warmest and driest parts of the state, they occupy only 1% of Colorado's overall precipitation range, and 34% of the statewide growing degree day range. These factors combine to lower the overall resilience score in this category, but may be somewhat overstated due to the current limited distribution of this type in Colorado.

***Growth form and intrinsic dispersal rate***
Score: 1

This ecosystem is dominated by relatively fast growing graminoid and herbaceous species, and is able to disperse to available habitat quickly in comparison with ecosystems dominated by woody species.

***Vulnerability to increased attack by biological stressors***
Score: 0.5

Semi-desert grasslands are vulnerable to invasion by exotic species, particularly cheatgrass. Extended drought can lead to widespread mortality of perennial grasses and allow the invasion of cheatgrass.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 1

Drought and warmer temperatures may change species composition, or allow invasion by drought-tolerant woody or invasive species in some areas. Drought can increase extent of bare ground and decrease forb coverage, especially in more xeric grasslands (Debinski et al. 2010).

Although frequent fires in grasslands may have been common historically, the introduction of cheatgrass has altered the dynamics of the system, and fire often results in cheatgrass dominance. Once overtaken by cheatgrass, more frequent fires are encouraged by the dry flammable material, leading to further domination by cheatgrass. Even a few cheatgrass plants in a stand will produce enough seed to dominate the stand within a few years after fire. Increasing drought is likely to facilitate this trend.

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.51

Semi-desert grassland landscapes in Colorado have been significantly impacted by anthropogenic activity, especially conversion to agriculture in areas near rivers. The current rate of conversion of lower elevation native grassland to agriculture is low, but remains a threat for some limited areas. Native grassland habitat can also be lost or fragmented by suburban and exurban development, and transportation, oil and gas, or utility infrastructure development.

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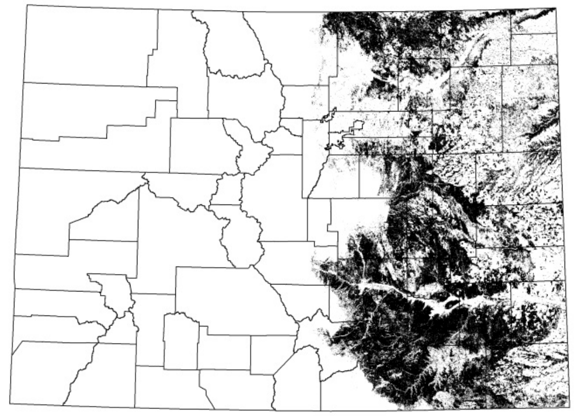
# SHORTGRASS PRAIRIE

Grasslands dominated by blue grama

R. Rondeau



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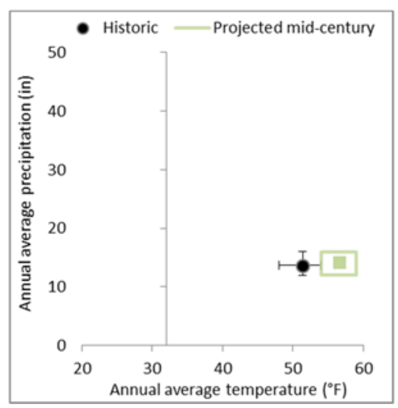
## Climate Vulnerability Rank: High

### Vulnerability summary

**Key Vulnerabilities:** Warmer summer nighttime low temperatures and/or extended periods of drought are likely to change the balance of warm- and cool-season grasses, and, if fire frequency remains low, allow the establishment of woody species, with the potential for conversion to a more arid grassland type or savanna.

Shortgrass prairie is ranked as having high vulnerability to the effects of climate change by mid-century. Primary factors contributing to this ranking are the fact that these grasslands are found on the eastern plains of Colorado, where the greatest levels of exposure for all temperature variables occur. In addition, anthropogenic disturbance in these grasslands has reduced the overall landscape condition of the habitat, which is likely to reduce its resilience in the face of increasing frequency of extreme events.




### Distribution

Shortgrass prairie is characteristic of the warm, dry southwestern portion of the Great Plains, lying to the east of the Rocky Mountains, and ranging from the Nebraska Panhandle south into Texas and New Mexico. The high plains of the *Llano estacado* define the southern extent of the shortgrass prairie, bounded by escarpments formed in the Ogalalla Caprock (called the Mescalero escarpment to the west and the Caprock escarpment on the east). The eastern boundary of the shortgrass prairie is a fluctuating ecotone on the east-west precipitation gradient between short and midgrass prairie, defined by a transition area where precipitation becomes insufficient to provide soil moisture for the taller grasses (Shantz 1923, Carpenter 1940). The northern boundary represents the transition to cooler, more mesic mixed-grass types, generally occuring in southeastern Wyoming and southwestern Nebraska, although occasional shortgrass stands may be found further north. In spite of extensive conversion to agriculture or other uses, shortgrass prairie still forms extensive tracts on the eastern plains of Colorado, at elevations below 6,000 feet.

### Characteristic species

This system spans a wide range and thus there can be some differences in the relative dominance of some species from north to south and from east to west.

Prior to settlement, the shortgrass prairie was a generally treeless landscape characterized by blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*). In much of its range, shortgrass prairie forms the matrix vegetation with blue grama dominant. Other grasses include three-awn (*Aristida purpurea*), side-oats grama (*Bouteloua curtipendula*), hairy grama (*Bouteloua hirsuta*),needle-and-thread (*Hesperostipa comata*), June grass (*Koeleria macrantha*), western wheatgrass (*Pascopyrum smithii*), James' galleta (*Pleuraphis jamesii*), alkali sacaton (*Sporobolus airoides*), and sand dropseed (*Sporobolus cryptandrus*). Local inclusions of mesic or sandy soils may support taller grass species including sand bluestem (*Andropogon hallii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and prairie sandreed (*Calamovilfa longifolia*), as well as scattered shrub species including sandsage (*Artemisia filifolia*), prairie sagewort (*Artemisia frigida*), fourwing saltbush (*Atriplex canescens*), tree cholla (*Cylindroputia imbricata*), spreading buckwheat (*Eriogonum effusum*), snakeweed (*Gutierrezia sarothrae*), pale wolfberry (*Lycium pallidum*), and soapweed yucca (*Yucca glauca*) may also be present. One-seed juniper (*Juniperus monosperma*) and occasional pinyon pine (*Pinus edulis*) trees are often present on shale breaks within the shortgrass prairie matrix.

This ecosystem, in combination with the associated wetland systems, represents one of the richest areas in the United States for large mammals. A healthy shortgrass prairie system should support endemic grassland birds, prairie dog complexes, viable populations of pronghorn, and other Great Plains mammals. Historically, such areas would also have been populated by bison in sufficient numbers to support populations of wolves. Grassland bird species may constitute one of the fastest declining vertebrate populations in North America (Knopf 1996).

### Environment

The climate of the shortgrass prairie is characterized by large seasonal contrasts, as well as interannual and longer term variability (Pielke and Doesken 2008). Winters in the shortgrass prairie can be mild and dry when Pacific air masses are blocked by the Rocky Mountains under zonal flow conditions, or cold and snowy under meridional flow patterns that bring arctic air or upslope snow. Spring is transitional with warming conditions and lingering arctic air and possible heavy snow. Spring warming brings thermal instability and atmospheric mixing producing windy conditions, and thunderstorms become common. Tornados and slow-moving storms producing heavy precipitation may also occur. In summer a dryline separating humid Gulf air from dry desert southwest air forms in the western plains, and thunderstorms often form along this boundary.

Summer thunderstorms can produce locally heavy precipitation. In late summer, the North American monsoon can bring moisture from the southwest. Typical autumn weather in the shortgrass region is relatively fair and dry, with periodic cool, wet weather and the possibility of early snow (Pielke and Doesken 2008).

These grasslands occur primarily on flat to rolling uplands with loamy, ustic (dry, but usually with adequate moisture during growing season) soils ranging from sandy to clayey, at elevations generally below 6,000 feet (1,830 m). Organic matter accumulation in shortgrass prairie soils is primarily confined to the upper 8 in (20 cm, Kelly et al. 2008). The action of a freeze-thaw cycle on these grassland soils increases their vulnerability to wind erosion in late winter and spring (Pielke and Doesken 2008).

### Dynamics

Large-scale processes such as climate, fire and grazing influence this system. The role of fire in maintaining herbaceous cover and suppressing woody vegetation is well demonstrated in most prairie types. Although fire is of somewhat lesser importance in shortgrass prairie compared to other prairie types, it is still a significant source of disturbance (Engle et al. 2008), and documented historic fires were often expansive. Both flora and fauna of the shortgrass prairie are sensitive to the seasonality and frequency of fire (Ford and McPherson 1997). Large scale climatic conditions act to determine seasonality and frequency of wildfire on the shortgrass prairie, while extent and local fire effects are dependent on topographic and edaphic conditions. The xeric climate of the shortgrass reduces overall fuel loads, but also dries vegetation sufficiently for it to become flammable. The generally open, rolling plains and often windy conditions in the shortgrass prairie facilitate the spread of fire when fuel loads are sufficient (Axelrod 1985). Conversely, breaks and rocky areas that are protected from fire are able to support woody vegetation, even in the dry conditions typical of the region (Wells 1965).

The short grasses that dominate this system are extremely drought- and grazing-tolerant. These species evolved with drought and large herbivores and, because of their stature, are relatively resistant to overgrazing.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank:

| | |
|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 58.3% |
| Initial Exposure-Sensitivity Rank | High |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (20.2%) |
| Final Exposure-Sensitivity Rank | **High** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 57% of the current range of shortgrass prairie in Colorado would experience annual mean temperatures above the current statewide maximum.

***Exposure to precipitation change***
About 78% of shortgrass prairie in Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century.

***Sensitivity of ecosystem to temperature and precipitation***
Temperatures in the shortgrass region show significant variation both daily and seasonally. Average daily temperature spans are 25-30°F, and diurnal variation is generally greatest in summer. Winter temperatures are cold, with nights below freezing and chilly daytime temperatures. Seasonal extreme lows below -20°F (-29°C) have been recorded throughout most of the region (WRCC 2014). In general, the number of frost free days is greater in more southern latitudes, although freezing temperatures have been recorded in all months except July and August. Summer maximum temperatures are frequently in the 90's, especially in southern locations; temperatures of 100°F (38°C) or above have been recorded even in the northern part of the shortgrass prairie (WRCC 2014).

Grasslands in areas where mean annual temperature is above 50°F (10°C) are generally dominated by $C_4$ (warm-season) grass species, which are tolerant of warmer temperatures and more efficient in water use (Sims and Risser 2000). In Colorado, shortgrass prairie has a historic annual mean temperature slightly greater than 50°F, although the range includes slightly cooler annual mean temperatures as well. Although these grasslands are adapted to warm, dry conditions, Alward et al. (1999) found that warming night-time temperatures in spring were detrimental to the growth of blue grama, and instead favored cool-season ($C_3$) species, both native and exotic. Consequently, the effect of increasing temperatures on shortgrass prairie is difficult to predict.

Precipitation trends in the shortgrass prairie are similar to those of the larger Great Plains area, in that western areas are driest. Annual precipitation is generally less than 20 inches (51 cm), and soils are periodically moist only in a shallow top layer typically less than 1-2 feet deep (Shantz 1923). Mean annual precipitation varies from 20+ inches in the east to 12 inches (30 cm) in some western locations (Pielke and Doesken 2008). Precipitation may be the most important ecological driver in the shortgrass prairie. Lauenroth and Sala (1992) found that shortgrass productivity was primarily influenced by precipitation rather than temperature in northeastern Colorado. A large proportion (70-80%) of annual precipitation falls during the growing season (WRCC 2014), and most of this is received during a limited number of large rainfall events (Pielke and Doesken 2008). Daily precipitation amounts are typically quite small (5mm or less), and do not contribute significantly to soil water recharge, which instead is primarily dependent on large but infrequent rainfall events (Parton et al. 1981, Heisler-White et al. 2008). Snowfall amounts are highest in the north, but generally snow is a small component of annual precipitation. Most of the annual precipitation is quickly evaporated and transpired into the atmosphere rather than soaking into the soil (Pielke and Doesken 2008). Larger rainfall events permit deeper moisture penetration in the soil profile, and enable an increase in above-ground net primary production (Heisler-White et al. 2008).

Soil moisture level is a key determinant of the distribution of shortgrass prairie habitat; change in precipitation seasonality, amount, or pattern will affect soil moisture. Grasslands generally occur in areas where there is at least one annual dry season and soil water availability is lower than that required for tree growth (Parton et al. 1981, Sims and Risser 2000). Soil water availability acts on both plant water status and nutrient cycling (Sala et al. 1992). The dominant shortgrass species blue grama is able to respond quickly to very small rainfall events, although this ability is apparently reduced during extended drought periods (Sala and Lauenroth 1982, Sala et al. 1982, Cherwin and Knapp 2012). Nevertheless, blue grama exhibited extensive spread during the drought of the Dustbowl years (Albertson and Weaver 1944). If large rainfall events are more common, the sensitivity of shortgrass prairie is reduced (Cherwin and Knapp 2012).

Warmer and drier conditions would be likely to reduce soil water availability and otherwise have detrimental effects on ecosystem processes, while warmer and wetter conditions could be favorable. Furthermore, changing climate may lead to a shift in the relative abundance and dominance of shortgrass prairie species, giving rise to novel plant communities (Polley et al. 2013). Because woody plants are more responsive to elevated $CO_2$, and may have tap roots capable of reaching deep soil water (Morgan et al. 2007), an increase of shrubby species (e.g., cholla, yucca, snakeweed, sandsage), or invasive exotic species, especially in areas that are disturbed (for instance, by heavy grazing) may also result.

### Resilience and Adaptive Capacity Rank

Overall Score: 0.62 Rank: **Moderate**

***Bioclimatic envelope and range***
Averaged category score: 0.66

Shortgrass prairie experiences a much drier and warmer climate than most other habitat types in Colorado. Annual average precipitation is on the order of 10-18 inches (25-47 cm), with a mean of 15 in (38 cm), and the growing season is generally long, with frequent high temperatures.

***Growth form and intrinsic dispersal rate***
Score: 1

This ecosystem is dominated by relatively fast growing graminoid and herbaceous species, and is able to disperse to available habitat quickly in comparison with ecosystems dominated by woody species.

***Vulnerability to increased attack by biological stressors***
Score: 0.5

The short grasses that characterize this habitat are extremely drought- and grazing-tolerant. These species evolved with drought and large herbivores and, because of their stature, are relatively resistant to overgrazing. Grazing by domestic livestock is the primary use of remaining shortgrass prairie. Management for increased livestock production tends to produce a more homogeneous grassland dominated by key forage species (Fuhlendorf and Engle 2001), and requires additional management effort to restore a mosaic of habitat structure suitable for characteristic wildlife species. Thus, there is an ongoing threat of habitat degradation or loss of function for shortgrass prairie. Intact shortgrass prairie has generally resisted invasion by non-native species (Kotanen et al. 1998), including cheatgrass (*Bromus tectorum*), but disturbed areas are more suceptible to invasion.

***Vulnerability to increased frequency or intensity of extreme events***
Score: 0.5

Drought has been a natural process in shortgrass prairie both during historical recording, and in centuries prior to European settlement. Moreover, there is evidence for the occurrence of mega-droughts that significantly eclipsed the Dust Bowl years in severity, duration, and spatial extent (Woodhouse and Overpeck 1998). Although shortgrass prairie has adapted to and persisted under conditions of extreme drought, the differential impact of drought on component species may alter species composition (Rondeau et al. 2013). Cultivation of marginal lands may compound the vulnerability of remaining shortgrass occurrences to increased drought intensity or frequency.

Dry climate conditions can decrease the fuel load and thus the relative fire frequency within the ecosystem. Currently, fire suppression and certain grazing patterns in the region have likely decreased the fire frequency even more, and it is unlikely that fire frequency and intensity would increase under projected climate conditions. However, more frequent occurrence of climate extremes (e.g., very wet conditions followed by very dry conditions) could increase the frequency and extent of grassland wildfires (Polley et al. 2013).

***Other indirect effects of non-climate stressors – landscape condition***
Score: 0.44

Shortgrass landscapes in Colorado have been heavily impacted by anthropogenic disturbance, especially in the northeastern part of the state. A large part of the range for this system has been converted to agriculture. Areas in southeastern Colorado have been impacted by the unsuccessful attempts to develop dryland cultivation preceeding the Dust Bowl of the 1930s. Habitat loss is a continuing threat to shortgrass prairie. Tilled agriculture has been largely surpassed by increasing urbanization as the primary source of shortgrass prairie habitat conversion, although there is some possibility that this could reverse if demand for dryland biofuel crops were to accelerate. In the northeastern portion of Colorado, patterns of cultivated land have largely fragmented the matrix of the shortgrass prairie, reducing or eliminating connectivity for species that depend on them, and this trend is likely to continue. Residential and commercial development is a significant source of habitat loss and fragmentation on the western margins of Colorado's shortgrass prairie distribution, less so in other areas, but rarely entirely absent.

Development of oil and gas resources is ongoing in shortgrass prairie habitat, especially in the Niobrara shale of the Denver-Julesburg Basin that lies under most of the northern portion of shortgrass prairie extent in Colorado. The density of associated roads, pipeline corridors, and infrastructure is a primary ongoing source of anthropogenic disturbance, fragmentation, and loss in this habitat. Disturbance from renewable energy development remains small, and largely due to concentrated wind turbine "farms". Utility-scale solar installations have thus far been confined to areas near urban development, but there is a potential for future disturbance from this type of facility, which would require associated utility corridor development.

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## Riparian and Wetland

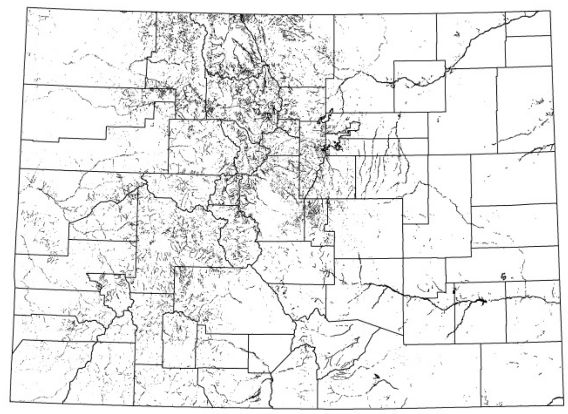
**Table 2.8**. Key vulnerabilities, riparian and wetland ecosystems.

| Habitat | Climate factor(s) | Consequences | Other considerations |
|---|---|---|---|
| Riparian - East | Warmer and drier conditions, runoff amount & timing | Earlier peak flows, low late summer flows, change in relative species abundance | Highly altered due to diversions and dams, agricultural land use patterns |
| Riparian - Mtn. | Warmer temperatures, runoff timing | Earlier peak flows, low late summer flows, change in relative species abundance | Connectivity |
| Riparian - West | Warmer and drier conditions, runoff amount & timing | Earlier peak flows, low late summer flows, change in relative species abundance | Highly altered due to diversions and dams, agricultural land use patterns |
| Wetland - East | Warmer, drier conditions | Lower water tables, reduced input | Strict irrigation control, highly altered |
| Wetland - Mtn. | Warmer temperatures, snowmelt timing | Potential change in species composition | Groundwater-driven types more stable |
| Wetland - West | Drier conditions | Lower water tables, reduced input | Highly altered |

# RIPARIAN WOODLANDS AND SHRUBLANDS

Areas of generally woody vegetation associated with moving water and intermittent flooding

K. Carsey



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## Climate Vulnerability Ranks:
## High (Eastern), Low (Mountain), Very High (Western)

### Vulnerability summary

**Key vulnerabilities:** Warmer and drier conditions and the consequent change in runoff amount and timing are expected to result in earlier peak flows and low late-summer flows, which are likely to impact the structure and species composition of riparian vegetation, especially at lower elevations.

Riparian woodland and shrublands of the eastern plains and western areas are ranked as having high to very high vulnerability to the effects of climate change by mid-century, while those of the mountain region are considered to have comparatively low vulnerability. The vulnerability of some species assemblages may be higher or lower than is reflected by the collective assessment. The primary factor contributing to these rankings is the degree to which riparian woodlands at lower elevations are expected to experience higher temperatures without compensatory precipitation increase. The low to moderate resilience ranks reflect the highly altered condition of most of these habitats, and in general, most riparian woodlands and shrublands throughout the state should probably be regarded as having some degree of vulnerability to climate change that is not captured by our broad-scale assessment methods.

### Distribution

We assessed the condition of riparian woodlands and shrublands in each of three regions in Colorado, corresponding roughly to ecoregions as defined by The Nature Conservancy (2009, modified from Bailey 1998): the eastern plains (Central Shortgrass Prairie ecoregion); mountains

(Southern Rocky Mountain ecoregion); and western plateaus and valleys (Colorado Plateau, Wyoming Basins, and other ecoregions).

Riparian woodlands and shrublands occur throughout Colorado. In eastern Colorado they are found along small, medium and large streams on the plains, including the wide floodplains of the South Platte and Arkansas Rivers. Montane to subalpine riparian woodlands are seasonally flooded forests and woodlands throughout the Rocky Mountains. At montane to subalpine elevations, riparian shrublands may occur as narrow bands of shrubs lining streambanks and alluvial terraces, or as extensive willow carrs in broad floodplains and subalpine valleys. They include the conifer and aspen woodlands that line montane streams. They are most often confined to specific streamside environments, occurring on floodplains or terraces of rivers and streams or in V-shaped, narrow valleys and canyons (where there is cold-air drainage). Less frequently, high elevation riparian woodlands are found in moderate to wide valley bottoms, on large floodplains along broad, meandering rivers, and on pond or lake margins. They can also be found around seeps, fens, and isolated springs on hillslopes away from valley bottoms. At lower elevations on the western slope, riparian woodlands and shrublands are found within the flood zone of rivers, on islands, sand or cobble bars, and immediate streambanks. They often occur as a mosaic of multiple communities that are tree-dominated with a diverse shrub component.

### Characteristic species

On the eastern plains, riparian woodlands and shrublands are generally dominated by plains cottonwood (*Populus deltoides*) and willow (*Salix* spp.), but also occur as a mosaic of multiple communities interspersed with herbaceous patches.

Dominant shrubs within the montane to subalpine elevation zone include alder (*Alnus tenuifolia*), birch (*Betula occidentalis*), dogwood (*Cornus sericea*), and willow species. Generally the upland communities surrounding these riparian systems are either conifer or aspen forests.

Western riparian forests are typically dominated by cottonwood (*Populus angustifolia*, *P. deltoides*) and willow, but may include maple (*Acer glabrum*), Douglas fir (*Pseudotsuga menziesii*), spruce (*Picea* spp.), and juniper (*Juniperus* spp.). Shrublands are primarily dominated by willow, alder, and birch.

### Environment

Riparian areas of Colorado's eastern plains are primarily associated with intermittently flowing streams of small to moderate size, but also include the larger floodplains of the large snowmelt-fed rivers (South Platte and Arkansas). Smaller streams receive water from precipitation and groundwater inflow, have greater seasonal flow variation than the larger rivers, and have minimal or no flow except during floods (Covich et al. 1997). In mountainous areas of Colorado, riparian areas are much more likely to be associated with perennially flowing streams, and these plant communities are adapted to high water tables and periodic flooding. Runoff and seepage from snowmelt is a primary source of streamflow. Lower elevation riparian areas in western Colorado are adapted to periodic flood disturbance and predominantly arid conditions. Larger streams and rivers are sustained by runoff from mountain areas. Smaller streams are primarily supported by groundwater inflow, or occasional large precipitation events, and are often dry for some portion of the year.

### Dynamics

Riparian woodlands are tolerant of periodic flooding and high water tables. Snowmelt moisture in this system may create shallow water tables or seeps for a portion of the growing season.

Many higher elevation riparian shrublands are associated with beaver (*Castor canadensis*) activity, which can be important for maintaining the health of the riparian ecosystem (historically this would have been true for lower elevation streams as well). Beaver dams abate channel down cutting, bank erosion, and downstream movement of sediment. Beaver dams also raise the water table across the floodplain and provide year-round saturated soils. Plant establishment and sediment build-up behind beaver dams raises the channel bed and creates a wetland environment.

Hydrologically, smaller rivers tend to have greater seasonal variation in water levels with less developed floodplain than the larger rivers, and can dry down completely for some portion of the year. Cottonwood die-offs related to prolonged, intense drought and hydrological alterations have affected some stands.

Lower elevation riparian woodlands and shrublands are dependent on a natural hydrologic regime, especially annual to episodic flooding. These woodlands and shrublands grow within a continually changing alluvial environment due to the ebb and flow of the river, and riparian vegetation is constantly being “re-set” by flooding disturbance. In some areas, Russian olive (*Elaeagnus angustifolia)*, tamarisk (*Tamarix* spp.), and other exotic species are common.

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Ranks

| | Eastern | Mountain | Western |
|---|---|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 55.5% | 1.8% | 37.2% |
| Initial Exposure-Sensitivity Rank | High | Low | High |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (6.7%) | No (25.3%) | No (14.7%) |
| Final Exposure-Sensitivity Rank | **High** | **Low** | **High** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 60% of the current range of riparian woodland and shrubland in eastern Colorado would experience annual mean temperatures above the current statewide maximum. The proportion is similar (54%) for western riparian areas, but much lower (2%) in mountain areas.

***Exposure to precipitation change***

About 62% of riparian woodland and shrubland in eastern Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century. For western riparian areas, the proportion is slightly lower (52%), and mountain riparian areas can expect to see effectively drier conditions in about 27% of their distribution.

***Sensitivity of ecosystem to temperature and precipitation***

Riparian woodlands and shrublands are adjacent to and affected by surface or ground water of perennial or ephemeral water bodies. They are characterized by intermittent flooding and a seasonally high water table. The close association of riparian areas with streamflow and aquatic habitats means that changing patterns of precipitation and runoff that alter hydrologic regimes are likely to have a direct effect on these habitats (Capon et al. 2013). In addition, the interaction of increased growth due to increased $CO_2$ concentration, warming-induced drought, and heat-stress with potentially reduced streamflows are likely to affect riparian community structure and composition, especially in more arid areas (Perry et al. 2012).

Climate projections for mid-century are generally for warmer and drier outcomes, although precipitation change is more uncertain in direction and magnitude (Lukas et al. 2014). Annual runoff and streamflow are affected by both temperature and precipitation, and effects of future changes in these factors are difficult to separate. Warming-induced changes in snowpack and snowmelt timing include earlier spring snowmelt, a shift towards precipitation falling as rain instead of snow in spring and fall, and increased sublimation from the snowpack throughout the season. These changes are expected to have greater impact at lower elevations (Lukas et al. 2014). The effects of warming temperatures are likely to change the hydrologic cycle by shifting runoff and peak flows to earlier in the spring, and reducing late summer-early autumn flows (Rood et al. 2008). Riparian vegetation is in part determined by flow levels (Auble et al. 1994). Reduced summer flows are predicted to result in more frequent drought stress for riparian habitats, with a resulting loss or contraction of the habitat (Rood et al. 2008).

## Resilience and Adaptive Capacity Ranks

| | | | | |
|---|---|---|---|---|
| Eastern | Overall Score: | 0.52 | Rank: | **Moderate** |
| Mountain | Overall Score: | 0.60 | Rank: | **Moderate** |
| Western | Overall Score: | 0.49 | Rank: | **Low** |

***Bioclimatic envelope and range***

Scores: 0.57 (Eastern), 0.81 (Mountain), 0.66 (Western)

These shrublands are not limited to high elevations, and in Colorado are well within the range of continental distribution. Lower elevation types of the east and west slope have somewhat narrower bioclimatic ranges than montane types.

***Growth form and intrinsic dispersal rate***

Score: 0.5

The mixed growth-forms (trees, shrubs, and herbaceous) that may be dominant or characteristic of these ecosystems gives them an intermediate resilience score in this category.

***Vulnerability to increased attack by biological stressors***
Scores: 0.5

Seeding with non-native pasture grasses, invasion by tamarisk and exotic forbs has already altered species composition in many eastern and western riparian ecosystem, and will have a lasting effect. Invasive species with the potential to alter ecosystem function (e.g., tamarisk) are an ongoing management challenge.

For higher elevation riparian habitats, invasive species and grazing are minor impacts (Chimner et al. 2010), but these factors are an ongoing source of disturbance in lower montane riparian areas. Many of these communities have degraded understories, with weedy herbaceous layers and Russian olive and tamarisk invading the shrub layers.

***Vulnerability to increased frequency or intensity of extreme events***
Scores: 0.5

Increased frequency and magnitude of drought is likely to have significant impact on these habitats. Although fire has often not been considered an important disturbance in wetland and riparian areas, recent evidence suggests that fires in most types of adjacent upland vegetation are likely to burn into these habitats as well (Charron and Johnson 2006, Stromberg and Rychener 2010).

***Other indirect effects of non-climate stressors – landscape condition***
Eastern Plains Score: 0.44

Riparian habitats of Colorado's eastern plains continue to be threatened by urban, exurban, and recreational development as well as agricultural activities (e.g., tillage and crop production, livestock grazing, concentrated animal feeding operations) in adjacent uplands whose effects contribute to a gradual loss of habitat area and quality. Land use within the riparian area as well as in adjacent and upland areas can fragment the landscape and reduce connectivity between riparian patches and between riparian and upland areas, adversely affecting the movement of surface/ groundwater, nutrients, and dispersal of plants and animals. Roads, bridges, and development can also fragment both riparian and upland areas. Gravel mining is an additional source of disturbance to these habitats, especially along the larger rivers.

Alteration of natural hydrological processes by dams, diversions, ditches, roads, etc., and abiotic resource consumption through groundwater pumping have considerably altered the presettlement condition of these habitats, and are an ongoing threat. Dams, reservoirs, diversions, ditches and other human land uses alter the natural flow regime of a stream, and can disrupt the ecological integrity of the riparian system. Physical changes resulting from altered flow regimes include downstream erosion and channelization, reduced channel morphology dynamics, reduced base and/or peak flows, lower water tables in floodplains, and reduced sediment deposition in the floodplain (Poff et al. 1997). Most hydrological alteration is due to agricultural needs, except in highly developed areas along the mountain front where other uses are overtaking agricultural use. Continued groundwater pumping from the Ogallala-High Plains aquifer has lowered the water table such that many formerly flowing streams are now dry for much of the year (Dodds 1997). Flood control can greatly reduce the spatial complexity of riparian and wetland habitat.

Mountain Score: 0.69

Riparian areas in mountain areas are generally in good condition, although not without impact from anthropogenic disturbance. Threats to riparian woodland and shrubland in mountain areas of Colorado vary with elevation. Additional fragmentation and loss of riparian habitats at lower elevation in mountainous areas of Colorado due to urbanization and agriculture is an ongoing threat in many areas. At higher elevations where lands are in public ownership these habitats are most threatened by recreational development and use where roads provide access and are a source of sedimentation and pollutant runoff. Except at the highest elevations, few mountain riparian habitats are without hydrological modification, and the ongoing stresses from reservoirs, dams, diversions, and similar alterations include downstream erosion and channelization, reduced channel morphology dynamics, reduced base and/or peak flows, lower water tables in floodplains, and reduced sediment deposition in the floodplain (Poff et al. 1997).

Western Slope Score: 0.40

Riparian areas in western Colorado are generally in fair condition, and have been heavily impacted by anthropogenic disturbance in many areas. Threats to riparian habitats from ongoing urban and exurban development are generally less in most areas of Colorado's west slope in comparison with the Front Range, but not absent. Agricultural activities are ubiquitous in lower elevation riparian habitats, including irrigated tilled and untilled crops, and domestic livestock grazing. Gravel mining is common along the larger rivers. These disturbances are likely to continue to produce a gradual reduction in habitat area and quality in west slope riparian habitats.

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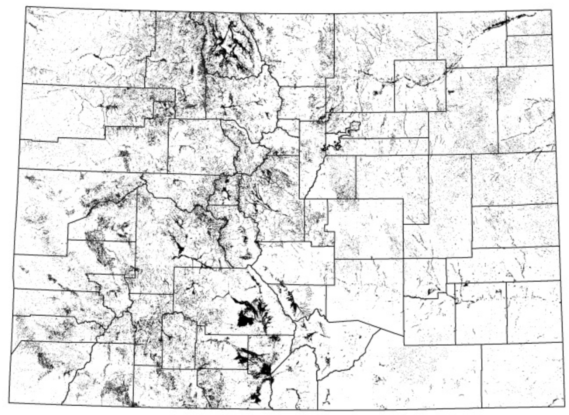
# WETLANDS

Herbaceous vegetation dominated areas characterized by water saturation and hydric soils

G. Doyle



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## Climate Vulnerability Ranks:
## High (Eastern), Moderate (Mountain and Western)

### Vulnerability summary

**Key vulnerabilities:** Warmer and drier conditions for lower elevation wetlands are likely to result in reduced inputs to these habitats, and lower groundwater levels in general that may reduce the extent and degrade the condition of wetlands. In higher elevations warmer temperatures and consequent earlier snowmelt may influence the species composition of wetland habitats. Ground-water dependent wetlands at higher elevations are expected to be somewhat buffered from hydrologic change.

Wetland habitats of the western valleys and mountain areas are ranked as having moderate vulnerability to the effects of climate change by mid-century, while those of the eastern plains are considered highly vulnerable. The primary factor contributing to the higher ranking for eastern plains wetlands is the degree of increased temperature projected for that region, in comparison with the other regions. The vulnerability of some species assemblages may be higher than is reflected by the collective assessment. The moderate resilience ranks reflect the highly altered condition of most of these habitats, and in general, all wetlands throughout the state should probably be regarded as having some degree of vulnerability to climate change that is not captured by our broad-scale assessment methods.

### Distribution

We assessed the condition of non-riparian wetlands in each of three sections of Colorado, corresponding approximately to ecoregions as defined by The Nature Conservancy (2009, modified from Bailey 1998): the eastern plains (Central Shortgrass Prairie ecoregion); mountains (Southern

Rocky Mountain ecoregion); and western plateaus and valleys (Colorado Plateau, Wyoming Basins, and other ecoregions). As considered herein, wetlands are areas characterized by water saturation and hydric soils typically supporting hydrophytic vegetation.

In Colorado, non-riparian wetland habitats include moist to wet meadows, emergent marshes, fens, and seeps and springs. Non-riparian wetlands of Colorado's eastern plains and western valleys are primarily marshes, seeps and springs, and wet meadows. Playas (shallow, temporary wetlands) are scattered throughout the eastern plains, and occur in limited distribution on the western slope as well. Although natural marshes and wet meadows are primarily found at higher elevations, irrigation practices (direct flood application, irrigation tail waters, elevated groundwater levels, etc.) have greatly increased the incidence of wet meadows on the eastern plains (Sueltenfuss et al. 2013). Most of the state's wet meadows occur in mountainous areas of Colorado, and marshes are generally less common. Fens are also characteristic of the mountain region.

### Characteristic species

Natural wet meadows are dominated by native sedges and grasses, while those influenced by irrigation may be dominated by non-native pasture grasses. Seeps and springs have generally similar vegetation to wet meadows.

Standing water in emergent marshes restricts the dominant species to robust wetland plants, such as cattail (*Typha*), bulrush (*Scirpus* and *Schoenoplectus* spp.), and large sedges (*Carex* spp.). At lower elevations, marshes can become densely vegetated if they are not periodically flushed by floodwater or mechanical thinning.

Fen vegetation is generally characterized by a dense cover of sedges and moss, often intermixed with forbs and short to dwarf shrubs such as willow and bog birch (*Betula nana*).

### Environment

Meadows occur throughout Colorado, but most natural wet meadows are found within the montane to subalpine zone. Natural wet meadows are tightly associated with snowmelt or subsurface groundwater discharge and typically not subjected to high disturbance events such as flooding. Within mountain valleys and at lower elevations, extensive acres of wet meadows are also linked to irrigation practices, including flood irrigation and seepage from irrigation ditches.

Emergent marshes are wetlands that experience frequent or prolonged ponding. Marshes occur in depressions and kettle ponds, as fringes around lakes, along streams and rivers, and behind many types of impoundments. They can be found at all elevations, but are more common at mid to lower elevations.

Fens are wetlands with thick organic soils that are supported by stable groundwater discharge. Fens are typically found within the montane to subalpine zone, generally above 7,000 ft., and can form along the edges of valley bottoms, at breaks in slope, around hillslope seeps, in shallow basins or anywhere where sufficient ground water emerges to perennially saturate soils. Fens are considered "old growth" wetlands, as the accumulation of thick organic soils can take thousands of years.

Seeps and springs include small wetlands that are hydrologically supported by groundwater discharge. They are found throughout Colorado and can be a component of the previously described wetland types, but are most notable within the cliff and canyon country of the Colorado Plateau and the Lower Arkansas basin.

### Dynamics

Hydrology is the primary determinant of the development and persistence of wetland ecosystems, and variations in timing and duration of inundation largely determine the type of wetland. The water budget or hydroperiod of a wetland includes precipitation, evapotranspiration, and both surface flow and groundwater. Although water may not be continuously present in wetlands, as a general rule of thumb inundation during at least 14 consecutive growing season days is sufficient to exert a significant influence on wetland processes (Culver and Lemly 2013).

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Rank

| | Eastern | Mountain | Western |
|---|---|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 37.2% | 0.8% | 15.3% |
| Initial Exposure-Sensitivity Rank | High | Low | Moderate |
| Percent Colorado acres with temp <= max & ppt delta < 5% more than 50%? | No (11.3%) | Yes (54.5%) | No (43.5%) |
| Final Exposure-Sensitivity Rank | **High** | **Moderate** | **Moderate** |

***Exposure to temperature change***

Under projected mid-century temperatures, about 43% of the current range of wetland ecosystem in eastern Colorado would experience annual mean temperatures above the current statewide maximum. The proportion is lower (19%) for western wetlands, and quite low (1%) in mountain areas.

***Exposure to precipitation change***

About 49% of wetland habitats in eastern Colorado will be exposed to effectively drier conditions even under unchanged or slightly increased precipitation projected for mid-century. For western wetland ecosystems, the proportion is somewhat higher (59%), and mountain wetlands can also expect to see effectively drier conditions in about 55% of their distribution.

***Sensitivity of ecosystem to temperature and precipitation***

Both temperature and precipitation can affect the presence and extent of wetlands on the landscape. Warmer, drier conditions are likely to lead to lower groundwater levels, at least during certain seasons, and can have a negative impact on these ecosystems. Earlier spring run-off would result in drying conditions by late summer, possibly reducing the size of existing wetlands. Similarly, wetlands currently supported by late-melting snowfields are likely to dry sooner than under current conditions.

Effects of climate change on wetlands are expected to be largely mediated through the source of water, either precipitation, groundwater discharge, or, for wetlands associated with riparian areas, surface flow (Winter 2000). Precipitation supported wetlands are thought to be most vulnerable to drier climatic outcomes, but decreasing precipitation would also be likely to lower water table levels and lead to contraction of groundwater-fed wetlands (Winter 2000, Poff et al. 2002). Under wetter conditions, some wetland types may be able to expand or at least maintain current extents. Consideration of the effects of changing precipitation is further complicated by the fact that wetlands may receive water input from the surrounding basin, not just the immediate environs (Gitay et al. 2001).

Temperature affects wetland distribution and function primarily through its effects on rates of chemical, physical and biological processes (Gage and Cooper 2007). Although wetlands are to some extent buffered from the immediate effects of warming on water temperature, warming could increase both plant growth and microbial activity driving decomposition (Fischlin et al. 2007). Temperature is also a driver of evapotranspiration rate, and the water cycle in general (Gitay et al. 2001).

Variation in climatic conditions affects groundwater levels both directly via recharge rates, and indirectly through changes in patterns of groundwater use, especially irrigation (Taylor et al. 2012). Drier future conditions are likely to result in tighter controls on irrigation seepage, and a consequent reduction in wetland acres supported by this source. Although climate change is expected to have a significant effect on wetlands through changes in the seasonality and variability of precipitation and extreme events (Gitay et al. 2005), changing water use patterns in response to climate change are also likely to play a major role in the future of wetlands (Taylor et al. 2012).

## Resilience and Adaptive Capacity Rank

| | | | | |
|---|---|---|---|---|
| Eastern | Overall Score: | 0.52 | Rank: | **Moderate** |
| Mountain | Overall Score: | 0.59 | Rank: | **Moderate** |
| Western | Overall Score: | 0.52 | Rank: | **Moderate** |

***Bioclimatic envelope and range***

Scores: 0.66 (Eastern), 0.77 (Mountain), 0.69 (Western)

Most wetlands are not limited to high elevations, and in Colorado are well within the range of continental distribution. Lower elevation types of the east and west slope have somewhat narrower bioclimatic ranges than montane types.

***Growth form and intrinsic dispersal rate***

Score: 0.5

This ecosystem is dominated by relatively fast growing graminoid and herbaceous species, but may be restricted in dispersal ability if habitats are isolated within the landscape.

***Vulnerability to increased attack by biological stressors***
Scores: 0.5

For higher elevation wetlands, invasive species and grazing are minor impacts (Chimner et al. 2010), but these factors are an ongoing source of disturbance in lower elevation wetlands that lower the resilience of these occurrences. Invasive species with the potential to alter ecosystem function are an ongoing management challenge. Impacted wetlands may be more vulnerable to invasion by exotic species.

***Vulnerability to increased frequency or intensity of extreme events***
Scores: 0.5

Increased frequency and magnitude of drought is likely to have significant impact on these habitats. Eventual impacts of climate change on aquifer source of water could eventually eliminate some types (seeps) from some areas.

***Other indirect effects of non-climate stressors – landscape condition***
Eastern Plains Score: 0.43

Wetlands of Colorado's eastern plains continue to be threatened by urban and exurban development as well as agricultural activities (e.g., tillage and crop production, livestock grazing, concentrated animal feeding operations) in adjacent uplands whose effects contribute to a gradual loss of habitat area and quality. The incidental creation of wetlands through water management activities is generally not sufficient to compensate for losses in this ecosystem.

Mountain Score: 0.67

With the exception of the extensive wetlands of the San Luis Valley, where water development for agricultural use is extensive, wetland habitats in mountain areas of Colorado are generally in good condition, with fewer anthropogenic impacts, and are overall less threatened by development and agriculture than those in lower elevations of the state.

Western Slope Score: 0.41

Wetland habitats in western Colorado have been heavily impacted by anthropogenic activities, and are often in only fair condition. Altered hydrology due to dams, diversions, and groundwater pumping may interact with warming temperatures and changes in precipitation pattern to alter groundwater recharge rates, and lead to drying or contraction of wetlands. Hanging gardens are an especially fragile wetland type of the western slope. Where they are accessible to foot traffic or livestock, erosion, trampling, and introduction of exotic species are an ongoing threat.

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# Freshwater Ecosystems – Methods

In consultation with BLM, CNHP identified six freshwater ecosystem groups to be assessed (Table 2.9). Our analysis evaluated the associated wetland and riparian ecosystems separately, so that vulnerability results here are not necessarily tied to the assessments presented above.

**Table 2.9**. Freshwater ecosystem targets.

| Freshwater Ecosystems | |
|---|---|
| Streams – high elevation (>6,500 ft) cold water | Rivers |
| Streams – mid elevation (<6,500 ft) cool and warmer water | Lakes |
| Cool to coldwater transitional stream areas | Reservoirs |

The vulnerability of freshwater ecosystems to climate change by mid-century was evaluated through a combination of spatial and narrative methods. The primary method of spatial evaluation is based on a model of projected change in water temperature around a cold to cool-water fisheries transition line.

### Transition line model

STORET water temperature data within Colorado were downloaded from the EPA website. Sample dates ranged from 1964 to 2013 during all times of year and day. The number of data records per station ranges from 1 to nearly 2,000. July was assumed to be the critical month during which water temperatures reaching 68°F (20°C) could negatively impact cold water fishes. From the full dataset (68,948 records), 7,373 data points from 1,413 stations were taken during the month of July, ranging over 1964 - 1984. July sample stations are not evenly distributed across the state, with relatively few across the eastern plains and near the Wyoming border, and with generally clumped spacing (Figure 2.10).

Multiple July data records for a single station were averaged. Mean July water temperature per station ranged from 33.8 - 87.1°F (1 - 30.6°C).

A 2-power, cross-validated local polynomial interpolation was calculated on the mean July water temperatures to derive water temperature contour lines across the state. Temperature values were weighted by number of sample records per station, to give higher weight to the more certain values. Not surprisingly, model fit was poor in those areas with few data points, but was excellent to good in those areas most likely to represent the temperature transition line (Figure 2.11), so we deemed the model acceptable for the current purpose.

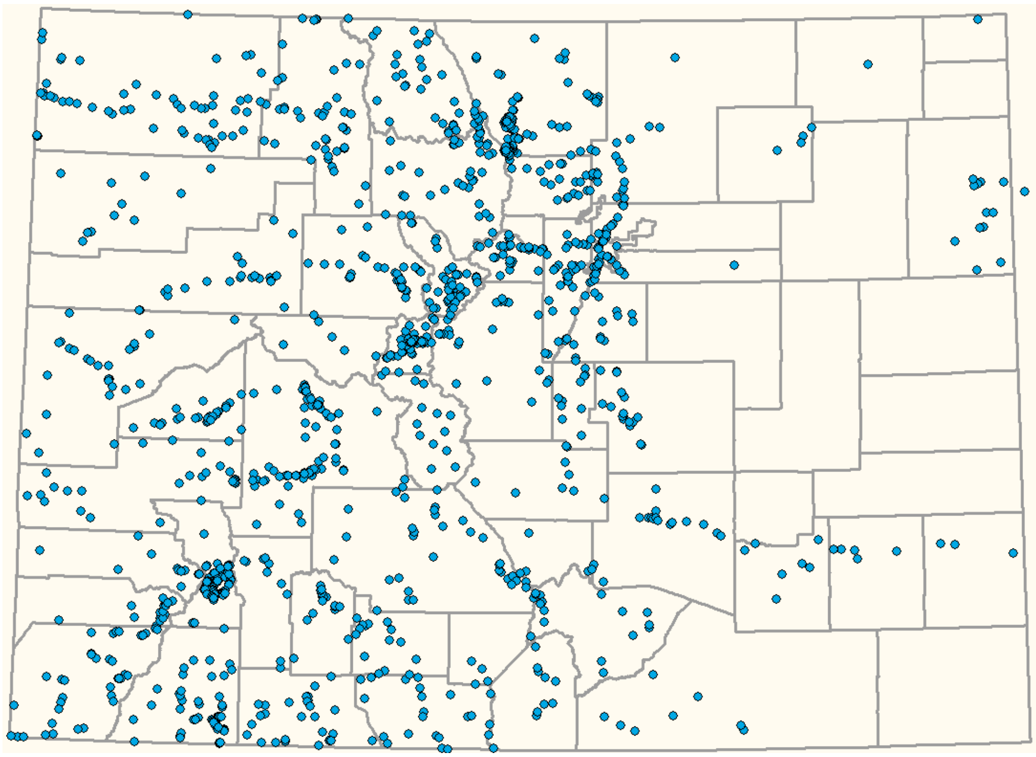

**Figure 2.10**. STORET stations with July water temperature readings.

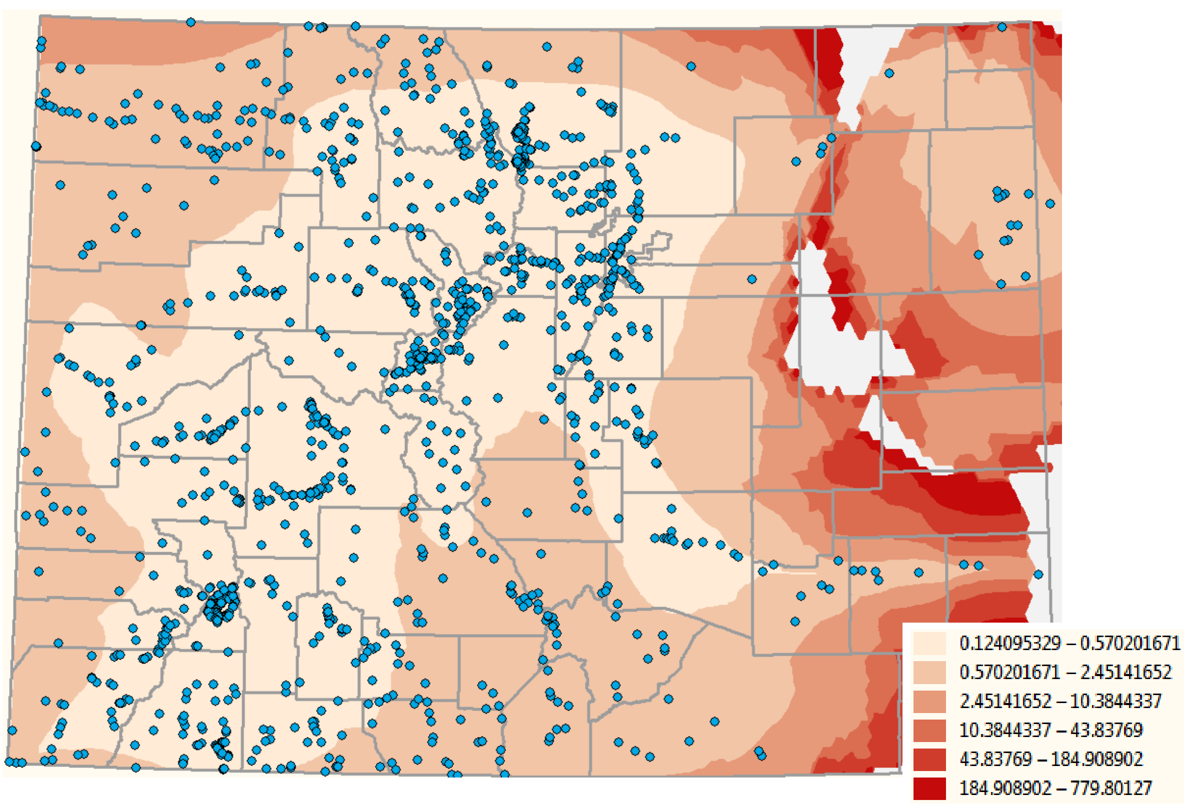


**Figure 2.11**. Prediction Standard Error.

A filled contour for July water temperatures between 67 - 69°F (19.5 - 20.5°C)was generated from the local polynomial interpolation prediction surface (Figure 2.12). Projected future temperature is available as surface air temperature, and there is not a one-to-one relationship between air and water temperatures over Colorado's complex topographical, elevational, and latitudinal ranges. To account for north-south and east-west gradients in translating the water temperature contour to air temperature, we divided the state into six equal sections. For each of four sections (the two eastern sections were not used due to lack of data) we calculated the mean and standard deviation of the current mean July air temperature for each water temperature contour segment within the section (the South-Central section has two separate contours to distinguish the conditions within the San Luis Valley (Figure 2.12).

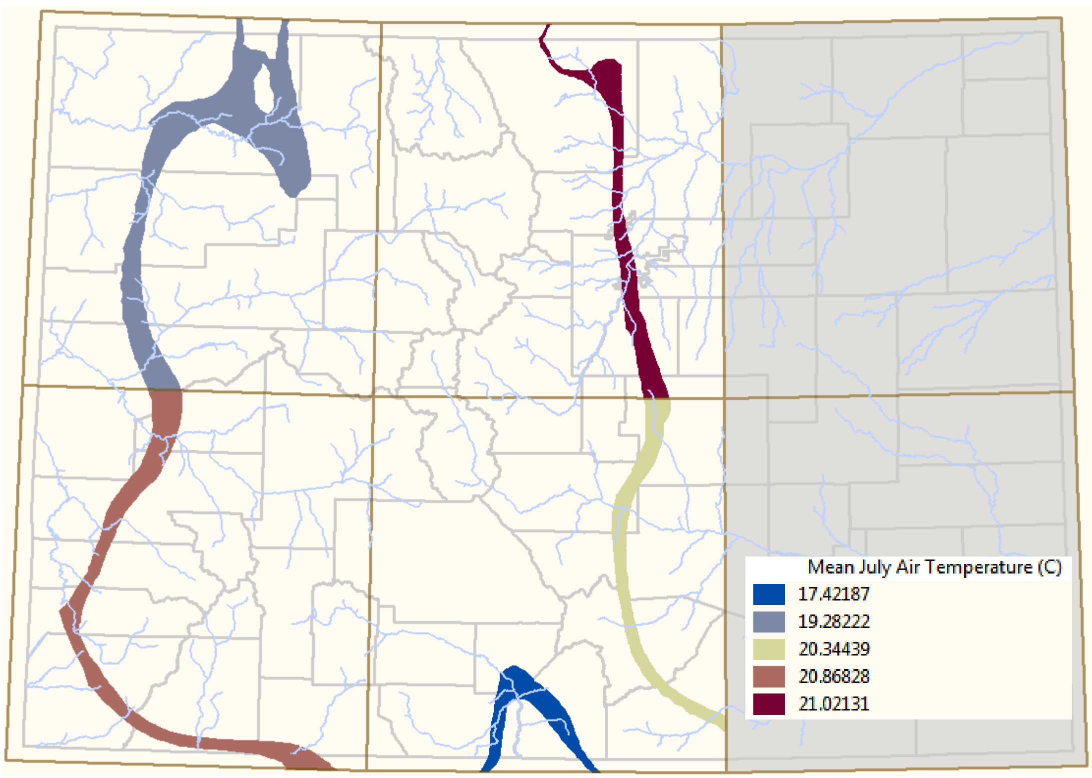


**Figure 2.12**. Interpolated water temperature 67 - 69°F filled contour, split into North-West, North-Central, South-West, and South-Central sections. Colors represent the mean July air temperature coinciding with each contour section.

Each filled contour section is not a single line but an area. Air temperatures below the mean can be thought of as representing the "leading" edge of the transition between cold and cool-water fisheries, while values above the mean would represent the "trailing" edge for the transition from cool to warm-water fisheries. Our analysis focused on mean values (Table 2.10) as the best representation of the overall transition area.

For each contour segment shown above (NW, NC, SW, SC, and the San Luis Valley), we generated a contour of the current July air temperature mean value (table column shaded in blue). These five sectional contours were then manually stitched together into a single cohesive temperature contour for the state, representing the current cold to warm-water fisheries transition line. The same procedure was followed to create projected future transition lines for RCP 4.5 and RCP 8.5 (Figure 2.13). The vulnerability analysis was made by comparing the current and RCP8.5 lines, to maintain consistency with the terrestrial ecosystem evaluation. Note that, because we are using air temperature as a proxy for water temperature, cold-water releases from reservoir storage are not accounted for in the model.

**Table 2.10.** Mean and standard deviation (STD) current July air temperature (°F) values for each contour segment within a section. Values in parentheses are °C.

| Section | Mean | STD |
|---|---|---|
| SC, valley | 63.4 (17.4) | 2.78 (1.55) |
| NW | 66.7 (19.3) | 3.61 (2.00) |
| SC, east | 68.6 (20.3) | 4.76 (2.64) |
| SW | 69.6 (20.9) | 3.49 (1.94) |
| NC | 69.8 (21.0) | 3.13 (1.74) |

The modeled transition line was used to assign stream and river reaches to cold, transitional, or warm water categories. Transitional reaches are those lying within approximately 0.5 km on either side of the transition line; exact distances are somewhat variable depending on local stream morphology and reach segment length.

Exposure to climate change was evaluated by comparing the total stream length currently falling in each category with the totals under projected mid-century conditions. Percent change between categories is summarized by region (Eastern, Mountain, Western), using the same divisions that were applied to wetland and riparian ecosystems.

To focus the vulnerability analysis on the loss of cold water and transitional reaches, we used a decision-tree based on current and projected stream lengths in these categories to assign exposure ranks for streams and rivers (Figure 2.14). Vulnerability is highest in regions where currently existing cold water and transitional reaches are essentially entirely eliminated. In regions where current presence of cold or transitional reaches is already very low, vulnerability is moderate, in that losses are minimal, but already warm reaches are exposed to additional warming and drying. Vulnerability is also moderate in areas where lengths of cold and transitional reaches will decline substantially, but remain present. Areas where cold and transitional reaches remain present in substantial lengths have comparatively low vulnerability.

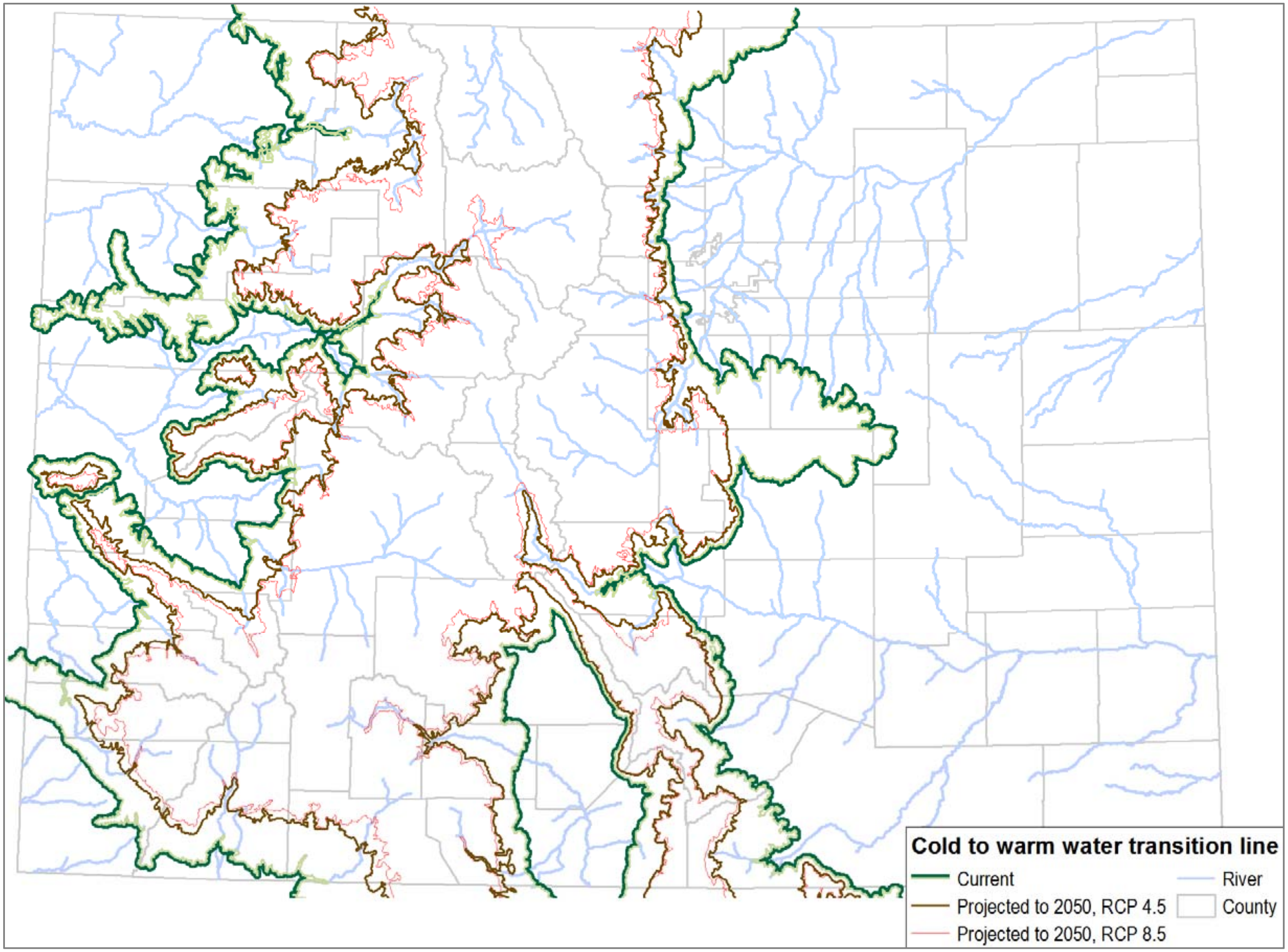


**Figure 2.13**. Modeled transition line.

| | | | | |
|---|---|---|---|---|
| Cold + Transitional reaches currently > 50km ? | | | | |
| **No** | **Yes** | | | |
| Moderate | Cold + Transitional reaches in mid-century > 50km? | | | |
| | **No** | **Yes** | | |
| | High | Cold + Transitional reaches in mid-century > 500km? | | |
| | | **No** | **Yes** | |
| | | Moderate | Cold + Transitional reaches in mid-century > 10,000km? | |
| | | | **No** | **Yes** |
| | | | Moderate | Low |

**Figure 2.14**. Decision-tree for exposure criteria applied to rivers and streams.

Lakes and reservoirs are poorly distinguished in most GIS data, and there are few natural lakes in Colorado that have not been modified to some extent for water storage. We considered any water body with surface area greater than or equal to 3 $km^2$ a reservoir, and smaller water bodies were classified as lakes. Both lakes and reservoirs were designated as either “high” or “low” elevation, according to their position in relation to the modeled transitional temperature line. GIS metrics were calculated using the same six divisions of the state shown in Figure 2.12, to account for north-south and east-west temperature differences inherent in Colorado. Exposure was calculated for lakes and reservoirs using methods similar for those used in evaluating terrestrial ecosystems (proportion of acreage where projected annual mean temperature for mid-century under RCP 8.5 was greater than any annual mean temperatures currently experienced by that ecosystem within Colorado, AND projected future precipitation changes were less than 5% increase over current levels, but without additional modifiers (Table 2.11).

**Table 2.11.** Criteria for scoring exposure of lakes and reservoirs freshwater ecosystems.

| | | | |
|---|---|---|---|
| Percent Colorado acres with projected temp > max & ppt delta < 5% | 36 – 100% | 16 – 35% | 0 – 15% |
| Initial Exposure-Sensitivity Score | High | Moderate | Low |

## Resilience-Adaptive Capacity Assessment – Freshwater Ecosystems

This score summarizes indirect effects and non-climate stressors that may interact with climate change to influence the adaptive capacity and resilience of an ecosystem. Factors evaluated are adapted from the methodology used by Manomet Center for Conservation Science and Massachusetts Division of Fish and Wildlife (MCCS and MAFW 2010), combined under five headings (Table 2.12). Factors were scored on a scale of 0 (low resilience) to 1 (high resilience).

**Table 2.12**. Description of factors used to assess resilience-adaptive capacity in freshwater ecosystems.

| Assessment factor | Description |
|---|---|
| Restriction to specific hydro-geomorphic setting | Fundamental geomorphic characteristics that define stream and wetland systems (elevation, slope, drainage area) do not change appreciably over decades. However, headwater streams are constrained by upper limits to watersheds, some larger streams or rivers are constrained at their lower limits by the presence of water bodies, including large reservoirs, and lakes or reservoirs are fixed in location. In addition, increasing temperature and accompanying changes in hydrology and water quality could result in the transition of one stream or river type to another. |
| Vulnerability to change in snowmelt timing and magnitude, and/or decreasing baseflows | The timing and magnitude of snowmelt runoff provide a key habitat component for some aquatic species. Earlier peak flows, reduced flows, changes in flood frequency or magnitude, and the overall shape of the hydrograph may change under projected climatic conditions. Effects could include shifts in spawning behavior, as well as loss or displacement of spawning beds and other important habitat structure. Lower base flows, and reduced groundwater discharge are possible under projected increased temperatures. These changes can reduce habitat area, as well as increasing habitat vulnerability to temperature and water quality stress. Finally, if overall water supplies decrease, anthropogenic efforts to divert and store water are likely to increase the level of hydrologic modification in these ecosystems. |
| Vulnerability to increased impact by biological stressors | This factor summarizes whether expected future biological stressors (invasive species, pests and pathogens) have had, or are likely to have, an increased effect due to interactions with changing climate. Climate change may result in more frequent or more severe outbreaks of these stressors. Ecosystems that are currently vulnerable to these stressors may become more so under climate change. Aquatic pathogens of concern include whirling disease, giardia, and cryptosporidium. Increased temperatures and the resulting hydrologic changes may make freshwater ecosystems more susceptible to invasion by non-native species, including quagga mussel, New Zealand mudsnail, rusty crayfish, Eurasian millefoil, and others. Finally, native species (e.g., the alga *Didymosphenia geminata*) can proliferate as nuisance species under changing climatic conditions. |
| Vulnerability to increased frequency or intensity of extreme events | This factor evaluates characteristics of an ecosystem that make it relatively more vulnerable to extreme events (floods, drought, fire) that are projected to become more frequent and/or intense under climate change. Flooding and drought frequency may alter geomorphic processes, sedimentation, water quality, and the stability of small populations. An increase in large fires may change sediment loads and water quality. |
| Other indirect effects of non-climate stressors | This factor summarizes the overall condition of the ecosystem at the landscape level across Colorado, and is derived from a summary impact score indexing the degree of hydrological modification and anthropogenic disturbance (TNC 2012). |

#### Restriction to specific hydro-geomorphic setting

Scores of 0 = low resilience, 0.5 = intermediate or uncertain resilience, and 1 = high resilience were assigned, based on best professional judgement focused on the relative vulnerability of each type in comparison with other types.

#### Vulnerability to change in snowmelt timing and magnitude, and/or decreasing baseflows

Scores of 0 = low resilience, 0.5 = intermediate or uncertain resilience, and 1 = high resilience were assigned, based on best professional judgement focused on the relative vulnerability of each type in comparison with other types.

#### Vulnerability to increased impact by biological stressors

For each biological stressor (invasive species and pathogens-pests) to which an ecosystem is believed vulnerable, 0.5 was subtracted from a default score of 1, to produce the final ecosystem score.

#### Vulnerability to increased frequency or intensity of extreme events

For each non-biological stressor (drought, flooding, and fire) to which an ecosystem is believed vulnerable, 0.33 was subtracted from a default score of 1, to produce the final ecosystem score.

#### Other indirect effects of non-climate stressors

Resilience to climate change was evaluated using the measures of aquatic resource condition database for Colorado developed by The Nature Conservancy (2012). The database includes a metric that summarizes condition factors under five primary headings as shown in Table 2.13 for each stream reach. The summary measure ranges from 1 (very good condition, little or no impact) to 4 (poor condition, heavily impacted). We report the length-weighted average of the summary metric by stream or river category within the same three regions (Eastern, Mountain, Western) described above.

**Table 2.13.** Factors included in TNC freshwater measures of condition database.

| Natural Flow Regime | Riparian Condition | Development | Connectivity | Water Quality |
|---|---|---|---|---|
| • Consumptive Use (Agricultural Use, Municipal Use, Transbasin Diversions)<br>• Reservoir Storage | • Riparian Land Use<br>• Non-native Plants – Tamarisk – in the Riparian Vegetation | • Land Use<br>• Road Density<br>• Road Crossings<br>• Oil and Gas<br>• Mining | • Instream Barriers to Fish Movement | • Streams with a 303d and/or Monitoring and Evaluation Designation |

## Vulnerability Assessment Ranking

#### Overall Vulnerability Ranking

The Exposure-Sensitivity score and the Resilience-Adaptive Capacity score are combined in the same way as for terrestrial ecosystems (Figure 2.2) to produce an overall vulnerability rank for each freshwater ecosystem.

# FRESHWATER ECOSYSTEMS - RESULTS

**Table 2.14.** Key vulnerabilities, freshwater ecosystems.

| Habitat | Climate factor(s) | Consequences | Other considerations |
|---|---|---|---|
| Streams - west | Warming water temps | Loss of cool-water reaches | Connectivity; altered hydrology due to diversions |
| Streams - mtn. | Timing and amount of snowmelt/runoff | Altered hydrographs | Connectivity (including transbasin diversion), potential for increased wildfire disturbance |
| Streams - east | Warmer and drier conditions | Loss of perennial reaches | Connectivity; altered hydrology due to diversions |
| Rivers - west | Warming water temps | Loss of cool-water reaches, low summer flows | Connectivity (including transbasin diversion), potential for increased wildfire disturbance |
| Rivers - mtn. | Timing and amount of runoff | Altered hydrographs | Connectivity (including transbasin diversion) |
| Rivers - east | Timing and amount of runoff | Altered hydrographs | Connectivity; altered hydrology due to dams and diversions |
| Lakes, high | Warmer and drier conditions | Reduced water quality | Nitrogen deposition |
| Lakes, low | Warmer and drier conditions | Low water levels | Municipal & agricultural supply pressure |
| Reservoirs, high | Timing and amount of snowmelt/runoff | Earlier high water levels | Flood control releases, reduced later storage |
| Reservoirs, low | Warmer and drier conditions | Low water levels | Municipal & agricultural supply pressure |

# Streams, Rivers, Lakes, and Reservoirs

Freshwater ecosystems in Colorado include both cold- and warm-water streams and rivers, as well as transitional cool-water stream and river reaches. Lakes and reservoirs are also included in our analysis.

CNHP photos

## Climate Vulnerability Ranks:

Three of the 10 regional ecosystem subtypes assessed have an overall vulnerability rank of High, and two are ranked Very High (Table 2.15). The primary factor contributing to the high exposure rankings for rivers is the essentially complete loss of current cold and transitional reaches. Lakes and reservoirs at all elevations are projected to experience temperatures outside the current range, as well as effectively drier conditions. Most ecosystem subtypes were assessed as having moderate resilience, with only mountain streams having high resilience and low overall vulnerability by mid-century.

**Table 2.15**. Vulnerability rank summary for all assessed freshwater ecosystems.

| Freshwater Ecosystem Target | Exposure - Sensitivity final ranking | Resilience - Adaptive capacity final ranking | Combined ranks | Overall vulnerability rank |
|---|---|---|---|---|
| Streams West | Moderate | Moderate | M/M | Moderate |
| Streams Mountain | Low | High | L/H | Low |
| Streams East | Moderate | Moderate | M/M | Moderate |
| | | | | |
| Rivers West | High | Moderate | H/M | High |
| Rivers Mountain | Moderate | Moderate | M/M | Moderate |
| Rivers East | High | Moderate | H/M | High |
| | | | | |
| Lakes - high | High | High | H/M | Moderate |
| Lakes - low | High | Low | H/L | Very High |
| | | | | |
| Reservoirs - high | Moderate | Moderate | M/M | Moderate |
| Reservoirs - low | High | Low | H/L | Very High |

## Vulnerability summary

**Key vulnerabilities:**

Rivers and Streams

Warming water temperatures are expected to lead to loss of cool-water reaches in both rivers and streams in western Colorado, and to lower summer flows. Warmer temperatures will generally result in earlier snowmelt and runoff for mountain streams and rivers. In eastern Colorado, warmer and drier conditions are likely to reduce the extent of perennial stream reaches, and alter the hydrographs of large rivers that depend on snowmelt. Nearly all river and stream habitats are already impacted by dams and diversions that have degraded the connectivity and hydrology of the ecosystem.

Lakes and Reservoirs

Warmer and drier conditions for lower elevation lakes and reservoirs are likely to result in generally lower water levels under pressure from municipal and agricultural consumers. High elevation lakes may see reduced water quality as temperatures warm; some areas are already affected by nitrogen deposition. Changes in timing and amount of snowmelt runoff may change storage patterns in higher elevation reservoirs; early flood control releases may lead to reduced late-season water levels.

Smaller lotic ecosystems (streams) have generally lower vulnerability, especially at higher elevations where cold water reaches are likely to remain viable. The primary factor contributing to high or very high vulnerability ranks for freshwater ecosystems is the projected change in the transition zone between warm and cold water areas. Most freshwater ecosystems were ranked as moderately resilient, indicating that there are likely to be management opportunities to mitigate some effects of exposure to warmer conditions.

### Distribution

Freshwater ecosystems in Colorado are found throughout the state, although perennial streams and lakes are more common at higher elevations. With the exception of the Green River, which crosses the northwestern corner of the state, all of Colorado's major rivers originate within the state and flow away from the continental divide. To the east of the divide, streams and rivers drain toward the Gulf of Mexico. On the western slope, flowing waters are tributary to the Colorado River, draining toward the Pacific Ocean. Conditions in Colorado watersheds affect many downstream users, both within the state's borders and beyond. Water distribution in Colorado has evolved a complex system of diversions, irrigation wells, and water storage facilities that have altered the original hydrologic regime of many areas.

### Environment

Freshwater ecosystems as evaluated in this assessment are all part of an interconnected hydrologic network that includes both surface and ground water. For the purposes of our assessment, we divide the surface waters of this network into several broad types by size, flow patterns, and location. Flowing waters of stream order 5 through 7 (the largest in Colorado) are discussed herein as "rivers", while flowing waters of lower order are termed "streams." Under this grouping, rivers include the larger perennial stream reaches, together with their major tributaries, that drain watersheds on the order 10,000+ square miles in extent. Streams include all other smaller reaches both perennial and intermittent, from headwaters to their junction with rivers, if any.

Lakes and reservoirs are also part of the hydrologic network, but have generally much slower current, such that they generally appear as standing bodies of water, and may be isolated from perennial surface flow. Because many lakes have been modified to some extent to regulate water flow, we grouped larger impoundments (greater than or equal to 3 $km^2$ in area) together as reservoirs, and smaller water bodies (less than 3 $km^2$ in area) as lakes, regardless of modification. Finally, we assessed freshwater habitats according to elevation and regional location within the state.

### Dynamics

Baron and Poff (2004) identified five dynamic factors that shape the structure and function of freshwater ecosystems: the flow pattern of water through the system, inputs of sediment and organic matter, nutrient and chemical conditions, temperature and light levels, and plant and animal assemblages.

Flow patterns describe the way water passes into and out of streams, rivers, lakes and associated wetlands. Important characteristics include base flow levels, the periodicity and magnitude of both annual or frequent floods and rare and extreme flood events, seasonality of flows, and annual variability (Baron and Poff 2004). Patterns of water flow and their interaction with local landforms and substrates at a variety of scales are the primary determinant of physical habitat for river organisms. Aquatic organisms evolved with and are adapted to the characteristic natural flow regime of their habitat; changes in flow regime can cause serious disruption to the reproduction and survival of many aquatic species, leading to an eventual loss of biodiversity (Bunn and Arthington 2002). Reduced connectivity in aquatic habitats, both in-stream and between the river channel and associated floodplain habitats, reduces habitat availability and diversity, with consequent negative effects on the population viability of aquatic species. Altered flow regimes, and transbasin diversions can facilitate the invasion and establishment of exotic species (Bunn and Arthington 2002). Finally, riverine systems act to integrate and collect the effects of disturbances within the catchment, including those due to flow modification (Naiman et al. 2002).

Sediment and organic matter inputs to freshwater ecosystems may include both natural and anthropogenic sources. The arrival of natural organic matter (e.g., plant material) from adjacent upland areas is a regular seasonal occurrence, and sediment movements occur naturally with seasonal and interannual variation in water flow. Many plant and animal species of these habitats are closely adapted to specific sediment and organic matter conditions, and are easily eliminated by changes in the environment (Baron and Poff 2004). Anthropogenic disturbances such as agriculture, logging, road construction, dams, and diversions have highly modified the natural sediment and organic input of freshwater ecosystems. Unmodified streams display a mosaic of habitats created by flow and sedimentation patterns. Extensive removal of beaver throughout Colorado in the first half of the 19$^{th}$ century probably had a considerable effect on channel structure, diversity, and stability, as well as sediment levels in mountain streams (Wohl 2006). Placer mining was an even stronger agent of hydrologic modification in many areas. Diversion dams tend to shift habitat toward slower flow and increased fine sedimentation (Baker et al. 2011). The legacy of these historic anthropogenic disturbances is reduced habitat suitability for native species.

Natural nutrient and chemical conditions in freshwater ecosystems are largely determined by climate, bedrock, soil, vegetation, and topography in the vicinity, and are consequently highly variable by locale (Baron and Poff 2004). Human activities can add nutrients (eutrophication), or a variety of man-made chemicals (herbicides, pesticides, pharmaceuticals, etc.) that change the species composition and quality of these habitats (Carpenter 1998).

Water temperature is key in determining oxygen concentration and the life processes of aquatic organisms. Patterns of temperature and solar energy absorption differ between moving and still waters. The release of cold water from reservoir storage interrupts the natural temperature patterns immediately downstream.

Changing climate conditions can affect all these factors, but directly act through temperature and flow.

### Characteristic species

The complete biotic community of an aquatic ecosystem includes plants and algae, as well as invertebrate and vertebrate animals. Environmental conditions and dynamics in part determine the plant and animal assemblages that will be associated with a particular freshwater ecosystem. In turn, the biota are active participants in ecological processes. A complete description of species characteristic of Colorado’s freshwater ecosystems is beyond the scope of this assessment, but common and important macroinvertebrates include crustaceans and species of Ephemeroptera, Plecoptera, Trichoptera, and Odonata, among others.

Fish of Colorado's freshwater ecosystems include both native and introduced species. Fish species shown in Table 2.16 are representative of some of the freshwater ecosystems evaluated. Vulnerability results from species-specific Climate Change Vulnerability Index analysis (see Chapter 3) are shown, if available.

**Table 2.16.** Representative fish species for freshwater ecosystems.

| **Representative fish species** | **CCVI rank** | **Cold Water** | | **Transitional** | | **Warm Water** | | **Lakes - high** |
|---|---|---|---|---|---|---|---|---|
| | | **Rivers** | **Streams** | **Rivers** | **Streams** | **Rivers** | **Streams** | |
| Colorado River Cutthroat | Extremely vulnerable | X | X | X | X | | | X |
| Greenback Cutthroat | | X | X | X | X | | | X |
| Rio Grande Cutthroat | Extremely vulnerable | X | X | X | X | | | X |
| Mottled sculpin | | X | X | X | X | | | |
| Speckled dace | | X | X | X | X | | | |
| Brown trout | | | | X | X | | | |
| Bluehead sucker | Highly vulnerable | | | X | X | X | X | |
| Flannelmouth sucker | Highly vulnerable | | | X | X | X | X | |
| Roundtail Chub | Highly vulnerable | | | X | X | X | X | |
| Bonytail chub | Extremely vulnerable | | | X | | X | | |
| Colorado pikeminnow | Extremely vulnerable | | | X | | X | | |
| Humpback chub | Extremely vulnerable | | | X | | X | | |
| Razorback sucker | Highly vulnerable | | | X | | X | | |

## CCVA Scoring

### Exposure-Sensitivity (Potential Impact) Ranks

| Ecosystem | Method | Score |
|---|---|---|
| Streams West | Decision tree | Moderate |
| Streams Mountain | Decision tree | Low |
| Streams East | Decision tree | Moderate |
| | | |
| Rivers West | Decision tree | High |
| Rivers Mountain | Decision tree | Moderate |
| Rivers East | Decision tree | High |
| | | |
| Lakes – high elev. | Avg. "out of range" | High |
| Lakes – low elev. | Avg. "out of range" | High |
| | | |
| Reservoirs – high elev. | Avg. "out of range" | Moderate |
| Reservoirs – low elev. | Avg. "out of range" | High |

Under the scope of our analysis, the total stream and river length present in the state is assumed to remain constant between the present and mid-century. The effects of warming temperature are measured by comparing the proportion of stream and river reaches that move from one category to the next. Under the constraints of the technique, a reach can remain in the same category, or move to a warmer category, but never move to a cooler category.

As expected, both streams and rivers in the mountain region are currently dominated by cold water reaches, and there are limited cold water reaches present in both the eastern and western regions (Figure 2.15, Table 2.17). Cool to coldwater transition reaches are currently most common in western rivers and streams. Both eastern and western rivers and streams currently have a significant proportion of warm water reaches.

Statewide patterns of transition are shown in Figure 2.16. An overall retreat of cold water conditions to higher elevations is evident. Major rivers on both the east and west slope are projected to see warmer water temperatures far upstream. This effect is particularly evident on the western rivers.

Under projected warming water temperatures at mid-century, for all regions the proportion of warm water reach length increases. Transitional areas generally move up in elevation, and become concentrated in the mountain region. Without accounting for water temperatures maintained by storage release, cold water reaches essentially disappear from the lower elevations of both eastern and western Colorado.

Exposure to "out of range" conditions for lakes and reservoirs was lowest for high elevation reservoirs. Both low and high elevation lakes were in the moderately vulnerable category, although higher elevation lakes had slightly less exposure. Low elevation reservoirs had highest exposure under projected mid-century climate conditions.

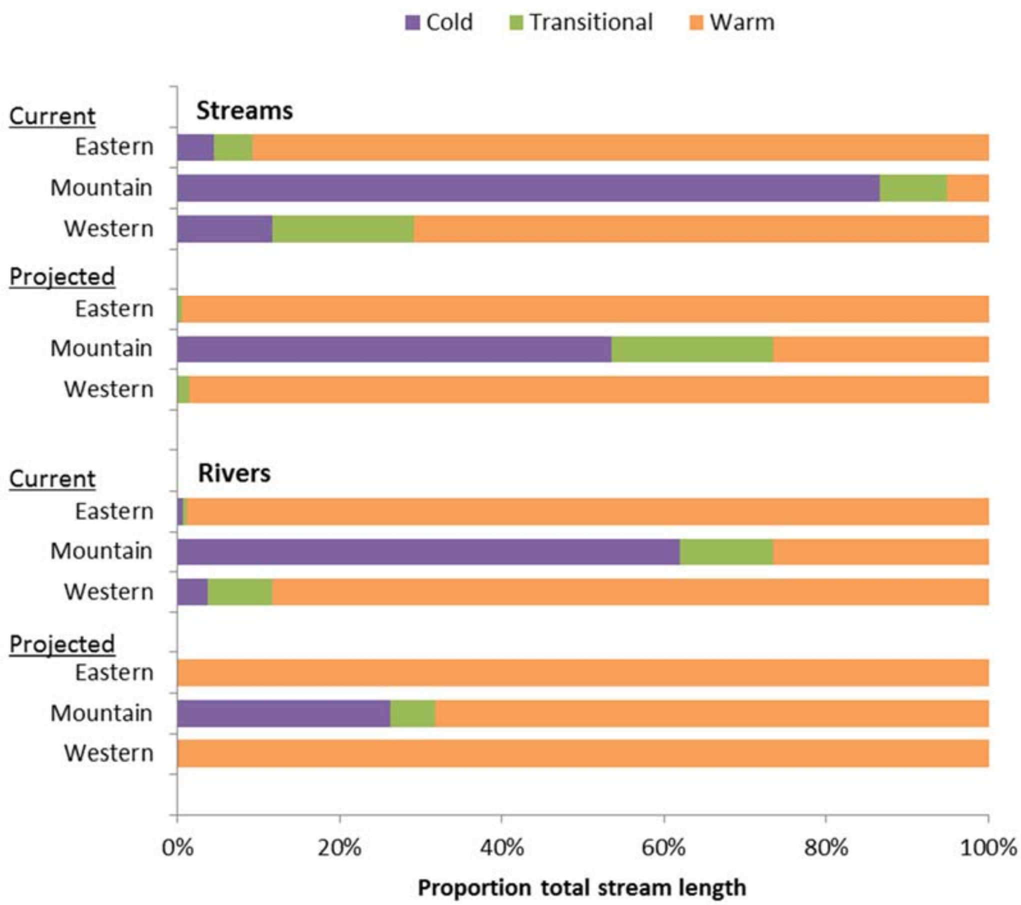


**Figure 2.15**. Category transitions between current and projected (RCP 8.5) conditions for streams and rivers.

**Table 2.17.** Reach length statistics (km) for water temperature categories both statewide and by region.

| | Cold Water | | Transitional | | Warm Water | |
|---|---|---|---|---|---|---|
| **Statewide:** | **Rivers** | **Streams** | **Rivers** | **Streams** | **Rivers** | **Streams** |
| Current | 1,394 | 64,728 | 395 | 12,342 | 4,480 | 63,386 |
| % Total | 1% | 44% | 0% | 8% | 3% | 43% |
| RCP 8.5 | 560 | 36,882 | 117 | 14,227 | 5,591 | 89,348 |
| % Total | 0.4% | 25% | 0.1% | 10% | 4% | 61% |
| % change from Current | -60% | -43% | -70% | 15% | 25% | 41% |
| **By Region:** | | | | | | |
| **West Slope** | | | | | | |
| Current | 58 | 3,044 | 129 | 4,564 | 1,408 | 18,515 |
| % Total | 0.2% | 11% | 0.5% | 16% | 5% | 67% |
| RCP 8.5 | 0 | 20 | 0 | 362 | 1,596 | 25,741 |
| % Total | 0% | 0.07% | 0% | 1% | 6% | 93% |
| % change from Current | -100% | -99% | -100% | -92% | 13% | 39% |
| **Southern Rocky Mountains** | | | | | | |
| Current | 1,321 | 59,640 | 245 | 5,640 | 569 | 3,547 |
| % Total | 2% | 84% | 0% | 8% | 1% | 5% |
| RCP 8.5 | 560 | 36,862 | 117 | 13,663 | 1,456 | 18,303 |
| % Total | 1% | 52% | 0.2% | 19% | 2% | 26% |
| % change from Current | -58% | -38% | -52% | 142% | 156% | 416% |
| **Eastern Plains** | | | | | | |
| Current | 15 | 2,044 | 14 | 2,138 | 2,510 | 41,324 |
| % Total | 0.03% | 4% | 0.03% | 4% | 5% | 86% |
| RCP 8.5 | 0 | 0 | 0 | 201 | 2,539 | 45,304 |
| % Total | 0% | 0% | 0% | 0.4% | 5% | 94% |
| % change from Current | -100% | -100% | -100% | -91% | 1% | 10% |

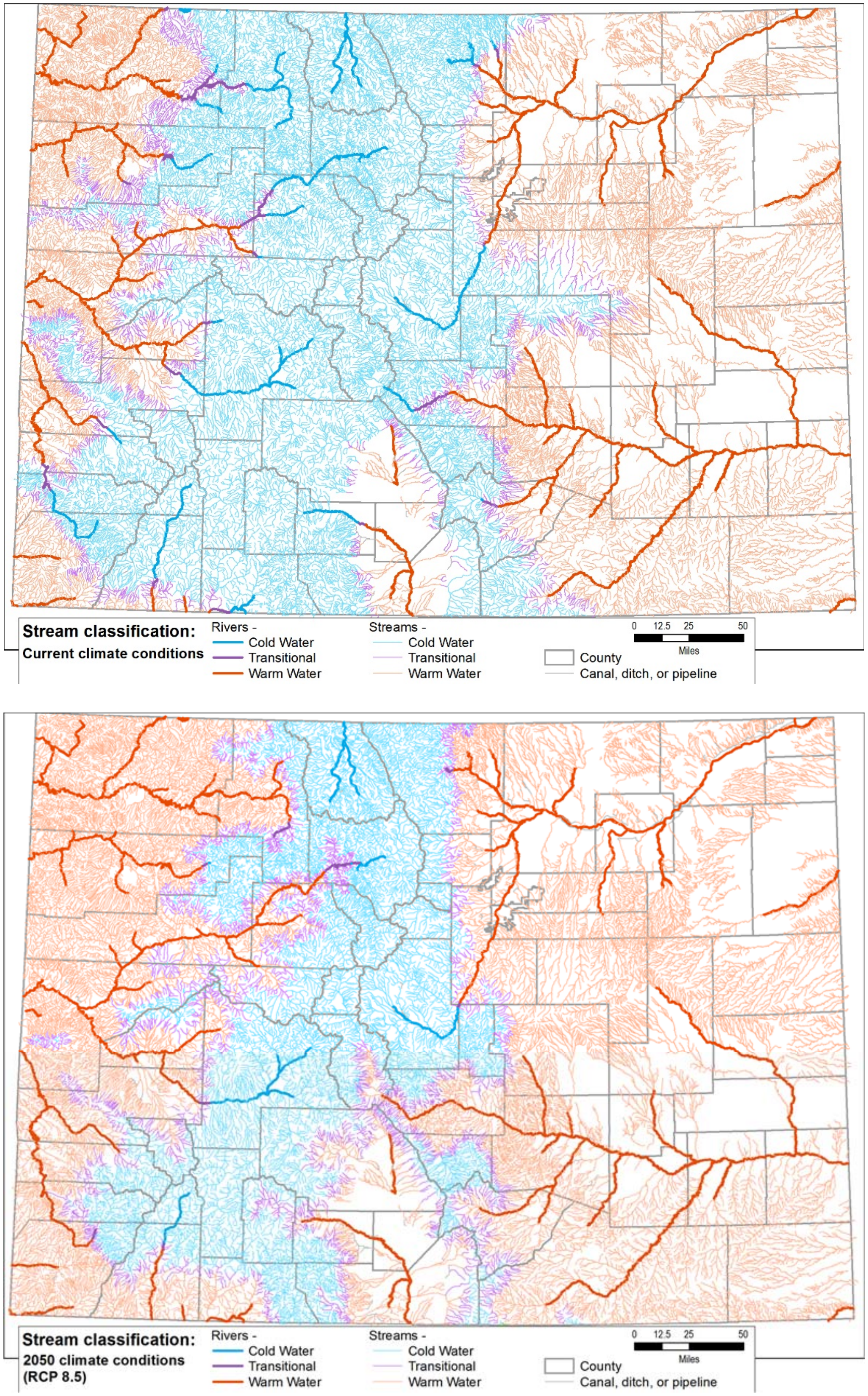


**Figure 2.16**. Comparison of current (top) and projected (bottom) stream temperature classification.

### Resilience and Adaptive Capacity Ranks

| Ecosystem | Score | Rank |
|---|---|---|
| Streams West | 0.54 | Moderate |
| Streams Mountain | 0.71 | High |
| Streams East | 0.61 | Moderate |
| | | |
| Rivers West | 0.49 | Moderate |
| Rivers Mountain | 0.58 | Moderate |
| Rivers East | 0.66 | Moderate |
| | | |
| Lakes - high | 0.68 | High |
| Lakes - low | 0.39 | Low |
| | | |
| Reservoirs - high | 0.59 | Moderate |
| Reservoirs - low | 0.27 | Low |

***Restriction to specific hydro-geomorphic setting***

High elevation lakes are scored as most restricted by their location. Other water bodies are scored as intermediate in location restriction, as are higher elevation streams and rivers. Lower elevation streams and rivers are presumed to be unrestricted.

| Ecosystem | Score |
|---|---|
| Streams West | 1 |
| Streams Mountain | 0.5 |
| Streams East | 1 |
| | |
| Rivers West | 1 |
| Rivers Mountain | 0.5 |
| Rivers East | 1 |
| | |
| Lakes – high elev. | 0 |
| Lakes – low elev. | 0.5 |
| | |
| Reservoirs – high elev. | 0.5 |
| Reservoirs – low elev. | 0.5 |

***Vulnerability to change in snowmelt timing and magnitude, and/or decreasing baseflows***

Streams, lakes, and reservoirs of high elevations are scored as least vulnerable to changes in snowmelt timing and magnitude, and with less vulnerability to decreasing baseflows, under the assumption that higher elevations are less likely to see effectively drier conditions by mid-century. Streams, rivers, and lakes of lower elevations are scored as having intermediate vulnerability for these factors, based on the assumption that the effects of increasing temperatures and effectively drier conditions will tend to accumulate in these downstream reaches. Low elevation reservoirs are assumed to be most vulnerable.

| Ecosystem | Score |
|---|---|
| Streams West | 0.5 |
| Streams Mountain | 1 |
| Streams East | 0.5 |
| | |
| Rivers West | 0.5 |
| Rivers Mountain | 0.5 |
| Rivers East | 1 |
| | |
| Lakes – high elev. | 1 |
| Lakes – low elev. | 0.5 |
| | |
| Reservoirs – high elev. | 1 |
| Reservoirs – low elev. | 0 |

***Vulnerability to increased impact by biological stressors***

In general, freshwater habitats of the highest elevations are scored as not vulnerable to increased impact by pathogens or invasives, due to comparatively cooler temperatures in these areas, and the current low levels of such stressors. Low elevation ecosystems are scored as more vulnerable to invasive species and pathogens, due to the warmer temperatures, and the fact that some invasives and pathogens are already present in these habitats.

| Ecosystem | Score | Factors |
|---|---|---|
| Streams West | 0.5 | Pathogens |
| Streams Mountain | 1 | --- |
| Streams East | 0.5 | Invasives |
| | | |
| Rivers West | 0 | Pathogens & Invasives |
| Rivers Mountain | 1 | --- |
| Rivers East | 0.5 | Invasives |
| | | |
| Lakes – high elev. | 1 | --- |
| Lakes – low elev. | 0 | Pathogens & Invasives |
| | | |

| Ecosystem | Score | Factors |
|---|---|---|
| Reservoirs – high elev. | 0.5 | Invasives |
| Reservoirs – low elev. | 0 | Pathogens & Invasives |

***Vulnerability to increased frequency or intensity of extreme events***

Increasing frequency and severity of drought is the primary factor that is likely to increase vulnerability of freshwater ecosystems. Streams in western and mountain areas are scored as being vulnerable to increased sedimentation following a potential increase in fire frequency. Mountain rivers are scored as vulnerable to a potential increase in extreme precipitation events. High elevation lakes are not thought to be vulnerable in this category.

| Ecosystem | Score | Factors |
|---|---|---|
| Streams West | 0.33 | Drought, fire |
| Streams Mountain | 0.67 | Fire |
| Streams East | 0.67 | Drought |
| | | |
| Rivers West | 0.67 | Drought |
| Rivers Mountain | 0.67 | Flooding |
| Rivers East | 0.67 | Drought |
| | | |
| Lakes – high elev. | 1 | --- |
| Lakes – low elev. | 0.67 | Drought |
| | | |
| Reservoirs – high elev. | 0.67 | Drought |
| Reservoirs – low elev. | 0.67 | Drought |

***Other indirect effects of non-climate stressors***

The length-weighted mean score by region for the summary condition factor (TNC 2012) was converted to a proportion of potential best score (4) using the formula: 1 – ((region mean-1) / 3). A lower mean before score conversion indicates better condition, and higher resilience. In general, higher elevation areas are in better condition.

| Ecosystem | Mean | Score |
|---|---|---|
| Streams West | 2.57 | 0.48 |
| Streams Mountain | 2.45 | 0.52 |
| Streams East | 2.57 | 0.48 |
| | | |
| Rivers West | 2.94 | 0.35 |
| Rivers Mountain | 3.08 | 0.31 |
| Rivers East | 3.53 | 0.16 |
| | | |
| Lakes – high elev. | 2.34 | 0.55 |
| Lakes – low elev. | 2.80 | 0.40 |
| | | |

| Ecosystem | Mean | Score |
|---|---|---|
| Reservoirs – high elev. | 2.94 | 0.35 |
| Reservoirs – low elev. | 3.25 | 0.25 |

## Conclusions

All freshwater ecosystems are expected to be affected to some extent by climate change. As water temperatures change, some warm-water habitat types may expand at the expense of cool- or cold-water types. Nearly all evaluated freshwater types were ranked with moderate to very high vulnerability in our analysis, with reasonable certainty that these habitats will be impacted by climate change. Although we did not incorporate freshwater fish species-specific scoring into our vulnerability analysis, those results (Chapter 3) tend to support the generally higher vulnerability levels for freshwater ecosystems. Uncertainty in the evaluation is due to uncertainty in climate projections, the scope of current knowledge, and ongoing management actions.

There is evidence from monitoring records that warmer air temperatures have already affected water temperatures and hydrographs in mountain streams (Isaak et al. 2012). By mid-century, under both moderate and high radiative forcing scenarios (RCP4.5 and RCP8.5), we can expect to see even warmer temperatures statewide, especially on the eastern plains. Warmer air temperatures are expected to lead to warmer water temperatures, earlier snowmelt, loss of permanent ice fields, and possibly drier conditions. Even if precipitation levels at higher elevations are essentially unchanged, warmer conditions will lead to more precipitation falling as rain instead of snow, a decreased snowpack, earlier runoff, and earlier dry conditions in late summer (Lukas et al. 2014). All of these factors are likely to interact with stresses arising from altered hydrology (dams, diversions, etc.), and socio-economic demands for continued water availability at previously established levels.

The highly managed nature of water resources in Colorado to some extent confounds our preliminary evaluation of vulnerability to climate change for these ecosystems. Water storage and release patterns do not always mimic conditions that would be found on an unmanipulated reach, and this may benefit some species while harming others. Furthermore, the impacts of warming temperatures and potentially changing precipitation patterns on freshwater ecosystems can be enhanced by fragmentation or mitigated by increased connectivity in these interconnected networks of habitats. For most species, intact connectivity within the hydrologic network will be crucial for adaptation to changing conditions; however, species assemblages are likely to change as less mobile community members are eliminated. Enhancing connectivity with concomitant reduction in anthropogenic stresses is likely to be the most productive approach for conserving freshwater ecosystems under future climatic conditions (Khamis et al. 2014).

Strategies for meeting the challenges of future conditions are perhaps most complex and yet most urgent for freshwater ecosystems. Although daunting, earlier action is likely to allow increased opportunity for future adaptive management than delay or inaction.

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# 3 ANIMALS


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# METHODS

## NatureServe Climate Change Vulnerability Index

### Overview

This overview has been synthesized and reprinted, with permission, from Young et al. (2011). The Climate Change Vulnerability Index (CCVI), developed by NatureServe, is a Microsoft Excel-based tool that facilitates rapid assessment of the vulnerability of plant and animal species to climate change within a defined geographic area. In accordance with well-established practices (Schneider et al. 2007, Williams et al. 2008), the CCVI divides vulnerability into two components:

> **exposure** to climate change within the assessment area (e.g., a highly sensitive species will not suffer if the climate where it occurs remains stable).
>
> **sensitivity** of the species to climate change (e.g., an adaptable species will not decline even in the face of significant changes in temperature and/or precipitation).

Exposure to climate change is measured by examining the magnitude of predicted temperature and moisture change across the species' distribution within the study area. CCVI guidelines suggest using the downscaled data from Climate Wizard (http://climatewizard.org) for predicted change in temperature. Projections for changes in precipitation are available in Climate Wizard, but precipitation estimates alone are often an unreliable indicator of moisture availability because increasing temperatures promote higher rates of evaporation and evapotranspiration. Moisture availability, rather than precipitation per se, is a critical resource for plants and animals and therefore forms the other part of the exposure measure within the CCVI, together with temperature. To predict changes in moisture availability, NatureServe and partners developed the Hamon AET:PET moisture metric as part of the CCVI. The metric represents the ratio of actual evapotranspiration (i.e., the amount of water lost from a surface through evaporation and transpiration by plants) to potential evapotranspiration (i.e., the total amount of water that could be evaporated under current environmental conditions, if unlimited water was available). Negative values represent drying conditions.

Sensitivity is assessed using 20 factors divided into two categories: 1) indirect exposure to climate change; and 2) species specific factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors). For each factor, species are scored on a sliding scale from greatly increasing, to having no effect on, to decreasing vulnerability. The CCVI accommodates more than one answer per factor in order to address poor data or a high level of uncertainty for that factor. The scoring system integrates all exposure and sensitivity measures into an overall vulnerability score that indicates relative vulnerability compared to other species and the relative importance of the factors contributing to vulnerability.

The Index treats exposure to climate change as a modifier of sensitivity. If the climate in a given assessment area will not change much, none of the sensitivity factors will weigh heavily, and a species is likely to score at the Not Vulnerable end of the range. A large change in temperature or moisture availability will amplify the effect of any related sensitivity, and will contribute to a score reflecting higher vulnerability to climate change. In most cases, changes in temperature and moisture availability will combine to modify sensitivity factors. However, for factors such as sensitivity to temperature change (factor 2a) or precipitation/moisture regime (2b), only the specified climate driver will have a modifying effect.

The six possible scores are:

**Extremely Vulnerable**: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

**Highly Vulnerable**: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

**Moderately Vulnerable**: Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

**Not Vulnerable/Presumed Stable**: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

**Not Vulnerable/Increase Likely**: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

**Insufficient Evidence**: Available information about a species' vulnerability is inadequate to calculate an Index score.

## Scoring Factors in the CCVI

The factors used to generate the CCVI score are listed in the following section. Detailed definitions of scoring categories are listed in Appendix B.

***A. Exposure to Local Climate Change***

1. Temperature
2. Moisture

***B. Indirect Exposure to Climate Change***

1. Exposure to sea level rise. (Not applicable to Colorado)
2. Distribution relative to natural and anthropogenic barriers.

3. Predicted impact of land use changes resulting from human responses to climate change.

***C. Sensitivity***

1. Dispersal and movements.
2. Predicted sensitivity to temperature and moisture changes.
    a. Predicted sensitivity to changes in temperature.
    b. Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
    c. Dependence on a specific disturbance regime likely to be impacted by climate change.
    d. Dependence on ice, ice-edge, or snow-cover habitats.
3. Restriction to uncommon geological features or derivatives.
4. Reliance on interspecific interactions.
    a. Dependence on other species to generate habitat.
    b. Dietary versatility (animals only).
    c. Pollinator versatility (plants only).
    d. Dependence on other species for propagule dispersal.
    e. Forms part of an interspecific interaction not covered by C4a-d.
5. Genetic factors.
    a. Measured genetic variation.
    b. Occurrence of bottlenecks in recent evolutionary history.
6. Phenological response to changing seasonal temperature and precipitation dynamics.

***D. Documented or Modeled Response to Climate Change***

1. Documented response to recent climate change.
2. Modeled future change in range or population size.
3. Overlap of modeled future range with current range.
4. Occurrence of protected areas in modeled future distribution.

*Factors not considered* —The Index development team did not include factors that are already considered in conservation status assessments. These factors include population size, range size, and demographic factors. The goal is for the NatureServe Climate Change Vulnerability Index to complement NatureServe Conservation Status Ranks and not to partially duplicate factors. Ideally, Index values and status ranks should be used in concert to determine conservation priorities.

## Application of Climate Data

Scoring factors related to historic and predicted future climate (temperature, precipitation, and moisture availability, Factors A1, A2, C2ai, and C2bi in the CCVI) were calculated in GIS using the methods described below. Refer to the species profiles in the following section of this report for details on scoring rationale and references for all other factors.

Exposure to predicted temperature increase was calculated using species distribution data and an ensemble average of 16 CMIP3 climate prediction models (see Appendix A) averaged over the summer season (June – August) using the high (A2) CO2 emissions scenario. The high emissions scenario was used because it is most similar to current emissions. Data were obtained from Climate Wizard, and the analysis period was to the year 2050 (which is actually an average of projections for years 2040 – 2069). The summer season – growing season for plants, breeding season for animals – was used because it was considered the most critical time period for most species.

Exposure to projected drying (integration of projected temperature and precipitation change, i.e., the Hamon AET: PET moisture metric) was calculated using the dataset created by NatureServe as part of the CCVI. Note that NatureServe based their moisture metric calculations on the same Climate Wizard dataset as above, *except* that they used the A1B carbon dioxide emissions scenario. Because the modeling methods used by NatureServe were not available, we were unable to recalculate using the A2 scenario. Thus, we used the data as provided, which we considered a reasonable alternative since the A1B and A2 scenarios predict similar changes through the mid-21st Century, the period used in this analysis. We calculated the percent of each species' range/ distribution that falls within each rating category. All calculations used the "summer" (June – August) data subset.

The *historical thermal niche* factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature). It is a proxy for species' temperature tolerance at a broad scale. This factor was calculated in GIS by assessing the relationship between species' distributions and historical temperature variation data downloaded from NatureServe. Historical temperature variation was measured as the mean July high minus the mean January low, using PRISM data from 1951-2006, expressed as a single averaged value for the entire species range.

The *historical hydrological niche* factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area. Ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from Climate Wizard, and subtracting the lowest pixel value from the highest value.

## Representing Species' Distributions

A variety of sources were used for animal species, including element occurrence records and/or observation data from CNHP's databases, online distribution data from CPW, existing species distribution models, range maps from published literature, and critical habitat maps.

The list of animal species included in this climate change vulnerability assessment was developed through consultation with BLM staff, using the BLM Sensitive Species list as a starting point. This list includes all federally listed species. The entire BLM sensitive list was beyond the scope of the project, so species were prioritized according to the level of prior work available and the management importance of the species. A few wide-ranging species of particular management interest that are not on the BLM sensitive list were included.

# RESULTS

CCVI results are summarized in Table 3.1, and presented in full in Appendix C. Animal species results are sorted alphabetically by common name within taxonomic group. The rationale for scoring and literature citations are included in the following species profiles.

**Table 3.9.** Climate change vulnerability scores for animal species. EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

| Taxonomic Group | English Name | Species | Score |
|---|---|---|---|
| Amphibian | Boreal Toad | *Anaxyrus boreas boreas* | **HV** |
| Amphibian | Canyon Treefrog | *Hyla arenicolor* | MV |
| Amphibian | Great Basin Spadefoot | *Spea intermontana* | PS |
| Amphibian | Northern Leopard Frog | *Lithobates pipiens* | MV |
| Bird | American Peregrine Falcon | *Falco peregrinus anatum* | PS |
| Bird | Black Swift | *Cypseloides niger* | PS |
| Bird | Brewer's Sparrow | *Spizella breweri* | PS |
| Bird | Burrowing Owl | *Athene cunicularia hypugaea* | MV |
| Bird | Golden Eagle | *Aquila chrysaetos* | MV |
| Bird | Greater sage-grouse | *Centrocercus urophasianus* | **HV** |
| Bird | Gunnison Sage-grouse | *Centrocercus minimus* | **HV** |
| Bird | Long-billed Curlew | *Numenius americanus* | **HV** |
| Bird | Mountain Plover | *Charadrius montanus* | PS |
| Bird | Norhern Goshawk | *Accipiter gentilis* | MV |
| Bird | Western Snowy Plover | *Charadrius alexandrinus nivosus* | **HV** |
| Bird | Western Yellow-billed Cuckoo | *Coccyzus americanus occidentalis* | MV |
| Bird | White-faced Ibis | *Plegadis chihi* | MV |
| Fish | Bluehead Sucker | *Catostomus discolobus* | **HV** |
| Fish | Bonytail Chub | *Gila elegans* | **EV** |
| Fish | Colorado Pikeminnow | *Ptychocheilus lucius* | **EV** |
| Fish | Colorado River Cutthroat Trout | *Oncorhynchus clarkii pleuriticus* | **EV** |
| Fish | Flannelmouth Sucker | *Catostomus latipinnis* | **HV** |
| Fish | Humpback Chub | *Gila cypha* | **EV** |
| Fish | Razorback Sucker | *Xyrauchen texanus* | **HV** |

| Taxonomic Group | English Name | Species | Score |
|---|---|---|---|
| Fish | Rio Grande Cutthroat Trout | *Onchorhynchus clarkii virginalis* | **EV** |
| Fish | Roundtail Chub | *Gila robusta* | **HV** |
| Invert-Insect | Great Basin Silverspot | *Speyeria nokomis nokomis* | **HV** |
| Mammal | American Beaver | *Castor canadensis* | MV |
| Mammal | Desert Bighorn Sheep | *Ovis canadensis nelsoni* | MV |
| Mammal | Fringed Myotis | *Myotis thysanodes* | PS |
| Mammal | Gunnison's Prairie Dog | *Cynomys gunnisoni* | PS |
| Mammal | Townsend's Big-eared Bat | *Corynorhinus townsendii* | PS |
| Mammal | White-tailed Prairie Dog | *Cynomys leucurus* | PS |
| Reptile | Desert Spiny Lizard | *Sceloporus magister* | PS |
| Reptile | Longnose Leopard Lizard | *Gambelia wislizenii* | PS |
| Reptile | Midget Faded Rattlesnake | *Crotalus oreganus concolor* | **HV** |

Animal species included four amphibians, thirteen birds, nine fish, one insect, six mammals, and three reptiles. Five species were ranked as extremely vulnerable to climate change. Fish, in particular, were ranked on the high to extremely vulnerable end of the range (Figure 3.1); other taxonomic groups were generally more evenly distributed between presumed stable to highly vulnerable. No evaluated species were assessed as likely to increase under future conditions.

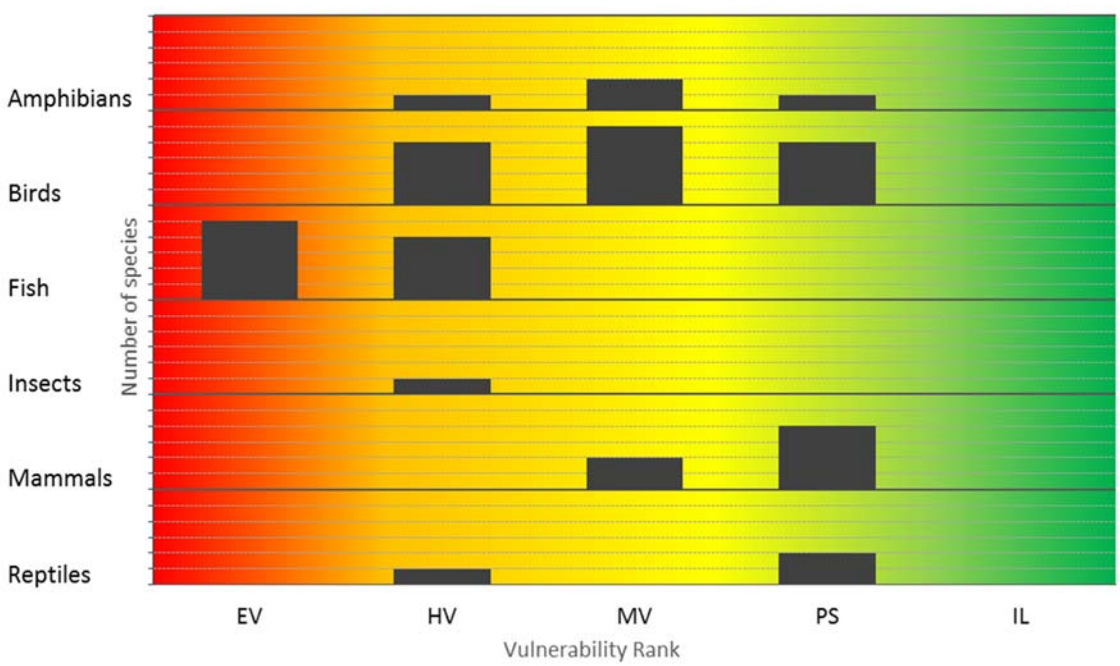
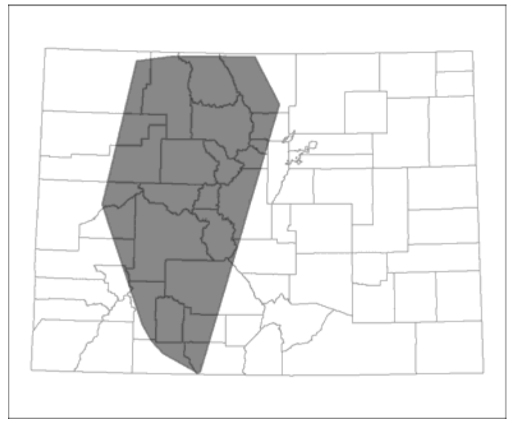



**Figure 3.1.** Summary of climate change vulnerability scores for animal species. EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

# Animal Species CCVI Summaries

## Boreal toad

***Anaxyrus boreas boreas***
**G4T1/S1**
**Family: Bufonidae**



## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on: the majority of boreal toad populations in Colorado being bordered by high mountains that act as natural barriers, which could limit the ability of this species to shift its range in response to climate change; the physiological niche of this species being cooler high elevation areas where snowfall and summer evaporation could affect seasonal wetland breeding habitat; the dependence of this species on specific hydrology for breeding and the potential disruption of the timing of breeding and larval development by climate change. Additional important ranking factors include the importance of snowpack levels for breeding pond water levels and as an insulator for hibernation. Boreal toads are also often dependent on beavers to create and maintain breeding habitat.

**Distribution*:*** Boreal toads were found historically throughout the mountainous areas of Colorado, but have not been reported from the Sangre De Cristo Mountain Range, Wet Mountains, or the Pikes Peak region (Hammerson 1999). Boreal Toads are also absent from the La Plata Mountains and Uncompahgre Plateau in Southwest Colorado (CNHP 2014). **Habitat:** Boreal toads are restricted to montane habitats at elevations of 8,000 – 12,200 feet (2,400 – 3,400 meters). Common habitats include beaver ponds, wet meadows, glacial kettle ponds and lakes in subalpine forests (Hammerson 1999). Breeding occurs along the margins of shallow ponds in still water. Occasionally, flooded tire ruts, man-made ponds and stream backflows are used as well for breeding (Loeffler 2001).

## CCVI Scoring

**Temperature**: Calculated using ClimateWizard: ensemble average, high emission scenario (A2), mid-century timeframe, average annual change. In Colorado by mid-century this species is expected to be exposed to mean annual temperature increases of 5.0$^{\circ}$F to 5.5$^{\circ}$F over 100 percent of its range (NatureServe 2012).

**Moisture:** Calculated in GIS using NatureServe Hamon AET:PET moisture metric data (this index integrates projected temperature and precipitation changes to indicate how much drying will take place). Rangewide this species is predicted to be exposed to net drying of greater than 11.9 percent on 17 percent of its range, 9.7 to 11.9 percent drying on 49 percent of its range and 7.4 to 9.6 percent drying on 32 percent of its range (NatureServe 2012).

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Mountain ranges with high, > 12,500 ft. passes should be considered as natural barriers for boreal toad movement (NatureServe 2014). The majority of boreal toad populations in Colorado are mostly bordered by high mountains.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Intensive residential or commercial development and high traffic volume highways could be considered as anthropogenic barriers (NatureServe 2014). The majority of boreal toad populations occur on USFS managed land where development is very low.

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase to neutral. Land alterations such as, timber harvest, grazing, recreation and water development would likely not be beneficial for boreal toad habitat, but have not been shown as primary causative agents for declines in the southern Rocky Mountains (Loeffler 2001). Land use changes associated with climate change may be considered a threat but the scope and type of change in the range of the boreal toad is hard to predict.

**C1) Dispersal and movements.** Somewhat decrease to neutral. Boreal toads are dependent upon breeding, foraging and hibernating habitat, which encompasses both wetland and upland habitat (Adams et al. 2005). The evidence shows seasonal variability in toad movements and individual movements and individual toads may move 4 km or more between breeding and nonbreeding habitat (Hammerson 1999; Jones 2000) and up to approximately 7.6 km for an adult male (Lambert and Schneider 2013).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. The range occupied by the boreal toad in the assessed area has experienced average (57.1 - 77° F/31.8 - 43° C) mean seasonal temperature variation in the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche. :** Somewhat increase. The range of this species in Colorado is restricted to cooler high elevation areas. Reduced snowfall and increased summer evaporation could have dramatic effects on the duration or occurrence of seasonal wetlands (Corn 2005). Longer active seasons were found to increase recruitment at two breeding sites in Chaffee County, Colorado (Lambert et al. In Prep), e.g., increased temperatures will allow for earlier development of young with larger metamorphs entering hibernation thus increasing overwinter survival.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat decrease. This species has undergone greater than average (>40 inches/1,016 mm) precipitation variation over the last 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. The boreal toad is highly dependent of specific hydrology for breeding. Holland (2002) found that boreal toad tadpoles in Colorado experienced that greatest larval growth rates at breeding sites with the warmest and least variable water temperatures. Timing of breeding and time for larval development could also be impacted by changes in hydrological levels (Corn 2005).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The boreal toad is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Somewhat increase. Boreal toad breeding ponds often depend on snowpack melt to maintain water levels for breeding. Depth of Snowpack can be important in protecting hibernating toads from freezing (Campbell 1970; Corn 2003; Scherer et al. 2005).

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Boreal toads are not dependent on any specific geologic feature.

**C4a) Dependence on other species to generate habitat.** Increase. Boreal toad breeding ponds are commonly found in beaver pond complexes (Hammerson 1999; Holland 2002) and are often dependent on beavers to maintain breeding habitat.

**C4b) Dietary versatility (animals).** Neutral. Boreal toads feed on a wide variety of invertebrates (Hammerson 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The boreal toad is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral. No other interspecific interactions are important to the persistence of the boreal toad.

**C5a) Measured genetic variation.** Somewhat decrease. Switzer et al. (2009) found patterns of high levels of genetic differentiation among relatively close breeding sites of boreal toads and found the populations within the southern Rocky Mountains to be isolated with limited gene flow among populations.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. There is no evidence that the total population of boreal toads were reduced to <1000 individuals or the occupied area was reduced by > 30% over the last 500 years.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral. The effects of changes in temperature and precipitation may have a large effect on the timing of breeding for amphibians (Corn 2005) and has been observed in some species (Blaustein et al. 2001).

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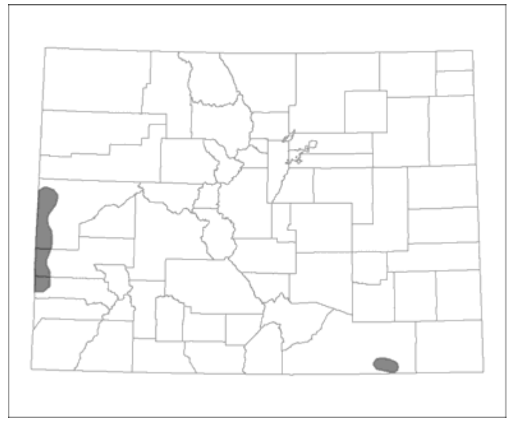
## Canyon Treefrog

***Hyla arenicolor***
**G5/S2**
**Family: Hylidae**

Photo: Copyright by Lauren J. Livo and Steve Wilcox



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on: the majority of canyon treefrog populations in Colorado being restricted to rocky canyons and canyon-bottom pools that act as natural barriers, which could limit the ability of this species to shift its range in response to climate change; The canyon treefrog is highly dependent on specific hydrology (rainfall) for breeding and the potential disruption of the timing of breeding and larval development by climate change is a concern.

**Distribution:** Canyon treefrogs occur in western Colorado at elevations ranging from about 4,500 - 6,300 ft. along the southern edge of the Colorado River valley and along the Dolores River and its tributaries south to San Miguel County, (Hammerson 1999). There is an isolated population in Las Animas County at Mesa de Maya (CNHP 2014). **Habitat:** Canyon treefrogs are found along intermittent streams in deep rocky canyons (Hammerson 1999).

## CCVI Scoring

**Temperature**: Calculated using Climate Wizard: ensemble average, high emission scenario (A2), mid-century timeframe, average annual change. In Colorado by mid-century this species is expected to be exposed to mean annual temperature increases of 5.0°F to 5.5°F over 100 percent of its range (NatureServe 2012).

**Moisture:** Calculated in GIS using NatureServe Hamon AET:PET moisture metric data (this index integrates projected temperature and precipitation changes to indicate how much drying will take place). Rangewide this species is predicted to be exposed to net drying of greater than 11.9 percent on 12.1 percent of its range, 9.7 to 11.9 percent drying on 43.2 percent of its range and 7.4 to 9.6

percent drying on 31.3 percent of its range and 5.1 to 7.3 percent drying on 13 percent of its range (NatureServe 2012).

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat increase vulnerability. In Colorado, this species is restricted to rocky canyons and breeds in canyon bottom pools (Hammerson 1999). Genetic analysis suggests that geographic barriers are responsible for phylogeographic patterns in canyon treefrogs from Arizona and New Mexico (Barber 1999).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Intensive residential or commercial development and high traffic volume highways could be considered as anthropogenic barriers (NatureServe 2014). The majority of canyon treefrog populations occur on federally managed lands in deep canyons where development is very low.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Land alterations such as, timber harvest, grazing, recreation and water development would likely not be beneficial for canyon treefrog habitat, but the remoteness of occurrences makes it unlikely areas for future human disturbances. Land use changes associated with climate change may be considered a threat but the scope and type of change in the range of the canyon treefrog is hard to predict.

**C1) Dispersal and movements.** Neutral. Canyon treefrogs are dependent on rocky canyon slopes and bottoms for breeding, foraging and hibernating habitat (Hammerson 1999). Hylids generally exhibit limited movements on a short-term basis (NatureServe 2014). Except for warm rainy nights, canyon treefrogs do not range far from canyon-bottom pools (Hammerson 1999).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. The range occupied by the canyon treefrog in the assessed area has experienced average (57.1 - 77° F/31.8 - 43° C) mean seasonal temperature variation in the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat decrease. This species shows a preference for environments with warmer temperatures (Synder and Hammerson 1993).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. This species has undergone average (21-40 inches/509 - 1,016 mm) precipitation variation over the last 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. The canyon treefrog is highly dependent on specific hydrology (rainfall) for breeding (Hammerson 1999).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The canyon treefrog is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Canyon treefrogs do not depend on ice or snow-cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase. Canyon treefrogs are associated with rocky canyon bottoms where they perch on solid rock surfaces and at night retreat to rock crevices (Hammerson 1999).

**C4a) Dependence on other species to generate habitat.** Neutral. Canyon treefrogs do not rely on other species to generate habitat.

**C4b) Dietary versatility (animals).** Neutral. Canyon treefrogs feed on a wide variety of invertebrates (Hammerson 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The canyon treefrog is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral. No other interspecific interactions are important to the persistence of the canyon treefrog.

**C5a) Measured genetic variation.** Somewhat increase. Barber (1999) found low genetic variation from differences among populations in Arizona and New Mexico.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. There is no evidence that the total population of canyon treefrogs were reduced to <1000 individuals or the occupied area was reduced by > 30% over the last 500 years.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral. The effects of changes in temperature and precipitation may have a large effect on the timing of breeding for amphibians (Blaustein et al. 2001; Corn 2005), but has not been reported for canyon treefrogs.

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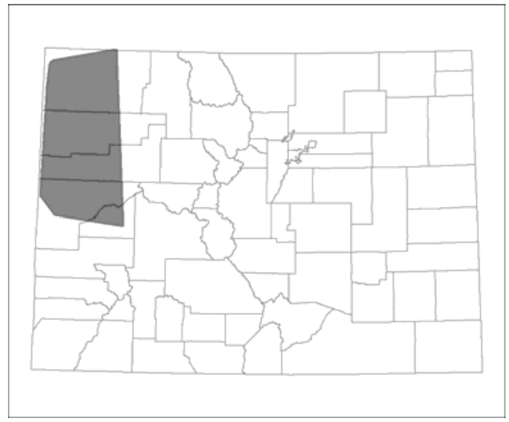
## Great Basin Spadefoot

***Spea intermontana***
**G5/S3**
**Family: Scaphiopodidae**

## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on: The only metric that increased the vulnerability for Great Basin spadefoots was their dependence on specific hydrology (ephemeral and permanent water sources) for breeding and the potential disruption of the timing of breeding and larval development by climate change. The rest of the scoring factors were neutral. The habitat this species inhabits is diverse and devoid of natural barriers; within the range of this species in Colorado, oil and gas development could impact habitat, but there has not been any evidence of that occurring. Irrigated agriculture may be beneficial in creating breeding habitat (Leonard et al. 1996). Great Basin spadefoots occur in pretty remote areas of Colorado and are at a low risk of threats from urban development.

**Distribution***:* Great Basin spadefoots occur in northwestern Colorado, north of the Uncompahgre Plateau (Hammerson 1999). **Habitat:** Great Basin spadefoots are found in wide variety of habitats in Colorado at elevations below 7,000 ft. (Hammerson 1999). Typical habitat types in Colorado for Great Basin spadefoots are pinyon-juniper woodlands, sagebrush and semidesert shrublands (Hammerson 1999). Breeding occurs in temporary pools from heavy rains (Hammerson 1999) and occasionally in permanent shallow ponds (Hovingh et al. 1995).

## CCVI Scoring

**Temperature**: Calculated using Climate Wizard: ensemble average, high emission scenario (A2), mid-century timeframe, average annual change. In Colorado by mid-century this species is expected to be exposed to mean annual temperature increases of 5.0°F to 5.5°F over 100 percent of its range (NatureServe 2012).

**Moisture:** Calculated in GIS using NatureServe Hamon AET:PET moisture metric data (this index integrates projected temperature and precipitation changes to indicate how much drying will take place). Rangewide this species is predicted to be exposed to net drying of greater than 11.9 percent on 9.1 percent of its range, 9.7 to 11.9 percent drying on 55.1 percent of its range and 7.4 to 9.6 percent drying on 22.6 percent of its range and 5.1 – 7.3 on 12.7 percent of its range (NatureServe 2012).

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. In Colorado, this species inhabits sagebrush flats, pinyon-juniper woodland and semi-desert shrublands (Hammerson 1999), areas that are typically devoid of natural barriers for spadefoot toads.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Intensive residential or commercial development and high traffic volume highways could be considered as anthropogenic barriers (NatureServe 2014), but for most of the Great Basin spadefoots range in Colorado urban development is low. There may be breeding habitat creation from irrigated agriculture, but in some cases grain fields could eliminate breeding ponds (Leonard et al. 1996).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Land alterations such as, timber harvest, grazing, recreation and water development would likely not be beneficial for Great Basin spadefoots, but the remoteness of occurrences makes it unlikely areas for future human disturbances. Land use changes associated with climate change may be considered a threat but the scope and type of change in the range of the canyon treefrog is hard to predict.

**C1) Dispersal and movements.** Neutral. Great Basin spadefoots are dependent on sagebrush/semi-desert shrubland habitat with temporary pools for breeding and foraging (Hammerson 1999). Specific dispersal data for this species is lacking but in general spadefoot toads exhibit high fidelity to breeding site with movements up to several hundred meters from breeding sites (NatureServe 2014). There have been reports of adults migrating up to 100 meters between breeding pools and non-breeding habitat (Buseck et al. 2005).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. The range occupied by the boreal toad in the assessed area has experienced average (57.1 - 77° F/31.8 - 43° C) mean seasonal temperature variation in the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not restricted to cold environments that are vulnerable to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. This species has undergone average (21-40 inches/509 - 1,016 mm) precipitation variation over the last 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. The great basin spadefoot is highly dependent on specific hydrology (ephemeral and permanent water sources) for breeding (Hovingh et al. 1995; Hammerson 1999; Buseck et al. 2005). Timing of breeding and time for larval development in amphibians could also be impacted by changes in hydrological levels (Corn 2005).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The great basin spadefoot is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Great Basin spadefoots do not depend on ice or snow-cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Great Basin spadefoots are not dependent on any specific geologic feature.

**C4a) Dependence on other species to generate habitat.** Neutral. Great Basin spadefoots do not rely on other species to generate habitat.

**C4b) Dietary versatility (animals).** Neutral. Great Basin spadefoots feed on a wide variety of invertebrates (Hammerson 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Great Basin spadefoot is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Great Basin spadefoot.

**C5a) Measured genetic variation.** Neutral. Phylogenetic analysis on two populations of Great Basin spadefoots suggested possible geographic variation within the species (Wiens and Titus 1991).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. There is no evidence that the total population of Great Basin spadefoots were reduced to <1000 individuals or the occupied area was reduced by > 30% over the last 500 years.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral. The effects of changes in temperature and precipitation may have a large effect on the timing of breeding for amphibians (Corn 2005) and has been observed in some species (Blaustein et al. 2001).

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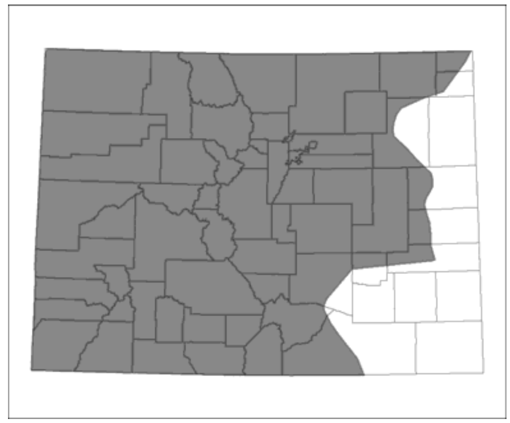
## Northern Leopard Frog

***Lithobates pipiens***
**G5/S3**
**Family: Ranidae**



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on: the northern leopard frog's dependence on specific hydrology for breeding and the potential disruption of the timing of breeding and larval development by climate change. The predicted effects of climate change in the West include a reduced snowpack and shorter periods of snow cover, snowmelt that occurs earlier in the season, a hydrologic cycle that is more dynamic as extreme rainfall events occur with greater frequency and an overall warmer, drier, and more drought-like conditions (Melillo et al. 2014). Climate change has the potential to alter the timing of pond breeding amphibians (Blaustein et al. 2001). Additional important ranking factors include the vulnerability of northern leopard frogs to development and habitat fragmentation from busy paved roads.

**Distribution*:*** Northern leopard frogs occur throughout Colorado, excluding most of the southeastern and east east-central portion of the state (Hammerson 1999). **Habitat:** Northern leopard frogs are found in wide variety of habitats in Colorado at elevations ranging from 3,500 ft. to 11,000 ft. (Hammerson 1999). Typically in Colorado, northern leopard frogs are found in wet meadows, marshes, ponds, streams, lakes and reservoirs. Breeding occurs in mid-sized ponds (Merrell 1997) and shallow areas of permanent ponds and in seasonally flooded areas adjacent to permanent pools or streams (Hammerson 1999).

## CCVI Scoring

**Temperature**: Calculated using Climate Wizard: ensemble average, medium emission scenario (A1B), mid-century timeframe, average annual change. In Colorado by mid-century this species is expected to be exposed to mean annual temperature increases of 5.0$^{o}$F to 5.5$^{o}$F over 100 percent of its range (NatureServe 2012).

**Moisture:** Calculated in GIS using NatureServe Hamon AET:PET moisture metric data (this index integrates projected temperature and precipitation changes to indicate how much drying will take place). Rangewide this species is predicted to be exposed to net drying of greater than 11.9 percent on 12.6 percent of its range, 9.7 to 11.9 percent drying on 52.8 percent of its range and 7.4 to 9.6 percent drying on 29.1 percent of its range and 5.1 – 7.3 on 5.4 percent of its range (NatureServe 2012).

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. The northern leopard frog occupies a variety of habitat types and is widely distributed in Colorado (Hammerson 1999). While patchiness occurs, there are few natural barriers to their dispersal to other landscapes. Rivers could be a barrier depending on width and flow dynamics (NatureServe 2014).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Intensive residential or commercial development and high traffic volume highways could be considered as anthropogenic barriers (NatureServe 2014). Disturbed areas devoid of cover disrupted the ability for northern leopard frogs to reach habitat patches in New Brunswick (Mazerolle and Desrochers (2005). Bouchard et al. (2009) found that leopard frogs were highly vulnerable to road mortality.

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase to neutral. The northeastern Colorado habitat of this species is susceptible to potential development of wind farms/solar farms and biofuels production. In the face of rising climate change and costs to extract fossil fuels, wind energy development is expected to increase within the range of the northern leopard frog in Colorado (NRDC 2014).

**C1) Dispersal and movements.** Somewhat decrease to neutral. Northern leopard frogs have good movement and dispersal capability as they are dependent upon breeding, foraging and hibernating habitat, which encompasses both wetland and upland habitat (Hammerson 1999; NatureServe 2014). The evidence shows seasonal variability in leopard frog movements and individual movements up to 4 km for adults (Seburn et al. 1997) and 5.2 km for juveniles (Dole 1971) in Alberta and Michigan respectively.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. The range occupied by the boreal toad in the assessed area has experienced average (57.1 - 77° F/31.8 - 43° C) mean seasonal temperature variation in the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche. Increase.** Somewhat Increase. The range of this species in Colorado includes some higher elevation montane areas. Reduced snowfall and increased summer evaporation could have dramatic effects on the duration or occurrence of seasonal wetlands (Corn 2005).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat decrease. This species has undergone greater than average (>40 inches/1,016 mm) precipitation variation over the last 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. The northern leopard frog is highly dependent on specific hydrology for breeding. Reproductive success is tied to appropriate temperature in breeding sites (shallow ponds); timing of this would change with early snowmelt and warmer temperatures (Smith and Keinath 2007).Timing of breeding and time for larval development could also be impacted by changes in hydrological levels (Corn 2005). Increased drought could cause reductions in habitat and potentially increase mortality from egg to adult. Drought was responsible for the extirpation of a population of leopard frogs in Larimer County, Colorado (Corn and Fogleman 1984).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The northern leopard frog is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Northern leopard frogs inhabit a wide range of habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Northern leopard frogs are not dependent on any specific geologic feature.

**C4a) Dependence on other species to generate habitat.** Neutral to somewhat increase. Northern leopard frogs sometimes use beaver ponds for breeding (Hammerson 1999).

**C4b) Dietary versatility (animals).** Neutral. Northern leopard frogs feed on a wide variety of invertebrates (Hammerson 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The northern leopard frog is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral. No other interspecific interactions are important to the persistence of the northern leopard frog.

**C5a) Measured genetic variation.** Somewhat decrease. Mushet et al. (2013) found high levels of genetic diversity in populations of northern leopard frogs in North Dakota.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. There is no evidence that the total population of northern leopard frogs were reduced to <1000 individuals or the occupied area was reduced by > 30% over the last 500 years.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral. The effects of changes in temperature and precipitation may have a large effect on the timing of breeding for amphibians (Corn 2005) and has been observed in some species (Blaustein et al. 2001).

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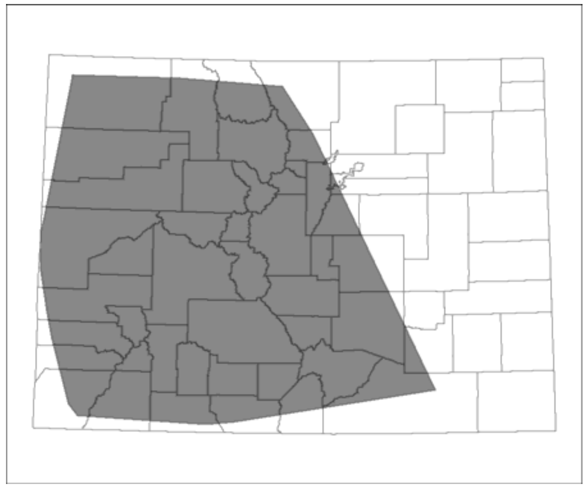
## American Peregrine Falcon

***Falco peregrinus anatum***
**G4T4/S2B**
**Family: Falconidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state wide rank is based on: the extensive dispersal and migratory abilities of this raptor, the lack of impacts from land use changes associated with climate change, the average genetic variation measured for the species in North America, and the predicted 68 percent expansion of the Peregrine falcons winter range in response to climate change. Climate models project increased warming and drought across the assessed area with annual average temperatures rising by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014). Projections of precipitation changes are less certain, but under a continuation of current rising emissions trends (A2), reduced winter and spring precipitation is consistently projected for the southern part of the Southwest by 2100 (Melillo et al. 2014). These projected changes in climate are not expected to have important negative impacts to the Peregrine falcon within the assessment area.

**Distribution:** Peregrine Falcons breed along the foothills of Colorado's Front Range and (in higher concentrations) in the river valleys and canyons of the Western Slope (Kingery 1998). **Habitat:** Peregrine Falcons nest on ledges of high cliffs in the foothills and mountains from 4,500 to over 9,000 feet (1,388 to 2,776 m) in elevation (U.S. Fish and Wildlife Service 1984). The steepest and most inaccessible locations on the tallest cliffs are preferred; especially those that offer flat, protected ledges at least 18 inches wide, with sheer rock above and below (Johnsgard 2009). In Colorado, pinyon/juniper woodland occurs in the vicinity of about half of all Peregrine Falcon nest sites, and ponderosa pine woodland or forest is found at about one-quarter of the sites (Kingery 1998).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Significant natural barriers do not exist for this species. The Peregrine falcon is a volant long distant migrator that can traverse mountain ranges and large bodies of water.

**B2b) Distribution relative to anthropogenic barriers. Increase.** Neutral. Significant anthropogenic barriers do not exist for this species. This raptor is a volant species that can fly over or around potential anthropogenic barriers.

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. Although raptors and Peregrine falcons have been reported to be at risk of collision with wind turbines and disturbed by their construction during brooding (NHFG 2005) during migration only about 10% of their range in the assessed area is suitable for wind energy development (NRDC 2014). This is a low concern for the raptor within the assessed area.

**C1) Dispersal and movements.** Decrease. Although males tend not to disperse far from their natal sites, females are known to disperse 100s of km from natal sites (White et al. 2002). Additionally, Peregrine falcons have large home ranges with estimates in Colorado ranging from 358–1,508 km2 (Enderson and Craig 1997). Finally, the Peregrine falcon is long distant migrator and can travel over 10,000 kilometers during migration (White et al. 2002).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Peregrine falcon in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. There is no direct evidence that Peregrines require cool microclimates for nesting. They generally make a scrape on a ledge with shading, sheltering, or overhangs, and trend to south- or west-facing orientation in high latitudes but more random directions in lower latitudes. Presumably orientation or other micro-features of eyrie protect young from temperature extremes (White et al. 2002)

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat decrease. The range occupied by the Peregrine falcon in the assessed area has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral. The Peregrine falcon has no dependence on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The Peregrine falcon is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on snow-covered habitats.** Neutral. The Peregrine falcon is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase to increase. Peregrine falcons have preference for nesting on cliffs, although they will use artificial structures such as smokestacks and buildings (White et al. 2002).

**C4a) Dependence on other species to generate habitat.** Neutral. The Peregrine falcon is not dependent on any other species to create suitable habitat for its existence

**C4b) Dietary versatility.** Neutral. Within the assessed area peregrine falcons mainly feed on birds including columbids (e.g., Zenaida), swifts, and passerines, but may occasionally feed on mammals, amphibians, fish, and insects (White et al. 2002).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Peregrine falcon is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Peregrine falcon.

**C5a) Measured genetic variation.** Neutral. The peregrine falcon exhibits average genetic diversity across populations in North America with observed and expected heterozygosities being nearly equivalent (Johnson et al. 2010).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Decrease. It is projected that there will be a decrease in a threat to the Peregrine falcons winter range due to climate change. Rangewide, models predicted to increase by 69% by 2080 in the falcons winter range (NAS 2014). This includes predictions of an expansion of the winter range in the assessed area. Models of the impact of climate change on the falcon's population size are not available for the assessed area.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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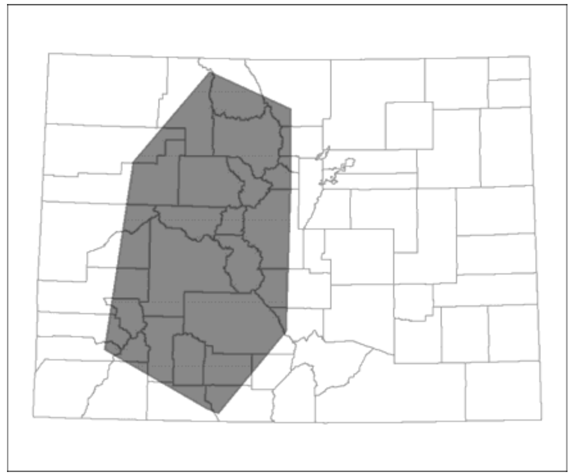
## Black Swift

***Cypseloides niger***
**G4/S3B**
**Family: Apodidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on the following factors: 1) few to no barriers to movement; 2) association with waterfalls for nesting that may be vulnerable to drying under projected increases in temperature due to climate change.

**Distribution*:*** In Colorado, Black Swifts breed primarily in the San Juan Mountains with populations concentrated in the southwest corner of the state. Breeding locations are also found in the Sangre de Cristo, Flat Tops, Gore, and Front ranges north to northern Routt County (Colorado Bird Atlas Partnership 1998; Levad et al. 2008). **Habitat:** In Colorado, Black Swifts nest on cliff faces with waterfalls and in some cases, wet caves (Colorado Bird Atlas Partnership 1998; Levad et al. 2008). **Elevation:** Nesting locations range from 6,640 to 11,680 feet in elevation, with a mean of 9,957 feet (Levad et al. 2008).

**Ecological System:** Cliff and canyon

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Volant – no barriers

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Volant – no barriers

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within Colorado.

**C1) Dispersal and movements.** Decrease. Black Swifts breed in Colorado and undertake long, seasonal migrations. Dispersal ability is great.

**C2) Sensitivity to temperature and moisture changes.** This species' close association with waterfalls for nest sites (Lowther and Collins 2002) greatly increases its vulnerability; this association within Colorado affects its score in both the hydrologic and geologic sections.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Black Swifts prefer cool sites near waterfalls for nesting, but these microclimates are not likely to be affected directly by climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Neutral

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. The degree to which streams on which these waterfalls are found will be affected by climate change is uncertain; Knorr (1961) first suggested that this species will not nest on intermittent streams and that even in drought years where the stream was reduced to a trickle, birds returned to their nesting sites (Knorr 1961; Knorr 1993). The degree to which perennial streams that feed waterfalls with nesting sites become intermittent due to climate change seems to be the primary factor in determining how vulnerable nesting sites may be. Levad et al. (2008) did find that increased stream flow contributed to a higher probability that a waterfall would be occupied.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. This species' close association with waterfalls for nest sites (Lowther and Collins 2002) increases its vulnerability.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. Diet items are diverse, but primarily limited to flying insects (Lowther and Collins 2002).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown. More information is needed on Black Swift genetics.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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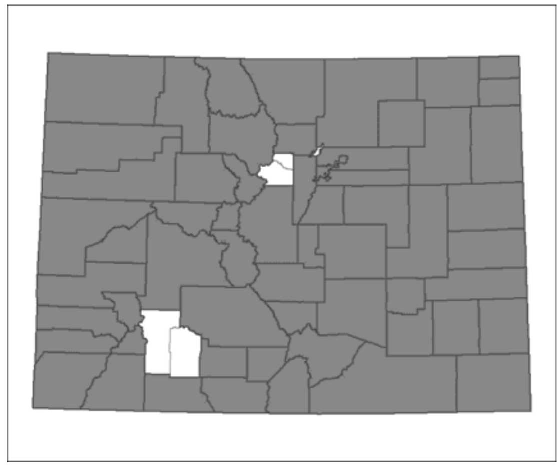
## Brewer’s Sparrow

***Spizella breweri***
**G5/S4B**
**Family: Emberizidae**

## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on the following factors: 1) potential increase habitat degradation due oil and gas development in Brewer’s sparrow habitat; 2) reliance on sagebrush habitats; and 3) positive correlation between winter precipitation and clutch size. The Brewer’s Sparrow may be less vulnerable than other bird species assessed in this report due to the lack of barriers to movement, high genetic variation, high dietary versatility, and long distance movement patterns.

**Distribution*:*** Brewer’s Sparrows are occur throughout most of Colorado, but are notably absent from the San Juan Basin (Colorado Bird Atlas Partnership 1998; Boyle and Reeder 2005). Breeding Brewer’s Sparrows are most common in the mesas and foothills of western Colorado, with the highest abundance estimates occurring in the northwestern corner of the state (Lambeth 1998). **Habitat:** In Colorado, Brewer’s Sparrows are most frequently documented in mountain big sagebrush habitats (Colorado Bird Atlas Partnership 1998). They also occur in the following vegetation types as defined by the Colorado Breeding Bird Atlas (1998): lowland sagebrush, tall desert shrub, shortgrass or tallgrass/sandsage, montane grassland, mountain shrub, pinyon-juniper woodland. **Elevation:** Commonly nesting between 5,000 and 7,500 ft (Andrews and Righter 1992).

**Ecological System:** Sagebrush shrubland, Sandsage, Desert Shrublands, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Brewer's Sparrows are found on both the East and West Slope of Colorado, from low elevation areas on the plains, to high elevation sites near timberline (11,400 feet) (Hansley and Beauvais 2004).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. This species occupies a broad geographic and elevation range in CO. No anthropogenic barriers have been reported for the species (Hansley and Beauvais 2004).

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. Brewer's Sparrows are considered sagebrush obligates. NW Colorado, including Rio Blanco County, contains large expanses of sagebrush shrublands. A total of 2,915 active natural gas wells are currently operating in Rio Blanco County (COGCC 2015). A projected 1,845 new wells will be drilled in Rio Blanco County in 2035 to meet energy demands in Colorado (BBC 2008). Increased energy development in this area will result in further habitat fragmentation for Brewer's Sparrow.

**C1) Dispersal and movements.** Decrease. Brewer's Sparrows migrate long distances across the Western US, wintering in Texas, California, and Nevada, and traveling north to Canada, Wyoming, Colorado, and the Great Plains to breed (Colorado Bird Atlas Partnership 2008).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Less than 10% of sagebrush ecosystems in Colorado are projected to be outside of its current climatic envelope (See Ecosystem Section of report).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral. This species does not rely on a strongly seasonal hydrologic regime.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. This species does not rely on a specific disturbance regime that will be impacted by climate change.

**C2d) Dependence on snow-covered habitats.** Somewhat Increase. Clutch size appears to be positively correlated with winter precipitation (Peterson and Best 1986; Lack 1966).

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Greatly Increase. This species is most frequently associated with mountain big sagebrush habitats in Colorado.

**C4b) Dietary versatility.** Neutral. Brewer's Sparrows eat a wide variety of insects (Peterson and Best 1986). During migration, Brewer's Sparrows rely mainly on seeds and seed heads for food, with insects comprising only 10% of their diet (Short 1984).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Neutral. Genetic variation or inbreeding depression has not been identified as a concern for Brewer's Sparrow (Hansley and Beauvais 2004).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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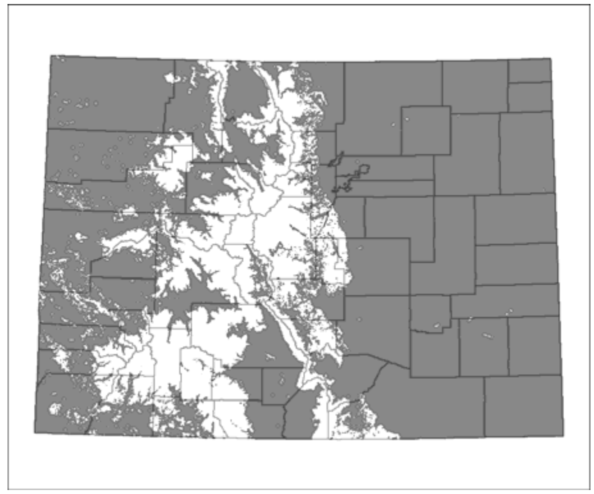
## Burrowing Owl

***Athene cunicularia hypugaea***
**G4/S4B**
**Family: Strigidae**

## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on the following factors: 1) dependence on prairie dogs and other mammals to create suitable nesting habitat; 2) low levels of genetic diversity; 3) lack of protection on private lands; 4) predicted loss of 77% of current breeding range due to climate change (Audubon Society 2015).

**Distribution*:*** Breeding records cover much of the state, although it is more common on the plains of eastern Colorado (Andrews and Righter 1992, Colorado Bird Atlas Partnership 1998). **Habitat:** This species is found in dry open treeless areas and is associated with burrowing mammals. Burrows are usually surrounded by bare ground and provide protection from weather extremes (Haug et al. 1993). Although capable of digging their own burrows where burrowing mammals are absent, burrowing owls usually use existing burrows, particularly those of prairie dogs.

**Ecological System:** Shortgrass Prairie

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. According to Department of Energy wind resource maps, the eastern quarter of

Colorado near the New Mexico and Nebraska borders has excellent wind resources (DOE 2004). Wind turbines can cause direct impacts to birds via collisions that result in injury or mortality (Kunz et al. 2007; Kuvlesky et al. 2007), as well as indirect impacts via habitat loss and barriers to movement (Drewitt and Langston 2006; Kuvlesky et al. 2007; Pruett et al. 2009; Kiesecker et al. 2011). Results from a study at a wind farm in California suggest that wind turbines annually kill between one-fifth and nearly twice the number of estimated owls in the available habitat area (Smallwood et al. 2010).

**C1) Dispersal and movements.** Decrease. The Burrowing Owl is capable of long distance migration, and Burrowing Owls banded in Alberta, Canada have been recovered in Mexico (USFWS 2003).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is associated with shortgrass prairie in Colorado and is not limited to cool or cold habitats (Colorado Bird Atlas Partnership 1998).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral. Studies on the Pawnee National Grassland showed decreased survival in owlets during wet summers (Conrey 2010). Prey populations may respond positively to increased rainfall, but Burrowing Owls typically do not hunt in wet weather (Conrey 2010).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Sandy soils may permit easier digging for prairie dogs, badgers, and Burrowing Owls that create burrows in the shortgrass prairie.

**C4a) Dependence on other species to generate habitat.** Somewhat Increase. Burrowing Owls nest in burrows that are created by prairie dogs and other mammals (Colorado Bird Atlas Partnership 1998).

**C4b) Dietary versatility.** Neutral. Burrowing Owls on the Pawnee Grassland ate beetles, grasshoppers, ants, rodents, and songbirds; insects comprised 95% of their diet by number and only 11% by biomass (Conrey 2010).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral.

**C5a) Measured genetic variation.** Increase. Low levels of genetic variation have been documented in Burrowing Owls, based on microsatellite data from populations distributed throughout North America (Macias-Duarte et al. 2010).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Neutral.

**D2) Modeled future change in population or range size.** Increase. Audubon Society's climate models predict that by 2080, Burrowing Owls could lose 77% of their current breeding range (Audubon Society 2015).

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Increase. In Colorado, most areas on the eastern plains in Burrowing Owl habitat are on private lands.

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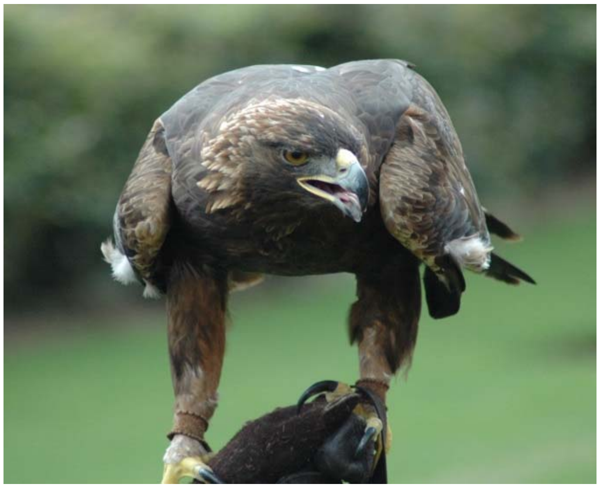
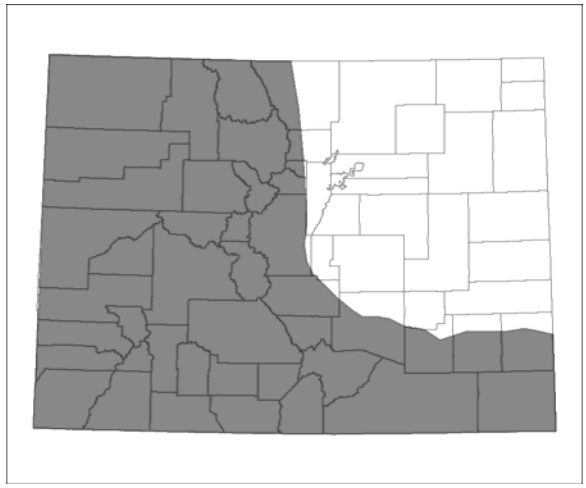
## Golden Eagle

***Aquila chrysaetos***
**G5/S3S4B, S4N**
**Family: Accipitridae**





## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state wide rank is based on: the projected increases in temperature for the assessed area, increased wind energy development and the greater risk to mortality from wind turbines than other raptors, limited precipitation variation the eagle has historically experienced, limited number of prey species the eagle depends upon, and a predicted decrease in breeding range. Climate projections suggest that summer temperatures across the range of the Golden Eagle in the assessed area will increase 6°F by the end of the century under a lower emissions scenario, with increases of more than 10°F by the end of the century under a higher emissions scenario (Karl et al. 2009).

**Distribution:** In Colorado, golden eagles breed primarily in montane habitats in the west and canyon habitats in the southeast. There is some limited breeding in northeast Colorado. In winter, golden eagles range more widely and occur commonly throughout Colorado. **Habitat:** Golden eagles use a very wide range of habitats. For nesting they most frequently use cliffs but will also nest in trees. Because of their large size and predatory nature, they require large areas of foraging habitat. For foraging they use high- and mid-elevation pine forest, piñon-juniper woodlands, sagebrush and other shrub habitats, grassland, and agricultural habitats are all used by Golden eagles.

## CCVI Scoring

**B1) Exposure to sea level rise**. Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Significant natural barriers do not exist for this species. This raptor is a volant species that can traverse mountain ranges and large bodies of water.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Significant anthropogenic barriers do not exist for this species. This raptor is a volant species that can fly over or around potential anthropogenic barriers.

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat increase. Golden Eagles are at greater risk to mortality from wind turbines than other raptors (USFWS 2011). Wind energy development is expected to increase within the range of the Golden Eagle in Colorado (NRDC 2014).

**C1) Dispersal and movements.** Decrease. Golden Eagles readily disperse more than 10 kilometers from hatching site to breeding areas (Kochert et al. 2002)

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Golden eagle in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase. In North America, Golden Eagle's breeding success appears to be compromised by the number of extremely hot days during the brood rearing period (Steenhof et al. 1997). Climate projections suggest that summer temperatures across the range of the Golden Eagle in the assessed area will increase 6°F by the end of the century under a lower emissions scenario, with increases of more than 10°F by the end of the century under a higher emissions scenario (Karl et al. 2009)

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat increase. Within the assessed area the Golden Eagle has experienced slightly lower than average (20-30 inches/255-508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral. Golden Eagle reproductive success appears to be independent of any particular precipitation regime (Steenhof et al. 1997 and Crandall 2005).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The Golden Eagle is not dependent on any disturbance regime such as fire or flooding and are most dependent upon suitable prey populations in foraging areas (Steenhof et al. 1997 and Crandall 2005).

**C2d) Dependence on snow-covered habitats.** Neutral. The Golden Eagle is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The Golden Eagle is not dependent upon any uncommon geological elements. However, they often nest on cliffs, but also will nest in trees and on the ground, river banks and human structures (Kochert et al. 2002). Climate change should not impact the availability of suitable cliff sites for nesting.

**C4a) Dependence on other species to generate habitat.** Neutral. The Golden Eagle is not dependent on any other species to create suitable habitat for its existence.

**C4b) Dietary versatility.** Somewhat increase. The Golden Eagle depends upon a few small mammal as prey including hares (*Lepus* spp.) and rabbits (*Sylvilagus* spp.); also ground squirrels (*Spermophilus* spp.), prairie dogs (*Cynomys* spp.) and marmots (*Marmota* spp.) (Kochert et al. 2002).

**C4d) Dependence on other species for propagule dispersal**. Neutral. The Golden Eagle is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions, other than those discussed above, are important to the persistence of the Golden Eagle.

**C5a) Measured genetic variation.** Neutral. The genetic diversity of the golden eagle has been reported to be average (Doyle et al. 2014).

**C5b) Occurrence of bottlenecks in recent evolutionary history**. Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Increase. The predicted breeding range of the Golden Eagle in the assessed area is predicted to decline by 79 percent (National Audubon Society 2013).

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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## Greater Sage-grouse

***Centrocercus urophasianus***
**G3G4/S4**
**Family: Phasianidae**


## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank of Highly Vulnerable is based on the following factors: 1) less than 10% of sagebrush ecosystems in CO are projected to be outside of current climatic envelope (see Ecosystems chapter); 2) outside of their reliance on sagebrush for cover and food, this species has few restrictions to uncommon geologic features, no reliance on intraspecific relationships; 3) Greater Sage-grouse (GrSG) are capable of moving several kilometers; 4) GrSG have experienced average temperature variation in the past 50 years; 5) genetic variation in Colorado is higher than other parts of the GrSG range.

**Distribution*:*** Greater sage-grouse occur in the Western United States and Canada. Colorado is on the southeastern edge of the current GrSG range (Colorado Greater Sage-grouse Steering Committee [CGSGSC] 2008). Within Colorado, the occupied range of GrSG is in the northwest corner of the state in the following counties: Eagle, Garfield, Grand, Jackson, Larimer, Mesa, Moffat, Rio Blanco, Routt, and Summit. **Habitat:** The GrSG are dependent on sagebrush year around for food and cover. Females and broods may select riparian habitats in the sagebrush type that contain high cover of forbs and abundant moisture (see CGSGSC 2008 for discussion of seasonal habitat use within sagebrush shrublands). **Elevation:** 7,900-9,500 feet.

**Ecological System:** Sagebrush shrubland

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Several populations on the eastern edge of occupied habitat in CO are separated by the Park Range. These high alpine areas and rugged peaks may act as a natural barrier for movement.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. This mountain range is a potential natural barrier for GrSG. River valleys and large agricultural areas in Alberta, Saskatchewan, Montana, and Wyoming were significant barriers to GrSG movement (Bush et al. 2011). The eastern and southern edges of GrSG range in Colorado contain irrigated and dryland agricultural fields that may serve as barriers to GrSG movement (USGS National Gap Analysis Program 2004).

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. GrSG are considered sagebrush obligates. NW Colorado, including Rio Blanco County, contains large expanses of sagebrush shrublands. A total of 2,915 active natural gas wells are currently operating in Rio Blanco County (COGCC 2015). A projected 1,845 new wells will be drilled in Rio Blanco County in 2035 to meet energy demands in Colorado (BBC 2008). Increased energy development in this area will result in further habitat fragmentation for GrSG. Less than one percent of federal lands in Colorado contain wind energy development right-of-ways within Priority Areas for GrSG Conservation in Colorado (LeBeau et al. 2014).

**C1) Dispersal and movements.** Decrease. Average nest-to-winter movements in GrSG in Wyoming averaged 14.4km in a recent study (Fedy et al. 2012).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, GrSG has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Less than 10% of sagebrush ecosystems in Colorado are projected to be outside of its current climatic envelope (See Ecosystem Section of report).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, GrSG has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. High quality brood-rearing habitats are often located in mesic areas like streambeds and wet meadows (Connelly et al. 2000).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Fire is considered one of the top threats to GrSG. Although historically natural fires were often large and severe, they were typically infrequent in GrSG habitat (Brooks et al. 2015). However, during recent decades, fire probability and occurrence has increased across GrSG habitat, hindering the recovery of sagebrush, and posing a threat to GrSG habitat (Brooks et al 2015.)

**C2d) Dependence on snow-covered habitats.** Neutral. This species makes snow roosts and burrows (Back et al. 1987), but is not completely dependent on snow cover for survival.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Decrease. This species is not restricted to uncommon geologic features.

**C4a) Dependence on other species to generate habitat.** Greatly Increase. The GrSG rely on sagebrush year-round for food and cover.

**C4b) Dietary versatility.** Somewhat Increase. During the spring and summer, GrSG consume insects and forbs; their fall and winter diet is comprised entirely of sagebrush (CGSGSC 2008).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Neutral. North Park, Middle Park, and Eagle populations in high-elevation valley in Colorado are genetically distinct from populations in the Wyoming Basin that are more wide-spread (Oyler-McCance et al. 2005). No populations in Colorado have been identified as having an extremely low number of haplotypes, as compared to those in the Columbia Basin (Oyler-Mccance et al. 2005).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. Genetics testing across the range of GrSG did not reveal any population bottlenecks in Colorado populations (Oyler-Mccance et al. 2005).**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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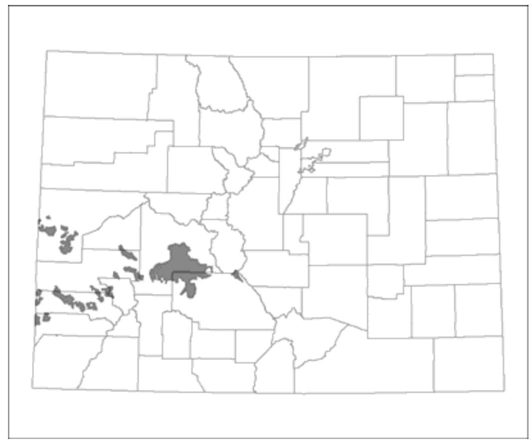
## Gunnison Sage-grouse

***Centrocercus minimus***
**G1/S1**
**Listed Threatened**
**Family: Phasianidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decrease in growth of mountain big sagebrush due to climate change; 3) reliance on mesic habitat types for brood-rearing habitat; 4) lack of genetic diversity; 5) potential increase in fire frequency in sagebrush habitats due to projected temperature increases.

**Distribution***:* Limited to southwest Colorado and southeast Utah. In Colorado, Gunnison-sage-grouse occur in the following counties: Delta, Dolores, Gunnison, Hinsdale, Mesa, Montrose, San Miguel, and Saguache (USFWS 2014). **Habitat:** Gunnison sage-grouse rely on large expanses of sagebrush habitat for food and cover; mesic areas along riparian corridors, as well as wet meadows provide brood-rearing habitat (USFWS 2014).

**Ecological System:** Sagebrush shrubland

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Gunnison sage-grouse rely on large, continuous, unfragmented landscapes for survival (GSGRSC 2005). The global distribution of Gunnison sage-grouse is limited to seven populations, six of which are located in Colorado. The remaining population straddles the Utah/Colorado border. Gunnison sage-grouse occur in areas with elevations ranging from 2,300 to 2,900 m (7,500 to 9, 5000 ft) of elevation. Areas between many of the Colorado populations do not contain suitable habitat and have elevations much higher than the documented range preferred by the species. The Gunnison River and the Black Canyon may also pose a natural barrier to movement.

**B2b) Distribution relative to anthropogenic barriers.** Increase/Somewhat Increase. As noted above in B2a, Gunnison sage-grouse rely on large, continuous, unfragmented landscapes for survival (GSGRSC 2005). Human populations and associated development are projected to increase near most Gunnison sage-grouse populations (USFWS 2014). Habitat decline from disturbance and fragmentation caused by roads and powerlines is a current and future threat to the survival of Gunnison sage-grouse in Colorado (USFWS 2014).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. Geothermal development potential is high in the Gunnison Basin, and if development increased in the Basin, it could affect the long-term viability of Gunnison sage-grouse within the Basin (USFWS 2014). No existing, pending, or authorized wind energy sites are within the Colorado portion of occupied Gunnison sage-grouse habitat (USFWS 2014). No information regarding solar energy development was included in the final rule issued by USFWS in 2014, so it is likely not a threat in occupied Gunnison sage-grouse habitat.

**C1) Dispersal and movements.** Somewhat Decrease. Gunnison sage-grouse are generally considered nonmigratory, but some seasonal movements have been documented. In the Gunnison Basin, individuals generally move less than 10 km (GSGRSC 2005), but movements as great as 56 km have also been reported in the Basin (Phillips 2013).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Increase. Predicting temperatures in occupied habitat for Gunnison sage-grouse is challenging. In one scenario, average summer temperatures are predicted to increase in western Colorado by 2.8˚C by 2050 (UCAR 2009), and average winter temperatures could increase by 2.2 ˚C by 2050 (UCAR 2009). Over time, increased temperatures could reduce growth of mountain big sagebrush, resulting in a reduction of suitable habitat for Gunnison sage-grouse (USFWS 2014).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Neutral. Considering the range of mean annual precipitation across occupied cells, the species has experienced average (21 - 40 inches/509 - 1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. High quality brood-rearing habitat includes mesic meadows, springs, seeps, and low vegetation riparian areas, all dependent on adequate moisture (GSGRSC 2005; USFWS 2014). These habitats types are highly vulnerable to climate change.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. In previous reports (TNC et al. 2011), fire has been cited as a naturally occurring event that benefits Gunnison sage-grouse by creating a patchwork of lower and higher density sagebrush, and that climate change is likely to alter fire regimes thereby reducing high-quality habitat for the species. More recent reports indicate that the impacts of fire on Gunnison sage-grouse habitat are not well understood. However, it is generally accepted that fire can cause an increase in weedy plant species such as cheatgrass, and can kill mountain big sagebrush, resulting in direct loss of habitat due to reduced cover and forage (Call and Maser 1985; USFWS 2014). Fire is not considered a current threat to Gunnison sage-grouse, but best available information on climate change indicates that fire frequency is likely a future threat to the species if fire frequency increases as predicted by climate change models (Lukas et al. 2014; USFWS 2014).

**C2d) Dependence on snow-covered habitats.** Neutral. This species is not directly dependent on snow or ice for survival.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Greatly Increase. This species relies on sage-brush as a critical component of their diet, as well as for cover through all seasons (GSGRSC 2005).

**C4b) Dietary versatility.** Increase. Gunnison's Sage-grouse rely on sage-brush (*Artemisia* spp.) as a critical component of their diet throughout all seasons; they also feed on a large number of grasses, forbs, buds, and insects when available (GSGRSC 2005). They also depend on herbs and forbs in the summer along with the insects that use the same habitat (important for chick growth); factors that could be impacted by climate change to the degree that it includes droughts and hot spells (TNC et al. 2011).

**C4c) Pollinator versatility (Plants only, not applicable)**.

**C4d) Dependence on other species for propagule dispersal.** Greatly Increase. This species relies on sage-brush as a critical component of their diet, as well as for cover through all seasons (GSGRSC 2005).

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Increase/Somewhat Increase. Genetic diversity in Gunnison sage-grouse has been investigated using mitochondrial DNA and nuclear microsatellite data (Oyler-McCance et al. 2005). Results indicate low levels of diversity, especially in comparison to diversity found in greater sage-grouse (Oyler-McCance et al. 2005).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Neutral. Across the entire range of occupied habitat for Gunnison sage-grouse, 54 percent occurs on Federal lands, 43 percent on private lands, and 3 percent on state lands (USFWS 2014).

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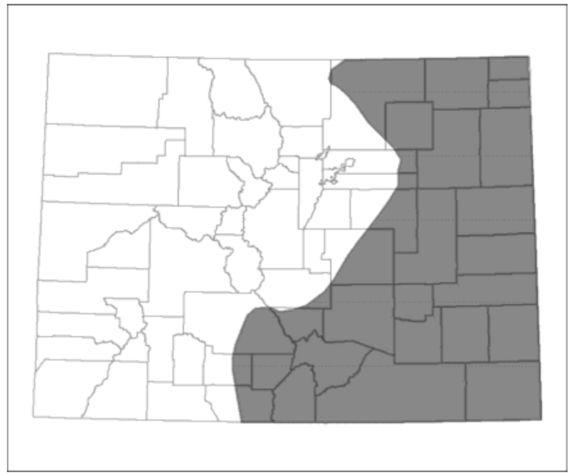
## Long-Billed Curlew

***Numenius americanus***
**G5/S2B**
**Family: Scolopacidae**



## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) potential increase in wind energy development in Long-Billed Curlew breeding habitat and 2) reliance on wetlands, ponds and playas that may be vulnerable to drying under projected increases in temperature due to climate change.

**Distribution***:* In Colorado, Long-Billed Curlew breed on the eastern plains with populations concentrated in the southeast corner of the state (Colorado Partners in Flight 2000; Colorado Bird Atlas Partnership 1998). **Habitat:** In Colorado, Long-Billed Curlews breed in shortgrass and mixed-grass prairie habitats, usually in close proximity to water (Colorado Bird Atlas Partnership 1998). **Elevation:** No information on specific elevation ranges is available, but due to their presence on the eastern plains, it is likely that the Long-Billed Curlew is most commonly found between 4,000 and 7,000 ft.

**Ecological System:** Shortgrass Prairie, Mixed-Grass Prairie

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. The Rocky Mountains may act as a barrier to migration (Page et al. 2014).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Large tracts of Colorado's shortgrass prairie have been converted to cropland. Long-Billed Curlew use cropland less than expected based on availability (Dechant et al. 1999). While this species is highly mobile and capable of flying over these areas, there may be energetic costs associated with crossing these croplands in order to reach more suitable habitat in shortgrass prairie.

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. Long-Billed Curlew nest primarily in eastern Colorado in shortgrass prairies, with a small contingent in Mesa County on the Western Slope (Colorado Bird Atlas Partnership 1998). According to Department of Energy wind resource maps, the eastern quarter of Colorado near the New Mexico and Nebraska borders has excellent wind resources (DOE 2004). Wind turbines can cause direct impacts to birds via collisions that result in injury or mortality (Kunz et al. 2007; Kuvlesky et al. 2007), as well as indirect impacts via habitat loss and barriers to movement (Drewitt and Langston 2006; Kuvlesky et al. 2007; Pruett et al. 2009; Kiesecker et al. 2011).

**C1) Dispersal and movements.** Decrease. Long-Billed Curlew breed in Colorado and undertake long, seasonal migrations.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is associated with shortgrass prairie in Colorado and is not limited to cool or cold habitats (Colorado Bird Atlas Partnership 1998).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Neutral. Considering the range of mean annual precipitation across occupied cells, the species has experienced average (21 - 40 inches/509 - 1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. This species relies on both dry and wet areas in the shortgrass prairie. Grassy floodplains along creeks in Colorado provide nesting habitat for Long-Billed Curlew in Colorado; wet meadows are often used as foraging areas (Davis 1949; Johnsgard 1979 and 1980).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Long-Billed Curlew rely on ponds, playas, and lakes for feeding, bathing and drinking (Colorado Bird Atlas Partnership 1998). On the shortgrass prairie, many of these are tied to seasonal precipitation such as spring and summer rain events.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives**. Somewhat Increase. Long-Billed Curlew use wet meadows and playas in eastern Colorado, which can be unusual features in many counties where shortgrass prairie has been converted to cropland.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. The Long-Billed Curlew is predominantly carnivorous, and consumes small invertebrates (grasshoppers, beetles, earthworms, spiders) as well as some wild fruits (Dugger and Dugger 2002; see all authors in Dark-Smiley and Keinath 2004). Larger prey items include toads and snails, which are consumed during migration (Redmond and Jenni 1986).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown. More information is needed on Long-Billed Curlew genetics.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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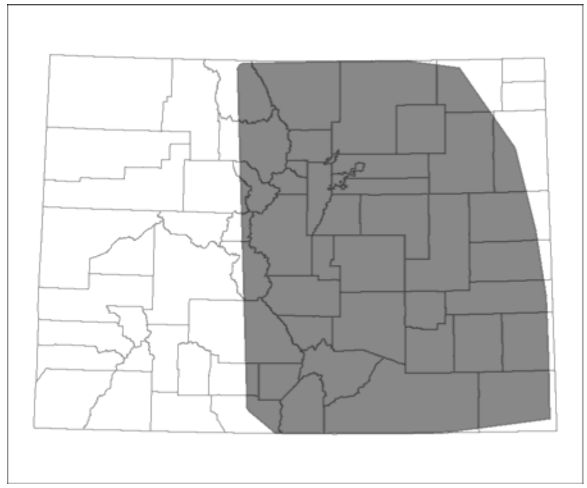
## Mountain Plover

***Charadrius montanus***
**G3/S2B**
**Family: Charadriidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state wide rank is based on: the lack of natural or anthropogenic barriers for this highly vagile bird, their capability to engage in long distance dispersal and movements allowing the plover to track shifting climate envelopes, their preference for burned sites (Augustine and Derner 2012) coupled with increased fire frequency projected due to climate change, high rates of adult survival and nest success rates during periods of drought that is projected to increase due to climate change, and the high genetic variability exhibited within Mountain plover populations that should increase their ability to adapt to climate change. Climate models project increased warming and drought across the assessed area with annual average temperatures rising by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer breeding season and during fall (Melillo et al. 2014).

**Distribution:** In Colorado, the greatest numbers of breeding Mountain Plovers occur in Weld County (Graul and Webster 1976). The breeding range of this species has undergone a dramatic long-term contraction, both in Colorado (Andrews and Righter 1992) and throughout the western Great Plains (Graul and Webster 1976). **Habitat:** Breeding Mountain Plovers occupy open habitats with low-growing vegetation, especially shortgrass prairie characterized by the presence of blue grama grass and buffalo grass (Graul 1975, Graul and Webster 1976, Knopf and Miller 1994). In grasslands where vegetation grows taller than approximately three inches in height, Mountain Plovers use intensively grazed areas (Graul and Webster 1976, Knopf 1996), prairie dog towns (Knowles et al. 1982; Knowles and Knowles 1984, Olson and Edge 1985, Shackford 1991), and fallow or recently plowed agricultural fields (Shackford 1991, Shackford et al. 1999).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers. .** Neutral. Significant natural barriers do not exist for this species. The Mountain Plover is a Great Plains inhabitant and is highly volant, capable of traversing mountain ranges and large bodies of water. It is a seasonal migrant, whose home ranges average over 50 hectares in size (Knopf and Rupert 1996).

**B2b) Distribution relative to anthropogenic barriers. Increase.** Neutral. Significant anthropogenic barriers do not exist for this species. This bird is a volant species that can fly over or around potential anthropogenic barriers.

**B3) Impact of land use changes resulting from human responses to climate change**. Increase. The habitat of this Great Plains species is highly susceptible to potential development of wind farms/solar farms and biofuels production (Andres and Stone 2010). In the face of rising climate change and costs to extract fossil fuels, wind energy development is expected to increase within the range of the Mountain Plover in Colorado (NRDC 2014).

**C1) Dispersal and movements.** Decrease. Mountain Plover are known to disperse up to 50 kilometers from their natal regions (Knopf and Wunder 2006).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Mountain plover in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase. Adults actively shade chicks on hot days, and adults and chicks often seek shade (Knopf and Wunder 2006). Increased temperatures associated with climate change in the assessed area (Melillo et al. 2014) could lead to increased brood rearing stress for Mountain Plover.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat decrease. Within the assessed area the Mountain Plover has experienced greater than average (>40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat decrease. Adult survival and nest success is highest during drought periods, but nest success is also enhanced by cooler temperatures (Dinsmore 2008, Dreitz et al. 2012). In the future, climate change is projected to increase temperatures, but it will also increase drought frequency (Melillo et al. 2014), which may increase adult survival and recruitment of young Mountain Plover. However, the interplay of climate change induced drought and warming within prairie ecosystems will be dynamic, making it difficult to assess how this will impact Mountain plover population trends over time.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat decrease. Mountain Plover react favorably to fire, and with the predicted increase in wildfire in the assessed area due to climate change (Melillo et al. 2014), this should lead to somewhat of a decrease in their vulnerability to how climate change will impact this index factor. In some parts of their range, Mountain Plovers are attracted to burned grasslands in breeding areas for nesting and in nonbreeding areas for foraging and night roosting (Wunder and Knopf 2003, Knopf 2008). Mountain Plover response to burns is often quick, with birds appearing on fields where fires are still smoldering (Knopf and Wunder 2006). Increased drought associated with climate change in the accessed area is expected to increase wildfire frequency (Melillo et al. 2014), potentially benefitting Mountain Plover.

**C2d) Dependence on snow-covered habitats.** Neutral. The Mountain Plover is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The Mountain Plover is not dependent upon any uncommon geological elements.

**C4a) Dependence on other species to generate habitat.** Somewhat Increase. The Mountain Plover uses areas of short grasses that have been grazed by prairie dogs, cattle and other herbivores (Dinsmore 2003).

**C4b) Dietary versatility.** Neutral. Mountain Plover are opportunistic foragers that feed on a broad range of insects (Knopf and Wunder 2006).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Mountain Plover is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Mountain Plover.

**C5a) Measured genetic variation.** Somewhat Decrease. Mountain Plover populations exhibit considerable genetic mixing, which results in high genetic variability within populations (Oyler-McCance et al. 2005).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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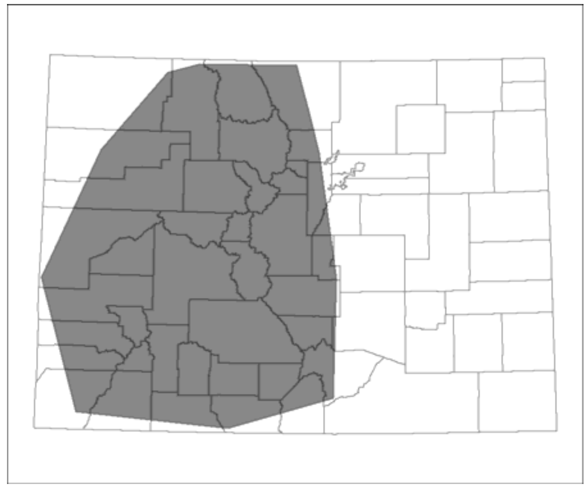
## Northern Goshawk

***Accipiter gentilis***
**G5/S3B**
**Family: Accipitridae**



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state wide rank is based on: the projected increase in temperature and drought for the assessed area, selection of cool microclimates for nest placement, dependence on old-forest structure that may be threatened by increased frequency of wildfire caused by drought and warming, and low levels of genetic variability questioning the goshawks adaptability to a changing environment. Regional annual average temperatures are projected to rise by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014). Under a continuation of current rising emissions trends (A2), reduced winter and spring precipitation is consistently projected for the southern part of the Southwest by 2100 elevating the potential for wildfire (Melillo et al. 2014).

**Distribution:** The Northern goshawk is found throughout the state of Colorado above 7500 feet in elevation (Andrews and Righter 1992). The Colorado Breeding Bird Atlas (Kingery 1998) shows goshawks to be well distributed in the San Juan Mountains and across the northern mountain ranges. **Habitat:** In northwestern Colorado, northern goshawks typically nest in aspen, sometimes in conifer stands less than 100 years old, and up to 10,000 feet in elevation (Kingery 1998). Goshawks tend to choose nest trees on shallow slopes, flat benches in steep country, and fluvial pans on small stream junctions (Kingery 1998).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers. .** Neutral. Significant natural barriers do not exist for this species. This raptor is a volant species that can traverse mountain ranges and large bodies of water (NatureServe 2014).

**B2b) Distribution relative to anthropogenic barriers. .** Neutral. Significant anthropogenic barriers do not exist for this species. This raptor is a volant species that can fly over or around potential anthropogenic barriers (NatureServe 2014).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. Although Northern Goshawk have been reported to be at risk of collision with wind turbines during migration (Brandes 2005) only a small portion of their range in the assessed area is suitable for wind energy development and there are not important flyways for this raptor within the potential areas of wind development (NRDC 2014). This is a low concern for the raptor within the assessed area.

**C1) Dispersal and movements.** Decrease. Northern Goshawks readily disperse more than 10 kilometers from hatching site to breeding areas and have home ranges that are from the 100s to 1000s of hectares in size (Squires and Reynolds 1997).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Northern goshawk in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase. In southern portions of the Goshawk range including the assessed area goshawk nest areas typically have northerly aspects indicating a selection for cooler microclimates (USFWS 1998). Climate projections suggest that summer temperatures in the assessed area will increase from 6°F more than 10°F by the end of the century under a higher emissions scenario (Karl et al. 2009), which could make the goshawk more vulnerable to climate change in the assessed area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat increase. Within the assessed area the Northern Goshawk has experienced slightly lower than average (20-30 inches/255-508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat decrease. Reproductive success seems to be negatively impacted by increased spring precipitation and positively influenced by warmer temperatures (Kennedy 2003, Patla 2997) and with increasing temperatures and drought projected for the assessed area (Karl et al. 2009) this could positively impact recruitment. However, population growth rates are most sensitive to changes in adult survival rates and changes that influence adult survival would probably have a greater influence on population persistence (Kennedy 2003).

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The goshawk is not dependent upon any uncommon geological elements.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Goshawks are dependent on old-forest structure and declining precipitation coupled with increasing temperatures and drought in the assessed area is projected to increase the area burned by wildfire (Karl et al. 2009). This potential threat to old growth forest is a concern for goshawks (Boyce et al. 2006).

**C2d) Dependence on snow-covered habitats.** Neutral. The goshawk is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The goshawk is not dependent upon any uncommon geological elements.

**C4a) Dependence on other species to generate habitat.** Neutral. The goshawk is not dependent on any other species to create suitable habitat for its existence.

**C4b) Dietary versatility.** Neutral. The goshawk captures a wide variety of prey and is classified as a prey generalist (Squires and Reynolds 1997), typically preying on a suite of 8 to 15 species (Reynolds et al. 1992).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The goshawk is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the goshawk.

**C5a) Measured genetic variation.** Somewhat Increase. The goshawk exhibits high haplotype diversity across populations in North America, but low nucleotide diversity within populations including the Rocky Mountain population, which is genetically differentiated from eastern and other western populations of the raptor (Bayard de Volo et al. 2013).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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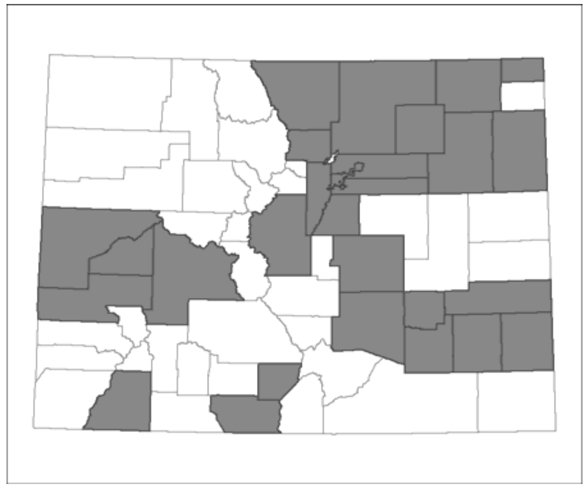
## Western Snowy Plover

***Charadrius alexandrinus nivosus***
**G3T3/S1B**
**Family: Charadriidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural barriers to movement; 2) potential increase in wind energy development in breeding habitat; 3) reliance on alkali-covered playas and sandy margins of reservoirs that may be vulnerable to drying due to projected warmer temperatures; 4) potential reliance on seasonal wetlands created by spring runoff that may be altered due to climate change; 5) low amounts of genetic differentiation.

**Distribution*:*** The Western Snowy Plover (Snowy Plover hereafter) is a small shorebird that breeds on the Pacific coast from southern Washington to southern Baja California, Mexico, and in interior western states including Utah, Idaho, Nevada and Colorado (USFWS 2012). In Colorado, Snowy Plovers nest on alkali-covered playas in the San Luis Valley, as well as along sandy shores of constructed reservoirs in the southeastern corner of the state in the Lower Arkansas River Basin (Andrews and Righter 1992; Colorado Bird Atlas Partnership 1998). They typically arrive in Colorado in mid-April and depart starting from mid-July into October (Andrews and Righter 1992). **Habitat:** In Colorado, Snowy Plovers nest on alkali-covered playas in the San Luis Valley, as well as along sandy shores of reservoirs in the Lower Arkansas River Basin. **Elevation:** No information is available on the elevation range of Snowy Plover in Colorado, but based on distribution, the species likely breeds at elevations ranging from 4,000 ft to 8,000 ft.

**Ecological System:** Shortgrass Prairie, Greasewood Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral. Sandy ocean beaches offer habitat for snowy plover, and these may be lost to sea level rise. However, the assessment area for this CCVI is limited to Colorado, so sea level rise is not considered here.

**B2a) Distribution relative to natural barriers.** Neutral. This species is highly mobile.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. This species is highly mobile.

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. Snowy Plover are known to nest in the San Luis Valley and in eastern Colorado along the Arkansas River (Colorado Bird Atlas Partnership 1998). According to Department of Energy wind resource maps, the eastern quarter of Colorado near the New Mexico and Nebraska borders have excellent wind resources (DOE 2004). Wind turbines can cause direct impacts to birds via collisions that result in injury or mortality (Kunz et al. 2007; Kuvlesky et al. 2007), as well as indirect impacts via habitat loss and barriers to movement (Drewitt and Langston 2006; Kuvlesky et al. 2007; Pruett et al. 2009; Kiesecker et al. 2011).

**C1) Dispersal and movements.** Decrease. This species is highly mobile. Snowy Plovers that breed in the Great Plains winter on the Gulf of Mexico coast (Page et al. 2009).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold habitats.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. Snowy Plovers nest on alkali-covered playas in the San Luis Valley, as well as along sandy shores of reservoirs in the Lower Arkansas River Basin. The San Luis Valley is located in the Rio Grande River Basin. Many wetlands in this basin are dependent on snow-melt from the surrounding mountains, and these wetlands are expected to be more acutely affected than other ecosystems in the area (USFWS 2012). Climate models project a range of -28% to +11% in annual runoff for the Rio Grande Basin, and a range of -10% to +19% for the Arkansas River Basin for mid-century (Lukas et al. 2014). Furthermore, changing demands for water in these river basins may result in greater fluctuations in reservoir levels in these areas, which in turn could lead to the flooding of reservoir shorelines and resulting loss of Snowy Plover nesting habitat. Lastly, increased groundwater pumping for agriculture could lead to a reduction in available surface water and a loss of Snowy Plover nesting habitat (Busby 2002).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Snowy Plovers in the Arkansas Basin have been documented nesting on the shorelines of constructed reservoirs, but in the San Luis Valley, the alkali flats that provide nesting habitat are likely tied to more seasonal hydroperiods associated with spring runoff.

**C2d) Dependence on snow-covered habitats.** Somewhat Increase. In the San Luis Valley, runoff from snowmelt provides flows to wetlands that provide habitat for Snowy Plover (Laubhan and Gammonley 2000).

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. The Snowy Plover occurs on alkali flats around reservoirs during the breeding season, while migrants occur on mudflats and sandy shorelines (Andrews and Righter 1992). Furthermore, Snowy Plovers in the Great Plains frequently nest near water bodies that contain high salinity levels, which they may use for evaporative cooling during periods of high temperatures (Purdue 1976).

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. In the Great Plains, Snowy Plover feed on a variety of invertebrates including flies (*Ephydra* sp.), beetles (*Bledius* sp., *Cicindela* sp.), and many terrestrial insects blown from surrounding areas including grasshoppers, lepidopterans, and beetles (Busby 2002; Purdue 1976, Grover and Knopf 1982).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Somewhat Increase. Genetic studies have revealed low amounts of genetic differentiation among populations of Snowy Plovers, with almost all variability found within populations (Funk et al. 2007).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Neutral. No evidence for a population bottleneck was found in a genetic study of Great Basin, Midwest, Gulf Coast, and Pacific Coast Snowy Plover populations (Funk et al. 2007).

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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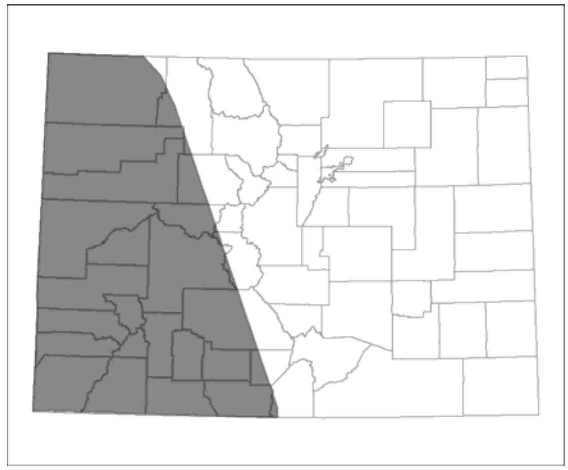
## Western Yellow-billed Cuckoo

***Coccyzus americanus occidentalis***
**G5T2T3/S1B**
**Family: Cuculidae**



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state wide rank is based on: narrow habitat requirements and difficulties in dispersal by juveniles and adults between patches of suitable riparian habitat, increased drying and drought projected due to climate change for the assessed area, drying associated with global climate change causing increased water withdrawal for human consumption resulting in additional loss and fragmentation of riparian breeding habitat, increased wildfire due to increased frequency of drought in historically wildfire free riparian habitat, and projected increases in tamarisk invasion into suitable riparian habitat due to climate change. Climate models project increased warming and drought across the assessed area with annual average temperatures rising by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014). Projections of precipitation changes are less certain, but under a continuation of current rising emissions trends (A2), reduced winter and spring precipitation is consistently projected for the southern part of the Southwest by 2100 (Melillo et al. 2014). These projected changes in climate are predicted to have dramatic effects on the distribution, quantity, and quality of suitable riparian habitat available for breeding, negatively impacting populations of the cuckoo within the assessed area.

**Distribution:** The Rocky Mountain Bird Observatory conducted surveys for cuckoos in western Colorado during the summers of 2008 through 2011 and found them along the North Fork of the Gunnison River (Delta County), the Colorado River (Mesa County), near Nucla (Montrose County), and the Yampa River (Moffat County) (Beason 2012). A handful of incidental detections were also recorded during this time, but it was concluded that the species is a very rare breeder in western Colorado after surveys were completed. **Habitat:** A riparian species, the western yellow-billed cuckoo breeds in low- to moderate-elevation native forests lining the rivers and streams of the western United States. Cottonwood willow forests (*Populus* spp. - *Salix* spp.) are most often used, although other riparian tree species can be important components of breeding habitat as well, such as alder (*Alnus* spp.), box elder (*Acer negundo*), mesquite (*Prosopis* spp.), Arizona walnut (*Juglans major*), Arizona sycamore (*Platanus wrightii*), oak (*Quercus* spp.), netleaf hackberry (*Celtis reticulata*), velvet ash (*Fraxinus velutina*), Mexican elderberry (*Sambucus mexicanus*), seepwillow (*Baccharis glutinosa*), and occasionally, tamarisk (*Tamarix* spp.).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers. .** Neutral. Significant natural barriers do not exist for this species. The cuckoo is a volant long distant migrator that can traverse mountain ranges and large bodies of water.

**B2b) Distribution relative to anthropogenic barriers. Increase.** Somewhat increase to increase. Habitat destruction, modification, and degradation from dam construction and operations; water diversions; riverflow management; stream channelization and stabilization; conversion to agricultural uses, such as crops and livestock grazing in the assessment area are considered barriers to dispersal by juvenile and adult yellow-billed cuckoos (USFWS 2014).

**B3) Impact of land use changes resulting from human responses to climate change**. Increase. Modifications to hydrology (impoundments, channelization, and alteration of river flows, and surface and ground water withdrawal) result in cuckoo habitat loss and fragmentation (USFWS 2014).The drying trend associated with global climate change may result in more dams, levees, water withdrawals or other activities to ensure fresh water for human consumption, which may result in additional habitat loss and fragmentation (USFWS 2014).

**C1) Dispersal and movements.** Somewhat decrease to decrease. Limited data on dispersal suggests high site fidelity with mating birds returning to their past nesting sites while natal birds do disperse up to 205 meters for males and 33,315 meters for females (McNeil et al. 2013). Additionally cuckoos are long-distance migrants, although details of their migration patterns are not well known (Hughes 1999). Mated pairs also have large home ranges that vary in size from 6 - 55 hectares (Halterman 2009).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Western-yellow billed cuckoo in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase to increase. There is no direct evidence that cuckoos require cool microclimates for nesting, but in the western U. S. they are restricted to riparian habitats with thick shaded overstory that are of higher humidity than the surrounding arid landscape (Hughs 1999, Wiggins 2005).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat decrease. The range occupied by the cuckoo in the assessed area has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly increase. in the western U. S. the cuckoo is restricted to riparian habitats with thick shaded overstory that are of higher humidity than the surrounding arid landscape (Hughs 1999, Wiggins 2005). The higher summer temperatures, earlier spring snowmelt, and lower summer flows caused by climate change (Melillo et al. 2014), will result in both short-term and long-term loss of required riparian habitat from excessive winter scouring, summer drying, and wildfire (USFWS 2014).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. The drying projected for the assessment area due to climate change is expected to increase the frequency of wildfire (Melillo et al. 2014). Historically, wildfire was uncommon in native riparian woodlands (Busch and Smith 1993) and the expected increased incidence of wildfire into cuckoo habitat will further degrade, isolate, or fragment cuckoo habitat (USFWS 2014).

**C2d) Dependence on snow-covered habitats.** Neutral. The cuckoo is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The cuckoo is not dependent upon any uncommon geological elements.

**C4a) Dependence on other species to generate habitat.** Neutral. The cuckoo is not dependent on any other species to create suitable habitat for its existence.

**C4b) Dietary versatility.** Neutral to somewhat increase. Cuckoos feed on a broad range of items, but primarily on slow moving insects including grasshoppers, butterflies and moths, hemiptera and beetles. However, larvae of the family Sphingidae (sphinx moths) have been noted as an important food source for yellow-billed cuckoos, and the lack of such prey has been implicated in the decline of the western subspecies. (Wiggins 2005).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The cuckoo is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Somewhat increase. Throughout most of its range, habitat for the Western yellow-billed cuckoo is threatened by the conversion of native riparian woodlands to riparian vegetation dominated by tamarisk and other nonnative vegetation (USFWS 2014). Models based on projected climate change predict that this invasive tamarisk will become more dominant in this region over the next 100 years (Kerns et al. 2009).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Decrease. Winter range is predicted to increase by 69% by 2080 (NAS 2014).

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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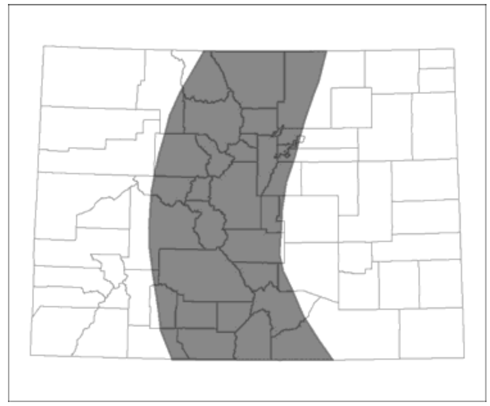
## White-faced Ibis

***Plegadis chihi***
**G5/S2B**
**Family: Threskiornithidae**

## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on the following factors: 1) potential wind farm development on Colorado's eastern plains and 2) potential decrease in runoff and precipitation that serves as a water source for wetlands in the San Luis Valley.

**Distribution***:* In Colorado, individuals primarily nest in the San Luis Valley and on portions of the eastern plains, and are typically migrants in the eastern plains and mountain parks (Andrews and Righter 1992). **Habitat:** The White-Faced Ibis is a large, long-legged bird that inhabits freshwater wetlands and marshes (Field Guide to the Birds of North America 1999, Dark-Smiley Keinath 2003).

**Ecological System:** Shortgrass Prairie**;** Wetlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. White-faced Ibis are a highly mobile species, and individuals that summer in Colorado undertake long migrations to winter in southern California, Louisiana, and Mexico (Rosenberg et al. 1991).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. See B2a above. This species is highly mobile.

**B3) Impact of land use changes resulting from human responses to climate change**. Somewhat Increase. White-faced Ibis are known to nest in the San Luis Valley and on the eastern plains of Colorado (Andrews and Righter 1992). According to Department of Energy wind resource maps, the eastern quarter of Colorado near the New Mexico and Nebraska borders have excellent wind resources (DOE 2004). Wind turbines can cause direct impacts to birds via collisions that result in injury or mortality (Kunz et al. 2007; Kuvlesky et al. 2007), as well as indirect impacts via habitat loss and barriers to movement (Drewitt and Langston 2006; Kuvlesky et al. 2007; Pruett et al. 2009; Kiesecker et al. 2011).

**C1) Dispersal and movements.** Decrease. See B2a. This species is highly mobile, and individuals that summer in Colorado travel long distances to spend the winter in the southern U.S. and Mexico (Rosenberg et al. 1991).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, White-Faced Ibis in Colorado has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche**. Neutral. This species is not limited to cool or cold environments. Drought could affect the availability of wetland habitats, but this is vulnerability is scored under C2bii.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Increase. Considering the range of mean annual precipitation across occupied cells, White-Faced Ibis has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. This species is a wetland obligate that prefers (almost exclusively) wetlands with emergent vegetation (Dark-Smiley and Keinath 2003). Drought conditions can cause drying of emergent vegetation and suitable nesting habitats, causing breeding adults to relocate. Furthermore, drought can make ibis eggs and young more susceptible to predation (Dark-Smiley and Keinath 2003). In Rio Grande Basin, wetlands dependent on snow-melt from the surrounding mountains, are expected to be more acutely affected than other ecosystems in the area (USFWS 2012). Climate models project a range of -28% to +11% in annual runoff for the Rio Grande Basin for mid-century (Lukas et al. 2014).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Shallow, seasonally flooded wetlands can provide foraging habitat for White-Face Ibis (Laubhan and Gammonley 2000).

**C2d) Dependence on snow-covered habitats.** Somewhat Increase. In the San Luis Valley, runoff from snowmelt provides flows to wetlands that provide habitat for White-Faced Ibis (Laubhan and Gammonley 2000).

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. The White-Faced Ibis feeds primarily on crustaceans, earthworms, and aquatic insects (Smiley and Keinath 2003).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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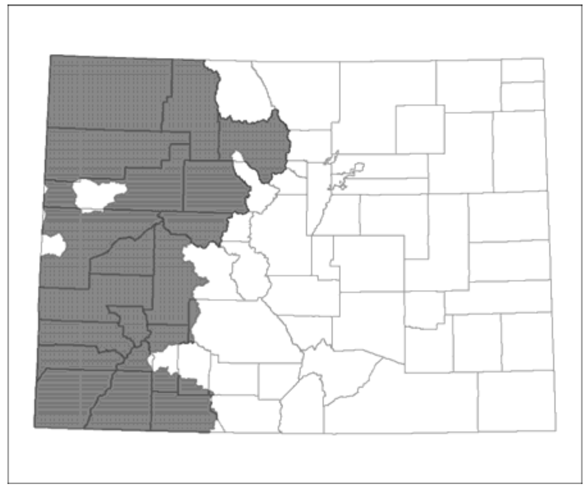
## Bluehead Sucker

***Catostomus discobolus***
**G4/S4**
**Family: Catostomidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) warming stream temperatures may affect bluehead sucker that generally inhabit cool streams 3) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 4) reliance on gravel bars for spawning; 5) lack of variability in annual precipitation in last 50 years; 6) hybridization with the nonnative white sucker could affect the genetic integrity of the species.

**Distribution*:*** In Colorado, the bluehead sucker is found throughout the Upper Colorado River drainage. **Habitat:** In Colorado, adult bluehead sucker most often are found in swifter, higher gradient streams; larval fish inhabit near-shore, low velocity habitats (Childs et al. 1998). Riffles and pools support algae and macroinvertebrates that are consumed by bluehead suckers (Sigler and Sigler 1996). Bluehead sucker occupy warm to cool streams (20˚C) with rocky substrates (Sigler and Sigler 1996; Bestgen 2000).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Bluehead sucker are found in the mainstem and tributaries of the Colorado River within the state of Colorado (Miller and Rees 2000). The species can occur in high gradient streams. Waterfalls could create upstream movements within these streams. Although the exact leaping abilities of bluehead sucker are not known, many stream fishes are not able to jump above heights of 1.0-1.5 m (Bjornn and Reiser 1991; Holthe et al. 2005).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Dams and impoundments along the Colorado River and its tributaries create barriers for bluehead sucker movement. This species prefers swifter velocity, higher gradient streams and does not do well in impoundments (Bezzerides and Bestgen 2002).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Somewhat Decrease. More studies are needed to investigate movement patterns of bluehead sucker. Some investigators have reported that the species relatively sedentary, moving only a few kilometers (Vanicek 1967, Rees and Miller 2001), while others report recapturing individuals 19 km from original capture locations (Holden and Crist 1981).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Increase. Bluehead sucker inhabit a wide variety of river systems from small creeks to large rivers. Although generally inhabiting streams with cool temperatures, they have been found in small creeks with high water temperatures (28 degrees C) (Ptacek et al. 2005, Smith 1966).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat Decrease. Species shows a preference for environments toward the warmer end of the spectrum

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. High base flows are important for the reproduction success of bluehead sucker (Anderson and Stewart 2007). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. High base flows are important for the reproduction success of bluehead sucker (Anderson and Stewart 2007). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014).

**C2d) Dependence on snow-covered habitats.** Neutral

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral

**C4b) Dietary versatility.** Neutral. Bluehead sucker larvae feed on diatoms, zooplankton, and dipteran larvae (Carter et al. 1986; Muth and Snyder 1995; Ptacek et al. 2005). Adults and juveniles feed on macroinvertebrates, algae, and insect larvae (Vanicek 1967, Childs et al. 1998, Osmundson 1999).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral

**C4e) Forms part of an interspecific interaction not covered by 4a-d.** Unknown

**C5a) Measured genetic variation.** Increase. Although studies have shown high genetic diversity in bluehead sucker across the species range (Douglas et al. 2009), hybridization with the nonnative white sucker could affect the genetic integrity of the species. Hybridization between the non-native white sucker (*Catostomus commersoni*) and bluehead sucker has been documented, as well as individuals with genetic contributions from the white sucker, bluehead sucker, and native flannelmouth sucker (*Catostomus latipinnus*) (McDonald et al. 2008). The non-native white sucker has facilitated introgression between two native species, and therefore threatens the genetic integrity of the bluehead and flannelmouth suckers. A genetic study of the species revealed three distinct geographic areas that are evolutionarily significant for maintaining the genetic integrity of the bluehead sucker (referred to as evolutionarily significant units): the Bonneville Basin, the Upper Little Colorado River, and the Colorado River (Hopken et al. 2013). All bluehead sucker populations in the state of Colorado belong to the Colorado River unit (Hopken et al. 2013).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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## Bonytail Chub

***Gila elegans***
**G1/SX**
**Listed Endangered**
**Family: Cyprinidae**

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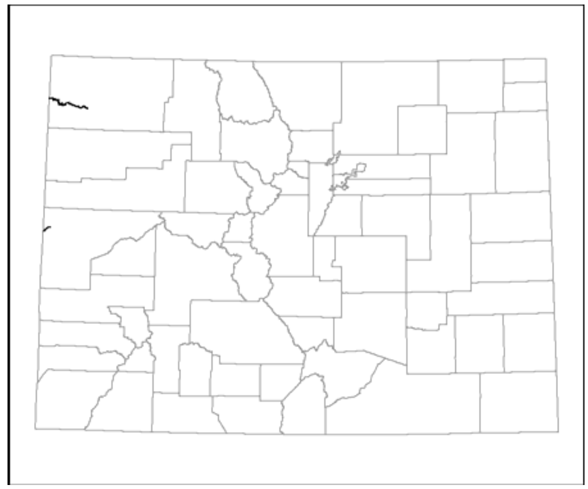

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) reliance on rocky substrates and gravel bars for spawning; 4) lack of variability in annual precipitation in last 50 years; 5) lack of genetic variation.

**Distribution*:*** The bonytail chub is considered functionally extinct in Colorado (Carlson and Muth 1989). No verifiable occurrences of wild bonytail chub have been documented in Colorado since 1984 when one individual was caught in the Black Rocks area near Grand Junction, Colorado (Kaeding et al. 1986). A captive broodstock was established from some of the last wild bonytail collected, and stocking of captive-reared individuals is a primary recovery strategy (Nesler et al. 2003). The distribution map above represents critical habitat as designated by USFWS (2003).
**Habitat:** Bonytail chub prefer backwaters with rocky or muddy bottoms and flowing pools, but reports suggest they can also occur in stream reaches with swift currents (USFWS 2012).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral/Somewhat Increase. Natural physical barriers to movement in the Colorado River and its tributaries are natural rapids and swift turbulent flows, and these are likely to fluctuate depending on flows (U.S. Fish and Wildlife Service 2002).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Dams and impoundments along the Colorado River and its tributaries create barriers for bonytail chub movement, and affect seasonal availability of habitat (U.S. Fish and Wildlife Service 2002).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Decrease. Little information is known regarding the life history and movements of bonytail chub, but fish released in Nevada traveled as much as 56 km (Marsh and Mueller 1999).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. The bonytail chub is adapted to the large, warm-water rivers and streams of the Colorado River Basin. Changes to thermal habitats have occurred due to the in-river hypolimnetic dam releases and the loss of warm, floodplain wetlands (Kappenman et al. 2012).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Maintenance of streamflow is important for the recovery and conservation of bonytail chub, a species now considered functionally extinct in the Upper Colorado River Sub-basin (USFWS 2012). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Little is known about spawning requirements for bonytail chub, but it is likely that like other members of the genus Gila, they spawn in rocky substrates (USFWS 2002). Pulses in spring flows are important for creating cobble bars as well as for flooding bottomland that serve as nursery habitat for young (USFWS 2002). Adequate base flows are necessary for the creation and maintenance of bonytail chub habitat. Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014), which could lead to further loss and degradation of habitat for razorback suckers. Increase. (USFWS 2002).

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Rocky substrates and gravel bars may be important spawning habitat for bonytail chub (USFWS 2002). The creation and maintenance of these habitats are jeopardized by dams and impoundments that alter natural hydrologic regimes.

**C4a) Dependence on other species to generate habitat.** Unknown**.**

**C4b) Dietary versatility.** Neutral. Bonytail chub are omnivorous, and consume organic material, aquatic macrophytes, invertebrates, bullfrogs, and fish (Marsh et al. 2013).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Increase. Historic genetic diversity of the bonytail chub is unknown, and so few wild individuals are left that the erosion of genetic variability may have already occurred (USFWS 2002).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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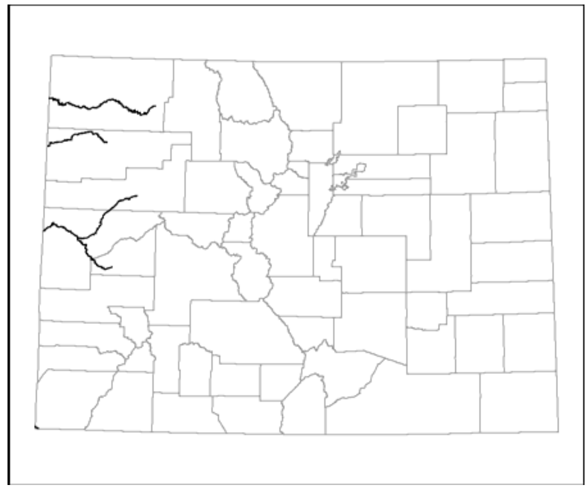
## Colorado Pikeminnow

***Ptychocheilus lucius***
**G1/S1**
**Listed Endangered**
**Family: Cyprinidae**

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) reliance on gravel-cobble substrates in high gradient streams for spawning; 4) lack of variability in annual precipitation in last 50 years; 5) lack of genetic variation.

**Distribution***:* The Colorado pikeminnow now occurs in approximately 1,090 miles of river habitat in the upper Colorado River Basin above Lake Powell in the Green River, upper Colorado River, and San Juan River sub-basins (USFWS 2011). The distribution map provided above is based on critical habitat designated by USFWS (2013). **Habitat:** Colorado pikeminnow adults are long-distance migrators that require uninterrupted reaches of medium to large rivers with pools, deep runs and eddy habitats maintained by high spring flows (USFWS 2011). Gravel and cobble deposits are used for spawning habitat; water temperatures during spawning are typically 18 to 23 ˚C (USFWS 2011).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral/Somewhat Increase. Historically, Colorado pikeminnow migrated long distances to and from spawning sites (Tyus 1991). Rapids and swift turbulent flows can create natural barriers to movement of Colorado pikeminnow during high flows, but these barriers are likely seasonal (USFWS 2002).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Extensive dam building in the 1930s through the 1960s has been cited as the primary cause for the extirpation of Colorado pikeminnow in the lower Colorado River basin (Mueller and Marsh 2002, Osmundson 2011). Although the species still persists in the upper Colorado River basin, dams have blocked upstream passage, converted free-flowing riverine segments into lentic reservoir habitat, and cooled downstream reaches with hypolimnetic releases (Osmundson 2011).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Decrease. Colorado pikeminnow in the San Juan River regularly travel an average of 4 to 62 km (Durst and Franssen 2014).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Increase/Neutral. Colorado pikeminnow evolved in warm-water rivers and tributaries in the Colorado River Basin. Evidence from recent studies suggest that warmer stream temperatures in the San Juan River Sub-basin contribute to faster growth and maturity in Colorado pikeminnow as compared to colder stream temperatures in the Upper Colorado River Sub-basin (Durst and Franssen 2014). Warmer stream temperatures as a result of climate change could result in higher rates of recruitment for Colorado pikeminnow.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower than average (11 - 20 inches/255 - 508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase/Neutral. Colorado pikeminnow adults require pools, deep runs, and eddy habitats that are created and maintained by high spring flows. The seasonal high flows created by spring runoff "maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, form gravel and cobble deposits used for spawning, and rejuvenate backwater nursery habitats" (USFWS 2002). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014). Lower flows could result in a further decline in the creation and maintenance of Colorado pikeminnow habitat.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Adult Colorado pikeminnow are piscivorous. Historically, the species relied on native prey fishes as a major food source. These native fishes spawn in May and June during high spring flows. Colorado pikeminnow prey on the small young of the year generated from these spawning events, and spawn once they are large enough (approx. 50 mm total length) in the early to mid-summer (Nesler et al. 1988, Tyus and Haines 1991, Franssen et al. 2007). Climate models project earlier peaks in streamflow, and this may alter the availability of prey fish for Colorado pikeminnow.

**Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Colorado pikeminnow spawn in gravel-cobble substrates in high-gradient streams (Haynes et al. 1984; Tyus and Haines 1991); backwaters formed in silt-sand bars are considered ideal nursery habitat (Osmundson et al. 2002). Dams and diversions in the Colorado River and its tributaries have altered natural flow regimes, and less high-quality habitat is available for the Colorado pikeminnow.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. Colorado pikeminnow adults are piscivorous and are the main native predator of the Colorado River Basin because of their large size and large mouth (Vanicek and Kramer 1969, Minckley 1973, Holden and Wick 1982, USFWS 2002). Young Colorado pikeminnow consume insects, copepods, cladocerans, and midge larvae (Vanicek 1967, Jacobi and Jacobi 1982, Muth and Snyder 1995, USFWS 2002).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Increase. Genetic diversity studies of mitochondrial DNA in hatchery stock and museum specimens has revealed low genetic diversity in Colorado pikeminnow (Borley and White 2006).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Somewhat Increase. A post-Pleistocene genetic bottleneck has been proposed as the cause of low levels of genetic variation in Colorado pikeminnow (Borley and White 2006).

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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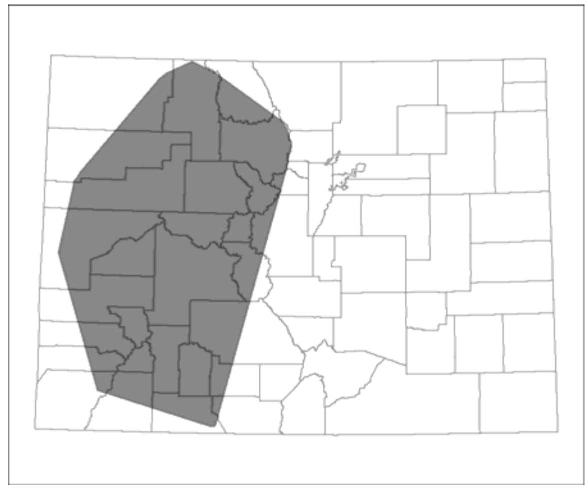
## Colorado River Cutthroat Trout

***Oncorhynchus clarkii pleuriticus***
**G4T3/S3**
**Family: Salmonidae**



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential complex effects of warming stream temperatures that may increase Colorado River cutthroat trout (CRCT hereafter) recruitment, as well as provide more suitable habitat for nonnative salmonids that hybridize and compete with CRCT; 3) reliance on gravel bars for spawning; 4) lack of variability in annual precipitation in last 50 years; 5) rainbow trout and other subspecies of cutthroat trout hybridize with CRCT and could threaten the genetic integrity of CRCT.

**Distribution***:* Colorado River cutthroat trout are found in the following river basins of Colorado: Dolores, Gunnison, Upper Green, Upper Colorado, Yampa, White, and San Juan (Hirsch et al. 2013). Recent genetic and meristic studies have identified two extant cutthroat lineages within this range, provisionally designated the Blue Lineage, native to the Yampa, Green and White River Basins, and the Green Lineage, native to the Upper Colorado, Gunnison and Dolores basins (Metcalf et al. 2012, Bestgen et al. 2013, USFWS 2014). A third lineage native to the San Juan basin is evidently extinct, though blue and green lineage populations have been established in this basin by stocking. In keeping with currently-recognized inland cutthroat taxonomy, this assessment considers all cutthroats indigenous to the West Slope as CRCT. **Habitat:** In Colorado, CRCT require cool, clear water in streams with well-vegetated, stable banks; deep pools, boulders, and logs are important for providing cover for CRCT (Young 1995, Young et al. 1998). CRCT also occur in lakes, but these are relatively rare (Hirsh et al. 2013). **Elevation:** CRCT occurs from 4,600 ft to nearly 12, 500 ft across its range (Hirsh et al. 2013). Specific elevation ranges for Colorado are not available.

**Ecological System:** Montane Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral/Somewhat Increase. Waterfalls, beaver dams, bedrock, debris and rapids are natural features in the river basins that provide habitat for CRCT (Hirsh et al. 2013). Many of these features may only appear during high flows. Nonetheless, they may create seasonal barriers to movement for CRCT.

**B2b) Distribution relative to anthropogenic barriers.** Neutral/Somewhat Increase. The effect of barriers can be complex for CRCT. The presence of a barrier can block the upstream movement of nonnative salmonids that negatively affect populations of CRCT through hybridization, food and space competition, and predation (Allendorf and Leary 1988, Forbes and Allendorf 1991, Hirsh et al. 2013). Dams and impoundments in the Colorado River Basin and its tributaries create barriers to CRCT movement (Young 2008).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Somewhat Decrease. Evidence from Young (1995) suggests that summer home ranges for CRCT range from 11 to 652 meters.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Increase/Neutral. Climate warming may have complex effects on CRCT populations. Many CRCT populations persist in higher elevation streams because unlike nonnative salmonids, they can tolerate colder water temperatures. However, these cold temperatures may not provide conditions that CRCT can thrive in, and growth and recruitment may be hindered by these low temperatures . Higher elevation streams that are currently too cold to sustain CRCT populations may warm enough in the future to provide suitable habitat for CRCT. Warmer stream temps could result in early spawning and higher overwinter survival for CRCT. It is also possible that these warmer stream temperatures will provide suitable habitat for nonnative fish as well.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower than average (11 - 20 inches/255 - 508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Lack of instream flows due to drought conditions is considered the highest climate change risk factor for CRCT (Haak et al. 2010).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral/Somewhat Increase. Spawning of CRCT begins after runoff has peaked in spring or early summer (Young 1995). Water temperatures may also provide spawning cues (Young 1995). Temperature increases due to climate change may lead to earlier peak runoff and warmer water temperatures. These may result in earlier spawning and higher overwinter survival for CRCT. Female CRCT deposit eggs 10-25 cm deep in spawning gravel. Natural hydrologic regimes that help create gravel bars have been altered by dam-related changes in timing and flow levels. Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Ray et al. 2008, Lukas et al. 2014), which could lead to further lack of hydrologic processes required to create and maintain habitat for CRCT.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Neutral/Somewhat Increase. Requires gravels for spawning, see above explanation in C2C.

**C4) Reliance on interspecific interactions.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. Amphipods, plankton, dipterans, and hymenopterans are all important components of CRCT diet (Colburn 1966, Bozek et al. 1994).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Increase. Nonnative rainbow trout (*Oncorhynchus mykiss*) and other subspecies of cutthroat trout (*Oncorhynchus clarkii spp*.) have hybridized with CRCT, thus reducing the genetic integrity of the subspecies (Allendorf and Leary 1988, Forbes and Allendorf 1991, CRCT Conservation Team 2006; Hirsch et al. 2013). Natural or constructed barriers exist to limit genetic mixing of rainbow and other subspecies of cutthroat trout and CRCT. However, these barriers also pose a threat to CRCT as it restricts individuals to short, headwater stream segments (Young 2008). This restriction renders populations more vulnerable to extirpation from stochastic events, and could result in the long term loss of genetic variability (Young 2008, Roberts et al. 2013).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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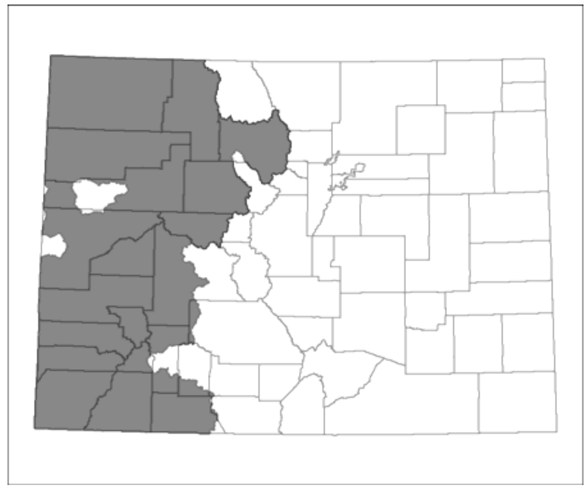
## Flannelmouth Sucker

***Catostomus latipinnis***
**G3G4/S3**
**Family: Catostomidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) reliance on gravel bars for spawning; 4) lack of genetic variation.

**Distribution*:*** In Colorado, the flannelmouth sucker is found throughout the Upper Colorado River drainage. **Habitat:** In Colorado, flannelmouth sucker reside in mainstem and tributary streams in the Upper Colorado River Basin. They are opportunistic benthic feeders. Adults occupy deep riffles and runs as well as deep, murky pools with sparse vegetation (McAda 1977; Sigler and Sigler 1996; Bezzerides and Bestgen 2002), while young fish are typically found in quiet, shallow riffles and near-shore eddies (Childs et al. 1998).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Flannelmouth sucker are most commonly found in pools and deeper runs of the mainstem and tributaries of the Colorado River within the state of Colorado (Bezzerides and Bestgen 2002; Sigler and Miller 1963; Minckley and Holden 1980).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Dams and impoundments along the Colorado River and its tributaries create barriers for flannelmouth sucker movement. This species does not do well in impoundments (McAda 1977, Sigler and Sigler 1996, Bezzerides and Bestgen 2002).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Decrease. Flannelmouth sucker are capable of long distance movements as far as 229 kilometers (Weiss 1993).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral/Somewhat Increase. Flannelmouth sucker occupy warm and cool water reaches of most main stem rivers and large tributaries in all the Colorado River Basin systems in Colorado including those in the San Juan, Dolores, Gunnison, Colorado, White, Yampa (including the Little Snake River), and Green River basins (Bestgen and Zelasko 2004; Colorado Parks and Wildlife 2015).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. High base flows are important for the reproduction success of flannelmouth sucker, as well as bluehead and razorback suckers (Anderson and Stewart 2007). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Ray et al. 2008). Reduced base flows may be associated with increases in the non-native white sucker (*C. commersonii*) populations. Hybridization of flannelmouth sucker and white sucker is a very serious threat to flannelmouth sucker in the Colorado River Basin (Anderson and Stewart 2007).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. This species evolved in the Colorado River Basin and is adapted to high spring runoff (Rees et al. 2005). Spring flows for the Colorado River are projected to peak earlier and be higher in 2035-2064 (Lukas et al. 2014).

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Neutral/Somewhat Increase. Females spawn over gravel (CPW 2014). Hydrologic processes that help create and maintain gravel bars may be altered duet to projected decreases in flows in the Colorado River Basin (Lukas et al. 2014; Ray et al. 2008).

**C4a) Dependence on other species to generate habitat.** Unknown**.**

**C4b) Dietary versatility.** Neutral.

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Increase. Although the species is widespread throughout the Colorado River Basin, a recent study found very low levels of genetic diversity basin-wide (Douglas and Douglas 2003). Furthermore, hybrids between nonnative white sucker (*Catostomus commersoni*) and flannelmouth sucker have been documented in the Colorado, Gunnison, and Yampa rivers (Anderson and Stewart 2007; Douglas and Douglas 2003; Shiozawa et al. 2003). Hybridization between the non-native white sucker and the native bluehead sucker has also been documented, as well as individuals with genetic contributions from the white sucker, bluehead sucker, and native flannelmouth sucker (*Catostomus latipinnus*) (McDonald et al. 2008). The non-native white sucker has facilitated introgression between two native species, and therefore threatens the genetic integrity of the bluehead and flannelmouth suckers. White suckers have become pervasive throughout the Colorado River Basin, hybridizing readily with flannelmouth suckers, thus creating a serious extinction risk to flannelmouth suckers (McDonald et al. 2008).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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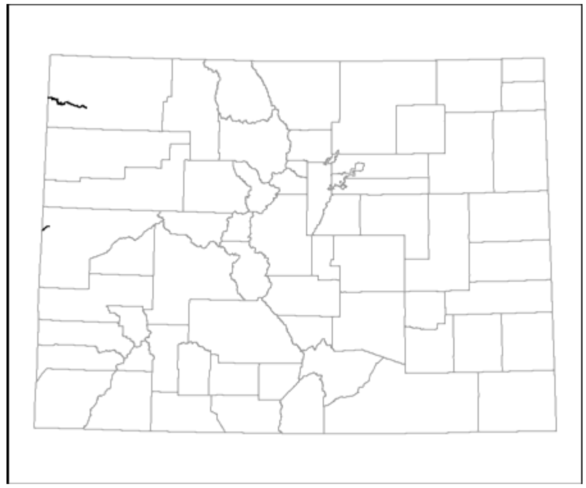
## Humpback Chub

***Gila cypha***
**G1/S1**
**Listed Endangered**
**Family: Cyprinidae**

No photo available



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) reliance on gravel bars for spawning; 4) lack of genetic variation.

**Distribution*:*** Only two humpback chub populations still exist in Colorado: the Yampa Canyon population on the Yampa River and the Black Rocks population on the Colorado River (U.S. Fish and Wildlife Service 2002). The distribution map above shows critical habitat as designated by the USFWS (2003). **Habitat:** In Colorado, adult humpback chub reside in swift, turbulent habitats and in deep pools in canyons (Kaeding et al. 1990; Lee et al. 1981). They are also found in whitewater in deep eddies (Minckley 1991). Juveniles are generally found in more shallow areas; young of the year have been documented in shallow areas near shore with slow currents and fine cobbles and boulders (Gorman and Seales 1995).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral/Somewhat Increase. Rapids and waterfalls may create natural barriers in the Colorado, Yampa, and Green rivers.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Dams and diversions in the Colorado River and its tributaries create barriers to humpback chub movement, and cause changes in channel geomorphology, sediment regimes, and streamflows (U.S. Fish and Wildlife Service 2011).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Neutral/Somewhat Decrease. Although many big river fish from the Colorado River Basin travel long distances, the humpback chub has been reported to have relatively limited movement (Paukert et al. 2006). The average spawning distances for humpback chub in the Black Rocks area of the Colorado River has been reported as 6.4 km (Valdez and Ryel 1995).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral/Somewhat Increase. The humpback chub is adapted to the large, warm-water rivers and streams of the Colorado River Basin. Humpback chub grow relatively quickly in warm water temperatures, and colder temperatures such as those caused by hypolimnetic dam releases have been shown to significantly lower growth rates (Clarkson and Childs 2000). Warmer water temperatures caused by projected increases in temperature may help increase recruitment rates in humpback chub populations.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Maintenance of streamflow is important for the recovery and conservation of bonytail chub (U.S. Fish and Wildlife Service 2011). Flow recommendations have been developed for humpback chub in the Green River (Muth et al. 2000), Yampa River (Modde et al. 1999), and upper Colorado River (McAda 2003). However, there may be less water available in future to provide these flows. Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Jay et al. 2008).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. High spring flows that create and clean gravel bars, as well as temporarily reduce non-native fish populations, are positively associated with reproduction of humpback chub in the Lower Colorado River (Gorman 1994).

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Humpback chub are associated with clean gravel bars for spawning (Gorman 1994; U.S. Fish and Wildlife Service 2002).

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. Humpback chub feed on small fishes, diatoms, planktonic crustaceans, algae, and aquatic and terrestrial arthropods (U.S. Fish and Wildlife Service 2002; Valdez and Ryel 1995).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Somewhat Increase. Genetic diversity has been identified as an issue for the humpback chub. Recent genetic studies have attempted to unravel genetic differences between roundtail chub and humpback chub. Results indicate that across its range, humpback chub and roundtail chub occupy six distinct management units (Douglas and Douglas 2007).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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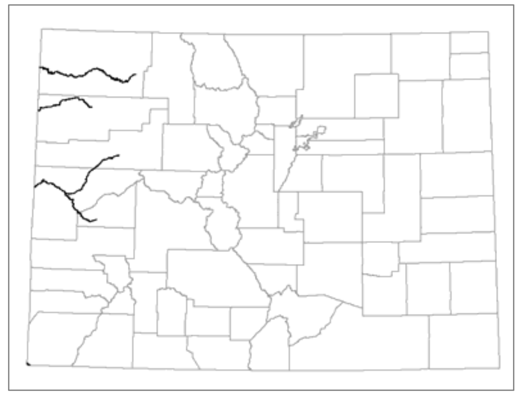
## Razorback Sucker

***Xyrauchen texanus***
**G1/S1**
**Listed Endangered**
**Family: Catostomidae**

Photo: James E. Johnson, U.S. Fish & Wildlife Service



## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) lack of variation in precipitation across occupied habitat in last 50 years; 4) requires clean cobble bars for spawning.

**Distribution***:* Razorback sucker are found only in the upper Green River in Utah, and the lower Yampa River in Colorado, and occasionally in the Colorado River near Grand Junction (U.S. Fish and Wildlife Service 2002). **Habitat:** Adult razorback sucker occupy deep runs, eddies, and flooded backwater habitats in the springs; summer habitat is typically low-velocity runs, pools, and eddies (USFWS 2002). Spawning occurs in cobble, gravels, and sand (USFWS 2002). Young razorback suckers are typically found in quiet, warm, shallow backwaters (USFWS 2002).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2) Distribution relative to barriers.** Razorback sucker occur in the mainstem of the Colorado River as well as its major tributaries (U.S. Fish and Wildlife Service 1998).

**B2a) Distribution relative to natural barriers.** Neutral/Somewhat Increase. Natural physical barriers to movement in the Colorado River and its tributaries are natural rapids and swift turbulent flows, and these are likely to fluctuate depending on flows (U.S. Fish and Wildlife Service 2002).

**B2b) Distribution relative to anthropogenic barriers.** Increase. The decline of the species throughout the Colorado River Basin is attributed largely to extensive habitat loss, modification, and fragmentation, and blocked fish passage from dam construction and operations (U.S. Fish and Wildlife 2012).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Decrease. Razorback sucker are capable of traveling long distances. Spawning migrations of 30 to 106 km (one way) have been reported in the Yampa River in Dinosaur National Monument (Tyus 1987; Tyus and Karp 1990).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Razorback sucker is a warm-water fish, and the availability of warm, productive wetlands may promote faster growth and higher survival of larvae (Bestgen 2008).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower than average (11 - 20 inches/255 - 508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase**.** High spring flows have been reported to be important to adults for feeding, temperature regulation, and spawning (Tyus and Karp 1990). Spawning movements and the appearance of ripe fish were associated with increasing spring flows and average water temperatures of 14°C (range 9-17°C or 48-63°F) (Tyus and Karp 1990). There may be less water available in future to provide these flows. Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Ray et al. 2008).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase/Somewhat Increase. Adult razorback suckers spawn over clean cobble bars during spring runoff, and their larvae flow into floodplain habitats inundated during the spring floods (McAda and Wydoski 1980; U.S. Fish and Wildlife Service 2002; Wick et al. 1982). The dam-related changes in timing and flow levels on the Colorado River and its tributaries, along with channelization, have led to a loss of floodplain nurseries that are necessary for the survival and reproduction of the razorback sucker (McAda and Wydoski 1980). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Ray et al. 2008), which could lead to further loss and degradation of habitat for razorback suckers.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase**. See C2c.** Adult razorback suckers spawn over clean cobble bars during spring runoff, and their larvae flow into floodplain habitats inundated during the spring floods (McAda and Wydoski 1980; U.S. Fish and Wildlife Service 2002; Wick et al. 1982).

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. The diet of the razorback sucker varies by life stage, and includes insects, zooplankton, phytoplankton, algae, and detritus (Bestgen 1990; Muth et al. 2000).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Neutral**.** Genetic diversity has been reported as high for the razorback sucker (Dowling et al. 1996; Dowling et al. 2005).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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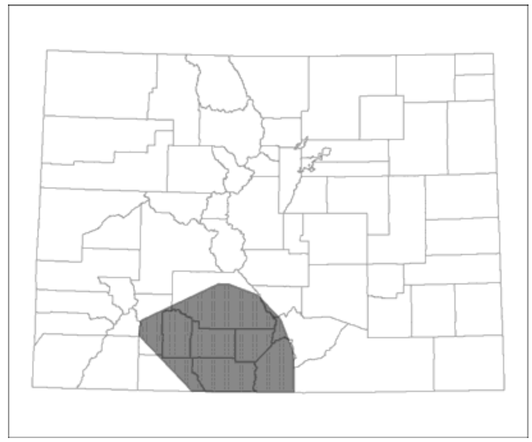
## Rio Grande Cutthroat Trout

***Oncorhynchus clarkii virginalis***
**G4T3/S3**
**Family: Salmonidae**

No photo available



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential dewatering of streams in the Rio Grande River Basin; 3) lack of genetic diversity.

**Distribution:** In Colorado, the Rio Grande cutthroat trout occurs in the Rio Grande River Basin.
**Habitat:** Rio Grande cutthroat trout occur in clear, cold, high elevation streams. Adults use deep pools, while fry use backwaters and side channels (USFWS 2014).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. In some headwater streams, waterfalls, cascades, bedrock chutes, or subterranean reaches may present natural barriers that block movement of Rio Grande cutthroat trout (Pritchard et al. 2008).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Dams and diversions in occupied Rio Grande cutthroat trout habitat can block dispersal of populations, increasing the risk of extinction (Zeigler et al. 2012). However, the effects of constructed barriers are complex. They also provide a barrier to the movement of non-native fish species that compete with and prey on Rio Grande cutthroat trout (Pritchard and Cowley 2006).

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1) Dispersal and movements.** Somewhat Decrease. No data exists on average movement capabilities for Rio Grande cutthroat trout (Pritchard and Cowley 2006). Cutthroat trout on Colorado's west slope were found to move a median distance of 91m-1.2 km during the summer (Schmetterling and Adams 2004).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Greatly Increase. Drought and increased stream temperatures have been identified as a major threat to Rio Grande cutthroat trout (Haak et al. 2010). Droughts in the southwestern United States are expected to increase in frequency and severity (Hoerling and Eischeid 2007). This could result in stream dewatering and a decrease in available habitat (U.S. Fish and Wildlife Service 2014; Zeigler et al. 2012). Average annual air temperature has increased across the range of Rio Grande cutthroat trout since the mid-20th century, and this trend could result in elevated stream temperatures that are unsuitable for Rio Grande cutthroat trout that rely on coldwater habitat to complete their life cycle (U.S. Fish and Wildlife Service 2014; Williams et al. 2009; Ziegler et al. 2012).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. Reduced streamflow has already been observed throughout the range of Rio Grande cutthroat trout (Zeigler et al. 2012). Recent climate models predict decreases in annual streamflow in the Rio Grande Basin (Lukas et al. 2014). Stream drying reduces available habitat for all life stages of Rio Grande cutthroat trout (see matrix in USFWS 2014).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. Rio Grande cutthroat trout are located in headwater streams. They spawn following peak runoff levels from snowmelt (Behnke 2002; Pritchard and Cowley 2006). Climate change has shifted peak runoff from snowmelt approximately 10 days earlier than 45 years ago (Zeigler et al. 2012). Earlier runoff could pose benefits and threats to Rio Grande cutthroat trout. Young-of-year would benefit from a longer growing season, but a long season of low flows could lead to increased stream temperatures and stream intermittency outside of the tolerance range for the species (USFWS 2014).

**C2d) Dependence on snow-covered habitats.** Neutral. As noted above in C2c, Rio Grande cutthroat trout are located in headwater streams. They spawn following peak runoff levels from snowmelt (Behnke 2002; Pritchard and Cowley 2006).

**C3) Restriction to uncommon geological features or derivatives.** Neutral/Somewhat Increase. Sediment-free gravels and cobbles are necessary for producing aquatic insects for food and create spawning habitats (USFWS 2014).

**C4a) Dependence on other species to generate habitat.** Unknown.

**C4b) Dietary versatility.** Neutral. Studies of Colorado River and Rio Grande cutthroat trout indicate that midge larvae, caddisflies, and mayflies, as well as a range of other benthic prey items comprise the main diet of these native trout species (Bozek et al. 1994; Pritchard and Cowley 2006; Moore and Gregory 1988; Young et al. 1997).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral.

**C5a) Measured genetic variation.** Increase. Genetic diversity is a conservation concern for this species that has experienced precipitous declines in the last century. Recent studies have shown that there are two "evolutionary significant units" of Rio Grande cutthroat trout: one in the Rio Grande Basin, and one in the Pecos and Canadian basins (Pritchard et al. 2009).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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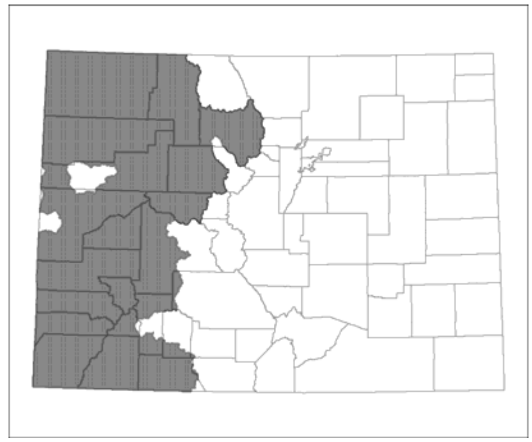
## Roundtail Chub

***Gila robusta***
**G3/S2**
**Family: Cyprinidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential decline in runoff and subsequent decrease in flows in the Upper Colorado River Basin; 3) potential shift in timing of spawning that could lead to lower recruitment; 4) lack of genetic diversity.

**Distribution:** In Colorado, the roundtail chub is found on the Western Slope in the Upper Colorado River Basin. The map above is based on information provided in the Colorado Parks and Wildlife (2015) conservation assessment plan draft. **Habitat:** Roundtail chub occupy mainstem and tributaries streams in the Upper Colorado River Basin. Adults use eddies and pools near areas with strong currents and boulders (CPW 2015); whiles juveniles are most frequently found in quiet, shallow backwaters (Brouder et al. 2000).

**Ecological System:** Streams

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase/Neutral. Adult roundtail chub occupy deep pools and runs in mainstem and smaller tributary system of the Colorado River Basin (Bestgen et al. 2011). Larvae prefer low velocity backwaters, young-of-the-year occupy shallow, low velocity habitats, and juveniles occupy pools (Bestgen et al. 2011). Rapids, swift turbulent flows, and waterfalls could create natural barriers to movement of roundtail chub during high flows, but these barriers are likely seasonal. High salinity levels in the Dolores River from Paradox Valley downstream to San Miguel could also pose as a natural barrier when concentrations are high during low flows (Bestgen et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Increase. The construction of dams along the mainstem of the Colorado River and its tributaries has fragmented and inundated riverine habitat; released cold, clear waters; altered ecological processes and sediment regimes; affected seasonal availability of habitat; and blocked fish passage (Marsh and Douglas 1997; Minckley and Deacon 1968; U.S. Fish and Wildlife Service 2002; Valdez and Ryel 1995). Roundtail chub declines are common in impoundments after reservoir construction (Bezzerides and Bestgen 2002). Wolford Mountain Reservoir hosts the only reservoir-dwelling population of roundtail chub in Colorado (Ewert 2010). Fish passageways have been created for the roundtail chub and other native fish at dam sites in the Colorado River near Palisade and on the Gunnison River (Landers 2012). The Green River Dam in Utah is slated for rehabilitation, and the final plans for renovation include a fish passageway to allow for the upstream and downstream movement of native fishes, including roundtail chub (U.S. Department of Agriculture 2014*).*

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral.

**C1*)* Dispersal and movements.** Neutral. Roundtail chub travel 5-80 km during spawning (Bestgen et al. 2011).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. The roundtail chub is adapted to the large, warm-water rivers and streams of the Colorado River Basin. Roundtail chub prefer stream temperatures that range from 18-20˚C (Bezzerides and Bestgen 2002). Dam releases have led to colder water temperatures in the Basin, and these are suggested as a reason for the overall decline in roundtail chub populations (Bestgen et al. 2011).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Decrease. Considering the range of mean annual precipitation across occupied cells, the species has experienced greater than average (> 40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Abundance of roundtail chub was positively correlated with moderate to high base flows in the Colorado River Basin (Anderson and Stewart 2007). However, there may be less water available in future to provide these flows. Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Jay et al. 2008).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Roundtail chub typically spawn in June to early July when water temperatures range from 16-22˚C (Colorado Parks and Wildlife 2015). Most published research indicates a decline in runoff in the Upper Colorado River Basin by the mid-to-late 21st century (Lukas et al. 2014; Jay et al. 2008). This could cause low flows in April and May, creating warmer water temperatures that could prematurely initiate spawning of roundtail chub, and subsequent cold high flows could kill eggs and larvae (Bestgen et al. 2011).

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Roundtail chub spawn over gravel in deep pools and runs (Bezzerides and Bestgen 2002; Brouder et al. 2000).

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. Roundtail chub feed on aquatic and terrestrial insects, fish, snails, algae, and occasionally lizards (Bestgen 2000; Brouder 2001; Colorado Parks and Wildlife 2015; Osmundson 1999; Sigler and Sigler 1996).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Somewhat Increase. The roundtail chub is very closely related to the humpback chub, and genetic diversity has been identified as a conservation issue for these two species (Clarkson et al. 2012; Douglas and Douglas 2007).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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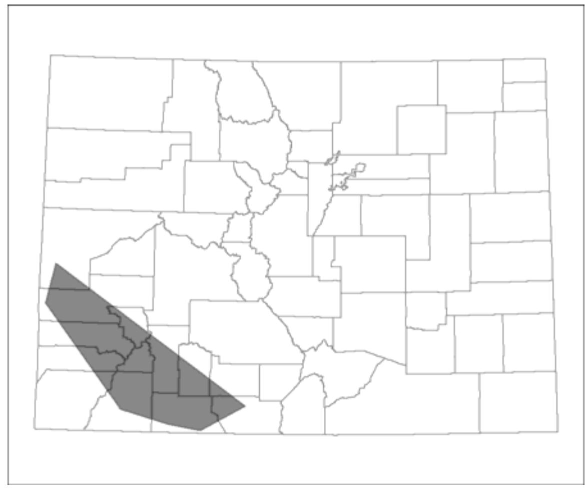
## Great Basin Silverspot

***Speyeria nokomis nokomis***
**G3T1/S1**
**Family: Nymphalidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state wide rank is based on: the projected increase in temperature and drought in the assessed area, the inability of the silverspot to disperse across dry landscapes, its dependence on wetland habitat within an arid landscape, the drying of its wetland habitat due to projected frequencies of drought, modifications to hydrology (e.g., water diversion projects, capping springs, and draining wetlands) to support the agriculture and livestock industries as the availability of water resources declines, limited precipitation variation the silverspot has historically experienced, the increased threat to suitable habitat from wildfire caused by drought and warming, dependence on a larval host plant that is restricted to wetlands, and low levels of genetic variability questioning the silverspots adaptability to a changing environment. Regional annual average temperatures are projected to rise by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014). Under a continuation of current rising emissions trends (A2), reduced winter and spring precipitation is consistently projected for the southern part of the Southwest by 2100 elevating the potential for wildfire (Melillo et al. 2014).

**Distribution:** In Colorado, colonies occur at only four previously known locations in La Plata, Mesa, Montrose, and Ouray counties (CNHP 2004). **Habitat:** The Nokomis fritillary is associated with the Upper Sonoran (pinyon-juniper, various shrubs) and Canadian (fir-spruce-tamarack, some pine, aspen-maple-birch-alder-hemlock) Life Zones of the southwestern United States and northern Mexico (Hammond 1974, Scott 1986, Selby 2007). Habitats are generally described as permanent spring-fed meadows, seeps, marshes, and boggy streamside meadows associated with flowing water in arid country (Hammond 1974, Scott 1986, Tilden and Smith 1986, Opler and Wright 1999, Brock and Kaufman 2003, Selby 2007).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Arid landscapes separating desert streams and wetlands are a severe barrier to this species. Great Basin silverspot butterflies do not migrate with documented routine dispersal distances of only up to 4 km (Fleischman et al. 2002). They require streamside meadows and seepage areas during their adult flight period and for their larval stage. In the arid Southwest, where this butterfly lives, these habitat conditions are widely separated and isolated (Selby 2007) and populations at one locale will not cross arid landscapes to distant colonies existing at other desert streams/wetlands.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Anthropogenic barriers are not thought to be a concern for this species because of the undeveloped desert landscapes this species inhabits.

**B3) Impact of land use changes resulting from human responses to climate change**. Increase. Modifications to hydrology (e.g., water diversion projects, capping springs, and draining wetlands) to support the agriculture and livestock industries are the greatest historic, current, and future threat to the long-term survival of the Great Basin silverspot butterfly in the assessed area. Increased water demand, combined with reduced availability due to climate change (Karl et al. 2009), will negatively impact this species.

**C1) Dispersal and movements.** Neutral. The Great basin silverspot has been documented to routinely disperse up to 4 km (2.5 miles), and in one study 26 percent of the recaptured butterflies had emigrated from their initial capture patch (Fleischman et al. 2002).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Great Basin silverspot in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat decrease. The Great Basin Silverspot has a preference for warmer environments and is associated with arid desert landscapes of the Upper Sonoran Life Zone (Selby 2007).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat decrease. Within the assessed area the Great Basin silverspot has experienced greater than average (>40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly increase. The Great basin silverspot is completely dependent upon widely separated isolated spots where there are permanent spring-fed meadows, seeps, marshes, and boggy streamside meadows associated with flowing water in the midst of otherwise arid country (Hovanitz 1970, Brock and Kaufman 2003). In the future, climate change is projected to increase drought frequency (Melillo et al. 2014, which may reduce these habitats within the assessed area.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Climate change is projected to increase wildfire frequency in the assessed area (Melillo 2014). Fire can cause direct mortality of larvae and eliminate required host plants. Given these factors, it should be assumed that extensive (e.g., burning all or most of the habitat in an area at one time) or frequent (e.g., every one to two years) fires are likely to negatively affect butterfly populations (Selby 2007). Alternatively, low severity and infrequent (every 5 years) fire can maintain the complex of wet meadows, willows, and other woody wetland species that provides optimal microclimates for the larval foodplant (bog violet) and adult nectar plants the Great Basin silverspot butterfly needs.

**C2d) Dependence on snow-covered habitats.** Neutral. The Great Basin silverspot is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. The Great Basin silverspot is not dependent upon any uncommon geological elements.

**C4a) Dependence on other species to generate habitat.** Increase. The Great Basin silverspot is dependent on the presence of an adequate supply of the larval foodplant (i.e., bog violet [*Viola nephrophylla])* (NatureServe 2014). Microhabitat conditions for the bog violet include soggy soil and shade, often under shrubs such as willows (Baird 1942). Willows are usually present (Hammond 1974) and probably help to create the microclimate that the violets need. Climate change is projected to increase drought frequency within the assessed area (Melillo et al. 2014), reducing the water available for sustaining the plant communities the bog violet depends upon.

**C4b) Dietary versatility.** Bog violet (*Viola nephrophylla*) is the exclusive larval food plant. Adults feed on nectar from a wide range of flowering alpine plants (Opler and Wright 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Great Basin fritillary is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Great Basin fritillary.

**C5a) Measured genetic variation.** Increase. Colonies of Nokomis fritillary subspecies tend to be small, local, restricted to a relatively narrow elevation range, and susceptible to occasional severe population declines; consequently, low levels of heterozygosity are not unexpected. Genetic research on the Great Basin silverspot indicates that there is very little genetic variation in these populations (Selby 2007).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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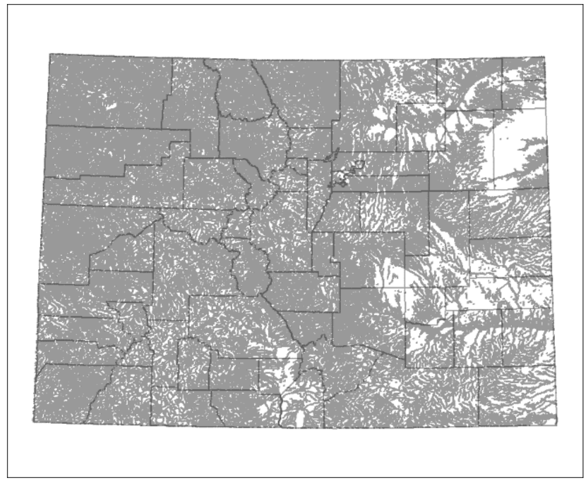
## American Beaver

***Castor canadensis***
**G5/S4**
**Family: Castoridae**



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on: the limited thermal niche for *C. canadensis*; *C. canadensis'* reliance on aquatic environments; and *C. canadensis'* susceptibility to varying water availability.

**Distribution:** *C. canadensis* is found in nearly all waterways in Colorado. **Habitat:** *C. canadensis* lives and feeds in and around waterways of Colorado, but are most abundant in areas with aspen, cottonwood, or willow especially in broad glacial valleys with low stream gradients (Armstrong et al. 2011). **Elevation:** 3,300 – 11,000 feet.

**Ecological System:** Waterways and adjacent riparian forests

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. There are few natural barriers for beavers.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Because beavers are adept at colonizing waterbodies and are ubiquitous in North America, there are few anthropogenic barriers.

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. There is not climate-change mitigating energy development that will limit beaver success.

**C1) Dispersal and movements.** Somewhat Decrease. Females typically disperse further than males (10 km vs. 3 km) (Sun et al. 2000). Juveniles in different systems may dispersal less (2 – 5 km) (McNew and Woolf 2005). Dispersal distances for transplanted beaver can be much higher (Boyle and Owens 2007), but natural dispersal is typically less than 10 km (Van Deelen and Pletscher 1986, Sun et al. 2000).

**C2ai) Predicted sensitivity to temperature: historical thermal niche**. Neutral**.** Much of the beaver range in Colorado falls within the 55-77°F range.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche**. Increase Vulnerability. Thermoneutral zone for beavers is between 32-82°F (MacArthur 1989) and the species spends most of its time in water where thermoregulation in cool aquatic environments can be physiologically challenging (MacArthur and Dyck 1990). However, beavers are tied to aquatic environments that may become more scarce and warming and drying continue.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat Increase Vulnerability. Based on the Climate Wizard map of historic hydrologic variation, much of the range in Colorado varies from the lowest variation to mid-levels of variability.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche**. Greatly Increase vulnerability. Beavers are 100% reliant on aquatic environments for subsistence, and it is likely as climate dries and warms the distribution (and beaver abundance) will be reduced.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase Vulnerability. Beavers do not rely on a particular disturbance regime and do not need an absence of disturbance. The most regular non-essential disturbance is water availability. Populations of beaver on low-flow streams will likely be the most disturbed by alternations in hydrology (Boyle and Owens 2007). Beavers and their habitat can be challenged by the absence of water (drought) or an abundance of water (flooding), but can modify their environment to limit the impact of these stressors. Climate change is likely to increase the frequency of drought and this may limit beaver distribution and numbers.

**C2d) Dependence on snow-covered habitats.** Neutral. There is no known relationship of this species to snow or ice-covered habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. This species is not known to specialize on uncommon geological features.

**C4a) Dependence on other species to generate habitat.** Neutral. Beavers generate their own habitat via dam building.

**C4b) Dietary versatility**. Neutral. Beavers are generalist herbivores feeding on inner bark, twigs, leaves, and buds of deciduous woody plants, and herbaceous and aquatic plants (Boyle and Owens 2007).

**C5a) Measured genetic variation**. Unknown. No data are available for genetic variability within North American beavers.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** only if 5A is unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown. No data available.

**D1) Response to recent climate change**. Unknown. No data available.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Neutral. Very few river miles are considered protected, but wetlands and waterways receive legal protection through Clean Water Act and other legislation.

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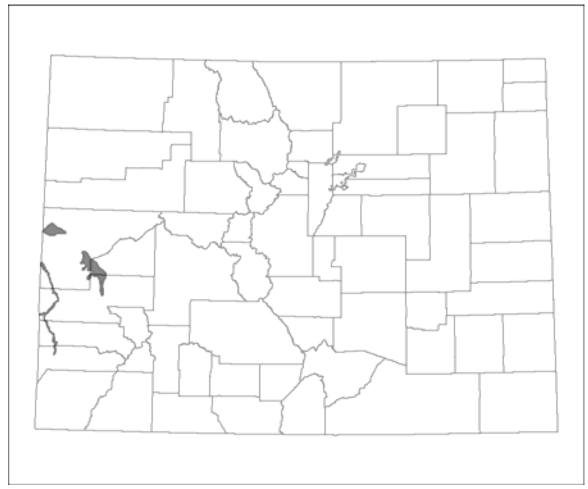
## Desert Bighorn Sheep

***Ovis canadensis nelsoni***
**G4/S4**
**Family: Bovidae**

No photo available



## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state-wide rank is based on: transportation corridors that can limit *O. canadensis nelsoni* dispersal; likely increase in drought conditions through its range; genetic bottlenecks; and modeled impacts from climate change. Despite these threats, *O. canadensis nelsoni* are well adapted to drought conditions, have broad ranges that may allow some populations to migrate away from inhospitable habitats and conditions, and have shown flexibility in timing of parturition that may better match periods of heightened resource availability.

**Distribution***:* *O. canadensis nelsoni* are found in western Colorado in a few specific populations near the Utah border. **Habitat:** can be found in a variety of habitats, but prefer areas with high-visibility with grass, low shrubs, much rock cover and topographic relief, and with abundant open areas for escape. **Elevation:** Varies, but typically less than 10,000 feet.

**Ecological System:** Cliffs, grasslands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. There is some desert bighorn sheep habitat north of current reintroduction sites (Black Ridge, Uncompahgre, and Dolores River populations), but it is separated by lower elevation valleys. Given bighorn sheep ability to utilize lower elevation habitats (Krausman and Bowyer 2003), populations have the potential to migrate north as climates change.

**B2b) Distribution relative to anthropogenic barriers.** Increase Vulnerability. Urban, suburban, and transportation development border bighorn sheep populations to the north. These may be minimally restrictive in some areas, but major transportation corridors can prohibit movement and restrict gene flow (Epps et al. 2005). Additionally, because hunted bighorn sheep show a greater response to human disturbance (Geist 1971, King and Workman 1986) this development pressure and the human populations in proximity to it may further prohibit migration. Because it is unclear if the potential isolation and sheep behavior are identical to those documented in California populations, this is considered "increase vulnerability" instead of "greatly increase vulnerability".

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Neither solar, wind, or biomass energy production appear to be high-reward targets for this region of western Colorado based on National Renewal Energy maps (apps1.eere.energy.gov/states/maps.cfm/state=CO).

**C1) Dispersal and movements.** Decrease Vulnerability. Bighorn sheep can move up to 70 km between seasonal ranges (Beecham et al. 2007).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Much of the desert bighorn range in Colorado falls within the 55-77°F range.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Decrease Vulnerability. Hotter temperatures do not appear to challenge bighorn physiology (Turner 1973).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase Vulnerability. Based on the Climate Wizard map of historic hydrologic variation, much of the desert bighorn sheep range in Colorado varies from the lowest variation to mid-levels of variability.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral to Somewhat Decrease. Desert bighorn sheep are well adapted to heat and drought stress, even able to concentrate urine better than camels (Turner 1973).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Desert bighorn sheep are occasionally exposed to and adapted to drought conditions. However, the recent trends in warming and drought may be impacting viability. Prolonged drought can cause increased sheep mortality (Monson 1960), impact recruitment (Wehausen et al. 1987), and contribute to decreased population viability (Weaver and Mensch 1971). Climate data suggest that drought will possibly increase in frequency, intensity and duration. Disease is a common factor causing periodic desert bighorn decline (Singer et al. 2001).

**C2d) Dependence on snow-covered habitats.** Neutral**.** There is no known relationship of this species to snow or ice-covered habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. This species is not known to specialize on uncommon geological features.

**C4a) Dependence on other species to generate habitat**. Neutral. No reliance on other species for habitat generation.

**C4b) Dietary versatility.** Neutral**.** Desert bighorn sheep are herbivorous, feeding largely on grasses and forbs, supplementing this diet with some shrubs (Armstrong et al. 2011).

**C5a) Measured genetic variation.** Neutral. Genetic diversity of desert bighorn populations is relatively high in some populations (Gutierrez-Espeleta et al. 2000) while low in others (Hedrick and Wehausen 2014).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Somewhat Increase Vulnerability to Neutral. Population isolation and reintroduction efforts with small populations have created genetic bottlenecks in some regions (Ramey et al. 2001, Hedrick et al. 2001).

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Somewhat Decrease Vulnerability to Neutral. Desert bighorn sheep have shown site-specific variability in parturition that allows flexibility to capitalizing on available resources, but this may come with fitness consequences for newly reintroduced populations (Whiting et al. 2011)

**D1) Response to recent climate change.** Neutral. Nothing reported.

**D2) Modeled future change in population or range size.** Somewhat Increase Vulnerability. Epps et al. (2004) modeled the potential of future population decline over the next 60 years. With minimum temperature change scenarios average extinction probability of populations was 20%. When combined with the projected decline in precipitation the probability increased to 30%.

**D3) Overlap of modeled future range with current range.** Unknown**.** Nothing documented.

**D4) Protected areas.** Somewhat Increase Vulnerability. Within the current range there are few protected areas that would protect populations.

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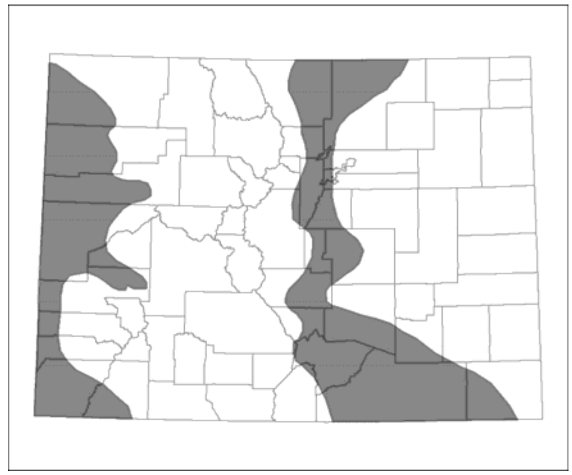
## Fringed Myotis

***Myotis thysanodes***
**G4/S3**
**Family: Vespertilionidae**

## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on the following factors: 1) few to no barriers to movement; 2) association with caves and mines as geologic features may be increase vulnerability under projected increases in temperature due to climate change, however this species is not found exclusively in caves and mines.

**Distribution***:* In Colorado, The fringed myotis this species has been found sparingly on both the eastern and western sides of the Continental Divide (Armstrong et al. 2011). H**abitat:** In Colorado, the fringed myotis is found in coniferous woodlands and shrublands such as ponderosa pine, greasewood, oakbrush, and saltbrush (Armstrong et al. 2011). **Elevation:** This species has been recorded up to 7,500 feet in Colorado (Armstrong et al. 2011).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Volant – no barriers

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Volant – no barriers

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. It is unlikely that any climate mitigation-related land use changes will occur within this species' range within Colorado.

**C1) Dispersal and movements.** Decrease. Long-distance dispersal abilities.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat increase. Adams and Hayes (2008) postulated that the impact of reduced water storage capacity as a result of climate change in the arid western United States would negatively impact lactating females of this species, especially at a local scale.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. This bat is found in caves and mines, but in Colorado is not restricted to these features.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. This species feeds broadly on moths, beetles, and other flying insects (Keinath 2004; Armstrong et al. 2011).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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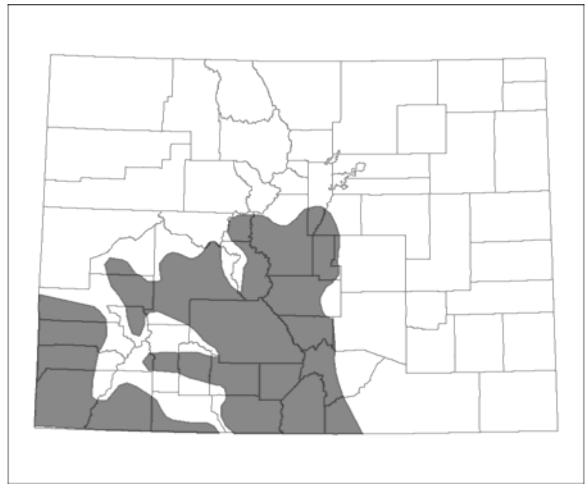
http://www.fs.fed.us/r2/projects/scp/assessments/townsendsbigearedbat.pdf

## Gunnison Prairie Dog

***Cynomys gunnisoni***
**G5/S5**
**Family: Sciuridae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

Despite *C. gunnisoni* being ranked as Stable, the factors that would lead it to be more vulnerable are: predicted decreases in precipitation; habitat loss; prairie dog susceptibility to plague: and limited genetic variability. Currently, none of the ranking factors consider the threats high enough that *C. gunnisoni* would be in imminent threat from on-going climate change. The species ability to disperse and its lack of reliance of mesic habitats buffer it from climate change threats.

**Distribution***:* *C. gunnisoni* is found in southwestern and south-central Colorado in grasslands, and semi-desert and montane shrublands (Armstrong et al. 2011). **Habitat:** *C. gunnisoni* are habitat architects, modifying the soil and vegetative characteristics around colonies. They inhabit shortgrass and mid-grass prairies, shrublands in low valleys, and wetter, high-elevation prairies. **Elevation:** 6000-12000 feet.

**Ecological System:** Grasslands, Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise - Neutral.**

**B2a) Distribution relative to natural barriers.** Neutral to Somewhat Increase Vulnerability. There are various low passes in and out of prairie dog range in Colorado that will not prevent the Gunnison Prairie dog from emigrating, but may limit dispersal if subjected to climate-caused shifts. Populations are known to have occurred as high as ~12,000' elevation in Colorado (Armstrong et al. 2011). However, the USFWS (2010) pointed out that numerous parts of the range are separated by mountain ranges that almost completely limit prairie dog movement between them.

**B2b) Distribution relative to anthropogenic barriers.** Neutral**.** Much of the prairie dog range in Colorado is on public land. Future planning scenarios for South Park suggest increased suburban and infrastructure development that may limit dispersal capacity for populations in this region. Much of the range is not hindered by anthropogenic disturbance to greatly limit rangewide climate-caused dispersal.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral to Somewhat Increase Vulnerability. Wind-energy development is increasing in Colorado. Along the eastern edges of the Gunnison and San Luis valleys wind speeds are attractive and may target wind-energy development in this area of the prairie dogs range. Similarly, solar energy may be targeted for the San Luis Valley where solar exposure is promising (Natural Resources Energy Laboratory, Concentrating Solar Power Energy map for Colorado, 2007 and Global Solar Radiation at Latitude Tilt map for Colorado, 2007). It is unclear how this species responds to energy development, but it is likely such development would further segment populations.

**C1) Dispersal and movements.** Somewhat Decrease. The movements and dispersal are poorly studied in this species. However, in other species of prairie dogs movements are known to be around 2-8 km (Garrett and Franklin 1988; Knowles 1985). Seglund and Schnurr (2010) reported dispersal distances as long as 7.7 km.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Based on ClimateWizard.org Past Exposure Temperature Variation, much of Gunnison's prairie dog range in Colorado is from 55-77°F.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral to Somewhat Increase Vulnerability. Because this species of prairie dog is an obligate hibernator (Shalaway and Slobodchikoff 1988) its overwinter survival can be challenged if overwinter thermal conditions do not maintain long, stable periods of cold temperatures (Arnold et al. 1991, Schorr et al. 2009). Thus, if thermal conditions are not appropriate for hibernation, survival may be depressed.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase. Based on ClimateWizard.org Average Annual Precipitation 1951-2006, much of Gunnison's prairie dog range in Colorado is middle-to-low precipitation variation.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral to Somewhat Decrease. Gunnison's prairie dogs inhabit grasslands and semidesert and montane shrublands (Armstrong et al. 2011). Vegetation conditions of many lands within the range of Gunnison's prairie dog have been altered through grazing (Fleischner 1994). The prairie dogs are possibly more susceptible to stress from drought where native vegetation has been severely altered (Seglund and Schnurr 2010). Most vegetation within used habitat has some level of tolerance to arid conditions and may not be dramatically impacted by increased drying predicted by climate modeling.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase to Increase**.** The most dramatic and recurring disturbance that can impact Gunnison's prairie dogs is plague (Cully et al. 1997). Gunnison's prairie dogs are occasionally exposed to drought conditions. These conditions cause stress and even population reduction/local extirpation in the black-tailed prairie dog (Facka et al. 2010). Climate data suggest that drought will possibly increase in frequency, intensity and duration.

**C2d) Dependence on snow-covered habitats.** Neutral**.** There is no known relationship of this species to snow or ice-covered habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral**.** This species is not known to specialize on uncommon geological features.

**C4a) Dependence on other species to generate habitat**. Neutral**.** Generates and modifies its own habitat by burrowing and grazing.

**C4b) Dietary versatility.** Neutral**.** Gunnison's prairie dog is an herbivore, feeding largely on grasses and forbs, supplementing this diet with some shrubs (Fitzgerald and Lechleitner 1974; Longhurst 1944).

**C5a) Measured genetic variation.** Neutral to Somewhat Increase Vulnerability. Genetic diversity in this species was determined to be low (Travis et al. 1997).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** only if 5A is unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral. No observations made.

**D1) Response to recent climate change.** Neutral**.** Nothing reported.

**D2) Modeled future change in population or range size.** Unknown**.**

**D3) Overlap of modeled future range with current range.** Unknown**.**

**D4) Protected areas.** Neutral**.**

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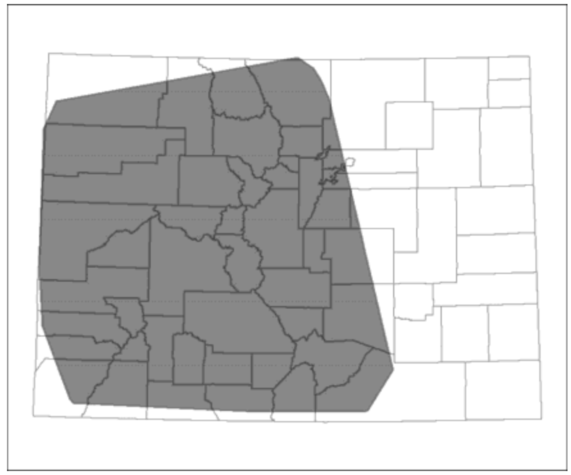
## Townsend’s Big-eared Bat

***Corynorhinus townsendii pallescens***
**G3G4T3T4/S2**
**Family: Vespertilionidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on the following factors: 1) few to no barriers to movement; 2) association with caves and mines as geologic features may be increase vulnerability under projected increases in temperature due to climate change.

**Distribution***:* In Colorado, Townsend’s big-eared bat occurs throughout the western two-thirds of the state, including the southeastern canyonlands (Armstrong et al. 2011). **Habitat:** In Colorado, Townsend’s big-eared bats occur in a wide range of habitats including semi-desert shrublands, pinyon-juniper woodlands, and dry coniferous forests (Armstrong et al. 2011). It is most often found roosting in caves and mines, but uses buildings, crevices, and cliff faces during the summer (Armstrong et al. 2011). **Elevation:** This species has been recorded up to 9,500 feet in Colorado (Armstrong et al. 2011).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Volant – no barriers

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Volant – no barriers

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. It is unlikely that any climate mitigation-related land use changes will occur within this species’ range within Colorado.

**C1) Dispersal and movements.** Decrease. Long-distance dispersal abilities.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Neutral.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral/Somewhat increase. Adams and Hayes (2008) postulated that the impact of reduced water storage capacity as a result of climate change in the arid western United States would negatively impact lactating females of *Myotis thysanodes*, especially at a local scale. This proposed impact could affect other species such as *Corynorhinus townsendii* as well.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on snow-covered habitats.** Neutral.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. This bat is a cave and mine obligate, but in Colorado is found in mines more frequently than caves.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4b) Dietary versatility.** Neutral. This species is a moth specialist, but will feed opportunistically on other flying insects (Gruver and Keinath 2006).

**C4c) Pollinator versatility (Plants only, not applicable).**

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Unknown.

**C5a) Measured genetic variation.** Neutral to Somewhat Decrease. In an analysis of genetic diversity among subspecies of *C. townsendii*, Piaggio et al. (2009) found that *C. t. pallescens* had a level of diversity similar to *C. t. townsendii* and both of these subspecies had a greater level of diversity than the endangered *C. t. virginianus* as measured by the average number of alleles per locus and average allelic richness per population.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Unknown.

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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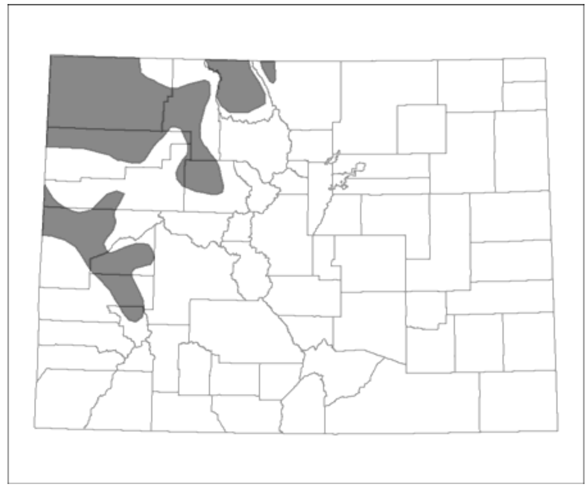
## White-tailed Prairie Dog

***Cynomys leucurus***
**G4/S4**
**Family: Sciuridae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

Similar to *C. gunnisoni*, *C. leucurus* is considered Stable, but the factors that would lead it to be more vulnerable are: predicted decreases in precipitation; necessity for cold environs for hibernation; habitat loss; prairie dog susceptibility to plague: and limited genetic variability. Currently, none of the ranking factors consider the threats high enough that *C. leucurus* would be in imminent threat from on-going climate change. The species ability to disperse and its lack of reliance of mesic habitats buffer it from climate change threats.

**Distribution***:* *C. leucurus* is found in northwest and west-central Colorado in semi-arid grasslands and shrublands, and mountain valleys (Armstrong et al. 2011). **Habitat:** *C. leucurus* are more often found in semidesert shrublands, but occasionally invading pastures and agricultural lands at lower elevations (Armstrong et al. 2011). **Elevation:** typically below 8,500 ft.

**Ecological System:** Grasslands, Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral**.**

**B2a) Distribution relative to natural barriers.** Neutral**.** There are no obvious natural barriers to white-tailed prairie dog movement in Colorado. Populations are known to have occurred as high as ~10,000' elevation in Colorado (Armstrong et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral**.** Much of the prairie dog range in Colorado is on public land and much of the range is not hindered by anthropogenic disturbance to greatly limit rangewide climate-caused dispersal.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral**.** Wind-energy development is increasing in Colorado. In northwestern Colorado wind speeds may be attractive for wind-energy development in this area of the prairie dogs range. However, it is unlikely that development will significantly impact by mitigation-related land use changes.

**C1) Dispersal and movements.** Somewhat Decrease. Maximum movement distances documented for white-tailed prairie dogs is 8 km (Cooke 1993, cited in Seglund et al. 2006), but most documented movements are less than this.

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral**.** Based on ClimateWizard.org Past Exposure Temperature Variation, much of white-tailed prairie dog range in Colorado is from 55-77°F.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral to Somewhat Increase Vulnerability. Because this species of prairie dog is an obligate hibernator (Harlow 1995) its overwinter survival can be challenged if overwinter thermal conditions do not maintain long, stable periods of cold temperatures (Arnold et al. 1991, Schorr et al. 2009). Thus, if thermal conditions are not appropriate for hibernation, survival may be depressed.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Somewhat Increase. Based on ClimateWizard.org Average Annual Precipitation 1951-2006, much of white-tailed prairie dog range in Colorado is middle-to-low precipitation variation.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** . Neutral to Somewhat Decrease. White-tailed prairie dogs inhabit arid grasslands and shrublands in Colorado (Armstrong et al. 2011). Most vegetation within used habitat has some level of tolerance to arid conditions and may not be dramatically impacted by increased drying predicted by climate modeling.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase to Increase. The most dramatic and recurring disturbance that can impact white-tailed prairie dogs is plague (Menkens and Anderson 1991). White-tailed prairie dogs are occasionally exposed to drought conditions. These conditions cause stress and even population reduction/local extirpation in the black-tailed prairie dog (Facka et al. 2010). Climate data suggest that drought will possibly increase in frequency, intensity and duration.

**C2d) Dependence on snow-covered habitats.** Neutral**.** There is no known relationship of this species to snow or ice-covered habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral**.** This species is not known to specialize on uncommon geological features.

**C4a) Dependence on other species to generate habitat**. Neutral. Generates and modifies its own habitat by burrowing and grazing.

**C4b) Dietary versatility.** Neutral. White-tailed prairie dogs largely feed on grasses and forbs, supplementing this diet with some shrubs (Armstrong et al. 2011).

**C5a) Measured genetic variation.** Neutral to Somewhat Increase Vulnerability. Genetic diversity in this species was determined to be low compare to black-tailed prairie dogs (Cooke 1993, cited in Seglund et al. 2006).

**C5b) Occurrence of bottlenecks in recent evolutionary history**. Only if 5A is unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown. No observations made.

**D1) Response to recent climate change.** Unknown**.** Nothing reported.

**D2) Modeled future change in population or range size.** Unknown**.**

**D3) Overlap of modeled future range with current range.** Unknown**.**

**D4) Protected areas.** Neutral**.**

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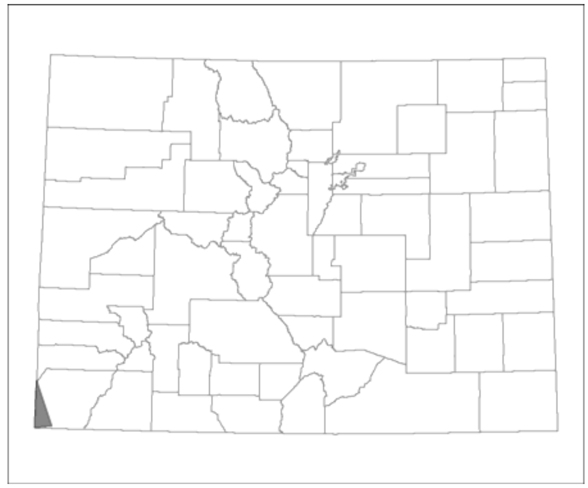
## Desert Spiny Lizard

***Sceloporus magister***
**G5/S2**
**Family: Phrynosomatidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state wide rank is based on: the Desert spiny lizards preference for warm temperatures coupled with the increasing temperatures projected under climate change, a thermoregulatory range of $27^0$ to $37^0$C (Brattstrom 1965) which should allow the lizard to cope with rising temperatures, the lizard's preference for arid and hot landscapes that are actually expected to increase in size within the assessed area due to increased drought and temperatures projected under climate change, and a 20 percent expansion in the range of the lizard in the assessed area as a result of climate change (Buckley 2010). Climate models project increased warming and drought across the assessed area with annual average temperatures rising by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014).

**Distribution:** In Colorado, this lizard occurs in the extreme southwestern corner of the State at elevations below 5,100 feet (Hammerson 1999). **Habitat:** The habitat in Colorado includes shrub-covered dirt banks and sparsely vegetated rocky areas near flowing streams and arroyos. They prefer soft soils beneath greasewood, rabbitbrush, salt cedar, and other shrubs and frequently perch on large rocks or in shrubs and trees (Hammerson 1999).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Large rivers and lakes act as effective barriers for this species as do other water obstructions such as ponds and marshes (NatureServe

2014), but smaller water obstacles would not impede large scale migratory movements like shifts in distribution due to a changing climate. However, there are no large rivers or water bodies within the assessment area that would prevent large scale movements of the Desert spiny lizard.

**B2b) Distribution relative to anthropogenic barriers**. Neutral. Busy highways, highways with obstructions, and urban areas can act as barriers to dispersal (NatureServe 2014), but in the assessment area there are no large, busy highways or large urban centers, rather there are few roads and small human populations.

**B3) Impact of land use changes resulting from human responses to climate change**. Neutral. Changes in land use associated with climate change are not considered a threat.

**C1) Dispersal and movements.** Neutral. Desert spiny lizard juveniles will disperse several 100 meters from their natal area before establishing a territory of their own (Tanner and Krogh 1973)

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Desert spiny lizard in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat decrease. The Desert spiny lizard prefers rather warm temperatures, attempting to thermoregulate such that it has a mean body temperature of about $35^0$C (range $27^0$ to $37^0$C) (Brattstrom 1965).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Increase. The range occupied by the Desert spiny lizard in the assessed area has experienced average (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral to somewhat decrease. The Desert spiny lizard is adapted to arid landscapes inhabiting areas receiving less than 30 centimeters of rain per year (Vitt and Ohmart 1974) and with the increased projections for drought due to climate change in the assessment area (Melillo et al. 2014), changing climate could even benefit the species.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The Desert spiny lizard is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on snow-covered habitats.** Neutral. The Desert spiny lizard is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase. Desert spiny lizards are restricted to sparsely vegetated rocky areas near flowing streams or arroyos within the assessment area (Hammerson 1999). Such areas, although not highly uncommon within the assessment area, are certainly not a dominant landscape type

**C4a) Dependence on other species to generate habitat.** Neutral. The Desert spiny lizard is not dependent on any other species to create suitable habitat for its existence.

**C4b) Dietary versatility.** Neutral. Desert spiny lizards are opportunistic predators with a flexible diet, feeding mainly on a variety of insects with some small lizards and plant material also taken (Hammerson 1999).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Desert spiny lizard is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Desert spiny lizard.

**C5a) Measured genetic variation.** Neutral. The genetic variation of the Desert spiny lizard is about average, when compared to related taxa (Wood et al. 2013).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Somewhat decrease. The predicted future range of the Desert spiny lizard is expected to increase within the assessment area by more than 20 percent (Buckley 2010).

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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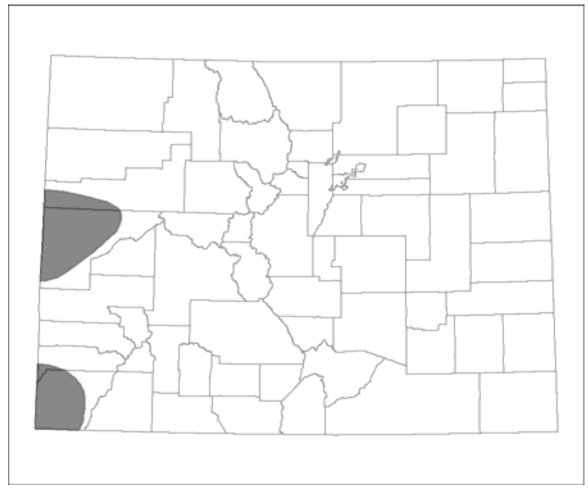
## Longnose Leopard Lizard

***Gambelia wislizenii***
**G5/S1**
**Family: Crotaphytidae**



## Climate Vulnerability Rank: Not Vulnerable/Presumed Stable

This Colorado state-wide rank is based on: *G. wislizenii* restricted to an area of Colorado that has seen little temperature and hydrologic variability and their susceptibility to habitat loss from encroaching weedy grasses. However, *G. wislizenii* is well-adapted to drought stress.

**Distribution***:* *G. wislizenii* is at the eastern limit of its range in western and southwestern Colorado. **Habitat:** *G. wislizenii* can be found in flat, arid and semiarid plains and canyonlands with various desert shrubs, including sagebrush, greasewood, saltbush, and junipers. **Elevation:** below 6,000 feet.

**Ecological System:** Xeric shrublands with much bare ground.

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase Vulnerability to Neutral. Areas of excessive grass cover can prohibit lizard use (Schorr et al. 2011), but it is unclear to what degree such expanses of grass exist around habitats in Colorado. However, some populations in western Colorado are bordered to the north by large rivers that may be unpassable.

**B2b) Distribution relative to anthropogenic barriers.** Neutral**.** There are few known human barriers to dispersal where lizards are found.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Neither solar, wind, or biomass energy production appear to be high-reward targets for this region of western Colorado based on National Renewal Energy maps (apps1.eere.energy.gov/states/maps.cfm/state=CO).

**C1) Dispersal and movements.** Neutral**.** Individuals can move up to 1.5 km (Parker and Pianka 1976, Schorr and Lambert 2010).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. Much of the desert bighorn range in Colorado falls within the 55-77°F range.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Decrease Vulnerability. Hotter temperatures do not appear to challenge lizard physiology. In Colorado, mean soil surface temperatures where lizards were found was 100°F (Schorr and Lambert 2010).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Increase Vulnerability**.** Based on the Climate Wizard map of historic hydrologic variation, much of the leopard lizard range in Colorado in in the lower variability range.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Neutral to Somewhat Decrease. Leopard lizards are adapted to heat and drought stress.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral to Somewhat Increase Vulnerability. Leopard lizards are not dependent on particular disturbance regimes. However, undisturbed habitats within their range appear to prevent expanse of invasive grasses (Westoby et al. 1989, Hammerson 1999).

**C2d) Dependence on snow-covered habitats.** Neutral**.** There is no known relationship of this species to snow or ice-covered habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral**.** This species is not known to specialize on uncommon geological features.

**C4a) Dependence on other species to generate habitat**. Neutral**.** This species does not rely on other species of habitat development.

**C4b) Dietary versatility.** Neutral**.** Leopard lizards feed on a variety of insects and some vertebrates (Hammerson 1999).

**C5a) Measured genetic variation.** Neutral**.** There are no data on the genetic variability of this species.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** only if 5A is unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Neutral**.** There are no data on seasonal dynamics.

**D1) Response to recent climate change.** Neutral**.** Nothing reported.

**D2) Modeled future change in population or range size.** Unknown**.**

**D3) Overlap of modeled future range with current range.** Unknown**.**

**D4) Protected areas.** Neutral**.** The southwestern Colorado populations exist within a national monument, while the central-western Colorado populations are within unprotected federal lands.

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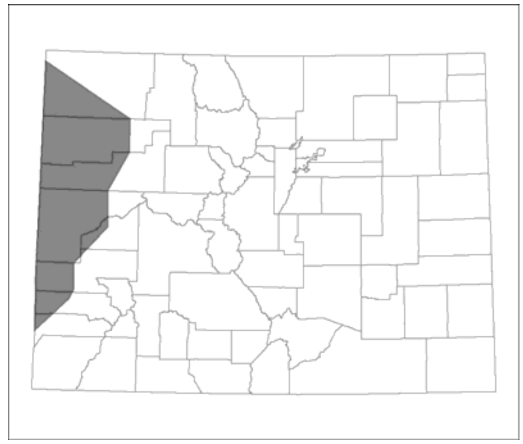
## Midget Faded Rattlesnake

***Crotalus oreganus concolor***
**G5T4/S3?**
**Family: Viperidae**

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state wide rank is based on: the Midget faded rattlesnakes reliance on rock outcrops suitable for denning and the narrow temperature ranges suitable for hibernating rattlesnakes at those dens, barriers to movement created by large rivers within the assessed area, fragmentation of the assessed area by both paved and unpaved roads that significantly impair movement, the low to moderate genetic variability of the snake lessening the adaptability of the snake to climate change, and the increase in temperatures projected for the assessed area due to climate change. Climate models project increased warming and drought across the assessed area with annual average temperatures rising by 2.5°F to 5.5°F by 2041-2070 and by 5.5°F to 9.5°F by 2070- 2099 with continued growth in global emissions (A2 emissions scenario), with the greatest increases in the summer and fall (Melillo et al. 2014).

**Distribution:** Colorado is at the eastern margin of the subspecies' range. In Colorado, it occurs in west central Colorado in Mesa, Delta, Garfield, Montrose, and San Miguel counties (CNHP 1998).
**Habitat:** Midget faded rattlesnakes occur in in a wide variety of terrestrial habitats including pinyon-juniper woodlands, plains grasslands, and desert and mountain shrublands. They tend to prefer arid to semi-arid sites and typically avoid wet sites. They will occupy sites with a wide range of soil types from sandy to rocky (Hammerson 1999).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase to neutral. Large, fast flowing rivers are a barrier to this rattlesnake, rivers like the Yampa, Colorado, and others that occur within the assessed area should be considered barriers (Reed and Douglas 2002). These rivers will impede distributional shifts in the assessment area, but will not greatly or completely impair distributional shifts caused by climate change. Busy highways, like Interstate 70 that bisects the distribution of the rattlesnake in the assessed area, also impede movements, but do not completely restrict movements (NatureServe 2014).

**B2b) Distribution relative to anthropogenic barriers.** Increase**.** Somewhat increase to neutral. Roads (both paved and unpaved) restrict fine-scale movement patterns of the Midget faded rattlesnake but not broad scale movements (Spear et al. 2011) and densely urbanized areas dominated by buildings and pavement are sufficient barriers to movement for the rattlesnake (NatureServe 2014). The only large city in the assessment area is Grand Junction and this single urban center should not significantly impede the rattlesnake's ability to shift its distribution within the area in response to climate change.

**B3) Impact of land use changes resulting from human responses to climate change**. Increase. Neutral. Changes in land use associated with climate change are not considered a threat.

**C1) Dispersal and movements.** Somewhat decrease to neutral. Midget faded rattlesnakes are dependent upon winter dens and migrate to and from those dens on an annual basis. Although they have some of the largest activity ranges reported in rattlesnakes, annual movements still only movements average around 2000 meters per year, only 300 meters for gravid females (Parker and Anderson 2007).

**C2ai) Predicted sensitivity to temperature: historical thermal niche.** Neutral. The range occupied by the Midget faded rattlesnake in the assessed area has experienced an average (51.7 - 77° F/31.8 - 43.0° C) zonal mean seasonal temperature over the last 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. The Midget faded rattlesnake is restricted to rock outcrops where their hibernacula are located. Modeling of denning habitat indicates a very narrow temperature range that represents suitability for rattlesnake denning (Spear et al. 2011) suggesting that increasing temperatures projected for the assessment area (Melillo et al. 2014) could negatively impact currently suitable denning habitat, influencing the future distribution of the Midget faded rattlesnake.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche**. Neutral. The range occupied by the Midget faded rattlesnake in the assessed area has experienced average (21 - 40 inches/509 - 1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat increase to neutral. There is some evidence to suggest that reproductive success is positively influenced by precipitation, but long-term continuous monitoring is needed to understand whether precipitation consistently explains reproductive output and to predict the potential effects of future climate change on rattlesnake recruitment. (Spear et al. 2011).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The Midget faded rattlesnake is not dependent upon specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

**C2d) Dependence on snow-covered habitats.** Neutral. The Midget faded rattlesnake is not dependent on habitats with ice, snow, or on snowpack.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Midget faded rattlesnakes require rock outcrops for hibernacula/denning (Parker and Anderson 2007 and Spear et al. 2011).

**C4a) Dependence on other species to generate habitat.** Neutral. The Midget faded rattlesnake is not dependent on any other species to create suitable habitat for its existence.

**C4b) Dietary versatility.** Neutral. Midget faded rattlesnakes mainly prey on lizards, but eat a broad range of prey including small mammals and birds (Parker and Anderson 2007).

**C4d) Dependence on other species for propagule dispersal.** Neutral. The Midget faded rattlesnake is a self-disperser.

**C4e) Forms part of an interspecific interaction not covered by 4a-d**. Neutral. No other interspecific interactions are important to the persistence of the Midget faded rattlesnake.

**C5a) Measured genetic variation.** Somewhat increase to neutral. Overall, genetic diversity is low to intermediate across midget faded rattlesnake (Spear et al. 2011).

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Response to recent climate change.** Unknown.

**D2) Modeled future change in population or range size.** Decrease. Winter range is predicted to increase by 69% by 2080 (NAS 2014).

**D3) Overlap of modeled future range with current range.** Unknown.

**D4) Protected areas.** Unknown.

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# 4 PLANTS

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# METHODS

## NatureServe Climate Change Vulnerability Index

### Overview

This overview has been synthesized and reprinted, with permission, from Young et al. (2011). The Climate Change Vulnerability Index (CCVI), developed by NatureServe, is a Microsoft Excel-based tool that facilitates rapid assessment of the vulnerability of plant and animal species to climate change within a defined geographic area. In accordance with well-established practices (Schneider et al. 2007, Williams et al. 2008), the CCVI divides vulnerability into two components:

> **exposure** to climate change within the assessment area (e.g., a highly sensitive species will not suffer if the climate where it occurs remains stable).
>
> **sensitivity** of the species to climate change (e.g., an adaptable species will not decline even in the face of significant changes in temperature and/or precipitation).

Exposure to climate change is measured by examining the magnitude of predicted temperature and moisture change across the species' distribution within the study area. CCVI guidelines suggest using the downscaled data from Climate Wizard (http://climatewizard.org) for predicted change in temperature. Projections for changes in precipitation are available in Climate Wizard, but precipitation estimates alone are often an unreliable indicator of moisture availability because increasing temperatures promote higher rates of evaporation and evapotranspiration. Moisture availability, rather than precipitation per se, is a critical resource for plants and animals and therefore forms the other part of the exposure measure within the CCVI, together with temperature. To predict changes in moisture availability, NatureServe and partners developed the Hamon AET:PET moisture metric as part of the CCVI. The metric represents the ratio of actual evapotranspiration (i.e., the amount of water lost from a surface through evaporation and transpiration by plants) to potential evapotranspiration (i.e., the total amount of water that could be evaporated under current environmental conditions, if unlimited water was available). Negative values represent drying conditions.

Sensitivity is assessed using 20 factors divided into two categories: 1) indirect exposure to climate change; and 2) species specific factors (including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors). For each factor, species are scored on a sliding scale from greatly increasing, to having no effect on, to decreasing vulnerability. The CCVI accommodates more than one answer per factor in order to address poor data or a high level of uncertainty for that factor. The scoring system integrates all exposure and sensitivity measures into an overall vulnerability score that indicates relative vulnerability compared to other species and the relative importance of the factors contributing to vulnerability.

The Index treats exposure to climate change as a modifier of sensitivity. If the climate in a given assessment area will not change much, none of the sensitivity factors will weigh heavily, and a species is likely to score at the Not Vulnerable end of the range. A large change in temperature or moisture availability will amplify the effect of any related sensitivity, and will contribute to a score reflecting higher vulnerability to climate change. In most cases, changes in temperature and moisture availability will combine to modify sensitivity factors. However, for factors such as sensitivity to temperature change (factor 2a) or precipitation/moisture regime (2b), only the specified climate driver will have a modifying effect.

The six possible scores are:

**Extremely Vulnerable**: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

**Highly Vulnerable**: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

**Moderately Vulnerable**: Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

**Not Vulnerable/Presumed Stable**: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

**Not Vulnerable/Increase Likely**: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

**Insufficient Evidence**: Available information about a species' vulnerability is inadequate to calculate an Index score.

## Scoring Factors in the CCVI

The factors used to generate the CCVI score are listed in the following section. Detailed definitions of scoring categories are listed in Appendix B.

***A. Exposure to Local Climate Change***

1. Temperature
2. Moisture

***B. Indirect Exposure to Climate Change***

1. Exposure to sea level rise. (Not applicable to Colorado)
2. Distribution relative to natural and anthropogenic barriers.

3. Predicted impact of land use changes resulting from human responses to climate change.

***C. Sensitivity***

1. Dispersal and movements.
2. Predicted sensitivity to temperature and moisture changes.
    a. Predicted sensitivity to changes in temperature.
    b. Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
    c. Dependence on a specific disturbance regime likely to be impacted by climate change.
    d. Dependence on ice, ice-edge, or snow-cover habitats.
3. Restriction to uncommon geological features or derivatives.
4. Reliance on interspecific interactions.
    a. Dependence on other species to generate habitat.
    b. Dietary versatility (animals only).
    c. Pollinator versatility (plants only).
    d. Dependence on other species for propagule dispersal.
    e. Forms part of an interspecific interaction not covered by C4a-d.
5. Genetic factors.
    a. Measured genetic variation.
    b. Occurrence of bottlenecks in recent evolutionary history.
6. Phenological response to changing seasonal temperature and precipitation dynamics.

***D. Documented or Modeled Response to Climate Change***

1. Documented response to recent climate change.
2. Modeled future change in range or population size.
3. Overlap of modeled future range with current range.
4. Occurrence of protected areas in modeled future distribution.

*Factors not considered* —The Index development team did not include factors that are already considered in conservation status assessments. These factors include population size, range size, and demographic factors. The goal is for the NatureServe Climate Change Vulnerability Index to complement NatureServe Conservation Status Ranks and not to partially duplicate factors. Ideally, Index values and status ranks should be used in concert to determine conservation priorities.

## Application of Climate Data

Scoring factors related to historic and predicted future climate (temperature, precipitation, and moisture availability, Factors A1, A2, C2ai, and C2bi in the CCVI) were calculated in GIS using the methods described below. Refer to the species profiles in the following section of this report for details on scoring rationale and references for all other factors.

Exposure to predicted temperature increase was calculated using species distribution data and an ensemble average of 16 CMIP3 climate prediction models (see Appendix A) averaged over the summer season (June – August) using the high (A2) CO2 emissions scenario. The high emissions scenario was used because it is most similar to current emissions. Data was obtained from Climate Wizard, and the analysis period was to the year 2050 (which is actually an average of projections for years 2040 – 2069). The summer season – growing season for plants, breeding season for animals – was used because it was considered the most critical time period for most species.

Exposure to projected drying (integration of projected temperature and precipitation change, i.e., the Hamon AET: PET moisture metric) was calculated using the dataset created by NatureServe as part of the CCVI. Note that NatureServe based their moisture metric calculations on the same Climate Wizard dataset as above, *except* that they used the A1B carbon dioxide emissions scenario. Because the modeling methods used by NatureServe were not available, we were unable to recalculate using the A2 scenario. Thus, we used the data as provided, which we considered a reasonable alternative since the A1B and A2 scenarios predict similar changes through the mid-21st Century, the period used in this analysis. We calculated the percent of each species' range/distribution that falls within each rating category. All calculations used the "summer" (June – August) data subset.

The *historical thermal niche* factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature). It is a proxy for species' temperature tolerance at a broad scale. This factor was calculated in GIS by assessing the relationship between species' distributions and historical temperature variation data downloaded from NatureServe. Historical temperature variation was measured as the mean July high minus the mean January low, using PRISM data from 1951-2006, expressed as a single averaged value for the entire species range.

The *historical hydrological niche* factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area. Ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from Climate Wizard, and subtracting the lowest pixel value from the highest value.

### Representing Species' Distributions

For plant species, we used element occurrences from CNHP's BIOTICS database to generate distribution maps and perform the GIS calculations referenced above.

The plant species included in this climate change vulnerability assessment include all the federally listed (threatened, endangered and candidate) species known to occur on BLM lands. Also included are all the plant species from the BLM Sensitive Species list, with the exception of 13 species for which there was not sufficient information available to evaluate the effects of climate change. The omitted species were: *Arabis crandallii (Boechera crandallii), Astragalus musiniensis, Astragalus* *sesquiflorus, Cymopterus duchesnensis, Eriogonum acaule, Eriogonum tumulosum, Eriogonum viridulum, Frasera paniculata, Lygodesmia doloresensis, Packera pauciflora, Sphaeromeria capitata, Townsendia strigosa, Trichophorum pumilum (Scirpus rollandii).*

# RESULTS

CCVI results are summarized in Table 4.1, and presented in full in Appendix C. Plant species results are sorted alphabetically by scientific name. The rationale for scoring and literature citations are included in the following species profiles.

**Table 4.10.** Climate Change Vulnerability Scores for Plant Species. EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

| Species | English name | Score |
|---|---|---|
| *Aletes latilobus (Lomatium latilobum)* | Canyonlands aletes | EV |
| *Aletes lithophilus (Neoparrya lithophila)* | Rock-loving neoparrya | EV |
| *Amsonia jonesii* | Jones' bluestar | MV |
| *Aquilegia chrysantha var. rydbergii* | Golden columbine | EV |
| *Asclepias uncialis ssp. uncialis* | Dwarf milkweed | EV |
| *Astragalus anisus* | Gunnison milkvetch | EV |
| *Astragalus debequaeus* | DeBeque milkvetch | EV |
| *Astragalus equisolensis* | Horseshoe milkvetch | EV |
| *Astragalus microcymbus* | Skiff milkvetch | EV |
| *Astragalus naturitensis* | Naturita milkvetch | EV |
| *Astragalus osterhoutii* | Kremmling milkvetch | EV |
| *Astragalus piscator* | Fisher Towers milkvetch | EV |
| *Astragalus rafaelensis* | San Rafael milkvetch | EV |
| *Astragalus ripleyi* | Ripley milkvetch | EV |
| *Astragalus tortipes* | Sleeping Ute milkvetch | EV |
| *Bolophyta ligulata (Parthenium ligulatum)* | Ligulate feverfew | EV |
| *Camissonia eastwoodiae* | Eastwood evening primrose | HV |
| *Cleome multicaulis* | Slender spiderflower | EV |
| *Corispermum navicula* | Boat-shaped bugseed | EV |
| *Cryptogramma stelleri* | Slender rock-brake | EV |
| *Erigeron kachinensis* | Kachina daisy | EV |
| *Eriogonum brandegeei* | Brandegee wild buckwheat | EV |
| *Eriogonum clavellatum* | Comb Wash buckwheat | EV |
| *Eriogonum coloradense* | Colorado wild buckwheat | EV |
| *Eriogonum contortum* | Twisted Buckwheat | EV |
| *Eriogonum pelinophilum* | Clay-loving wild buckwheat | EV |

| Species | English name | Score |
|---|---|---|
| *Eriogonum ephedroides* | Ephedra buckwheat | EV |
| *Eutrema penlandii* | Penland alpine fen mustard | EV |
| *Gentianella tortuosa* | Utah gentian | EV |
| *Gilia (Aliciella) stenothyrsa* | Narrow-stem Gilia | EV |
| *Gutierrezia elegans* | Lone Mesa snakeweed | EV |
| *Ipomopsis polyantha* | Pagosa skyrocket | EV |
| *Lomatium concinnum* | Colorado desert-parsley | EV |
| *Lupinus crassus* | Payson lupine | EV |
| *Mimulus eastwoodiae* | Eastwood's monkeyflower | EV |
| *Nuttallia (Mentzelia) chrysantha* | Golden blazing star | EV |
| *Nuttallia (Mentzelia) densa* | Arkansas Canyon stickleaf | EV |
| *Nuttallia (Mentzelia) rhizomata* | Roan Cliffs Blazingstar | EV |
| *Oenothera acutissima* | Narrow-leaf evening primrose | HV |
| *Oreocarya (Cryptantha) caespitosa* | Tufted Cryptanth | EV |
| *Oreocarya (Cryptantha) rollinsii* | Rollins' Cats-eye | EV |
| *Oreocarya osterhoutii (Cryptantha osterhoutii)* | Osterhout's cat's-eye | EV |
| *Oreocarya revealii (Cryptantha gypsophila)* | Gypsum Valley cat's-eye | EV |
| *Pediomelum aromaticum* | Paradox breadroot | EV |
| *Penstemon debilis* | Parachute penstemon | EV |
| *Penstemon degeneri* | Degener beardtongue | EV |
| *Penstemon gibbensii* | Gibben's beardtongue | EV |
| *Penstemon grahamii* | Graham beardtongue | EV |
| *Penstemon harringtonii* | Harrington's beardtongue | EV |
| *Penstemon penlandii* | Penland penstemon | EV |
| *Penstemon scariosus var. albifluvis* | White River penstemon | EV |
| *Phacelia formosula* | North Park phacelia | EV |
| *Phacelia submutica* | DeBeque phacelia | EV |
| *Physaria (Lesquerella) congesta* | Dudley Bluffs bladderpod | EV |
| *Physaria (Lesquerella) parviflora* | Piceance bladderpod | EV |
| *Physaria (Lesquerella) pruinosa* | Pagosa bladderpod | EV |
| *Physaria (Lesquerella) vicina* | Good-neighbor bladderpod | EV |
| *Physaria obcordata* | Piceance twinpod | EV |
| *Physaria pulvinata* | Cushion bladderpod | EV |
| *Sclerocactus glaucus* | Colorado hookless cactus | EV |
| *Sisyrinchium pallidum* | Pale blue-eyed grass | EV |
| *Thalictrum heliophilum* | Sun-loving meadow rue | EV |

Nearly all of the 62 plant species analyzed scored as extremely vulnerable to predicted climate change in Colorado. Only three species (*Amsonia jonesii*, *Camissonia eastwoodiae* and *Oenothera acutissima*) were highly to moderately vulnerable. None of the plant species scored as presumed stable or likely to increase under the climate change scenario used in this analysis. (Table 4.1). Factors that were most likely to contribute to the vulnerability of plants include: natural barriers to movement and poor dispersal ability, physiological hydrological niche, restriction to uncommon geologic features or substrates, and pollinator specificity. Of the 62 plant species evaluated for Colorado the confidence ratings were very high for all species.

Despite the development of numerous climate change models, there remains some uncertainty about what climatic changes will actually occur and how species fitness and population stability will be affected. When evaluated at a regional (i.e., smaller than statewide) scale, some species scored as less vulnerable to climate change. For example, in the San Juan region of Colorado, *Amsonia jonesii* is presumed stable where there are few natural or anthropogenic barriers to movement and it has been exposed to greater historical temperature variation, whereas it scores as moderately vulnerable on a statewide scale where the presence of natural and anthropogenic barriers increases and there is less exposure to historic temperature extremes. *Mimulus eastwoodiae* scored as highly vulnerable in the San Juan region but is considered extremely vulnerable on a statewide scale for the same reasons, increased barriers to movement and less exposure to historic temperature variation. The same was true for *Pediomelum aromaticum* which is moderately vulnerable in the San Juan's and extremely vulnerable statewide. Thus, it is important to consider the species range in relation to the assessment area when developing adaption strategies, and to consider how such factors, such as precipitation and temperature averages can affect the scores when species are evaluated at different scales.

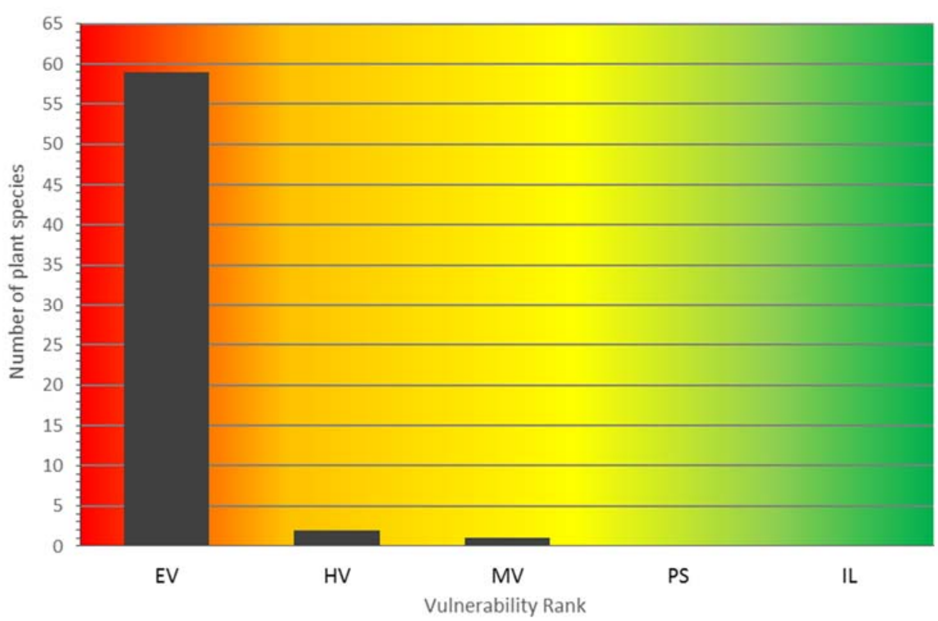


**Figure 4.1**. Summary of climate change vulnerability scores for plant species. EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely.

# PLANT SPECIES CCVI SUMMARIES

## *Aletes latilobus (Lomatium latilobum)*

**Canyonlands aletes**
**G1G2/S1**
**Family: Apiaceae**

Photo: Gina Glenne

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) 1) *Aletes latilobus* habitat is surrounded by anthropogenic and natural barriers that may inhibit range shift 2) potential increase in energy development in *A. latilobus* habitat; 3) *A. latilobus* has experienced a small range in mean annual precipitation over the last 50 years; 4) seed dispersal distances are probably fairly limited; 5) potential decrease in soil moisture availability under projected warmer temperatures; 6) restriction to sandstone Entrada and Navajo Formations.

**Distribution:** Colorado Plateau, Navajo Basin; Grand and San Juan Counties, Utah, and Mesa County, Colorado. **Habitat:** On Entrada Sandstone and Navajo Sandstone, between fins and in slot canyons, in sandy soil and in crevices. Surrounding plant communities are desert shrub, pinyon-juniper, or ponderosa pine-mountain brush. Found in canyonlands in pinyon-juniper and desert shrub communities; on sandstone ledges and in sandy soils derived from the Entrada Formation or the contact point of the Wingate and Chinle Formations (Spackman et al. 1997, Ackerfield 2012, Weber and Wittmann 2012). **Elevation:** 4541-5807 feet.

**Ecological System:** Cliff and Canyon, Desert Shrub

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Range shift in response to climate change is inhibited by unsuitable geology and the Colorado River Valley (to the north) that do not contain suitable habitat for this species (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Extensive habitat alteration due to oil and gas extraction in and around habitat occupied by this species (FracFocus Wells 2013) inhibits range shift. Additionally, much of the landscape surrounding occurrences of *A. latilobus* has been altered by livestock grazing (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Desert shrublands have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Cliff and canyon species were rated 'Increase' based on the assumption that these habitats are likely to be altered as Colorado becomes warmer.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. latilobus* occurs in a semi-arid climate with an average of 11.33 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. latilobus.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. Restricted to sandstones of the Entrada and Navajo Formations (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Unknown.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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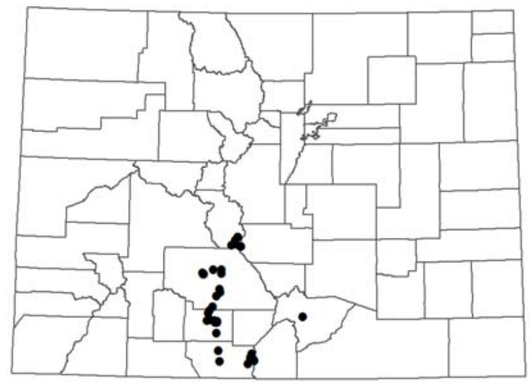
## *Aletes lithophilus (Neoparrya lithophila)*

**Rock-loving neoparrya**
**G3/S3**
**Family: Apiaceae**

Photo: Jim McCain



## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on: predicted decreases in precipitation; the discontinuity of suitable habitat that isolates populations and creates natural barriers and habitat alteration that results from livestock grazing which acts as an anthropogenic barriers; possible wind power development that may occur in current and potential future range; limited successful seed dispersal; and alteration of the natural fire disturbance regime. Suitable habitat is likely to be reduced as this species' range becomes drier. Climate models project annual net drying across the range of this species (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014)

**Distribution:** *Aletes lithophilus* is endemic to the southern Rocky Mountains where this species is known from seven counties in south-central Colorado: Chaffee, Conejos, Fremont, Huerfano, Mineral, Rio Grande, and Saguache; and has also been reported from one site in north-central Rio Bravo County in New Mexico (Anderson 2004, SEINet 2014). Most occurrences are known from the western rim of the San Luis Valley, but important outlying occurrences are also found in the Arkansas Valley in the Salida area and at Farisita Dike in Huerfano County (Anderson 2004).

**Ecological System/Habitat:** *Aletes lithophilus* is found in the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province (Anderson 2004). In this ecosystem *N. lithophila* typically occupies volcanic substrates, in the cracks or shelves of moderate to steep rock outcrops, or outcrops of volcanic soils, usually with minimal talus but is also known to occur on sedimentary rock derived from extrusive volcanics. Habitat surrounding the rock outcrops is typically grasslands or pinon-juniper woodlands with associated taxa often including *Festuca, Artemisia, Muhlenbergia, Hymenoxys,* and *Ribes* (NatureServe 2014). **Elevation:** Reports document that *Aletes lithophilus* ranges from 6,700 to 10,000 feet, but is most commonly found between 7,280 to 9,800 feet in elevation (Anderson 2004).

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Occurrences of *Aletes lithophilus* are naturally isolated by the discontinuity of suitable habitat (Anderson 2004). This species occupies rock outcrops, dikes and cliffs that are distributed on the landscape as islands surrounded by a sea of grassland and woodland habitats where the intervening environment is apparently unsuitable for the establishment of *A. lithophilus* and acts as barriers to range shift.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Habitat alteration as a consequence of livestock grazing both indirectly and directly impairs range shift driven by climate change. *Aletes lithophilus* is highly vulnerable to habitat alteration as indicated by a "coefficient of conservatism" value (C value) of "9" (Rocchio 2007). The majority of *A. lithophilus* occurrences are either on or adjacent to land that is managed for livestock grazing (BLM 2014, CNHP 2014) and the majority of those grazing allotments are categorized as "improve" (BLM 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Natural history requirements of *Aletes lithophilus* are incompatible with the land use changes that may possibly occur in its current and future range as a result of wind energy development. Potential for wind power development is high throughout the western perimeter of the San Luis valley (NRDC 2011) where the majority of the documented occurrences of *N. lithophila* are located (CNHP 2014).

**C1) Dispersal and movements.** Somewhat increase. Successful seed dispersal is limited by unsuitable habitat**.** Although *Aletes lithophilus* seeds may be dispersed by a variety of mechanisms, including wind and animals, with potential maximum dispersal distances of up to 15 and 1,500 meters respectively (Jongejans and Telenius 2001, Vittoz and Engler 2007), the probability of dispersal decreases rapidly with increasing distance from the source (Barbour et al. 1987). Flat areas surrounding the rock outcrops inhabited by *N. lithophila* present unsuitable habitat that undoubtedly act as sinks when seeds are blown or washed onto these areas (Anderson 2004).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average temperature variation (57.1 - 77°F) in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Aletes lithophilus* is not restricted to cool or cold environments. Additionally, habitat preferences (Anderson 2004) suggest that *A. lithophilus* is tolerant of warmer temperatures.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells, the species has experienced average precipitation variation (36.5 inches) in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat increase. *Aletes lithophilus* is somewhat dependent on a seasonal hydrologic regime that is vulnerable to alteration with climate change and associated predicted increased severity and frequency of drought (USGCRP 2009). Although *A. lithophilus* occupies xeric sites, population maintenance via recruitment is dependent on seedling success which appears to be dependent on periods of one or several wet years during which plants can become established (Anderson 2004).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. While severe droughts are already part of the Southwest climate, human-induced climate change will likely result in more frequent and more severe droughts with associated increases in wildfires (USGCRP 2009). Additionally, the presence of cheatgrass (*Bromus tectorum*) in many occurrences may further exacerbate climate change-induced alteration to natural fire regimes. Increased fire frequency will favor fire-dependent or fire-tolerant species, which this species is not (Anderson 2004), leading toward changes in species composition (Noss 2001).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase. *Aletes lithophilus* is primarily restricted to Tertiary volcanic substrates with the species primarily distributed along the eastern margin of the San Juan Volcanic Area (Anderson 2004). Tertiary volcanic substrates are widely distributed in south central and southwestern Colorado with Tertiary ash flow tuff and pre-ash flow volcanics underlying much of the eastern San Juan Mountains (Tweto 1979, Chronic and Williams 2002).

**C4a) Dependence on other species to generate habitat.** Neutral. *Aletes lithophilus* is not known to be dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. Species in the family Apiaceae have a high degree of floral uniformity with very little floral specialization and thus utilize a broad suite of pollinators for pollen vectors (Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Aletes lithophilus* is not known to be dependent on other species for dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d.** Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Amsonia jonesii*

**Jones' bluestar**
**G4/S2**
**Family: Apocynaceae**

Photo: Joe Leahy

## Climate Vulnerability Rank: Moderately Vulnerable

This Colorado state wide rank is based on: predicted increased temperature and decreased precipitation during period of flowering and fruiting; the presence of high escarpments that act as natural barriers as well as habitat alteration that results from energy extraction, agricultural development and livestock grazing that act as anthropogenic barriers to range shift; possible wind power development which may impact potential future range; alteration to the natural fire disturbance regime; pollinator limitation; predicted decrease in modeled future range with little habitat included in protected areas. Suitable habitat is likely to be lost to this species and reproductive success diminished. Climate models project annual net drying throughout the range of this species (NatureServe 2012) which may impact recruitment and population survivability.

**Distribution:** *A. jonesii* is known from NE Arizona, Utah, NW New Mexico, and SW Colorado in the United States (NatureServe 2014). In Colorado, it is known from Mesa and Montezuma counties (USDA NRCS 2013, CNHP 2014). **Habitat:** Dry, open areas with clay, sandy, or gravelly soils, in desert-steppe, rocky drainages and draws (CNHP 2014). **Elevation:** 4400-5800 feet.

**Ecological System:** Desert Shrublands, Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. With a changing climate *Amsonia jonesii* is predicted to move northward, tracking climate more suitable to its evolved environmental tolerances and ecological niche (UVUH 2014). Colorado populations will encounter the Roan Plateau, an east-west trending escarpment, which presents a natural elevational, environmental and habitat barrier that restricts the ability of this species to shift range.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Some Colorado populations in will be inhibited from range shift by oil and gas development (FracFocus Wells 2013), habitat conversion to hay agriculture and habitat alteration by livestock (USDA 2012).

**B3) Predicted impact of land use changes resulting from human responses to climate change.** Neutral. Although portions of western Colorado have high potential for wind and solar energy development, the species is unlikely to be significantly affected by mitigation-related land use changes that may occur within its current and/or potential future range (NRDC 2011).

**C1) Dispersal and movements.** Somewhat increase. Similar to related species, the cylindrical and corky seeds of *Amsonia jonesii* may be dispersed by water. Dispersal by water is highly unpredictable and undocumented (Vittoz and Engler 2007) but in general most plant seeds do not disperse farther than 100m (Cain et al. 2000).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation over the range of this species, *Amsonia jonesii* has experienced average temperature variation (57.1-77°F) over the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat decrease. This species is not restricted to cool or cold environments and shows a preference for environments toward the warmer end of the spectrum.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells, *A. jonesii* has experienced average (21-40 inches/509-1,016 mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Species is found in coarse, sandy soils often in the bottoms of draws and drainages. Predicted climate drying during the spring growing season will reduce this species recruitment, abundance and habitat suitability. Long term survivability may consequently be diminished even though increased autumn moisture may enhance dispersal and germination potential. During late summer and early autumn, *A. jonesii* is predicted to be exposed to precipitation decreases of up to 3 percent over approximately 30 percent of its range and increases of up to 6 percent over 70 percent of its range.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Fire frequencies in the Pinyon-Juniper woodlands and sage and desert shrublands occupied by this species are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Little et al. 2009, Stephens 2005, Westerling et al. 2006, USFS no date).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat decrease. Species is reported to be widely adaptable in the nursery trade, and is reported to grow on various substrates.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species depends on other species to generate its habitat.

**C4c) Pollinator Versatility.** Neutral. Inferred from a related species *Amsonia kearneyana* which has a wide variety of pollinators (USFWS 2013).

**C4d) Dependence on other species for propagule dispersal.** Neutral. Similar to other related species, seed morphology suggests that this species may disperse by water and is thus not likely reliant on other species for dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**D1) Documented Response to Recent Climate Change (e.g., range contraction or phenology mismatch with critical resources).** Unknown.

**D2) Modeled Future (2050) Change in Range or Population Size.** Increase. Rangewide predicted future range represents a 20 percent to 50 percent decline relative to current range (UVUH 2014).

**D3) Overlap of Modeled Future (2050) Range with Current Range.** Neutral. Predicted future range overlaps the current range by greater than 60 percent within the assessment area (UVUH 2014).

**D4) Occurrence of Protected Areas in Modeled Future (2050) Distribution.** Somewhat Increase. Five to thirty percent of the modeled future distribution within the assessment area is encompassed by one or more protected areas (USDI 2014).

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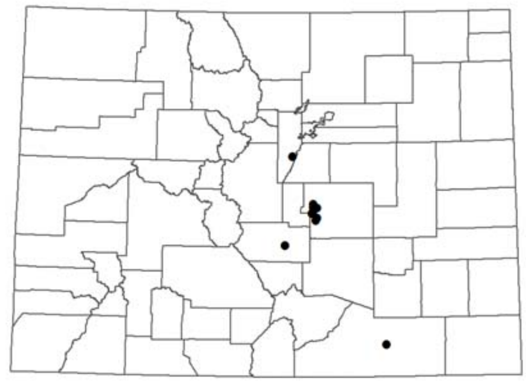
## *Aquilegia chrysantha* var. *rydbergii*

**Golden columbine**
**G4T1Q/S1**
**Family: Ranunculaceae**


Photo: Steve Olson



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide vulnerability rank is based on the following: 1) restriction to moist micro-habitats in cliffs, canyons, and seeps 2) reliance on hawkmoths as a major pollinator 3) short seed dispersal distances.

**Distribution***:* Known from Fremont, El Paso, Jefferson, and Las Animas counties. The Plants Database (USDA NRCS 2015) shows *A. chrysantha* var. *rydbergii* in Arizona, Colorado, and New Mexico. The Flora of North America (Vol. 3, 1997) states that Colorado populations have been called *A. chrysantha* var. *rydbergii* and does not mention New Mexico or Arizona. Reports from New Mexico and Arizona (USDA NRCS 2015) are probably erroneous, possibly originating because NM and AZ are listed in the range of var. *rydbergii* in the 1985 Notice of Review for Listing as Endangered or Threatened Species. These reports have not otherwise been substantiated. **Habitat:** In canyons and foothills along streams or in rocky ravines (Spackman et al. 1997, Weber and Wittmann 2012). *Aquilegia chrysantha* var. *rydbergii* grows in organic soils and has also been observed in gravel derived from granite parent material. Often found near the base of boulders on the canyon sides and floor, it may also grow on seep-fed rocky ledges. It grows in shady and moist areas on slopes above a creek, along the side drainages, and within the riparian area of a perennial stream. **Elevation:** 5,000-8,240 feet.

**Ecological System:** Mountain Streams, Seeps and Springs, Douglas Fir

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to the parent plant, and do not contain specialized structures for dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Increase. Considering the mean seasonal temperature variation over the range of this species, *Aquilegia chrysantha* var*. rydbergii* has experienced slightly lower than average temperature variation (47.1-57°F) over the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. This species occurs in cool, shaded, moist habitats that may be reduced if Colorado becomes warmer and drier, as projected in many climate models.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *A. chrysantha* var. *rydbergii* has experienced slightly lower than average (15.56 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. This species occurs in cool, shaded areas in cliffs and canyons. These micro-habitats often contain moist soils and seasonal seeps that may be vulnerable to climate change.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat decrease. This species occurs in several habitat types.

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4c) Pollinator Versatility.** Somewhat Increase. Crepuscular hawkmoths serve as a major pollinator for *A. chrysantha* var. *rydbergii* in the southwest U.S. and northern Mexico (Miller 1985).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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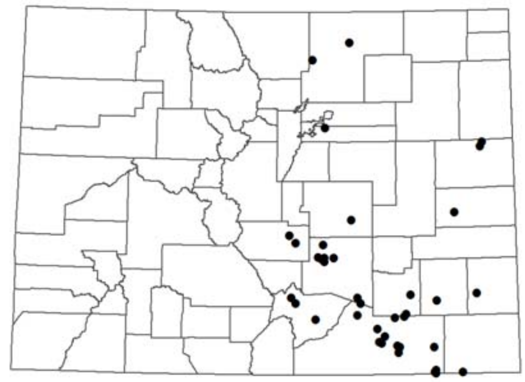
## *Asclepias uncialis* ssp. *uncialis*

**Dwarf milkweed**
**G3G4T2T3/S2**
**Family: Asclepiadaceae**

Photo: Steve Olson



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) lack of variability in mean annual precipitation in the past 50 years; 2) short seed dispersal distances; 3) cropland and urban development may act as a barrier to seed dispersal; and 4) potential for wind energy development on Colorado's eastern plains.

**Distribution***:* Estimated range is 71,964 square kilometers (27,785 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. There is potentially about 40,000 square miles of habitat in eastern Colorado (although perhaps as much as 50% of this area is no longer suitable habitat), roughly 45% of the total potential range of the species. The current known distribution of *Asclepias uncialis* ssp. *uncialis* forms an arc along the flank of the Southern Rocky Mountains from northeastern Colorado to southwestern New Mexico and adjacent southeastern Arizona. Currently known from nine Colorado counties (Las Animas, Weld, Kit Carson, Huerfano, Pueblo, Otero, Prowers, Fremont, and El Paso), and historically known from at least eight additional counties (Arapaho, Adams, Baca, Bent, Cheyenne, Larimer, Denver and Washington). Occurrences are primarily in southeastern Colorado. **Habitat:** *Asclepias uncialis* ssp. *uncialis* is primarily associated with species typical of shortgrass prairie. Associated vegetation is comprised mostly of grasses, with forbs, shrubs, and trees typically comprising less than 15% of the total vegetation cover. Although plants are often found at the base of escarpments or mesas, the species does not occur on rock ledges or outcroppings, and is absent from highly disturbed habitats such as sand dunes, erosion channels, wash slopes, and badlands. Occurrences are known from soils derived from a variety of substrates, including sandstone, limestone, and shale, but are most often found in sandy loam soils. It does not occur in pure sand.

**Elevation:** 3890-7730 feet.

**Ecological System:** Shortgrass Prairie, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Cropland and urban/ex-urban development in the shortgrass prairie may act as barriers for seed dispersal.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. According to Department of Energy wind resource maps, the eastern quarter of Colorado near the New Mexico and Nebraska borders has excellent wind resources (DOE 2004). Wind development could result in the loss of *A. uncialis* var. *uncialis* habitat.

**C1) Dispersal and movements.** Somewhat Increase. Seeds contain a tuft of silky hairs to aid in wind dispersal (Decker 2006).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Not restricted to cool or cold climates that are projected to be lost due to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied *A. uncialis* var. *uncialis* habitat, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Occurrences are known from soils derived from a variety of substrates, including sandstone, limestone, and shale, but are most often found in sandy loam soils (CNHP 2014; Decker 2006). It does not occur in pure sand.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. Likely to be pollinated by generalist species (Decker 2006).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Neutral.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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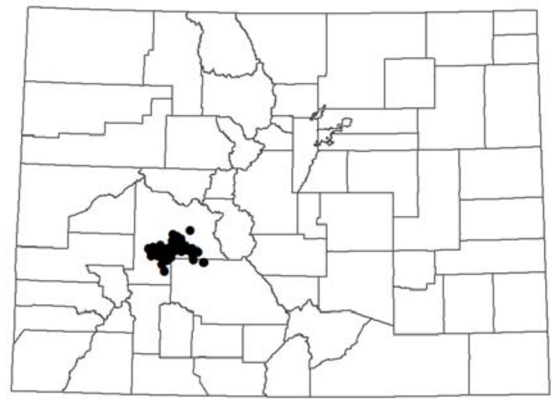
## *Astragalus anisus*

**Gunnison milkvetch**
**G2G3/*S2S3***
**Family: Fabaceae**


Photo: Lori Brummer



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) high mountain ranges surrounding *A. anisus* populations create natural barriers to dispersal; 2) probable limited seed dispersal distances; 3) potential geothermal energy development in the Gunnison Basin; 4) species has experienced a small range of precipitation in the last 50 years and 5) possibly reliance on nodulization.

**Distribution*:*** The species entire global range is contained within the upper Gunnison Basin, in Gunnison and Saguache counties, Colorado. Estimated range is 1,962 square kilometers (757 square miles), calculated in GIS in 2008 by the Colorado Natural Heritage Program by drawing a minimum convex polygon around the known occurrences*.* **Habitat:** Dry gravelly flats and hillsides, in sandy clay soils overlying granitic bedrock, usually among or under low sagebrush*.* **Elevation:** 7500-8500 feet.

**Ecological System:** Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Range shift in response to climate change is inhibited by high mountain ranges that surround the Gunnison Basin.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase Urban and exurban development in the Gunnison Basin act as current and potential future barriers to *A. anisus* movement.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Geothermal development potential is high in the Gunnison Basin, and if development increased in the Basin, it could fragment habitat in the Basin (USFWS 2014).

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant, and do not contain specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, *A. anisus* has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Based on field observations, this plant is well adapted to drought and temperature extremes (Johnston, pers. comm. 2011).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. The species has experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Species is somewhat dependent on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change. Precipitation amounts are fairly evenly distributed throughout the seasons, with somewhat more moisture occurring during the "monsoon" season of July and August (Decker and Anderson 2004).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. *Astragalus anisus* requires a high quality matrix community of sagebrush shrubland or pinyon-juniper woodlands which depend on a natural fire regime to maintain appropriate vegetation structure (NatureServe 2014) Further, modeled future changes in fire probability and of vegetation patterns show increased probability of fire throughout the region occupied by this species (Krawchuk et al. 2009).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. No data, forced score.

**C4d) Dependence on other species for propagule dispersal.** Neutral. No data, forced score.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. Although *Astragalus anisus* has not been investigated for nodulization, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. anisus* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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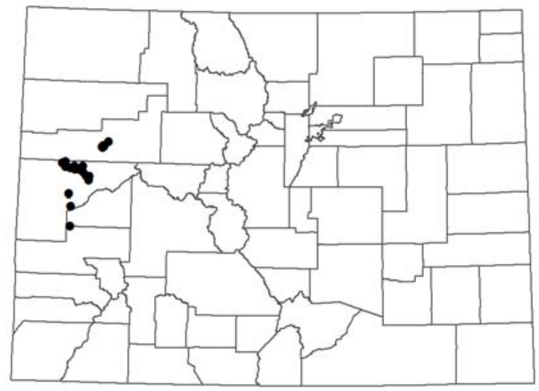
## *Astragalus debequaeus*

**DeBeque milkvetch**
**G2/S2**
**Family: Fabaceae**

Photo: Peggy Lyon



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) *Astragalus debequaeus* habitat is surrounded by anthropogenic and natural barriers that may inhibit range shift 2) potential increase in natural gas development in *A. debequaeus* habitat; 3) *A. debequaeus* has experienced a small range in mean annual precipitation over the last 50 years; 4) seed dispersal distances are probably fairly limited; 5) potential symbiotic relationship with root-nodulating bacteria.

**Distribution***:* Known from Delta, Garfield and Mesa counties, in the Colorado River Valley near DeBeque. The plant's range evidently corresponds to the extent of the Atwell Gulch Member of the Wasatch Formation. Estimated range is 1,736 square kilometers (670 square miles), calculated in 2008 by the Colorado Natural Heritage Program in GIS by drawing a minimum convex polygon around the known occurrences*.* **Habitat:** *Astragalus debequaeus* occurs in vari-colored, fine textured, seleniferous, and apparently saline soils of the Wasatch Formation-Atwell Gulch Member (Welsh 1985). It is found in areas surrounded by pinyon-juniper woodlands and desert shrub (Scheck 1994). *Astragalus debequaeus* is found on barren outcrops of dark clay interspersed with lenses of sandstone. The plants occur on sandy spots. Plants are mostly clustered on toe slopes and along drainages, but many occur on steep sideslopes. Soils are clayey but littered with sandstone fragments. **Elevation:** 4950-6680 feet.

**Ecological System:** Barrens, Pinyon-Juniper, Desert Shrub, Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Range shift in response to climate change is inhibited by unsuitable geology and high mountain habitats that would not contain suitable habitat for this species (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers. Somewhat** Increase. Extensive habitat alteration due to oil and gas extraction in and around habitat occupied by this species (FracFocus Wells 2013) inhibits range shift. Additionally, much of the landscape surrounding occurrences of *A. debequaeus* has been altered by livestock grazing (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. The habitat of A. *debequaeus* has a high potential for natural gas extraction, and moderate potential for solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seed dispersal is likely fairly limited, considering that *A. debequaeus* seeds do not contain any specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, *A. debequaeus* has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *A. debequaeus* occupies open sites over a wide range of elevations (CNHP 2014) with temperatures that vary adiabatically with elevation, suggesting that this species is not limited to cool environments.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, *A. debequaeus* has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. debequaeus* occurs in a semi-arid climate with an average of 11.33 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. debequaeus.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. Although this species occurs in several habitat types including barrens, pinyon-juniper, desert shrub, and sagebrush, it has a preference for barren outcrops of dark clay soils of the Atwell Gulch Member of the. Wasatch Formation-.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All Astragalus species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. A*stragalus. debequaeus* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. equisolensis* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Astragalus equisolensis (Astragalus desperatus* var. *neeseae)*

**Horseshoe milkvetch**
**G5T1/S1**
**Family: Fabaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: 1) *A. equisolensis* has experienced a small range in mean annual precipitation over the last 50 years; 2) seed dispersal distances are probably fairly limited; 3) pinyon-juniper habitats occupied by *A. equisolensis* may be subject to increased wildfires and decreases in soil moisture under the climate change projections of hotter temperatures; 4) potential symbiotic relationship with root-nodulating bacteria.

**Distribution*:*** Known from one county in Utah (USDA NRCS 2015) and one county in Colorado (CNHP 2014). **Habitat:** *A. equisolensis* is associated with mixed desert and salt desert shrub vegetation communities that are generally dominated by sagebrush, shadscale and horsebrush. The populations in Mesa County are in an open juniper/blackbrush community on rocky convex slopes with red soils. **Elevation:** 4520-6030 feet.

**Ecological System:** Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase/Neutral. Range shift in response to climate change is inhibited by unsuitable geology and high mountain habitats that would not contain suitable habitat for this species (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat Increase. Habitat disturbance and alteration may occur with increased development of uranium mines in the area.

**C1) Dispersal and movements.** Increase. Seed dispersal distances are likely short since *Astragalus* seeds generally do not contain specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, this species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *A. equisolensis* occupies open sites over a wide range of elevations (CNHP 2014) with temperatures that vary adiabatically with elevation, suggesting that this species is not limited to cool environments.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. equisolensis* occurs in a semi-arid climate with an average of 8.7 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. equisolensis.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. *A. equisolensis* occurs in pinyon-juniper habitats. These habitats are more likely to burn with increased temperatures and an increase in weedy species that comprise the understory, such as cheatgrass.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All *Astragalus* species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *Astragalus equisolensis* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. equisolensis* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Astragalus microcymbus*

**Skiff milkvetch**
**G1/S1**
**Family: Fabaceae**

Photo: Michelle DePrenger-Levin

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) movement barriers; 2) poor dispersal capacity; 3) restriction to specific geologic features; 4) potential future threats from livestock grazing and geothermal energy development; 5) potential increase in fire frequency in occupied habitat; 6) potential reliance on seasonal moisture regimes for fruit production.

**Distribution***:* Gunnison County, and extending into the edge of Saguache County. Estimated range is 168 square kilometers, calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Open sagebrush or juniper-sagebrush communities on moderately steep to steep slopes. Often found in rocky areas with a variety of soil conditions from clay to cobbles, gray to reddish in color*.* **Elevation:** 7600-8400 feet.

**Ecological System:** Sagebrush, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase/Neutral. Range shift in response to climate change is inhibited by unsuitable geology and high mountain habitats that would not contain suitable habitat for this species (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase/Neutral. The following potential factors that may affect the habitat or range of *Astragalus microcymbus* are (1) Residential and urban development; (2) recreation, roads, and trails; (3) utility corridors; (4) nonnative invasive plants; (5) wildfire; (6) contour plowing and nonnative seedings; (7) livestock, deer and elk use of habitat; (8) mining, oil and gas leasing; (9) climate change; and (10) habitat fragmentation and degradation (USFWS 2010).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Geothermal development potential is high in the Gunnison Basin, and if development increased in the Basin, it could affect the long-term viability of *A. microcymbus* within the Basin (USFWS 2014).

**C1) Dispersal and movements.** Increase. Seed dispersal is likely fairly limited, considering that *A. microcymbus* seeds do not contain any specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. *A. microcymbus* has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat Increase. Species is somewhat restricted to cool or cold environments that may be lost as a result of climate change. Temperatures in the *Astragalus microcymbus* occupied habitat can dip below freezing any month of the year. Climate models predict earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. The species has experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Precipitation influences fruit production in *A. microcymbus* with additional fruit produced in years with higher than average winter precipitation (DePrenger-Levin et al. 2013).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Sagebrush shrublands and pinyon-juniper habitats may experience increased fire frequencies due to increased temperatures.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral**.**

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All *Astragalus* species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. Although *A. microcymbus* has not been studied for nodulization, many species of *Astragalus* form mycorrhizal associations.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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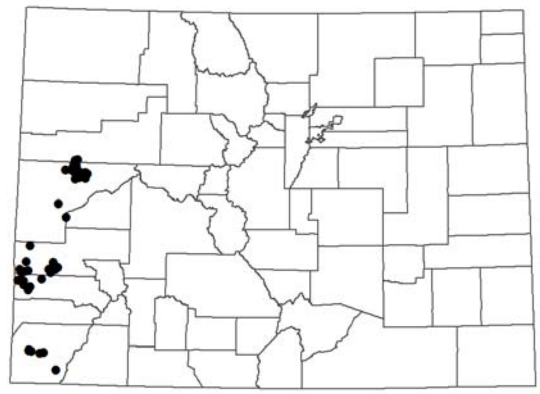
## *Astragalus naturitensis*

**Naturita milkvetch**
**G2G3/*S2S3***
**Family: Fabaceae**

Photo: B. Kuhn



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors 1) barriers to movement; 2) limited seed dispersal capabilities; 3) lack of temperature and precipitation variability in last 50 years; 4) potential decrease in soil moisture availability with increased temperatures; 5) restriction to specific geologic features and soil types; 6) potential for increased fire frequency in occupied *A. naturitensis* habitat.

**Distribution*:*** Known from New Mexico, Utah, the Navajo Nation and Colorado (Garfield, Mesa, Montezuma, Montrose, and San Miguel counties). **Habitat:** *Astragalus naturitensis* occurs on sandstone ledges, crevices of sandstone bedrock, dry rock mesas, ledges, and detrital slopes at 5000-7000 feet. Pinyon-juniper woodlands in areas with shallow soils over exposed bedrock. Usually it is in small soil pockets or rock crevices in sandstone pavement along canyon rims. Sometimes it is found nearby in deeper sandy soils with or without soil. **Elevation:** 4830-7030 feet.

**Ecological System:** Cliff and Canyon, Pinyon-Juniper, Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase/Somewhat Increase. High mountains, unsuitable habitat, and large river valleys (Gunnison, Colorado, and San Miguel rivers) may act as natural barriers that inhibit range shifts associated with climate change.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase/Neutral. Extensive habitat alteration due to oil and gas extraction in Western Colorado (FracFocus Wells 2013) inhibits range shift.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seed dispersal is likely fairly limited, considering that *A. naturitensis* seeds do not contain any specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, *A. naturitensis* has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Considering the mean seasonal temperature variation for occupied cells, *A. naturitensis* has experienced small (37 - 47° F/20.8 - 26.3° C) temperature variation in the past 50 years.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. naturitensis* occurs in a semi-arid climate with an average of 11.33 inches of precipitation per year in nearby Grand Junction, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. naturitensis.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Sagebrush shrublands and pinyon-juniper habitats may experience increased fire frequencies due to increased temperatures.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. *Astragalus naturitensis* occurs on sandstone ledges, crevices of sandstone bedrock, dry rock mesas, ledges, and detrital slopes at 5000-7000 feet (CNHP 2014). It is often found growing in shallow soils on top of sandstone ledges and slickrock, but occasional is found in deeper, sandy soils.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All Astragalus species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. naturitensis* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. naturitensis* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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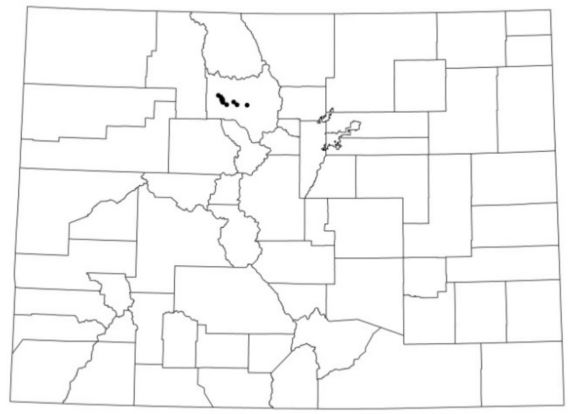
## *Astragalus osterhoutii*

**Kremmling milkvetch**
**G1/S1**
**Listed Endangered**
**Family: Fabaceae**

Photo: Denise Culver



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) limited seed dispersal distance; 3) lack of variation in annual precipitation in the last 50 years; 4) potential lack of soil moisture due to projections of hotter temperatures; 5) potential increase in fire frequency in sagebrush ecosystems; 6) restriction to highly seleniferous soils and unique geologic substrates 6) potential symbiotic relationship with root-nodulating bacteria.

**Distribution***:* Endemic to Grand County, Colorado. Estimated range is 120 square kilometers, calculated in GIS by drawing a minimum convex polygon around the known occurrences. Imprecisely reported occurrences are not included. **Habitat:** Highly seleniferous soils (grayish-brown clay) derived from Niobrara Shale; sometimes growing up through sagebrush. **Elevation:** 7370-8000 feet.

**Ecological System:** Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. According to SWReGAP vegetation layers, unsuitable habitat and geology surrounding known locations of *A. osterhoutii* may restrict range shifts due to climate change (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Housing development, motorized recreation areas, oil and gas drilling, and roads all create barriers to movement for *A. osterhoutii*.

**B3) Impact of land use changes resulting from human responses to climate change. Somewhat** Increase. Increased oil and gas drilling could lead to loss of individual *A. osterhoutii* plants, and increased habitat fragmentation and degradation.

**C1) Dispersal and movements.** Increase. Seed dispersal distances are likely somewhat limited due to the lack of specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *A. osterhoutii* is not limited to cool or cold habitats that may be lost to climate change. Less than 10% of sagebrush ecosystems in Colorado are projected to be outside of its current climatic envelope (See Ecosystem Section of report).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. osterhoutii* occurs in a semi-arid climate with an average of 11.88 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. osterhoutii.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Climate models project hotter temperatures for Colorado (Lukas et al. 2014), and this could result in increased fire frequency in sagebrush ecosystems.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. Species is restricted to white shale outcrops of Niobrara, Pierre, and Troublesome Formations in Grand County (CNHP 2014). It is most often found growing in highly seleniferous soils.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. osterhoutii* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. osterhoutii* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Astragalus piscator*

**Fisher Towers milkvetch**
**G2G3/S1**
**Family: Fabaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) *A. piscator* has experienced a very small range in mean annual precipitation over the last 50 years; 2) seed dispersal distances are probably fairly limited; 3) potential increase in uranium and vanadium mining in *A. piscator* habitat 4) pinyon-juniper habitats occupied by *A. piscator* may be subject to increased wildfires under the climate change projections of hotter temperatures; 5) potential lack of available soil moisture under projected climate warming; 6) potential symbiotic relationship with root-nodulating bacteria.

**Distribution***:* Known from one occurrence in Mesa County in Colorado. Also known from Utah. **Habitat:** In sandy, sometimes gypsiferous soils of valley benches and gullied foothills. In Gateway, it is found on slightly gravelly soils with mixed red and white particles. In addition, it was often found on the sides of dry gullies (Spackman et al. 1997)*.* **Elevation:** 4500-5580 feet.

**Ecological System:** Sandy Areas, Desert Shrub, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. This species is known from the Colorado/Utah border in rugged canyonlands. No mountain ranges or large river valleys occur here.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Few anthropogenic disturbances are present in the rugged canyons near Gateway, Colorado. Roads, railroads, and sparse housing development are the main disturbances located near *A. piscator* habitat, but these occupy a fairly small footprint.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Future increases in uranium and vanadium mining are possible within *A. piscator* habitat (CNHP 2014).

**C1) Dispersal and movements.** Increase. Seeds do not contain specialized structures to aid in dispersal, and likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, *A. piscator* has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold environments. It occurs in dry, upland areas dominated by pinyon-juniper and desert shrubs.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, *A. piscator* has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. piscator* occurs in a semi-arid climate with an average of 8.7 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. piscator.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. *A. piscator* occurs in pinyon-juniper habitats. These habitats are more likely to burn with increased temperatures and an increase in weedy species that comprise the understory, such as cheatgrass.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All *Astragalus* species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. piscator* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. piscator* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

## Literature Cited


Colorado Natural Heritage Program. 1997+. Colorado Rare Plant Guide. www.cnhp.colostate.edu. Latest update: June 30, 2014.

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Western Regional Climate Center. 2015. Average annual precipitation for Gateway, Colorado. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?co3246. Accessed Feb 24, 2015. Period of Record: 1947 to 2015.

## *Astragalus rafaelensis*

**San Rafael milkvetch**
**G2G3/S1**
**Family: Fabaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) *A. rafaelensis* has experienced a very small range in mean annual precipitation over the last 50 years; 2) seed dispersal distances are probably fairly limited; 3) pinyon-juniper habitats occupied by *A. rafaelensis* may be subject to increased wildfires under the climate change projections of hotter temperatures; 5) potential lack of available soil moisture under projected climate warming; 6) potential symbiotic relationship with root-nodulating bacteria.

**Distribution:** This is a Navajo Basin endemic; Emery and less commonly in Grand County, Utah (Welsh et al. 1993), also in Montrose, Mesa and La Plata counties in Colorado (CNHP 1998). **Habitat:** Gullied hills, washes, and talus under cliffs; in seleniferous clayey, silty, or sandy soils. Sometimes colonial on roadcuts. Colorado plants are found on soils derived from the Morrison formation, even when this has washed down onto Entrada or Chinle formations (Spackman et al. 1997). **Elevation:** 4720-6700 feet.

**Ecological System:** Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Range shift in response to climate change is inhibited by unsuitable geology and high mountain habitats that would not contain suitable habitat for this species (USGS 2004).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Few anthropogenic disturbances are present in the rugged canyons near Paradox and Nucla, Colorado. Roads, railroads, and sparse housing development are the main disturbances located near *A. rafaelensis* habitat, but these occupy a fairly small footprint.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds do not contain specialized structures to aid in dispersal, and likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, *A. rafaelensis* has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold environments. It occurs in dry washes and cliff bases in areas dominated by pinyon-juniper.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, *A. rafaelensis* has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. rafaelensis* occurs in a semi-arid climate with an average of 11.73 inches of precipitation per year (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. rafaelensis.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. *A. rafaelensis* occurs in pinyon-juniper habitats. These habitats are more likely to burn with increased temperatures and an increase in weedy species that comprise the understory, such as cheatgrass.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All *Astragalus* species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. rafaelensis* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. rafaelensis* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

## Literature Cited

Colorado Natural Heritage Program. 1997+. Colorado Rare Plant Guide. www.cnhp.colostate.edu. Latest update: June 30, 2014.

Colorado Natural Heritage Program (CNHP). 2014. Biodiversity Tracking and Conservation System (BIOTICS). Colorado Natural Heritage Program, Colorado State University, Fort Collins.

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USGS National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.

## *Astragalus ripleyi*

**Ripley's milkvetch**
**G3/S2**
**Family: Fabaceae**

Photo: Courtesy of Colorado Natural Areas Program

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted precipitation decreases; high mountains that act as natural barriers and habitat alteration that results from conversion to farmland, and livestock grazing, which act as anthropogenic barriers to range shift; limited seed dispersal distance; alteration to the natural fire disturbance regime; restriction to a somewhat uncommon geology; and pollinator limitations. Suitable habitat is likely to be reduced and reproductive success diminished. Climate models project annual net drying throughout this species range (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution:** *Astragalus ripleyi* has been reported from Colorado in Conejos County (Spackman 1997+) and from New Mexico in Taos and Rio Arriba Counties (NMRPTC 2014). However, within these regions, *A. ripleyi* does not occupy all potential habitat but rather is restricted to volcanic-derived substrates (Ladyman 2003). **Habitat:** *Astragalus ripleyi* exhibits a high degree of habitat specificity. It is apparently restricted to volcanic substrates, in open-canopy ponderosa pine-Arizona fescue savannah, or along the edges of mixed coniferous woodland/forest where Arizona fescue is dominant. **Elevation:** In Colorado, 8200-9300 ft. (Spackman et al. 1997).

**Ecological System:** Ponderosa Pine Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat increase. Natural barriers border the distribution of this species to the east, west and north impairing range shift. *Astragalus ripleyi 's* range is bordered to the west by the high peaks of the northwest-southeast trending San Juan Mountains, to the east by the north-south trending Sangre de Cristo Mountain Range and to the north by the east-west trending La Garita Mountains. Northward migration through the center of the range is inhibited by unsuitable habitat in the San Luis valley (USGS 2014).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Conversion of habitat to farmland (USDA 2012) and habitat alteration by livestock grazing (USDOI BLM 2014) impairs range shift.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Neither existing nor planned renewable energy development will likely impact this species (NRDC 2011).

**C1) Dispersal and movements.** Somewhat increase. Limited and localized dispersal distance in combination with infrequent seedling recruitment increases this species vulnerability to climate change by decreasing migration and establishment potential. Seeds may be dispersed by small mammals, ants and wind or water (Ladyman 2003). Wind can result a dispersal distance of 1- 15 meters, small mammals and ants up to 15 meters and water dispersal distance is highly unpredictable (Vittoz and Engler 2007) but typically not farther than 100m (Cain et al. 2000).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation over the range of *A. ripleyi*, this species has experienced average temperature variation (57.1-77°F) over the past 50 years (NatureServe 2012).

**C2aii) Physiological thermal niche.** Neutral. This species is not dependent on cool or cold environments.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells, the species has experienced average precipitation variation (21-40 inches) over the last 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted precipitation decreases from March through June during this species' growth and reproductive season are likely to reduce establishment and flowering (Ladyman 2003)thus impact abundance, distribution and habitat quality.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. *Astragalus ripleyi* often occupies Ponderosa (*Pinus ponderosa*) forests (CNHP 2014). Historically, short-interval, low-severity surface fires maintained sparse, open stands in most dry

Ponderosa pine forests (Schoennagel et al. 2004). Consequences of decades of fire suppression with the accumulation of fuels in combination with impacts of recent climate change have contributed to an altered fire regime with unprecedentedly large, high-severity wildfires that are beyond the range of natural variability (Schoennagel et al. 2004).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *Astragalus ripleyi* is an edaphic endemic that occurs exclusively on volcanic derived soils associated with the San Juan volcanic field (NatureServe 2014) with a commensurately limited range.

**C4a) Dependence on other species to generate habitat.** Neutral. *Astragalus ripleyi* is not known to be reliant on other species for habitat generation.

**C4c) Pollinator Versatility.** Somewhat increase. *Astragalus ripleyi* appears to be bee-pollinated. Bees and ants have been observed on flowers and bumblebees (*Bombus ternaries*) have been reported as the most common arthropod visitor (NatureServe 2014).

**C4d) Dependence on other species for propagule dispersal.** Neutral. Little evidence has been documented for any particular method of dispersal. However, seed dispersal has been speculated to be effected by ants, mice, and other seed storers, tumbling of dried plants, and wind or water transport (Ladyman 2003) and likely not dependent on a specific species.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. rafaelensis* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. rafaelensis* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown. No studies have been undertaken to determine the genetic structure of either range-wide or local populations although locally endemic species of Astragalus tend to exhibit reduced levels of polymorphism that may imply a reduced robustness against environmental uncertainty (Ladyman 2003).

**C5b) Occurrence of bottlenecks in recent evolutionary history. Unknown.**

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Astragalus tortipes*

**Sleeping Ute milkvetch**
**G1/S1**
**Family: Fabaceae**

Photo: Anderson and Porter

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: 1) *A. tortipes* has experienced a very small range in mean annual precipitation over the last 50 years; 2) seed dispersal distances are probably fairly limited; 3) barriers to movement 4) shrubland habitats occupied by *A. tortipes* may be subject to increased wildfires under the climate change projections of hotter temperatures; 5) potential lack of available soil moisture under projected climate warming; 6) potential symbiotic relationship with root-nodulating bacteria.

**Distribution:** Colorado endemic (Ute Mountain Ute Reservation, Montezuma County). Estimated range is 10 square kilometers (4 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** *A. tortipes* occurs in a mixed desert scrub, consisting of *Atriplex confertifolia*, *Chrysothamnus greenei*, and *Gutierrezia sarothrae* (Anderson and Porter 1994). It is endemic to granite-derived gravels south of the Sleeping Ute (Colorado National Heritage Program 1997). Elevational range 5400-5700 ft (Spackman et al. 1997). **Elevation:** 5450-5700 feet.

**Ecological System:** Desert Shrub

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase/Somewhat Increase. High mountains and unsuitable habitats surround many of the *A. tortipes* occurrences.

**B2b) Distribution relative to anthropogenic barriers.** Increase/Somewhat Increase. Cropland on the western edge of occupied habitat may act as a barrier to movement for *A. tortipes*.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shrubland species were ranked 'Increase' due to the potential of wind and solar development.

**C1) Dispersal and movements.** Increase. Seeds do not contain specialized structures to aid in dispersal, and likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, *A. tortipes* has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold environments. It occurs in dry, upland areas dominated by desert shrubs.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, *A. tortipes* has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *A. tortipes* occurs in a semi-arid climate with an average of 12.95 inches of precipitation per year in nearby Cortez, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *A. tortipes*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. *A. tortipes* occurs in shrubland habitats. These habitats may be more likely to burn with increased temperatures and an increase in weedy species that comprise the understory, such as cheatgrass.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. All *Astragalus* species are ranked 'Neutral' based on USFS species assessments that indicate several western *Astragalus* species are visited by over 20 species of bees (Decker and Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase. *A. tortipes* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. tortipes* also possesses this ability (Decker and Anderson 2004).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Bolophyta ligulata (Parthenium ligulatum)*

**Colorado feverfew**
**G3/S2**
**Family: Asteraceae**

Photo: Bob Skowron

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted temperature increases and precipitation decreases; presence of high mountain ranges and escarpments that present natural barriers; habitat alteration related to oil and gas development and livestock grazing, which act as anthropogenic barriers; possible wind power development on potential future habitat; limited seed dispersal distance; restriction to a relatively uncommon geology; and pollinator limitations. Suitable habitat is likely to be reduced and reproductive success diminished as this species' range becomes warmer and drier. Climate models project annual net drying across the range of this species (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution:** *Bolophyta ligulata* has been reported from Colorado in Rio Blanco and Moffat Counties, and from Utah in Emery County (NatureServe 2014, Welsh et al. 1987).

**Ecological System/Habitat:** *Bolophyta ligulata* is known from barren or semi-barren calciferous or gypsiferous outcrops of the Green River, Uinta, Ferron, Summerville, and Carmel formations in salt desert shrub, serviceberry, rabbitbrush, Indian rice-grass, greasebush, galleta, black sagebrush, pygmy sagebrush, and pinyon-juniper communities (NatureServe 2014). **Elevation:** 1705-2135 meters (NatureServe 2014).

## CCVI Scoring

**Temperature**: Calculated using Climate Wizard: ensemble average, medium emission scenario (A1B), mid-century timeframe, average annual change. In Colorado, this species is expected to be exposed to mean annual temperature increases of 4.5°F by mid-century (NatureServe 2012).

**Moisture:** Calculated in GIS using NatureServe Hamon AET:PET moisture metric data (this index integrates projected temperature and precipitation changes to indicate how much drying will take place). In Colorado this species is predicted to be exposed to net drying of 9.7 to 11.9 percent on 2 percent of its range, 7.4 to 9.6 percent drying on 13 percent of its range, 5.1 to 7.3 percent drying on 71 percent of its range and 2.8 to 5.0 percent drying on 14 percent of its range.

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers. Somewhat increase**. Several mountain ranges and escarpments (USGS 2014) act as barriers to climate change-induced range shift for the majority of populations of *Parthenium ligulatum*.

**B2b) Distribution relative to anthropogenic barriers. Increase. Habitat alteration related to energy extraction and livestock grazing impair a**ll populations of *Bolophyta ligulata* from climate change–induced range shift. All populations occur in or near shale plays and basins and are surrounding by active oil and gas development (FracFocus Wells 2013). Additionally, the majority of this habitat in species range is public land managed by the BLM as rangeland for livestock (BLM 2014).

**B3) Impact of land use changes resulting from human responses to climate change. Somewhat increase.** Existing and planned wind power development on the Utah-Wyoming border (NRDC 2011) may alter habitat on the potential future range of *Bolophyta ligulata.* Because *Bolophyta ligulata* is moderately vulnerable to habitat alteration (Rocchio 2007), wind power-related development may negatively impact this species survivability.

** Bolophyta ligulata's* life history strategies can be suggested by *Bolophyta alpina (Parthenium alpinum)* strategies. *Bolophyta ligulata* is very closely related to *P. alpinum,* such that the original taxonomic rank of *P. ligulatum* was a variety of *P. alpinum* that was later elevated to species level (Heidel and Handley 2004).

**C1) Dispersal and movements**. **Somewhat increase**. Wind is the likely dispersal agent for *Bolophyta alpina* (*Parthenium alpinum),* and thus for *B. ligulata*. Achenes of *B. alpina* have fringed, wing-like membranous extensions of the pappus which can improve dispersal distance up to 15 meters (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average temperature variation (57.1 - 77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat increase.** *Bolophyta ligulata* may require cold temperatures to induce flowering. Winter and spring temperatures are predicted to warm by 4.6$^{o}$F to 4.7$^{o}$F (NatureServe 2012) and thus may be inadequate to promote flowering or conversely may provide miscues that alter flowering phenology. Timing of life history traits is central to lifetime fitness and nowhere is this more important as in the phenology of flowering in governing plant reproductive success (Inouye 2008).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat increase.** Considering the range of mean annual precipitation across occupied cells, the species has experienced small (10.1 inches) precipitation variation in the past 50 years (NatureServe 2014).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat increase**. Although *Bolophyta ligulata* is well adapted to environmental extremes, predicted precipitation decreases during the period of flowering and fruiting may diminish reproductive success.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Unknown.** In Colorado, *Bolophyta ligulata* typically occupies sparsely vegetated sites that do not carry fire well. Although, these sites are also typically surrounded by communities such as sage shrublands and pinyon-juniper woodlands where fire frequencies are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009. However, as yet, impacts on *B. ligulata* has not been documented.

**C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral.** This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives. Increase.** *Bolophyta ligulata* is edaphically restricted to calciferous or gypsiferous outcrops of shales and clays of the Green River, Uinta, Ferron, and Carmel formations (Welsh et al. 1987).

**C4a) Dependence on other species to generate habitat. Neutral.** *Bolophyta ligulata* has not been shown to be dependent on other species to generate habitat.

**C4c) Pollinator Versatility. Somewhat increase.** Pollination of the closely related *B. alpina* may require specialized pollination vectors, suggesting similar pollination requirements for *B. ligulata*.

**C4d) Dependence on other species for propagule dispersal. Neutral.**

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. **Unknown.**

**C5a) Measured genetic variation. Unknown.**

**C5b) Occurrence of bottlenecks in recent evolutionary history. Unknown.**

**C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.**

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## *Camissonia eastwoodiae*

**Eastwood evening primrose**
**G2/S1**
**Family: Onagraceae**

Photo: Janis Huggins

## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) *C. eastwoodiae* has experience a small range in precipitation in the last 50 years; 2) available soil moisture may decrease if temperatures increase as predicted in climate models; 3) potential for increased energy development within suitable habitat; 4) likelihood of short seed dispersal distance; 5) potential for increased fire frequency in pinyon-juniper and shrubland habitat that support *C. eastwoodiae* populations.

**Distribution:** Endemic to the Colorado Plateau. Found in Utah (seven counties), Arizona (2 counties), and Colorado (2 counties, USDA NRCS 2012). **Habitat:** In Colorado this species is found on clay soils derived from Mancos shale with *Atriplex gardneri* a dominant associate. **Elevation:** 4,570-6,050 feet.

**Ecological System:** Saltbush Flats and Fans, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Areas of *C. eastwoodiae* habitat may have potential for increased oil and gas, as well as wind and solar development.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold habitats that are expected to be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *C. eastwoodiae* occurs in a semi-arid climate with an average of 11.33 inches of precipitation per year in nearby Grand Junction, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *C. eastwoodiae.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Increased fire frequency may occur in shrublands and pinyon-juniper ecosystems that support populations of *C. eastwoodiae.*

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Cleome (Peristome) multicaulis*

**Slender spiderflower**
**G2G3/*S2S3***
**Family: Capparaceae**

Photo: Georgia Doyle

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential for solar and wind development in San Luis Valley; 3) likelihood of limited seed dispersal; 4) species has experience very small precipitation variation in last 50 years; 4) restriction to alkaline or saline soils in wetlands.

**Distribution:** Mexico, Texas, Arizona, New Mexico, Wyoming, and Colorado (USDA NRCS 2013). Weber and Wittmann (2012) report that this species is widely distributed in Mexico. **Habitat:** *Cleome multicaulis* is restricted to saline or alkaline soils, around alkali sinks, ponds, alkaline meadows, or old lake beds. The surrounding plant community is saline bottomland shrubland (dominated by *Sarcobatus* and *Chrysothamnus*). The plant often grows in bands just above rushes (*Juncus* sp.) and may extend into greasewood and saltgrass (Graff 1992, Spackman et al. 1997, Colorado Natural Heritage Program 2014). **Elevation:** 7,500-8,200 feet.

**Ecological System:** Grass/Forb Dominated Wetlands; Playas

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Greatly increase. Known occurrences are limited to the floor of the San Luis Valley, and surrounding high mountains may act as a barriers to movement.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. An increase in solar and wind development could occur in the San Luis Valley.

**C1) Dispersal and movements.** Increase. No information is available on dispersal, but seeds likely fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold habitats that are likely to be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. *Cleome multicaulis* is restricted to saline or alkaline soils, around alkali sinks, ponds, alkaline meadows, or old lake beds. These wetland sites occur in the arid climate San Luis Valley, where average annual precipitation is 9.39 inches in Del Norte, CO (Western Regional Climate Center 2015).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Corispermum navicula*

**Boat-shaped bugseed**
**G1?/S1**
**Family: Chenopodiaceae**

Photo: David G. Anderson

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural barriers that would prevent range shifts due to climate change; 2) likelihood of short seed dispersal distances; 3) potential lack of soil moisture under projected climate warming; 4) lack of precipitation variability in last 50 years; 5) restriction to uncommon geologic substrates.

**Distribution:** Considered a Colorado endemic based on recent genetic testing, occurring in Jackson County (Neale et al. 2013). Genetic evidence suggests that North Sand Dunes populations are a separately evolving metapopulation that is well supported as a distinct species compared to C. americanum and C. villosum. A population previously considered to be *C. navicula* in the East Sand Dunes is considered a *C. navicula* x *C. americanum* hybrid (Neale et al. 2013). Estimated range is 17 square kilometers (6 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** Sand dunes (Neale et al. 2013; CNHP 2014). **Elevation:** 8,250-8,730 feet.

**Ecological System:** Barrens, Sandy Areas

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. This species is limited to sand dunes, and surrounding areas contain unsuitable geology and soils.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, *C. navicula* has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. This species occurs in sand dunes that may become drier as a result of higher temperatures.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *C. navicular* occurs in a semi-arid climate with an average of 10.52 inches of precipitation per year in nearby Walden, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *C. navicula.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *C. navicula* is a sand dune endemic (Neale et al. 2013; CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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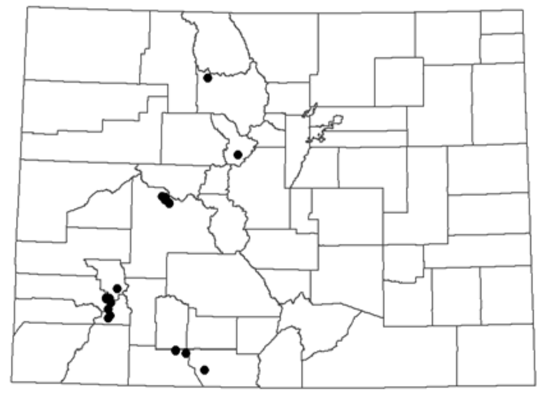
## *Cryptogramma stelleri*

**Slender rock-brake**
**G5/S2**
**BLM sensitive**
**Family: Pteridaceae**

Photo: Peggy Lyon



## Climate Vulnerability Rank: Extremely Vulnerable

This statewide rank is based on restriction to cool, shaded cliff faces, the presence of cliffs and canyons that serve as natural barriers in suitable habitat, restriction to calcareous cliff faces and overhangs with dripping water. Climate models project annual net drying across the range of this species (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). These hotter and drier conditions may result in a loss of suitable habitat for *C. stelleri*.

**Distribution:** Distribution of *C. stelleri* is nearly circumpolar (NatureServe 2013). It is widespread throughout the United States. In Colorado it has been reported from Archuleta, Conejos, Garfield, Grand, Gunnison, Ouray, San Juan, San Miguel, and Summit Counties (CNHP 2013). **Habitat:** Occurs in cracks and crevices of limestone cliffs in moist coniferous forests, generally associated with dripping water. **Elevation:** 4700-10,900 feet.

**Ecological System/Habitat:** Groundwater Dependent Wetlands, Cliff and Canyon Seeps

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Species grows on cliff walls and in shallow rock overhangs that serve as natural barriers.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. There are no significant anthropogenic barriers for this species in the assessment area (Radeloff et al. 2005).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Occurs cliff walls and in shallow rock overhangs. We rate all cliff and canyon species 'Neutral' based on the assumption that development in this habitat is unlikely in most mitigation scenarios.

**C1) Dispersal and movements.** Neutral. Although dispersal mechanisms are unknown, wind and water likely transport spores.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Species has experienced average temperature variation (57.1 to >77°F/31.8-43°C) in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Species that occur in seeps in cliffs and canyons were all rated 'Increase' under the assumption that this habitat may be lost as Colorado becomes warmer, and presumably drier.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat decrease. The species has experienced greater than average (>40 inches/1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. Species occurs on cliff walls and in shallow rock overhangs with dripping water. We rated cliff and canyon species that prefer wetter micro sites as 'Greatly Increase' based on the assumption that these habitats may be lost as Colorado's climate becomes warmer and drier.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Little dependence on snow or ice cover.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Species is restricted to calcareous cliffs and canyons (Hulten 1968).

**C4a) Dependence on other species to generate habitat.** Neutral.

**C4c) Pollinator Versatility.** Neutral. *C. stelleri* is a fern that produces spores, so it does not rely on pollinators.

**C4d) Dependence on other species for propagule dispersal.** Unknown.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5) Genetic factors.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Erigeron kachinensis*

**Kachina daisy**
**G2/S1**
**Family: Asteraceae**

Photo: Lorainne Yeatts

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) restriction to wet, saline soils along cliff and canyon walls that may become hotter and drier; 3) lack of variation in precipitation in last 50 years.

**Distribution:** Endemic to the Colorado Plateau in Colorado and Utah. Know from one county in Utah (San Juan County), and several in Colorado. **Habitat:** Occurs in wet, saline soils in alcoves, seeps, and hanging gardens on sandstone cliffs and canyon walls (Allphin 1991, Spackman et al. 1997, Ackerfield 2012, Culver and Lemly 2013). Associated species include *Epipactis gigantea*, *Aquilegia micrantha*, *Mimulus eastwoodiae*, and *Calamagrostis*. Surrounding plant communities include Pinyon-juniper, *Fraxinus,* and *Salix* (CNHP 2014). **Elevation:** 4,700-6,700 feet.

**Ecological System:** Cliff and Canyon

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. *E. kachinensis* occurs in hanging gardens and alcoves in canyons. Cliffs and canyons that serve as habitat for the species also present barriers to movement.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. **B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Cliff and canyon species, such as *E. kachinensis*, were rated 'Increase' based on their restriction to cool, moist pockets in canyons that may become warmer and drier due to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. *E. kachinensis* relies on a localized moisture regime from seeps. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Tolerance levels for *E. kachinensis* are unknown, but increased temperatures may lead to soil drying and a loss of suitable habitat for this rare plant species.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. *E. kachinensis* occurs on wet, saline soils in alcoves and hanging gardens on canyon walls.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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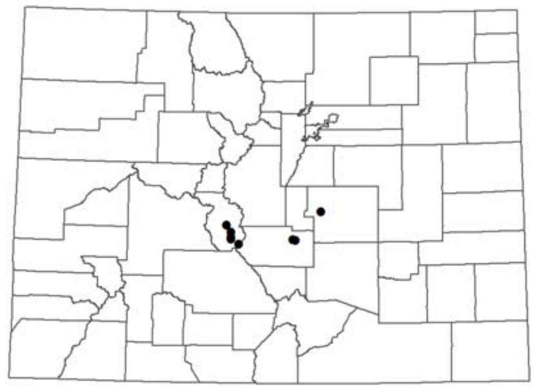
## *Eriogonum brandegeei*

**Brandegee wild buckwheat**
**G1G2/S1S2**
**Family: Polygonaceae**

Photo: Susan Spackman Panjabi



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to dispersal; 2) lack of range of variability in precipitation in the past 50 years; 3) potential decrease in soil moisture availability with increased temperatures; 4) restriction to specific geologic features and soil types.

**Distribution:** Endemic to Colorado; Fremont and Chaffee counties. Six of the nine verified occurrences are located within a 5 by 15 mile area along the Arkansas River in Chaffee County. The other three are about 50 miles away in a 2 by 3 mile area at Garden Park, north of Canon City in Fremont County (Anderson 2006). Questionable reports of *E. brandegeei* in other areas are considered to be mislabeled (Anderson 2006). Estimated range is 6,828 square kilometers (2,636 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** Occurrences of *Eriogonum brandegeei* are limited mostly to outcrops of the Dry Union Formation (in Chaffee County) and lower members of the Morrison Formation (in Fremont County), or to Quaternary strata that are derived from these formations (O'Kane 1988; Spackman et al. 1997; Anderson 2006). The unifying feature of all the known occurrences is the presence of a significant portion of bentonite clay in the soil (Anderson 2006). *Eriogonum brandegeei* is most commonly found on active, very steep slopes, and less frequently on flat sites (Anderson 2006). In general, this species is found on barren outcrops of white to grayish soils within open sagebrush and pinyon-juniper communities. **Elevation:** 5,715-8,648 feet.

**Ecological System:** Barrens, Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. High mountains and the Arkansas River are located between populations of *E. brandegeei*, and these may present barriers to dispersal.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Energy development is unlikely to occur on the steep slopes occupied by this species.

**C1) Dispersal and movements.** Somewhat Increase/Neutral. *Eriogonum* species have potential for effective dispersal by wind, water, and animals (Anderson 2006).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, *E. brandegeei* has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *E. brandegeei* occurs in a semi-arid climate with an average of 12.77 inches of precipitation per year in nearby Canon City, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *E. brandegeei.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *E. brandegeei* occurs on outcrops of the Dry Union Formation and the Morrison Formation, as well as Quaternary strata derived from these formations; soils that support these occurrences contain bentonite clay (O'Kane 1988; Spackman et al. 1997; Anderson 2006).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. Species of *Eriogonum* are typically pollinated by generalist pollinators (Reveal pers. comm. in Anderson 2006; Tepedino 2002).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Eriogonum clavellatum*

**Comb Wash buckwheat**
**G2/S1**
**Family: Polygonaceae**

Photo: Courtsey of the Colorado Natural Areas Program

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) potential for wind and solar energy development in *E. clavellatum* habitat; 3) likelihood of short seed dispersal distances; 4) potential decrease in soil moisture due to projected higher temperatures; 5) lack of variability in annual precipitation in last 50 years; 6) potential increase in fire frequency in *E. clavellatum* occupied habitat.

**Distribution:** Known from Montezuma County in Colorado. Estimated range in Colorado is 117 square kilometers (45 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** This species is found in fine textured soils, sandy silt to clay silt. Dominant plant communities are shadscale and blackbrush associations. Other associated species include *Atriplex confertifolia* and *Coleogyne ramosissima* (Welsh 1978). **Elevation:** 4,813-6,033 feet.

**Ecological System:** Desert Shrub, Saltbrush Fans and Flats

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Irrigated cropland may create barriers to dispersal.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. The relatively flat, semiarid lands in SW Colorado have potential for solar and wind energy development.

**C1) Dispersal and movements.** Increase. No information is available on seed dispersal distances, but it is likely that *E. clavellatum* seeds fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species occurs in dry, upland areas in SW Colorado and is not restricted to cool or cold climates.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *E. clavellatum* occurs in a semi-arid climate with an average of 12.95 inches of precipitation per year in nearby Cortez, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *E. clavellatum.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Shrublands may experience more frequent wildfires if temperatures increase as projected.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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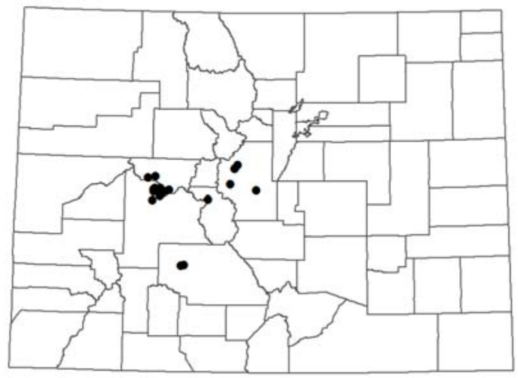
## *Eriogonum coloradense*

**Colorado wild buckwheat**
**G2/S2**
**Family: Polygonaceae**

Photo: Delia Malone



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) likelihood of short seed dispersal distances; 3) potential loss of soil moisture due to projected climate warming.

**Distribution:** Endemic to Colorado; known from Chaffee, Gunnison, Park, Pitkin, and Saguache counties. Estimated range is 9,318 square kilometers (3,598 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** *Eriogonum coloradense* is unusual in that it has an extremely broad ecological range. It has been documented on every soil texture, slope, and aspect. It has been found on sedimentary, granitic, and volcanic substrates, with *Artemisia* species (sagebrush) and *Bouteloua gracilis* (blue grama) and also with alpine cushion plants. It is found on a variety of geomorphic landforms, usually on talus, fellfields, rock shoots, and ridges, but also on roadsides (Anderson 2004). Reveal (personal communication 2002) described the habitat as rocky talus on the margins of meadows, grassland communities, high elevation sagebrush, sometimes with montane or subalpine conifers, and on sandy to gravelly flats and slopes. **Elevation:** 8,714-14,259 feet.

**Ecological System:** Foothill/Mountain Grassland, Shrub Tundra, Meadow Tundra

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Known occurrences are from a broad elevation range: 8,714 to 14,259 ft. High mountains and river valleys may act as natural barriers to dispersal.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Somewhat Increase/Neutral. Wind, rain, streams, and animals may all act as dispersal agents for *Eriogonum* seeds (Stokes 1936).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. This species occurs in subalpine and alpine habitats that are predicted to warm under most climate change scenarios.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells, the species has experienced average (21 - 40 inches/509 - 1,016 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants, and this may have negative consequences for *E. coloradense*, although tolerance thresholds are unknown. Under climate modeling scenarios that predict faster snowmelt and increased summer temperatures, lower amounts of soil moisture would be available for *E. coloradense*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Somewhat Increase. This species occurs in alpine habitats that may be covered in snow for extended periods of time.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Occurs at a wide range of elevations, and on several different soils types (see habitat description above).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. Species of *Eriogonum* are typically pollinated by generalist pollinators (Reveal pers. comm. in Anderson 2006; Tepedino 2002).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Eriogonum contortum*

**Grand buckwheat**
**G3/S2**
**Family: Polygonaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted increase in temperatures and decreasing precipitation during flowering; natural barriers in the form of high elevation mountains and escarpments that present unsuitable environments, and anthropogenic barriers from oil and gas development; possible wind power development on potential future range; limited seed dispersal distance; alteration to the natural fire disturbance regime; and limitation to a somewhat uncommon geologic feature. Climate models project annual net drying across the range of this species in Colorado (NatureServe 2012) which may result in more severe soil-moisture drought in Colorado (Lukas et al.2014).

**Distribution:** *Eriogonum contortum* has been reported from Colorado in Garfield and Mesa Counties, and in Utah from Grand and Emery Counties (Kartesz 2014). Plant distribution is localized on Mancos Shale in western Mesa County, Colorado and in the Grand Valley of eastern Grand County, Utah with disjunct populations occurring just outside Grand Valley in Garfield County, Colorado, and in Emery County, Utah (FNA 2013). **Habitat:** *Eriogonum contortum* occupies cold-desert shrubland ecosystems commonly occurring with plant communities such as big sage shrublands, semi-desert grasslands, and shadscale and other saltbrush communities (Welsh et al. 1993, SEINet 2014). **Elevation:** 4500 -5100 feet.

**Ecological System:** Desert Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Greatly increase. High escarpments of the east-west trending Roan Plateau and Bookcliffs, which routinely reach 7,000 to 9,000 feet in elevation (USGS 2014) present environmental conditions and vegetation communities that are beyond the natural range of variation of this low elevation plant species and are thus barriers to range shift.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Range shift is impaired by habitat alteration related to oil and gas development which occurs 25 to 50 miles north of *Eriogonum contortum's* current distribution which is also underlain by shale plays and basins (FracFocus Wells 2013).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat Increase. Potential for wind energy development is high on the southern border of Wyoming (NRDC 2011) and may possibly occur within the future range of *Eriogonum contortum*. Associated infrastructure development and habitat alteration are incompatible with natural history requirements of *E. contortum.* Impacts to flora from wind power development-related habitat and ecosystem modification include but are not limited to displacement from an area, habitat destruction and reduced reproduction (IPCC 2011).

**C1) Dispersal and movements.** Somewhat increase. Seed dispersal strategies likely depend on wind, animals or water (Taliga and Glenne 2011) and thus limit *Eriogonum contortum* ability to shift range with climate change. Seed dispersal by wind is typically limited to less than 15m, dispersal by small mammals is typically less than 30 m, by insects less than 15m, and dispersal by water such as would occur with heavy rain, is highly unpredictable and undocumented (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average temperature variation (>77$^{o}$F) within the last 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase. *Eriogonum contortum* is not restricted to cold or cool environments. However, all Eriogonum species studied thus far have seeds that require a cold period to break dormancy (vernalization) (NatureServe 2014). Temperatures during winter are predicted to increase an average of 4.5$^{o}$F across this species range which may impact vernalization and thus reproductive success (NatureServe 2012).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across the range of this species, *E. contortum* has experienced small precipitation variation (4.8 inches) over the last 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Precipitation is predicted to decrease during the majority of the period of flowering (May-August (Spackman et al. 1997)(NatureServe 2012). Flowering may be considered one of the most vulnerable times to environmental stressors and declines in precipitation during this period may reduce seedling recruitment and population abundance.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Fire frequencies in ecosystems occupied by this species are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009, USFS no date). Climate change models also predict increases in fire area and severity throughout the region occupied by this species (Krawchuk et al. 2009, Westerling et al. 2011). Further, invasion of cheatgrass (*Bromus tectorum*) into these systems promotes fire spread that contributes to altered fire disturbance regimes (Chambers et al. 2013).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on cool or cold habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase. Current distribution of *Eriogonum contortum* is limited to Mancos shale (CNHP 2014). With climate change, suitable climate for this species may shift away from this geologic feature resulting in loss of habitat. Due to the limited range of the Mancos shale formation (Tweto 1979), successful migration in response to climate change to habitat with suitable geology is uncertain.

**C4a) Dependence on other species to generate habitat.** Neutral. *Eriogonum contortum* is not dependent on other species for habitat generation.

**C4c) Pollinator Versatility.** Neutral. *Eriogonum contortum's* pollination strategy may be similar to the related species, *E. pelinophilum* which is visited by more than 50 species pollinators in a season (Taliga and Glenne 2011). However, Tepedino (2011) noted that of all Eriogonum species studied to date, none has as many pollinators as *E. pelinophilum.*

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Eriogonum contortum* seeds, similar to the seeds of *E. pelinophilum*, are likely dispersed by several mechanisms including wind, water, animals and gravity (Taliga and Glenne 2011) and thus not dependent on other species for dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Eriogonum ephedroides*

**Ephedra buckwheat**
**G3/S1**
**Family: Polygonaceae**

Photo: Janis Huggins

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted increased temperatures and decreased precipitation; natural barriers in the form of high elevation mountains that present unsuitable environments, and anthropogenic barriers resulting from oil and gas development and livestock grazing; possible wind power development on potential future range; limited seed dispersal distances; alteration of the natural fire disturbance regime; and limitation to the relatively uncommon geology of the Mahogany zone of the Green River shale formation. Climate models project annual net drying across the entire species' range (NatureServe 2012) which may result in soil drought.

**Distribution:** *Eriogonum ephedroides* has been reported from Colorado in Rio Blanco and Moffat counties (CNHP 2014) and from adjacent Uintah County in Utah (NRCS 2012) where populations occupy the south and west slopes of the Uinta basin (USGS 2014). **Habitat:** *Eriogonum ephedroides* is found in open canopy pinyon-juniper woodlands and cold desert shrublands that include sagebrush and mixed desert shrublands. It occurs on white shale of the Green River Shale Formation (CNHP 2014, Welsh et al. 1987). **Elevation:** 5300 - 6100 feet.

**Ecological System:** Pinyon-Juniper Woodlands, Sagebrush Shrublands, Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Natural barriers may limit the ability of *Eriogonum ephedroides* to shift range in response to climate change. Distribution of *E. ephedroides* in Colorado is bounded by the Colorado Rocky Mountains to the east and the Wasatch Mountains to the west (USGS 2014).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Anthropogenic development-related habitat alteration from energy extraction (FracFocus Wells 2013) and livestock grazing (BLM 2014) has created barriers which inhibit *E. ephedroides* populations from shifting range in response to climate change.

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Existing and planned wind power development on the Utah-Wyoming border (NRDC 2011) may impact the potential future range of *Eriogonum ephedroides. Eriogonum ephedroides* is highly vulnerable to habitat alteration as indicated by a "C" (coefficient of conservatism) value of "8" (Rocchio 2007). Impacts to flora from wind power development-related habitat and ecosystem modification include but are not limited to displacement, habitat destruction and reduced reproduction (IPCC 2011, Risser 2007).

**C1) Dispersal and movements.** Somewhat increase. Seed dispersal strategies likely depend on wind, animals or water (Taliga and Glenne 2011) and thus limit *Eriogonum ephedroides* ability to shift range with climate change. Seed dispersal by wind is typically limited to less than 15m, dispersal by small mammals is typically less than 30 m, by insects less than 15m, and dispersal by water such as would occur with heavy rain, is highly unpredictable and undocumented (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells *Eriogonum ephedroides* has experienced average temperature variation (57.1 - 77$^{o}$F) in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche:** Somewhat increase. *Eriogonum ephedroides* is not restricted to cool or cold climates and shows a preference for environments at the warmer end of the spectrum. However, all *Eriogonum* species studied thus far have seeds that require a cold period to break dormancy (vernalization) (NatureServe 2014). Temperatures during winter are predicted to increase an average of 4.5$^{o}$F across this species range which may impact vernalization and thus reproductive success (NatureServe 2012).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, *Eriogonum ephedroides* has experienced small precipitation variation (9.8 inches) in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat increase. Predicted precipitation decreases over the entirety of this species range throughout the growth and flowering season (NatureServe 2012) may result in decreased flowering and seedling recruitment (USFWS 2009) thereby negatively impacting reproductive success and long-term population viability**.**

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Current trends and modeled future changes in fire probability show increased probability of fire throughout the region occupied by this species (Cleetus and Mulik 2014, Krawchuk et al. 2009, Westerling et al. 2006, Chambers et al. 2013). Multiple studies have found that, in response to predicted climate change scenarios, sagebrush and pinyon-juniper ecosystems, such as those occupied by this species, will decline and become more fragmented over the next century, following current trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009, USFS no date). Further, invasion of cheatgrass (*Bromus tectorum*) into these systems promotes fire spread that contributes to altered fire disturbance regimes (Chambers et al. 2013).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *Eriogonum ephedroides* is an edaphic endemic that is limited to shale of the Green River formation and specifically to the shale layers just above the oil rich shale layers of the Mahogany Zone (NatureServe 2014, Schultz and Mutz 1979). Areal extent of the mahogany zone is limited (Tweto 1979) which limits potential for range shift.

**C4a) Dependence on other species to generate habitat.** Neutral. *Eriogonum ephedroides* is not known to be dependent on other species for habitat generation.

**C4c) Pollinator Versatility.** Unknown. *Eriogonum ephedroides'* pollination strategy may be similar to the related species, *E. pelinophilum* which is visited by more than 50 species of pollinators in a season (Taliga and Glenne 2011). However, Tepedino (2011) noted that of all Eriogonum species studied to date, none has as many pollinators as *E. pelinophilum.*

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Eriogonum ephedroides* seeds, similar to the seeds of *E. pelinophilum*, are likely dispersed by several mechanisms including wind, water, animals and gravity (Taliga and Glenne 2011).

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Eriogonum pelinophilum*

**Clay-loving wild buckwheat**
**G2/S2**
**Listed Endangered**
**Family: Polygonaceae**

Photo: Lori Brummer

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers to movement; 2) likelihood of short seed dispersal distances; 3) lack of variation in annual precipitation in occupied habitat over last 50 years; 4) potential increase in climate influenced disturbances within its habitat, 5) potential for wind and solar energy development within its range, and; 5) preference for Mancos shale badlands.

**Distribution***:* Endemic to Colorado, known from Delta and Montrose counties, Colorado. Estimated range is 420 square kilometers, calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** *Eriogonum pelinophilum* occurs on Mancos Shale badlands (Spinks 1991), in salt desert shrub community with *Atriplex confertifolia* and *Atriplex corrugata* (Reveal 1973). **Elevation:** 5220-6378 feet.

**Ecological System:** Desert shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Many areas surrounding occupied *Eriogonum pelinophilum* habitat do not contain Mancos shale badlands that are necessary to support this species.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Agricultural, residential and commercial development in the Montrose area may act as barriers to *E. pelinophilum* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren and shrubland habitats are rated Increase due to the potential for wind, solar, and bioenergy development (Grunau et al. 2011).

**C1) Dispersal and movements.** Increase. Seeds most likely fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *Eriogonum pelinophilum* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Eriogonum pelinophilum* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *E. pelinophilum* has experienced small (4-10 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *E. pelinophilum*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. Species that inhabit shrublands and pinyon-juniper are more likely to burn under climate change scenarios due to increased temperatures and increase in weedy understory (especially cheatgrass) (Grunau et al. 2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives**. Somewhat Increase. Prefers Mancos Shale derived soils which are common in the species range (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *Eriogonum pelinophilum* has a high diversity of pollinators and a generalized flower morphology (Tepedino et al. 2011), and is reported to be visited by more than 50 species of pollinators in a season (Taliga and Glenne 2011).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Eriogonum pelinophilum* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Eutrema penlandii*

**Penland alpine fen mustard**
**G1G2/S1S2**
**Listed Threatened**
**Family: Brassicaceae**

Photo: Jill Handwerk

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *Eutrema penlandii's* preference for wet soils with year round moisture, dependence on moisture from ice and snow melt, its predicted sensitivity to changes in precipitation, the presence of natural barriers to range shift, and limited dispersal ability.

**Distribution***:* Colorado endemic known from Lake, Park and Summit counties. Limited to a 25 mile stretch of the Continental Divide, above 12,000 feet. **Habitat:** Alpine tundra, downslope from snowfields, which provide melt water all summer. The plants are usually found on south- and east-facing flat to gently sloping benches with steep walls that provide some protection from snow-melting winds. On these wet benches, the plants are found in moss-covered peat fens, bogs, or marshes that are wet year-round with a constant source of flowing water. Most of the populations are on limestone substrates, which have created unusually basic wetland soils, but it is not certain that the species is restricted to calcareous substrates. **Elevation:** 11,975-13,350 feet.

**Ecological System:** Wetland

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on wetlands habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of old mining operations, there are few anthropogenic barriers to *Eutrema penlandii* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. No wind or solar energy development is likely in *Eutrema penlandii* habitat.

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Eutrema penlandii* has experienced average temperature variation (57.1 to 77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Habitat for species occurring in alpine environments are likely to become warmer and drier (Grunau et al. 2011).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells in Colorado, *Eutrema penlandii* has experienced average (21-40 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. This species occurs in moss-covered peat fens, bogs, or marshes that are wet year-round with a constant source of flowing water. These micro-habitats may be vulnerable to climate change.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Somewhat increase. *Eutrema penlandii* is somewhat dependent on ice or snow melt water to maintain the wet habitat in which it grows.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Most of the populations of *Eutrema penlandii* are on limestone substrates, which have created unusually basic wetland soils, but it is not certain that the species is restricted to calcareous substrates.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Eutrema penlandii* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Gentianella tortuosa*

**Cathedral Bluff dwarf gentian**
**G3? /S1**
**Family: Gentianaceae**

Photo: Rusty Roberts

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: restriction to somewhat cooler environments; predicted temperature increases and precipitation decreases; the presence of unsuitable habitat in low elevation ecosystems which act as natural barriers; habitat alteration from oil and gas development and livestock grazing, that act as anthropogenic barriers to range shift; limited seed dispersal distance; possible wind power development which may impact potential future range; alteration to the natural fire disturbance regime; restriction to geology that is fairly uncommon and limited in distribution; and limitation to a specific suite of pollinators. Suitable habitat is likely to be reduced as this species' range becomes warmer and drier and reproductive success diminished. Climate models project annual net drying of 12 to 14 percent (NatureServe 2012) over the entirety of this species range.

**Distribution***:* *Gentianella tortuosa* has been reported from Colorado in Rio Blanco County as well as central and southwest Utah and southern Nevada (NatureServe 2014). **Habitat:** *Gentianella tortuosa* occurs in sagebrush shrublands through spruce-fir forests on shale outcrops of the Green River Formation (NatureServe 2014, ESCO 2009). **Elevation**: 8500 to 10,800 feet.

**Ecological System:** Barrens, Sagebrush Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Colorado populations of *Gentianella tortuosa* occur at higher elevations on the Roan Plateau, where they are impaired from range shift by the intervening White River basin (USGS 2014). Lower elevation habitats in the White River basin range from 5,000 to 5,700 feet and are characterized by saltbush shrublands, shale badlands, semi-desert grasslands and sagebrush shrublands (CNHP 2014) which presents unsuitable habitat and thus impairs range shift for this species.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Colorado populations are inhibited from range shift by habitat alteration that has resulted from oil and gas development on the Roan Plateau and in the Rangely oil field (FracFocus Wells 2013) as well as by livestock grazing on lands surrounding the occurrences and north of the oil fields (BLM 2014). *Gentianella tortuosa* is highly vulnerable to habitat alteration as indicated by a "C" (coefficient of conservatism) value of "8" (Rocchio 2007).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Existing and planned wind power development on the Utah-Wyoming border (NRDC 2011) may impact the potential future range of *Gentianella tortuosa.* Impacts to flora from wind power development-related habitat and ecosystem modification include but are not limited to displacement from an area, habitat destruction and reduced reproduction (IPCC 2011, Risser 2007).

**C1) Dispersal and movements.** Somewhat increase. Likely dispersal strategies include wind and possibly water, both which provide only limited dispersal capacity (GRN 2011). As suggested by dispersal mechanisms of related species, seeds are often aided by special structures or morphology that enhances dispersal by wind (GRN 2011). Seed dispersal by wind is typically limited to less than 15m, and dispersal by water, such as might occur with heavy rain, is highly unpredictable and undocumented (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells in Colorado, *Gentianella tortuosa* has experienced average temperature variation (57.1-77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat increase. *Gentianella tortuosa* is somewhat restricted to relatively cool environments that may be lost to this species as a result of climate change. Predicted annual temperature increases of 5.0 to 5.5oF (NatureServe 2012) may be beyond the range of natural variability. High temperatures may have a general negative effect on plant growth and development by impacting physiology, biochemistry and gene regulation pathways (Bita and Gerats 2013).

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *Gentianella tortuosa* has experienced very small precipitation variation (1.7 inches) in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat increase. Predicted precipitation declines during flowering of 1-3 percent (NatureServe 2012) may negatively impact reproductive success and consequently this species abundance and distribution. Drought at flowering is critical as it can increase pollen sterility and during growth period impairs normal growth, disturbs water relations, and reduces water use efficiency in plants (Farooq et al. 2012).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Multiple studies have found that, in response to predicted climate change scenarios, sagebrush and pinyon-juniper ecosystems, will decline and become more fragmented over the next century, following current trends which already document increased fire frequencies, burned area and also increasing fire severity (Cleetus and Mulik 2014, Stephens 2005, Westerling et al. 2006, Littell et al. 2009, USFS no date). Further, modeled future changes in fire probability and of vegetation patterns show increased probability of fire throughout the region occupied by this species and that both pinyon-juniper woodlands and sagebrush shrublands may be reduced in the future due to increased fire frequencies (Krawchuk et al. 2009, USFS no date, Westerling et al. 2006).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat increase. *Gentianella tortuosa* is endemic to Green River shale (CNHP 2014) which is not highly uncommon but neither is this formation one of the dominant types in the region (Tweto 1979).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. Flower morphology suggests conformation to a specific pollinator syndrome and pollination strategies of closely related genera (GRN 2011), suggest reliance on pollination by bumblebees (genus Bombus).

**C4d) Dependence on other species for propagule dispersal.** Neutral. As suggested by related species, *Gentianella tortuosa* is likely dependent on wind or water for dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d.** Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Gilia (Aliciella) stenothyrsa*

**Narrow-stem Gilia**
**G3/S1**
**Family: Polemoniaceae**

Photo: Delia Malone

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state rank is based on: predicted decreased precipitation; short dispersal distances; the presence of mountains that serve as natural barriers and the presence of oil and gas development that serve as anthropogenic barriers to range shift; altered fire disturbance regimes; pollinator limitation; and a decrease in modeled future range with little overlap with current range or inclusion in protected areas. Climate models project annual net drying across this species range (NatureServe 2014) which may impact recruitment and population survivability.

**Distribution:** *Gilia stenothyrsa* has been reported from Utah and Colorado in the United States (NatureServe 2014). In Colorado, the species is known from Rio Blanco and Mesa counties and in Utah from Carbon, Emery, Duchesne, and Uinta counties (NatureServe 2014). **Habitat:** Grasslands, sagebrush and mountain-mahogany shrublands, or pinyon-juniper woodlands on silty to gravelly loam soils derived from the Green River or Uinta Formations (Spackman et al. 1997). **Elevation:** 5300 to 6230 feet.

**Ecological System:** Sagebrush Shrublands, Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. With changing climate, *Gilia stenothyrsa* is predicted to move northward, tracking climate more suitable to its evolved environmental tolerances and ecological niche (UVUH 2014). Potential for successful range shift is inhibited by east-west trending Uinta Mountains, Douglas Mountain and the Blue Mountain escarpment which presents elevational, environmental and habitat barriers to range shift (CNHP 2014).

**B2b) Distribution relative to anthropogenic barriers.** Greatly increase. Oil and gas development occurs in a wide east-west trending belt across this region of Colorado extending into Utah (FracFocus Wells 2013), and presents a barrier to range shift for all populations of *A. stenothyrsa*. Additionally, all populations occupy either shale plays that are likely to contain significant oil and gas reserves or shale basins, broad depositional areas that may contain one or more shale plays (FracFocus Wells 2013).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Potential for wind energy development is high on the southern border of Wyoming (NRDC 2011). Associated infrastructure development and habitat alteration that may occur within its future range are incompatible with natural history requirements of *Gilia stenothyrsa*.

**C1) Dispersal and movements.** Somewhat Increase. Although the dispersal mechanism for *Gilia stenothyrsa* is unknown, dispersal likely occurs by wind and water, as suggested by dispersal strategy of several other species in this genus, including *A. penstemonoides* and *A. tenuis* (Beatty 2004, Grant 1959). Maximum wind dispersal distances for the type of seeds that this species has is less than 15 meters and water dispersal is highly unpredictable and undocumented (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average temperature variation (57.1-77°F) in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Somewhat decrease. *Gilia stenothyrsa* shows a preference towards environments that are at the warmer end of the environmental temperature spectrum.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower that average precipitation variation (11-20 inches) in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Although *A. stenothyrsa* evolved in an arid environment, future climate-change induced drought regimes (duration and frequency) are projected to produce more severe droughts in the southwest (USGCRP 2014) and may be outside of the range of evolved environmental tolerances of this species. Variable rainfall is known to drive fluctuations in plant populations. Very low recruitment of a closely related species, *Gilia caespitosa,* was noted by Carol Dawson (1998) and her observations suggest that fluctuations in recruitment are primarily related to precipitation patterns and availability of safe germination sites.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. This species commonly occupies Pinyon-Juniper woodlands and sage shrublands where fire frequencies are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009). Climate change models also predict increases in fire area and severity throughout the region occupied by this species (Krawchuk et al. 2009, Westerling et al. 2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. This species is not restricted to uncommon geological features but does specifically occupy silty to gravelly loam soils derived from the Green River or Uinta Formations (Spackman et al. 1997) which do occur over a relatively large area (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. This species does not require other species to create its habitat.

**C4c) Pollinator Versatility.** Somewhat increase. Cross pollination by insects (e.g., bumblebees, beeflies) is an important reproductive strategy for many Gilia species (Beatty et al. 2004) and typically includes hummingbird pollination (Porter and Heil 1994). Although no pollinator information is available for *A. stenothyrsa*, floral characteristics (Rosas-Guerrero et al. 2014) and pollinators of several closely related species can provide clues as to likely pollinators for this species suggesting that this species likely relies on a small suite of pollinators.

**C4d) Dependence on other species for propagule dispersal.** Neutral. Although little is known of the means of seed dispersal, as suggested by seed size (SEINet 2014) and methods of dispersal by other closely related species, this species likely disperses on its own and likely through the action of wind and rain (Beatty et al. 2004).

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

**Section D. Documented or Modeled Response to Climate Change *(optional)***

**1) Documented Response to Recent Climate Change (e.g., range contraction or phenology mismatch with critical resources).** Unknown.

**2) Modeled Future (2050) Change in Range or Population Size .** Increase. Colorado populations are located at similar latitudes and occupy similar habitats as Utah populations, which are predicted to experience 50-99 percent range contraction (UVUH 2014). Colorado populations can be expected to experience similar climate change impacts and can be expected to experience similar range change.

**3) Overlap of Modeled Future (2050) Range with Current Range .** Increase. Colorado populations are located at similar latitudes, and occupy similar habitats as Utah populations where predicted future range overlaps the current range by 30% or less (UVUH 2014). Colorado populations can be expected to experience similar range change.

**4) Occurrence of Protected Areas in Modeled Future (2050) Distribution.** Somewhat Increase. 5-30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas. Disturbance events or extractive or multiple uses are permitted in the majority of current and predicted range (USGS 2014).

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## *Gutierrezia elegans*

**Lone Mesa snakeweed**
**G1/S1**
**Family: Asteraceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) likelihood of short seed dispersal distances; 3) potential for energy development in occupied G. elegans habitat; 4) potential increase in fire frequency intervals in sagebrush habitats; 5) lack of variation in annual precipitation rates in the last 50 years; 6) restriction to Mancos shale substrates.

**Distribution:** This species is known only from Dolores County, Colorado. **Habitat:** This species is found on outcrops of grayish, argillaceous, bare Mancos shale outcrops with thin soil over the shale. *Gutierrezia elegans* is scattered to abundant in the barrens and also occurs with *Artemisia nova* and other species in sites with deeper soil over the shale. Associated species include *Helianthella microcephala, Tetraneuris acaulis, Eriogonum lonchophyllum, Petradoria pumila, Astragalus missouriensis* var. *amphibolus*, and *Heterotheca villosa. Pinus ponderosa* and pinyon-juniper characterize the surrounding slopes (Schneider et al. 2008, CNHP 2012). **Elevation:** 7,526-7,808 feet.

**Ecological System:** Barrens, Sagebrush

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Many areas surrounding occupied *G. elegans* habitat do not contain Mancos shale outcrops are necessary to support this species.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Water development and roads have fragmented suitable habitat and may create barriers to movement (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren habitats are rated Increase due to the potential for wind, solar, and bioenergy development.

**C1) Dispersal and movements.** Increase. Seeds are wind-dispersed, but most fall close to parent plant (Tirmenstein 1999).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat** Increase. Projected increases in temperatures may result in less soil moisture available for *G. elegans*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *G. elegans* is found on outcrops of grayish, argillaceous, bare Mancos shale outcrops with thin soil over the shale.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Ipomopsis polyantha*

**Pagosa skyrocket**
**G1/S1**
**Listed Endangered**
**Family: Polemoniaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) likelihood of short seed dispersal distances; 3) potential decrease in soil moisture availability due to increasing temperatures; 4) restriction to Mancos Shale-derived soils; 5) lack of variation in precipitation in occupied habitat over last 50 years; 6) potential for energy development in occupied habitat.

**Distribution:** Known from Archuleta County in southern Colorado. Estimated range is 48 square kilometers, calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** In Colorado, on rocky clay soils of the Mancos Shale in the southern San Juan Mountains, typically on road shoulders where the soil has been disturbed. Highest densities are under *Pinus ponderosa* forests with montane grassland understory (Anderson 1988, Anderson 2004). *Ipomopsis polyantha* occurs on Cretaceous Mancos Shale Formation where it can be either a pioneer on raw shale or a climax species under ponderosa pine forests or *Pinus edulis/Juniperus osteosperma/Quercus gambelii* communities. Most occurrences are along weedy roadsides within fenced highway right of ways. **Elevation:** 6,765-7,362 feet.

**Ecological System:** Barrens, Ponderosa Pine

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Occurrences are limited to Mancos Shale substrates, and much of the area surrounding occupied habitat does not contain the necessary soils to support *I. polyantha*.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Housing developments, commercial developments, roads, and utility corridors all present barriers to movement for *I. polyantha* (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren habitats were rated 'Increase' based on the potential for wind, solar, and bioenergy development.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Not restricted to cool or cold environments that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may result in higher evapotranspiration rates and decreases in soil moisture availability for *I. polyantha*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *I. polyantha* is restricted to rocky, clay soils derived from Mancos shales (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *I. polyantha* is apparently a generalist pollinated by a broad suite of insects (Anderson 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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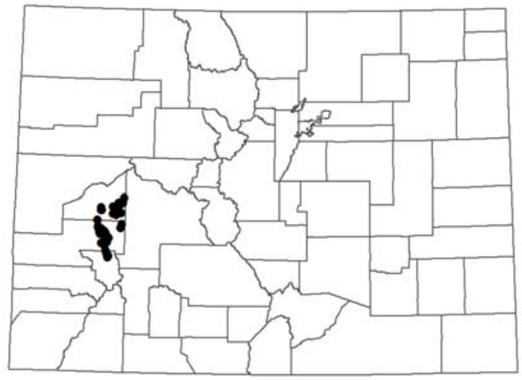
## *Lomatium concinnum*

**Colorado desert-parsley**
**G2G3/S2S3**
**Family: Apiaceae**

Photo: Delia Malone



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) likelihood of short seed dispersal distances; 3) lack of range of variation in annual precipitation in the last 50 years; 4) potential increases in fire frequency in occupied habitat; 5) potential decrease in soil moisture availability; 6) potential for wind, solar, and biofuel development in occupied habitat.

**Distribution:** Colorado endemic, known from Delta, Montrose, and Ouray Counties. Estimated range is 3,427 square kilometers (1,323 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Barren adobe soils derived from shales of the Mancos Formation. In shrub-dominated communities, sometimes with another rare plant, the clay-loving wild-buckwheat (*Eriogonum pelinophilum*). Also associated with shrub communities dominated by sagebrush, shadescale, greasewood, or scrub oak. 1680-2130 m elevation. Found on adobe hills and plains on rocky soils derived from Mancos Shale (pers. comm. Coles 1994; Harrington 1954). In cold desert shrub communities dominated by *Atriplex* spp. *Artemisia* spp., *Sarcobatus, Oryzopsis hymenoides, Hilaria jamesii*, and *Cymopterus* spp. (pers. comm. Coles 1994) or in shrublands under *Quercus gambelii* (pers. comm. Jennings 1995). Elevational range 5500-7000 ft (Spackman et al. 1997). **Elevation:** 5161-8793 feet.

**Ecological System:** Sagebrush, Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Areas surrounding most occupied habitat contain unsuitable habitat.

**B2b) Distribution relative to anthropogenic barriers.** Increase/Somewhat Increase. Roads and ATV trails have degraded suitable habitat for this species, and may act as barriers to movement (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren habitats were rated increase due to potential for wind, solar, and bioenergy development.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat** Increase. Climate models project warmer temperatures, and this could lead to higher evapotranspiration rates and less soil moisture availability for *L. concinnum*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Fire frequency may increase in sagebrush habitats due to climate change.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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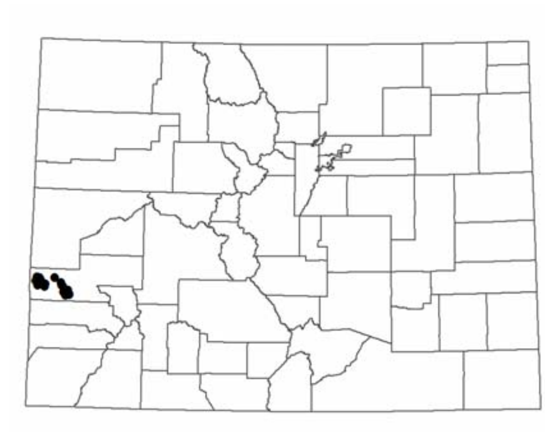
## *Lupinus crassus*

**Payson lupine**
**G2/S2**
**Family: Fabaceae**

Photo: Bernadette Kuhn



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) lack of suitable habitat to accommodate range shift due to climate change; 2) likelihood of limited seed dispersal capability; 3) lack of variation in precipitation in last 50 years; 4) potential decrease in soil moisture availability due to warmer temperatures; 5) potential increase in fire frequency in pinyon-juniper habitats.

**Distribution:** Colorado endemic; known from Montrose County. Estimated range is 502 square kilometers (194 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Pinyon-juniper woodland; on Mancos shale derived soils in the Naturita area; on quaternary alluvium derived from the Chinle Formation in the Paradox Valley; on sparsely vegetated soil, particularly in draws and dry hillsides (Peterson 1983); occasionally found on loamy to clayey soils and even on adobe hill (O'Kane 1988). Occurs on gypsiferous soil and often found growing on a loose hillside, occasionally found on loamy to clayey soils and even on adobe hills (O'Kane 1988), pinyon-juniper woodland, draws and washes of sparse vegetation. **Elevation:** 5069-6260 feet.

**Ecological System:** Pinyon Juniper, Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase Much of the surrounding area of occupied habitat does not contain gypsiferous soils and suitable habitats that would allow for a range shift due to climate change.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. **B3) Impact of land use changes resulting from human responses to climate change.** Somewhat Increase. There is potential for wind, solar, and biofuel development, as well as oil and gas development in *L. crassus* habitat (FracFocus 2013, NRDC 2014).

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Not restricted to cool or cold environments that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower than average (11 - 20 inches/255 - 508 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *L. crassus* occurs in a semi-arid climate with an average of 11.73 inches of precipitation per year in nearby Paradox, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *L. crassus.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Pinyon-juniper habitats may experience increased fire frequencies due to increased temperatures.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. *L. crassus* occurs on several soil types in the Paradox Valley (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Somewhat Increase Although *L. crassus* has not been studied for nodulization, legume species are well known for forming symbiotic relationships with nitrogen fixing bacteria. (COLO Plant Database 2014).

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Mimulus eastwoodiae*

**Eastwood's monkeyflower**
**G3G4/S2**
**BLM sensitive**
**Family: Scrophulariaceae**

Photo: Lori Brummer

## Climate Vulnerability Rank: Extremely Vulnerable

This statewide rank is based on restriction to cool, shaded cliff faces that may become warmer and drier in Colorado. Other contributing factors are the presence of cliff faces that serve as natural barriers in suitable habitat, reliance on hummingbirds for pollination, restriction to seeps on canyon walls composed of the Wingate or Mesa Verde Formation, and the present of urban development, and oil and gas infrastructure which are anthropogenic barriers. Climate models project annual net drying across the range of this species (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014; Nydick et al. 2012). These hotter and drier conditions may result in a loss of suitable habitat for *M. eastwoodiae*.

**Distribution:** *M. eastwoodiae* has been reported from Utah, Arizona, and Colorado. Occurrences in Colorado have been documented in Delta, Mesa, Montrose, and San Miguel Counties (CNHP 2013). **Habitat:** Occurs in hanging garden communities around seeps on steep canyon walls and in shallow caves**. Elevation:** 4700-5800 feet.

**Ecological Systems:** Groundwater Dependent Wetlands, Cliff and Canyon Seeps

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat Increase. Species occurs on steep canyon walls that serve as natural barriers.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase. Urban development in Grand Junction map somewhat impede northward movement of the species in Colorado (Radeloff et al. 2005). Oil and gas development may also be a barrier to movement (FracFocus 2013)

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Occurs in shallow caves and seeps on steep canyon walls, and we rated cliff and canyon species 'Neutral' based on the assumption that development in this habitat is unlikely in most mitigation scenarios.

**C1) Dispersal and movements.** Neutral. Although dispersal mechanisms are unknown, wind and water likely transport *M. eastwoodiae* seeds.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Mimulus eastwoodiae* has experienced average temperature variation (57.1-77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Increase. Species that occur in seeps in cliffs and canyons are rated 'Increase' under the assumption that this habitat may be lost as Colorado becomes warmer, and presumably drier.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. The species has experienced average (25.5 inches) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly Increase. Species occurs in hanging garden communities around seeps on steep canyon walls and in shallow caves. We rated cliff and canyon species that prefer wetter micro sites as 'Greatly Increase' based on the assumption that these habitats may be lost as Colorado's climate becomes warmer and drier.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. No data, forced score.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Little dependence on snow or ice cover.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. Species is restricted to cliffs and canyons, usually occurring on Wingate sandstone or Mesa Verde Formation cliff alcoves (CNHP 2013).

**C4a) Dependence on other species to generate habitat.** Neutral. No data, forced score.

**C4c) Pollinator Versatility.** Somewhat Increase. *M. eastwoodiae* is hummingbird pollinated (Vickery 1978). No data is available on how many species of hummingbirds pollinate this species.

**C4d) Dependence on other species for propagule dispersal.** Neutral. No data, forced score.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5) Genetic factors.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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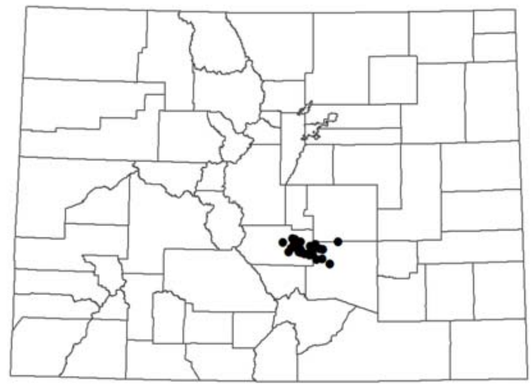
## *Nuttallia (Mentzelia) chrysantha*

**Golden blazing star**
**G2/S2**
**Family: Loasaceae**

Photo: Stephanie Neid



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers may block potential range shifts due to climate change; 2) potential for wind and solar energy development; 3) potential short seed dispersal distances; 4) species has experienced a lack of variation in annual precipitation in the last 50 years; 5) predicted decrease in precipitation during flowering period; 6) restriction to Smoky Hill member of Niobrara Formation.

**Distribution:** Colorado endemic (Fremont and Pueblo counties). Estimated range is 1,373 square kilometers (530 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** *Nuttallia chrysantha* is typically found on barren slopes and road cuts of limestone, shale, or alkaline clay. The habitat of *M. chrysantha* consists of moderately disturbed, wasting slopes such as those above the Arkansas River. Slopes are usually moderately steep in the shale barrens; no particular aspect is favored. *Nuttallia chrysantha* occupies slopes and road cuts, where it grows prolifically and is often the only plant species growing in large numbers. *Nuttallia chrysantha* is found on a variety of geologic formations, mainly marine deposits from the upper (late) Cretaceous period. *Nuttallia chrysantha* is found primarily on the Smoky Hill member of the Niobrara shale, which is widespread throughout the middle Arkansas Valley. **Elevation:** 4751-6854 feet.

**Ecological System:** Barrens, Pinyon Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Higher elevation areas to the north and west of occupied *N. chrysantha* habitat are forested, montane areas that do not contain suitable habitat to accommodate at range shift for this species.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase/Neutral. Housing developments, mining, roads and railroads, and utility corridors in the Canon City area near occupied habitat may act as barriers to movement.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barrens are rated 'Increase' for the potential development of wind and solar energy (Grunau et al. 2011).

**C1) Dispersal and movements.** Increase/Somewhat Increase. *N. chrysantha* seeds are potentially dispersed by wind and animals (Anderson 2004).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *N. chrysantha* grows on barren slopes in dry upland habitats; it is not restricted to cool or cold habitats that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *N. chrysantha* is primarily found on the Smoky Hill member of the Niobrara Formation (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *Nuttallia (Mentzelia) chrysantha* utilizes a broad suite of insects for pollination (Anderson 2006).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Nuttallia (Mentzelia) densa*

**Arkansas Canyon stickleaf**
**G2/S2**
**Family: Loasaceae**

Photo: Susan Spackman Panjabi

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers may block potential range shifts due to climate change; 2) potential short seed dispersal distances; 3) species has experienced a lack of variation in annual precipitation in the last 50 years; 4) predicted decrease in precipitation during flowering period; 6) potential increase in fire frequency in pinyon juniper habitats.

**Distribution*:*** Endemic to Colorado; known from Fremont County, and adjacent Chaffee County. Estimated range is 2,545 square kilometers (982 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences (calculated by the Colorado Natural Heritage Program in 2008). **Habitat:** *Nuttallia densa* occupies dry open areas in washes, roadsides, naturally disturbed sites, and steep rocky slopes. Plants grow in gravel, scree, or on cliffs formed from Precambrian granodiorite and gneiss. The species occurs in pinyon-juniper woodland and lower montane shrubland communities with a poorly developed understory and an open canopy. **Elevation:** 5400-7684 feet.

**Ecological System:** Pinyon Juniper, Upland Shrub

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase/Somewhat Increase. Areas of unsuitable, higher elevation habitats surround existing occurrences of *N. densa*, and the Arkansas River may act as a natural barrier to climate-induced range shifts for *N. densa*.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat Increase/Neutral. Railroads, highways, and urban/ex-urban development in areas west of Canon City may create barriers to climate-induced range shifts for *N. densa*.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Fire frequency may increase in pinyon juniper habitats due to projected temperature increases.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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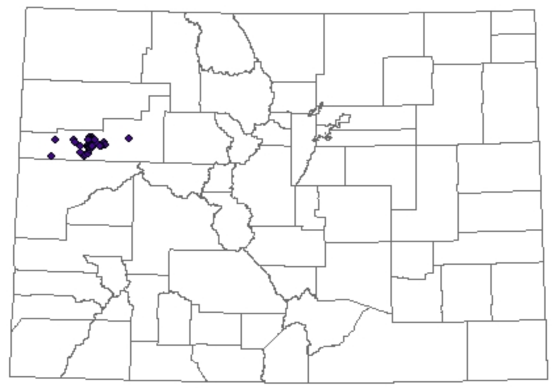
## *Nuttallia (Mentzelia) rhizomata*

**Roan Cliffs blazingstar**
**G2/S2**
**Family: Loasacea**

Photo: Susan Spackman Panjabi



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted decreases in precipitation; habitat alteration that results from oil and gas development and livestock grazing which act as anthropogenic barriers; and restriction to the Parachute member of the Green River shale geologic formation. Suitable habitat is likely to be reduced as this species' range becomes warmer and drier. Climate models project annual net drying of 9.6 percent to 11.9 percent across the entirety of this species' range (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution***:* *Nuttallia rhizomata* is a Colorado endemic known only from the Roan Plateau in Garfield County with an estimated range of 1,365 square kilometers (527 square miles) (CNHP 1997+). **Habitat:** *Nuttallia rhizomata* occupies steep, shale talus slopes derived from the Parachute Creek Member of the Green River Formation (CNHP 1997+). Commonly associated plant species include Gambel oak, western chokecherry, mountain mahogany, Utah juniper and oil shale fescue (Reveal 2002). Rare species occasionally found with *M. rhizomata* include *Lesquerella parviflora*, *Penstemon debilis* and *Thalictrum heliophilum* (Reveal 2002). **Elevation:** 5243 - 9186 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Range shift in response to climate change may be limited by a wide, east-west and north-south trending bands of unsuitable geology with soils and natural communities that present inappropriate habitat for *N. rhizomata* (USGS 2014)

**B2b) Distribution relative to anthropogenic barriers.** Neutral

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011). **C1) Dispersal and movements.** Increase. Seed dispersal strategies likely include wind and animals which enhance dispersal distance. Seeds of *Nuttallia rhizomata* are winged (Anderson 2006) which may improve and allow dispersal up to 15 m (Vittoz and Engler 2007). Seeds also have velcro-like hairs (Reveal 2002) which may enable transport in the fur of animals and may result in dispersal distances up to 1,500m (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Nuttallia rhizomata* has experienced average temperature variation (57.1 - 77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Nuttallia rhizomata* occupies open sites over a wide range of elevations (CNHP 2014) with temperatures that vary adiabatically with elevation, suggesting that this species is not limited to cool environments.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *Nuttallia rhizomata* has experienced small (4-10 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution. Drought at flowering is critical as it can increase pollen sterility and during growth period impairs normal growth, disturbs water relations, and reduces water use efficiency in plants (Farooq et al. 2012).

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. This species occupies steep, shale talus slopes (CNHP 2014) that are unlikely to be impacted by altered fire regimes. Although, these habitats often occur in a mosaic with communities such as Pinyon-Juniper woodlands and sage shrublands where fire frequencies are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009). Climate change models also predict increases in fire area and severity throughout the region occupied by this species (Krawchuk et al. 2009, Westerling et al. 2011). However, as yet impacts to *M. rhizomata* are not documented.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *Nuttallia rhizomata* is an oil shale endemic, and may be edaphically restricted to the Parachute Creek Member of the Green River Formation found in west-central Colorado (Reveal 2002, Anderson 2006). The Parachute Creek Member of the Green River Formation is not highly uncommon but neither is this formation one of the dominant types in the region (Tweto 1979).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. As suggested by flower morphology, which has little floral specialization, and pollination strategies of related species such as *Nuttallia (Mentzelia) chrysantha,* which utilizes a broad suite of insects for pollination (Anderson 2006), *N. rhizomata* likely utilizes a broad suite of pollinators.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Nuttallia rhizomata* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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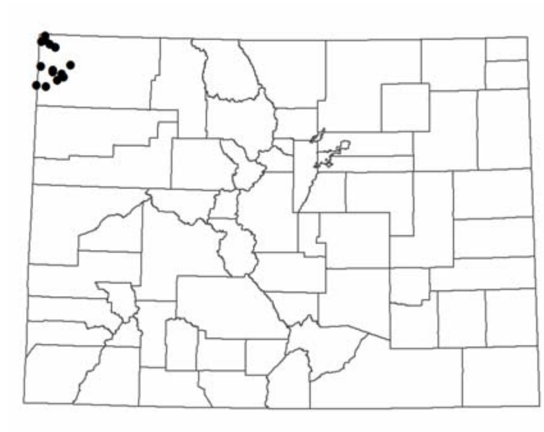
## *Oenothera acutissima*

**Narrow-leaf evening primrose**
**G2/S2**
**Family: Onagraceae**

Photo: Delia Malone



## Climate Vulnerability Rank: Highly Vulnerable

This Colorado state-wide rank is based on the following factors: 1) likelihood of short seed dispersal distances; 2) lack of variation in annual precipitation in last 50 years; 3) reliance on habitats that are seasonally moist and may be subject to drying under projected increases in temperature.

**Distribution:** Restricted to Moffat County, Colorado and Daggett, Uintah, and Duchesne counties, Utah; Duchesne County, UT has just one occurrence. The Center for Native Ecosystems and Colorado Native Plant Society (2006) describe the range as "in the vicinity of the Flaming Gorge National Recreation Area and around Diamond Mountain, Cold Spring Mountain, and Douglas Mountain at the eastern end of the Uinta Mountains. It has been found as far west as Burnt Mill Spring, northwest of Roosevelt, and as far east as Boone Draw, below Sand Wash Basin in Moffat County, Colorado. **Habitat:** Areas that are temporarily moist in spring and early summer such as along arroyos, in meadows, and in depressions. Soils must be sandy to gravelly, but community type varies from sagebrush scrub to grass-forb to ponderosa pine. Restricted to sandy, gravelly and rocky soils, in seasonally wet areas; in meadows, depressions, or along arroyos in mixed conifer forest to sagebrush scrub (Wagner 1981). This species occurs in short outcrops or "rock reefs", drainages, and gullies (pers. comm. Denise Culver 2014). **Elevation:** 5299-9108 feet.

**Ecological System:** Sagebrush, Grass/Forb Dominated Wetlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. *O. acutissima* is found near the CO/UT border, and there are few natural barriers to movement in the area.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. There are few major anthropogenic disturbances in occupied *O. acutissima* habitat.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Not limited to cool or cold environments that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. This species relies on seasonally wet areas within an otherwise semi-arid environment. Predicted drying during the flowering and fruiting period of *O. acutissima* (late April-June/May-early July (Spackman et al. 1997)) is likely to reduce this species reproductive success, abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Oreocarya (Cryptantha) caespitosa*

**Tufted cryptanth**
**G4/S2**
**Family: Boraginaceae**


Photo: David G. Anderson

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide range is based on: predicted precipitation decrease during flowering and fruiting; oil and gas development and livestock grazing that acts as anthropogenic barriers to range shift; limited seed dispersal distance; wind energy development in potential future habitat; and an altered natural fire disturbance regime. Suitable habitat is likely to be reduced as this species' range becomes warmer and drier. Climate models project annual net drying across this species range (NatureServe 2012) with consequent trends towards increased soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution:** *Oreocarya caespitosa* is a regional endemic of northwest Colorado in Moffat County, central and southern Wyoming and adjacent northeast Utah and disjunct to the north in Bear Lake County, Idaho (Spackman et al. 1997, Moseley 1991). **Habitat:** *Oreocarya caespitosa* typically occupies sparsely vegetated rocky, shale, or chalky ridgetops and knolls with other cushion plants in habitat characterized by sagebrush, pinyon-juniper and limber pine (Spackman et al. 1997, NatureServe 2014, Welsh et al. 1987). **Elevation:** 6200-8100 ft.

**Ecological System:** Sagebrush shrublands, Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. Although natural barriers, such as the Vermillion Bluffs escarpment (USGS 2014), are present for some Colorado populations of *Oreocarya caespitosa*, the majority of populations are not inhibited from range shift by natural barriers.

**B2b) Distribution relative to anthropogenic barriers.** Increase. *Oreocarya caespitosa* is inhibited from range shift by oil and gas development (FracFocus Wells 2013) and habitat alteration related to livestock grazing (BLM 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Potential for wind energy development is high on the southern border of Wyoming (NRDC 2011) and may possibly occur within the future range of this species. Associated infrastructure development and habitat alteration are incompatible with natural history requirements of *Oreocarya caespitosa.* Impacts to flora from wind power development-related habitat and ecosystem modification include but are not limited to displacement from an area, habitat destruction and reduced reproduction (IPCC 2011).

<u>**Risk Factors Section C: Sensitivity or Species Specific Factors**</u>

**C1) Dispersal and movements.** Somewhat increase. Dispersal distance is somewhat limited which constrains *Oreocarya caespitosa's* response to climate change**.** As suggested by seed characteristics and dispersal mechanisms of related species such as *O. flava* and *O. humilis*, seeds of *O. caespitosa* are likely also dispersed by both wind and animals, including rodents and ants (Casper 1987, Kartesz 2012). Wind dispersal for this type of seed is usually less than 15m however, on barren landscapes, seeds may be dispersed up to 150 meters while small mammals typically disperse seeds less than 30m and ants may disperse seeds up to 15m (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Rangewide, considering the mean seasonal temperature variation for occupied cells, the species has experienced average temperature variation (57.1 - 77$^{o}$F) within the last 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Species' distribution (CNHP 2014) does not suggest a preference for cold or cool climates either permanently or seasonally.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (10.3 inches) precipitation variation over the last 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted drying during *O. caespitosa's* flowering and fruiting period (late April-June/May-early July (Spackman et al. 1997)) is likely to reduce this species reproductive success, abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. This species commonly occupies Pinyon-Juniper woodlands and sage shrublands (USGS 2014). Multiple studies have found that, in response to predicted climate change scenarios sagebrush and pinyon-juniper ecosystems will decline and become more fragmented over the next century, primarily due to increased fire frequency following current trends that already show increased fire frequencies, area burned and fire severity (Cleetus and Mulik 2014, Stephens 2005, Westerling et al. 2006, Littell et al. 2009, USFS b). Modeling of future vegetation patterns also shows that both pinyon-juniper woodlands and sagebrush shrublands may be reduced in the future due to increased fire frequencies, area burned and severity (Westerling et al. 2006).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. This species is not restricted to uncommon geological features.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that *Oreocarya caespitosa* relies on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown. Although plant morphology suggests conformation to a specific pollinator syndrome with limitation to the long-tongued bees (Anthophoridae)(Weber and Wittmann 2012) a specific suite of pollinators has not been identified (USFS No date).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Oreocarya caespitosa*, as suggested by dispersal mechanisms of other related species, is likely primarily wind dispersed and is not reliant on others species for dispersal (Casper 1987).

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Oreocarya (Cryptantha) osterhoutii*

**Osterhout's cat's-eye**
**G2G3/S2**
**Family: Boraginaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) barriers to movement; 2) limited seed dispersal capabilities; 3) lack of precipitation variability in last 50 years; 4) potential decrease in soil moisture availability with increased temperatures; 5) restriction to specific geologic features and soil types.

**Distribution:** This species occurs in Colorado, Utah and perhaps Arizona; it is found on the Colorado Plateau and is considered endemic to the Navajo Basin (Welsh et al. 1993). The species is known from Mesa County (type locality), western Colorado (Spackman et al. 1997; Weber and Wittmann 1992); and Grand, Wayne, Garfield and San Juan counties, southeastern Utah (Welsh et al. 1993). It is also thought to occur in Arizona (Kartesz 1999) based on a 1980 report, but it is not listed in most pertinent publications such as the Arizona Floras (pers. com. Sabra Schwartz Arizona HDMS to K. Fayette 1999). **Habitat:** Grows in dry, sandy soils of the desert with *Artemisia*, *Coleogyne*, or *Juniperus* (B84CRO04HQUS). In Gateway area on dark red sandy soils of the Moenkopi formation (Spackman et al. 1997). **Elevation:** 4,500-6,500 feet.

**Ecological System:** Barrens, Desert Shrub

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Surrounding habitats do not contain suitable soils and geology to accommodate range shifts due to climate change. The Colorado River Valley, located on northern border of occupied habitat, may act as a natural barrier to dispersal.

**B2b) Distribution relative to anthropogenic barriers.** Increase/Somewhat Increase. Areas on the northern border of occupied habitat contain large areas of irrigated cropland along the Colorado River.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. *O. osterhoutii* occupies barrens, and these were rated 'Increase' based on the potential for wind and solar development.

**C1) Dispersal and movements.** Increase. No data is available on seed dispersal, but it is likely that seeds fall close to the parent plant based on their lack of specialized structures to aid in dispersal.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat Decrease. Considering the mean seasonal temperature variation for occupied cells, the species has experienced greater than average (> 77° F/43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *O. osterhoutii* is not restricted to cool or cold places that may be lost to climate change. It occurs on dry uplands in a semiarid climate.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, *O. osterhoutii* has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *O. osterhoutii* occurs in a semi-arid climate with an average of 11.33 inches of precipitation per year in nearby Grand Junction, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *O. osterhoutii.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. In Gateway area, *O. osterhoutii* occurs on dark red sandy soils of the Moenkopi formation (Spackman et al. 1997).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Oreocarya revealii (Cryptantha gypsophila)*

**Gypsum Valley cat's-eye**
**G2/S2**
**Family: Boraginaceae**

Photo: Susan Spackman Panjabi

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) lack of suitable habitat to accommodate range shift due to climate change; 2) restriction to gypsum soils; 3) potential wind and solar energy development in occupied habitat; 4) likelihood of limited seed dispersal capability; 5) lack of variation in precipitation in last 50 years; 6) potential decrease in soil moisture availability due to warmer temperatures; 7) potential increase in fire frequency in pinyon-juniper habitats.

**Distribution:** Colorado endemic previously thought to occur Montrose and San Miguel counties, recent taxonomic and genetic studies indicate it is occurs only within San Miguel County in a very small area (Bresowar and McGlaughlin 2014). Our range maps will be updated when new data from these studies becomes available. **Habitat:** *O. revealii* is often the dominant vascular plant on the grayish, near-barren gypsum hills of the Paradox Member of the Hermosa Formation in western Colorado (Reveal and Broome 2006). It is also found on other barren shale substrates in the area. In some sites, the dominant plant is a whitish gray cryptobiotic lichen. **Elevation:** 5400-6800 feet.

**Ecological System:** Barrens, Pinyon-Juniper

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. *O. revealii* occurs on barren gypsum hills. Much of the surrounding area of occupied habitat does not contain gypsiferous soils and suitable habitats that would allow for a range shift due to climate change.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change. Somewhat** Increase. There is for potential for wind, solar, and biofuel development, as well as oil and gas development in the species habitat (FracFocus Wells 2013, NRDC 2014).

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not restricted cool or cold areas that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Climate models project hotter temperatures for Colorado, with trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014). Warmer temperatures will result in higher evapotranspiration rates for plants. *O. revealii* occurs in a semi-arid climate with an average of 11.73 inches of precipitation per year in nearby Paradox, CO (Western Regional Climate Center 2015). Although tolerance limits for lack of moisture are unknown for this species, a hotter climate combined with higher evapotranspiration may result in stressful conditions for *O. revealii.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Pinyon-juniper habitats may experience increased fire frequencies due to increased temperatures.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *O. revealii* is restricted to gypsum hills that are often dominated by rare, crustose lichens (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Oreocarya (Cryptantha) rollinsii*

**Rollins' cats-eye**
**G3/S2**
**Family: Boraginaceae**


Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted precipitation decreases; natural barriers in the form of high mountains and escarpments, and anthropogenic barriers from oil and gas development and livestock grazing; wind energy development in potential future habitat; limited seed dispersal distance; and alteration to the natural fire disturbance regime. Suitable habitat is likely to be reduced as this species' range becomes warmer and drier. Climate models project annual net drying across the range of this species (NatureServe 2012) which may result in more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution:** *Oreocarya rollinsii* has been reported from northwest Colorado in Moffat and Rio Blanco counties, southwest Wyoming, and central and northeast Utah in Emery, Uintah, Duchesne, and Carbon counties (NatureServe 2014). **Habitat:** *Oreocarya rollinsii* is known from white shale slopes of the Green River Formation which are characterized by pinyon-juniper and cold desert shrubland ecosystems with vegetation types that commonly include desert scrub and sagebrush (Spackman et al. 1997+, Arnett 2014). **Elevation:** 5300-5800 feet.

**Ecological System:** Barrens, Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase . Populations in Colorado will be restricted from range shift by the east-west trending Uinta and Douglas Mountains with a band of cliffs and peaks that typically reach an elevation of 7,000 to 8,000 feet (USGS 2014).

**B2b) Distribution relative to anthropogenic barriers.** Increase. Populations of *Oreocarya rollinsii* occur in or near shale plays and basins and are surrounded by oil and gas development (FracFocus Wells 2013). Additionally, the majority of habitat in this species range is public land managed by the BLM as rangeland for cattle, sheep and horses (BLM 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat increase. Potential for wind energy development is high on the southern border of Wyoming (NRDC 2011) and may possibly occur within the future range of *Oreocarya rollinsii*. Impacts to flora from wind power development-related habitat and ecosystem modification include but are not limited to displacement from an area, habitat destruction and reduced reproduction (IPCC 2011).

**C1) Dispersal and movements.** Somewhat increase. Dispersal distance is somewhat limited. As suggested by seed characteristics and dispersal mechanisms of related species such as *C. flava* and *C. humilis*, seeds of *C. rollinsii* are likely also dispersed by both wind and animals, including rodents and ants (Casper 1987, Kartesz 2014). Wind dispersal is usually less than 15m but on barren landscapes wind may disperse seeds up 150 meters (Vittoz and Engler 2007). Ants may disperse seeds up to 15 meters while small mammals may disperse seeds up to 30 meters (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77°F) temperature variation within the last 50 years (NatureServe 2012).

**C2aii) Physiological thermal niche.** Neutral. Species' distribution (SEINet 2014) suggests that this species does not demonstrate a preference for cold or cool climates either permanently or seasonally.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Somewhat increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced slightly lower than average (12.6 inches) precipitation variation over the last 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation across *C. rollinsii's* range during period of flowering and fruiting period (Flowering May –June/fruit June- July (Arnett 2014, SEINet 2014)) may reduce this species reproductive success, distribution and abundance.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Increase. Habitats occupied by this species commonly include Pinyon-Juniper woodlands and cold sage shrublands and desert shrublands (USGS 2014). Multiple studies have found that, in response to predicted climate change scenarios, sagebrush and pinyon-juniper ecosystems will decline and become more fragmented over the next century, primarily due to increased fire frequency following trends that already show increased fire frequencies, area burned and fire severity (Stephens 2005, Westerling et al. 2006, Littell et al. 2009, USFS b). Modeled future changes also show an increased fire probability throughout the region occupied by this species (Krawchuk et al. 2009).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Surface lithology is often non-carbonate residual material which is relatively common and abundant (USGS 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. *Oreocarya rollinsii* is not known to rely on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown. Although plant morphology suggests conformation to a specific pollinator syndrome with limitation to the long-tongued bees (Anthophoridae), a specific suite of pollinators has not been identified (USFSa) and richness of Anthophorid bee species in the range of *O. rollinsii* has not been reported.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Oreocarya rollinsii,* as suggested by dispersal mechanisms of other related species, is likely primarily wind dispersed and is not reliant on others species for dispersal. Species such as *Oreocarya flava* are dispersed by wind and also by small mammals and insects (Casper 1987). Nutlet morphology suggests that *C. rollinsii* is similarly dispersed.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Pediomelum aromaticum*

**Paradox breadroot**
**G3/S2**
**Family: Fabaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This statewide rank is based on the species habitat preference for warmer, arid climates, sandy soils, pollinator specialization, and the presence of natural and anthropogenic barriers to northward movement. Although, warm, dry shrublands and pinyon-juniper woodlands are likely to increase with climate change, fire frequency and severity in these habitats is also expected to increase. Climate models project decreased summer precipitation and increased summer temperatures (Nydick et al. 2012).

**Distribution:** *Pediomelum aromaticum* is known from northern Arizona, SE Utah, and SW Colorado (Kartez 2013). In Colorado, it is known from Mesa, Montrose and possibly Montezuma counties. (CNHP 2013, Kartez 2013). **Habitat:** Adobe hills or sandy soils in open pinyon-juniper woodlands. **Elevation:** 4600-6700 ft.

**Ecological System:** Pinyon-Juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat increase. The desert scrub habitat of the Grand Valley may act as a natural barrier to northward movement in portions of the species range in Colorado.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Agricultural and urban development in the Grand Junction area act as barriers to *P. aromaticum* movement in portions of its Colorado range.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Although Mesa and Montrose counties have modest potential for renewable energy development, there are currently no planned developments for the area (NRDC 2014).

**C1) Dispersal and movements.** Increase. Reproduces by seed that falls close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Pediomelum aromaticum* has experienced average temperature variation (57.1-77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. Species shows a tolerance to a wide range of temperatures.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. aromaticum* has experienced average precipitation variation (22 inches) in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Species occurs in loose, sandy soils that are sensitive to changes in precipitation.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat Increase. Fire frequencies in the Pinyon-Juniper woodlands occupied by this species are expected to increase in the future, following trends that already show increased fire frequencies, area burned and fire severity (Krawchuk et al. 2009, Little et al. 2009, Stephens 2005, Westerling et al. 2006).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. Species occurs in xeric habitats (CNHP 2013).

**C3) Restriction to uncommon geological features or derivatives.** Neutral. In Colorado, the species prefers loose, sandy soils (CNHP 2013).

**C4a) Dependence on other species to generate habitat.** Neutral. No data, forced score.

**C4c) Pollinator Versatility.** Somewhat Increase. Inferred from other related species that are bee pollinated (Colorado Plant Database 2007).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Increase. Although *P. aromaticum* has not been studied for nodulization, legume species are well known for forming symbiotic relationships with nitrogen fixing bacteria. (COLO Plant Database 2014).

**C5) Genetic factors.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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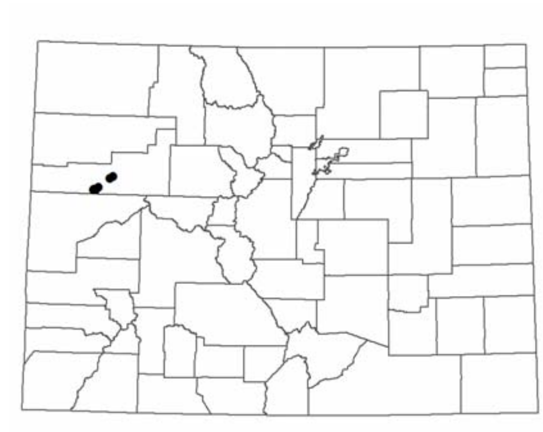
## *Penstemon debilis*

**Parachute penstemon**
**G1/S1**
**Listed Threatened**
**Family: Scrophulariaceae**

Photo: Susan Spackman Panjabi



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *P. debilis's* preference for soils derived from oil shale barrens of the Parachute Creek Member of the Green River Formation, its predicted sensitivity to changes in precipitation, limited dispersal ability and its reliance on a small suite of pollinators.

**Distribution:** *Penstemon debilis* is endemic to in the Piceance Basin, Garfield County, Colorado. **Habitat:** This species is restricted to the Mahogany Zone of the Parachute Creek Member of the Green River Formation. It is found on oil shale outcrops, on south-facing, steep slopes of white shale talus, which is a mixture of thin shale fragments and clay. **Elevation:** 5597-9167 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development on the Roan Plateau, there are few anthropogenic barriers to *P. debilis* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Penstemon debilis* has experienced average to temperature variation (57.1 to 77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. debilis* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. debilis* has experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. debilis* is an oil shale endemic, and may be edaphically restricted to the Mahogany Zone of the Parachute Creek Member of the Green River Formation found in west-central Colorado (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al.2011, Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Penstemon debilis* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Penstemon degeneri*

**Degener beardtongue**
**G2/S2**
**BLM Sensitive**
**Family: Scrophulariaceae**


Photo: Steve Olson

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *P. degeneri's* predicted sensitivity to changes in precipitation, limited dispersal ability, its reliance on a small suite of pollinators, and the potential for increased fire frequency in its habitat.

**Distribution:** A Colorado endemic, this species is known from Fremont, Custer, and Chaffee counties. **Habitat:** This species is found in open pinyon-juniper woodlands and montane grasslands, in rocky soils with igneous bedrock. The plants grow mainly near the rim of canyons, and also in cracks of large rock slabs, in full sun or shade. **Elevation:** 5991-9449 feet.

**Ecological System:** Pinyon-juniper Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Neutral. No significant natural barriers (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. No significant anthropogenic barriers (Grunau et al. 2011).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Energy development unlikely to occur in the woodland habitat where this species is found.

**C1) Dispersal and movements. .** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Penstemon degeneri* has experienced average temperature variation (57.1 to 77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Penstemon degeneri* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *Penstemon degeneri* has experienced small (4-10 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. Species that inhabit pinyon-juniper woodlands will be more likely to burn under most climate change scenarios due to increased temperatures and increase in weedy understory (especially cheatgrass) (Grunau et al.2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. *Penstemon degeneri* has not shown a marked preference for a specific substrate.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al.2011; Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Penstemon degeneri* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Penstemon gibbensii*

**Gibbens' beardtongue**
**G1G2/S1**
**BLM Sensitive**
**Family: Scrophulariaceae**

Photo: Alicia. Langton

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *P. gibbensii's* preference for soils derived from shale barrens of the Browns Park Formation, its predicted sensitivity to changes in precipitation, limited dispersal ability and its reliance on a small suite of pollinators.

**Distribution:** Known from extreme northwestern Moffat County in Colorado. Also known from Utah and Wyoming. **Habitat:** This species occurs on barren outcrops of white shale and sandstone of the Brown's Park Formation. It is commonly growing in very fine textured sandy clay soils with gravel and cobbles, and is often associated with cryptobiotic crusts. It is predominantly found on steep slopes that are highly susceptible to erosion. Surrounding vegetation is pinyon-juniper woodland, sagebrush or greasewood-saltbush (Spackman et al. 1999). **Elevation:** 5407-5728 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development in the species range, there are few anthropogenic barriers to *P. gibbensii* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *P. gibbensii* has experienced greater than average temperature variation (>77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. gibbensii* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. gibbensii* has experienced very small (<4 inches/100mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. gibbensii* is found on white shale substrates, and may be edaphically restricted to the Browns Park Formation found in west-central Colorado (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al.2011; Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Penstemon gibbensii* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Penstemon grahamii*

**Graham beardtongue**
**G2/S1**
**Family: Scrophulariaceae**


Photo: Delia Malone

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *P. grahamii's* preference for soils derived from oil shale barrens of the Parachute Creek Member of the Green River Formation, its predicted sensitivity to changes in precipitation, limited dispersal ability, and its reliance on a small suite of pollinators.

**Distribution:** The species is known from the area in Utah where the Carbon, Duchesne and Uintah counties meet in the Sand Wash and Nine Mile Creek drainages. The range extends east across the Utah border into Colorado and north to Rio Blanco County, CO (USFWS 2006). **Habitat:** Gravelly clay soils on semi-barren knolls of white calcareous shale (Green River Formation) in the pinon-juniper woodland zone at high elevations and at low elevations in sparse desert shrubland. **Elevation:** 5118-6385 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development in the Uinta Basin, there are few anthropogenic barriers to *P. grahamii* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *P. grahamii* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. grahamii* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. grahamii* has experienced very small (<4 inches/100mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. grahamii* is an oil shale endemic, and may be edaphically restricted to the Parachute Creek Member of the Green River Formation found in west-central Colorado (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al.2011; Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Penstemon grahamii* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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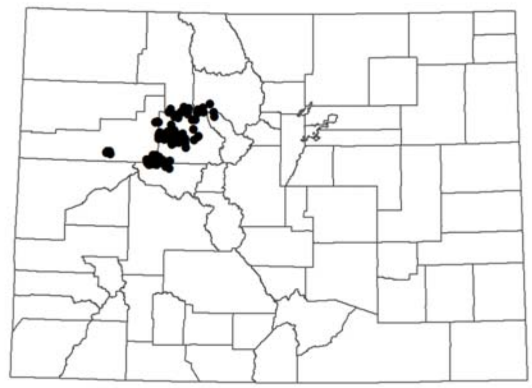
## *Penstemon harringtonii*

**Harrington's beardtongue**
**G3/S3**
**Family: Scrophulariaceae**


Photo: Peggy Lyon



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on: predicted precipitation decreases; the presence of high mountain uplifts that present natural barriers, and oil and gas development, livestock grazing and exurban development that act as anthropogenic barriers; limited seed dispersal distance; alteration to the natural fire disturbance regime; and pollinator limitations. Suitable habitat is likely to be reduced and reproductive success diminished as this species' range becomes drier. Climate models project annual net drying across the range of this species (NatureServe 2012) with resulting trends toward more severe soil-moisture drought conditions in Colorado (Lukas et al. 2014).

**Distribution:** *Penstemon harringtonii* is a Colorado endemic known from Grand, Eagle, Routt, Garfield, Pitkin, and Summit counties with an estimated range is 5,397 square kilometers (2,084 square miles)(NatureServe 2014). **Habitat:** *Penstemon harringtonii* occupies open sagebrush shrublands, mixed mountain shrublands or, less commonly, pinyon-juniper habitats (Panjabi and Anderson 2006, Spackman et al. 1997, NatureServe 2014). Soils are typically rocky loams and rocky clay loams derived from coarse calcareous parent materials (Spackman et al. 1997). **Elevation:** 6200-9400 feet.

**Ecological System:** Sagebrush Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise. Neutral.**

**B2a) Distribution relative to natural barriers. Neutral.**

**B2b) Distribution relative to anthropogenic barriers. Somewhat Increase.** *Penstemon harringtonii* is inhibited from climate change-induced range shift by anthropogenic habitat alteration related to energy extraction, livestock grazing and exurban development. *P. harringtonii* is restricted to sagebrush habitats (Panjabi and Anderson 2006) which have been used extensively for grazing (BLM 2014). Additionally, energy extraction occurs to the north and the majority of known populations are underlain by shale basins with extensive shale plays (FracFocus Wells 2013). Most importantly, exurban development surrounds much of the currently occupied habitat (USGS 2014).

**B3) Impact of land use changes resulting from human responses to climate change. Neutral.** No mitigation-related land use changes are present or are planned in the current or potential future range of *Penstemon harringtonii* (NRDC 2011).

**C1) Dispersal and movements. Increase.** *Penstemon harringtonii* dispersal is constrained by seed size and a dearth of dispersal adaptations. Dispersal probably occurs by surface water flow and granivorous small mammals (Panjabi and Anderson 2006). Small mammals generally disperse seeds less than 30 meters whereas water dispersal by surface flow is unpredictable and undocumented (Vittoz and Engler 2007).

**C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.** Considering the mean annual temperature variation of occupied cells, *Penstemon harringtonii* has experienced average temperature variation (57.1-77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral.** Distribution, habitat and elevational range of *Penstemon harringtonii* (CNHP 2014) suggest that this species is not limited to cold or cool environments.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Neutral.** Considering the range of mean annual precipitation across occupied cells in Colorado, *Penstemon harringtonii* has experienced average precipitation variation (31.4 inches) in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Increase.** Predicted precipitation decreases throughout *Penstemon harringtonii's* period of flowering and fruiting (NatureServe 2012) and increasing soil-moisture drought conditions (Lukas et al. 2014) may diminish seedling establishment and thus long-term population survivability.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Somewhat Increase.** *Penstemon harringtonii* requires a high quality matrix community of sagebrush shrubland or pinyon-juniper woodlands which depend on a natural fire regime to maintain appropriate vegetation structure (NatureServe 2014) Further, modeled future changes in fire probability and of vegetation patterns show increased probability of fire throughout the region occupied by this species (Krawchuk et al. 2009).

**C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral.** This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives. Neutral.** *Penstemon harringtonii* appears to have a preference for Pleistocene terraces and pediments which is fairly common geology within this species' range (Tweto 1979).

**C4a) Dependence on other species to generate habitat. Neutral.** There is no evidence that this species requires other species for habitat generation.

**C4c) Pollinator Versatility. Somewhat increase.** The presence of appropriate bee pollinators, with a few species being very important and specific to the timing of flowering, is required for the long-term persistence of *Penstemon harringtonii* (NatureServe 2014, Panjabi and Anderson 2006).

**C4d) Dependence on other species for propagule dispersal. Neutral.** *Penstemon harringtonii* does not depend on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.**

**C5a) Measured genetic variation. Unknown.**

**C5b) Occurrence of bottlenecks in recent evolutionary history. Unknown.**

**C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.**

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## *Penstemon penlandii*

**Penland penstemon**
**G1/S1**
**Listed Endangered**
**Family: Fabaceae**

Photo: Susan Spackman Panjabi

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the presence of both natural and anthropogenic barriers to *Penstemon penlandii's* movement, predicted sensitivity to changes in precipitation, its reliance on a small suite of pollinators, and preference for seleniferous soils.

**Distribution:** *Penstemon penlandii* is a narrow endemic; known from Grand County, Colorado. Estimated range is 13 square kilometers (5 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** *Penstemon penlandii* occurs on alkaline clays containing selenium. Optimum habitat for *P. penlandii* appears to be in runoff channels, shaded by the deeply cut banks. The species' deep root structure secures it to the underlying shales so that it is not dislodged by subsequent torrents. **Elevation:** 7400-7890 feet.

**Ecological System:** Sagebrush Shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Somewhat increase. The Rabbit Ears and Gore Ranges act as natural barriers to range shift in response to climate change (CNHP 2014).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Ranching and agricultural practices, and exurban residential development act as barriers to movement of the species (CNHP 2104).

**B3) Impact of land use changes resulting from human responses to climate change.** Somewhat Increase. Shrublands have high potential for solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *P. penlandii* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Penstemon penlandii* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. penlandii* has experienced very small (<4 inches/100mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. Species that inhabit shrublands will be more likely to burn under most climate change scenarios due to increased temperatures and increase in weedy understory (especially cheatgrass) (Grunau et al.2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. *Penstemon penlandii* has a clear preference for alkaline clays containing selenium (> 85% of occurrences found on), which is not particularly uncommon within the species' range (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al. 2011; Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Penstemon penlandii* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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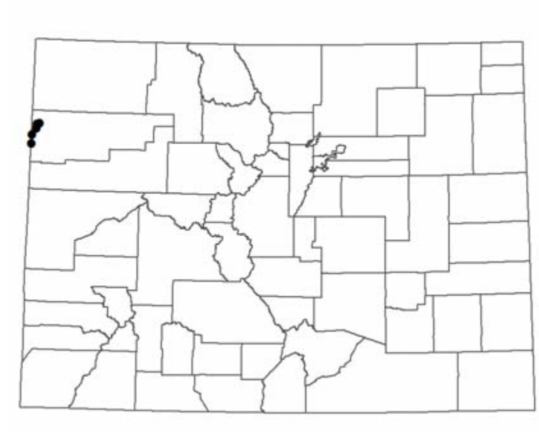
## *Penstemon scariosus* var. *albifluvis*

**White River penstemon**
**G4T1/S1**
**BLM Sensitive**
**Family: Scrophulariaceae**

Photo: Delia Malone



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *P. scariosus* var. *albifluvis* preference for soils derived from oil shale barrens of the Parachute Creek Member of the Green River Formation, its predicted sensitivity to changes in precipitation, limited dispersal ability and its reliance on a small suite of pollinators.

**Distribution:** Endemic to Raven Ridge near the White River in Rio Blanco County, Colorado, westward into southern Uintah Co., Utah, to the vicinity of Evacuation Creek, a distance of about 20 miles (CNHP 2014). **Habitat:** Found in mixed desert shrub and pinyon-juniper communities on sparsely vegetated white shale slopes. These soils are derived from oil shale barrens of the Parachute Creek Member, Green River Formation (CNHP 2014). **Elevation:** 5700-6690 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development in the Uinta Basin, there are few anthropogenic barriers to *P. scariosus* var. *albifluvis* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *P. scariosus var. albifluvis* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. scariosus var. albifluvis* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. scariosus var. albifluvis* has experienced very small (<4 inches/100mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. scariosus var. albifluvis* is an oil shale endemic, and may be edaphically restricted to the Parachute Creek Member of the Green River Formation found in west-central Colorado (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. *Penstemons* are predominantly bee pollinated (Grunau et al. 2011; Kimball and Wilson ND).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *P. scariosus var. albifluvis* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Phacelia formosula*

**North Park phacelia**
**G1/S1**
**Listed Endangered**
**Family: Hydrophyllaceae**


Photo: Bernadette Kuhn

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) large areas of unsuitable habitat may create barriers to climate-induced range shifts; 2) potential for increased wind, solar, and natural gas development in suitable habitat; 3) likelihood of short seed dispersal distances; 4) lack of variability in annual precipitation in the last 50 years; 5) potential decrease in precipitation during flowering and fruiting period; 6) restriction to Coalmont Formation.

**Distribution*:*** Known from Jackson and possibly Larimer counties, Colorado. The species is found within about 60 square miles in North Park, from Michigan Creek west to the North Platte River in Jackson County, and potentially in an additional six square miles in the Laramie River Valley in Larimer County. **Habitat:** Barren, raw exposures of the Coalmont Formation, a rusty-colored sandy substrate. The species grows most abundantly on the steepest, most sparsely vegetated, and most erodible slopes, such as on the sides of deeply cut ravines. Poorly vegetated raw exposures of the Coalmont Formation, steep-sided ravines. Grows on sandy bluffs of south-south easterly exposure, steep to moderately steep slopes, open to direct sunlight and winds. **Elevation:** 7933-8287 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Raw exposures of the Coalmont Formation are scattered throughout Jackson County, and are often surrounded by large expanses of unsuitable habitats.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. Occasional roads, railroads, and oil and gas well pads occur in occupied habitat but are not significant barriers to dispersal for *P. formosula*.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barrens habitats are rated 'Increase' based on the potential increase in solar, wind, and natural gas development.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold habitats that may be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Abundance of *P. formosula* is primarily limited by extremely xeric conditions which coincide with the transition from rosette to flowering plants (McCormick and Wu 1999). Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. formosula* is restricted to raw exposures of the Coalmont Formation.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat Increase. Field studies by Warren (1990) documented eighteen different insect visitors to *P. formosula*, with sweat bees (*Dialictus* sp.) and mason bees (*Anthidium* sp.) being the most frequent visitors and /or carrying the most *Phacelia* pollen.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Phacelia submutica*

**DeBeque phacelia**
**G2/S2**
**Listed Threatened**
**Family: Hydrophyllaceae**

Photo: Peggy Lyon

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *Phacelia submutica's* preference for soils derived from on Atwell Gulch and Shire Members of Wasatch Formation, the presence of natural and anthropogenic barriers to movement, its predicted sensitivity to changes in precipitation, limited dispersal ability and the presence of energy development within its habitat.

**Distribution:** *Phacelia submutica* is endemic to Colorado and known only from Garfield and Mesa counties. **Habitat:** Occurs on steep slopes and ridge-tops on xeric sites in chocolate-brown or gray clay adobe badlands which often have high shrink-swell potential (large cracks in the soil). The species is adapted to grow only in very early pioneer habitats with sparse vegetation cover (Scheck 1994). The species occurs on Atwell Gulch and Shire Members of Wasatch Formation (O'Kane 1987). Other rare species occurring in the area are *Sclerocactus glaucus* and *Astragalus debequaeus*. **Elevation:** 5003-6542 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Increase-somewhat increase. Agricultural residential and oil and gas development in the DeBeque areas act as barriers to movement (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *Phacelia submutica* has experienced greater than average temperature variation (>77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Phacelia submutica* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. submutica* has experienced very small (<4 inches/100mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *Phacelia submutica* is restricted to the Atwell Gulch and Shire Members of Wasatch Formation.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Phacelia submutica* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Physaria (Lesquerella) congesta*

**Dudley Bluffs bladderpod**
**G1/S1**
**Listed Threatened**
**Family: Brassicaceae**

Photo: Jill Handwerk

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural barriers to movement; 2) potential for increased energy development in occupied habitat; 3) likelihood of short seed dispersal distances; 4) lack of variation in annual precipitation in occupied habitat over last 50 years; 5) potential decrease in soil moisture availability; 6) restriction to shales of the Green River and Uinta Formations; 7) dependence on two major bee genera for pollination.

**Distribution:** Known from Rio Blanco County, Colorado; it is found only along the Piceance and Yellow Creek drainages. Estimated range is 88 square kilometers (34 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Barren white shale outcrops of the Green River and Uinta Formations that have been exposed along drainages through erosion from downcutting of streams in the Piceance Basin. **Elevation:** 6,119-6,555 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. This species is limited to patches of barren white shale outcrops. Range shifts due to climate change may be limited by the lack of suitable habitat in the areas surrounding most occurrences.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Oil and gas development has created large areas of unsuitable habitats in the Piceance Basin that may act as barriers to movement.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren habitats are rated 'Increase' due to the potential for wind, solar, and bioenergy development. Furthermore, a total of 2,915 active natural gas wells are currently operating in Rio Blanco County (COGCC 2015). A projected 1,845 new wells will be drilled in Rio Blanco County in 2035 to meet energy demands in Colorado (BBC 2008). Increased energy development in this area will result in further habitat fragmentation for *P. congesta*

**C1) Dispersal and movements.** Increase.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral/Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *P. congesta* has experienced average to greater than average temperature variation (57.1 to >77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Greatly Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced very small (< 4 inches/100 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *P. congesta.*

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. Restricted to barren white shale outcrops of the Green River and Uinta Formations.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat Increase. Studies have shown that members of the bee genera *Dialictus* and *Andrena* are responsible for most pollination that occurs in *P. congesta* (Clark 2013).

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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## *Physaria obcordata*

**Piceance twinpod**
**G1G2/S1S2**
**Listed Threatened**
**Family: Brassicaceae**

Photo: Bernadette Kuhn

## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural barriers to movement; 2) potential for increased energy development in occupied habitat; 3) likelihood of short seed dispersal distances; 4) lack of variation in annual precipitation in occupied habitat over last 50 years; 5) potential decrease in soil moisture availability; 6) restriction to shale barrens derived from the Parachute Creek Member of the Green River Formation.

**Distribution:** Endemic to Colorado; known from Rio Blanco County only along the Piceance and Yellow Creek drainages and at Calamity Ridge. Estimated range is 574 square kilometers, calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Found on steep slopes with very little other vegetation. Grows on white shale barrens outcrops in soils derived from the Parachute Creek Member of the Green River Formation. Associated plant species include *Atriplex* sp., *Astragalus lutosus, Oryzopsis hymenoides, Eriogonum* sp., *Mentzelia* sp., *Cirsium* sp., and *Machaeranthera* sp. (Anderson 1992). **Elevation:** 5935-7559 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development in the Piceance Basin, there are few anthropogenic barriers to *P. obcordata* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *Physaria obcordata* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. pruinosa* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. obcordata* has experienced small (4-10.56 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *P. obcordata*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. obcordata* is found only on the Parachute Creek Member of the Green River Formation (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *Physaria obcordata* likely utilizes a broad suite of pollinators.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Physaria obcordata* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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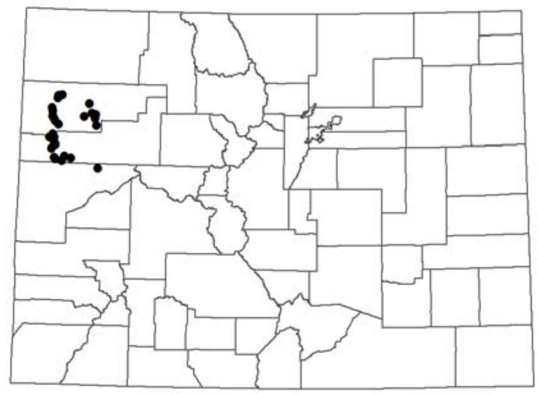
## *Physaria (Lesquerella) parviflora*

**Piceance bladderpod**
**G2/S2**
**Family: Brassicaceae**

Photo: Bernadette Kuhn



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural barriers to movement; 2) potential for increased energy development in occupied habitat; 3) likelihood of short seed dispersal distances; 4) lack of variation in annual precipitation in occupied habitat over last 50 years; 5) potential decrease in soil moisture availability; 6) restriction to Green River Formation shales.

**Distribution:** Colorado endemic known from Rio Blanco, Garfield, and Mesa Counties. Estimated range is 4,165 square kilometers (1,611 square miles), calculated in GIS by drawing a minimum convex polygon around the known occurrences. **Habitat:** Endemic to outcrops of the Green River Shale Formation in the Piceance Basin. It grows on ledges and slopes of canyons in open areas of pinon juniper communities. The soils are Torriorthent Rock outcrop complex (Peterson and Baker 1982). **Elevation:** 6115-8937 feet.

**Ecological System:** Barrens, Cliff and Canyon

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Many occurrences are surrounded by unsuitable habitat that does contain outcrops of Green River shales.

**B2b) Distribution relative to anthropogenic barriers.** Neutral.

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Barren habitats are rated 'Increase' due to the potential for wind, solar, and bioenergy development. Furthermore, a total of 2,915 active natural gas wells are currently operating in Rio Blanco County (COGCC 2015). A projected 1,845 new wells will be drilled in Rio Blanco County in 2035 to meet energy demands in Colorado (BBC 2008). Increased energy development in this area will result in further habitat fragmentation for *P. parviflora*.

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean seasonal temperature variation for occupied cells, the species has experienced average (57.1 - 77° F/31.8 - 43.0° C) temperature variation in the past 50 years.

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Physaria parviflora* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells, the species has experienced small (4 - 10 inches/100 - 254 mm) precipitation variation in the past 50 years.

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *P. parviflora*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. parviflora* is restricted to the Green River Shale Formation.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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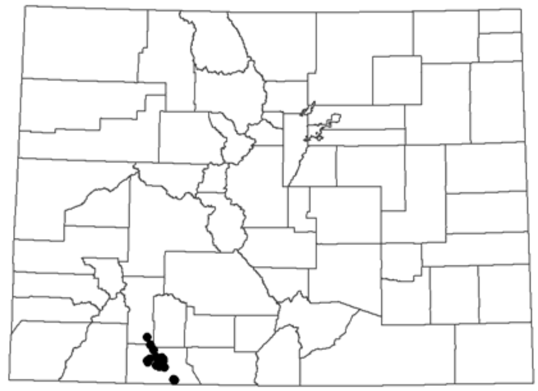
Peterson and Baker 1982

## *Physaria (Lesquerella) pruinosa*

**Pagosa bladderpod**
**G2/S2**
**Family: Brassicaceae**

Photo: Janis Huggins



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers to movement; 2) potential for increased energy development in occupied habitat; 3) likelihood of short seed dispersal distances; 4) lack of variation in annual precipitation in occupied habitat over last 50 years; 5) potential decrease in soil moisture availability; 6) restriction to Mancos shales.

**Distribution:** Known from southern Colorado (Archuleta County, and the extreme southern portion of Hinsdale County) and northern New Mexico (Rio Arriba County). **Habitat:** *Physaria pruinosa* is limited to soils derived from Mancos Shale. It is found on open clay barrens surrounded by montane grasslands, sometimes in open *Pinus ponderosa* stands with *Quercus gambelii*, it can also be associated with Douglas fir and Engelmann spruce communities at the upper limits of its range (Rouse 1981). Commonly associated species include: *Pinus ponderosa, Quercus gambelii, Mahonia repens, Comandra umbellatum, Townsendia glabella, Astragalus lonchocarpus*, and *Penstemon linarioides* (Anderson 1988). **Elevation:** 6827-8507 feet.

**Ecological System:** Barrens, Ponderosa Pine Woodlands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011). In addition, the San Juan Mountain range acts as a barrier to northward movement of the species.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase. Residential and commercial development in the Pagosa Springs area may act as barriers to *P. pruinosa* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *Physaria pruinosa* has experienced greater than average temperature variation (>77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. pruinosa* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. pruinosa* has experienced small (4-10.56 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *P. pruinosa*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. pruinosa* exhibits a preference for Mancos shale (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *Physaria pruinosa* likely utilizes a broad suite of pollinators.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Physaria pruinosa* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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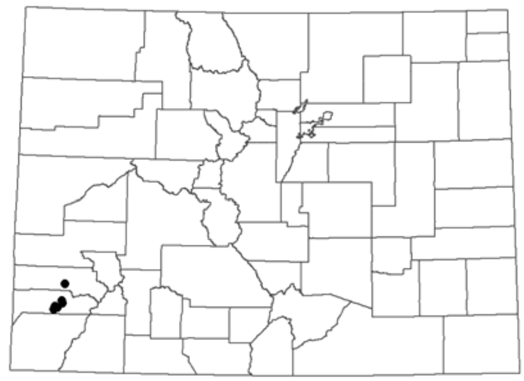
## *Physaria pulvinata*

**Cushion bladderpod**
**G1/S1**
**Family: Brassicaceae**

Photo: Peggy Lyon



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *Physaria pulvinata's* preference for soils derived from Mancos shale, its predicted sensitivity to changes in precipitation, and limited dispersal ability.

**Distribution:** Endemic to Colorado; known from San Miguel and Dolores counties. **Habitat:** This species is known from widely scattered outcrops of grayish, argillaceous (Mancos) shale. It grows in openings between low shrubs *Artemisia nova, Chrysopsis*, and *Tetraneuris,* and forbs *Sphaeralcea* and *Cryptantha* (O'Kane and Reveal 2006). **Elevation:** 7543-8488 feet.

**Ecological System:** Shrublands; barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase-Neutral. There are few anthropogenic barriers to *P. pulvinata* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change .** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds likely fall close to parent plants (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Physaria pulvinata* has experienced average temperature variation (57.1 to 77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. pulvinata* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. pulvinata* has experienced small (4 -10 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Predicted decreases in precipitation during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *P. pulvinata* exhibits a preference for Mancos shale (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Physaria pulvinata* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

## Literature Cited

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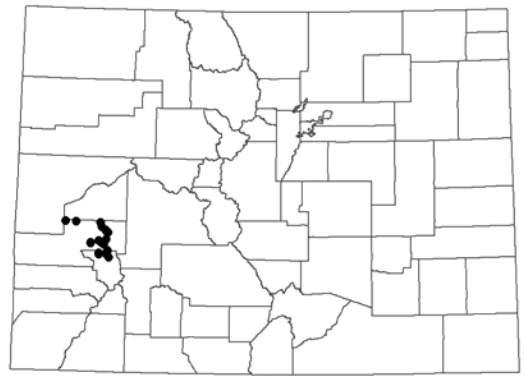
## *Physaria (Lesquerella) vicina*

**Good-neighbor bladderpod**
**G2/S2**
**Family: Brassicaceae**

Photo: Lori Brummer



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers to movement; 2) likelihood of short seed dispersal distances; 3) lack of variation in annual precipitation in occupied habitat over last 50 years; 4) potential increase in climate influenced disturbances within its habitat, and; 5) preference for Mancos shales.

**Distribution:** This species is considered endemic to Montrose and Ouray counties, western Colorado. **Habitat:** This species grows on Mancos shale at the ecotone between pinyon-juniper woodland and salt desert scrub (Anderson et al. 1997). It also has been found in sandy soils derived from Jurassic sandstones and in sagebrush steppe. It is often found in disturbed areas, including old road beds and cattle trails. Associated species include *Juniperus osteosperma, Forsellesia meionandra, Cercocarpus montanus* and *Yucca harrimaniae* (Colorado Natural Heritage Program 2012). **Elevation:** 5700-7500 feet.

**Ecological System:** Pinyon-Juniper Woodlands; Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011). In addition, the San Juan Mountain range acts as a barrier to northward movement of the species.

**B2b) Distribution relative to anthropogenic barriers.** Increase. Agricultural, residential and commercial development in the Montrose area may act as barriers to *P. vicina* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral.

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *Physaria vicina* has experienced average temperature variation (57.1 to 77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *P. vicina* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *P. vicina* has experienced small (4-10.56 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *P. vicina*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. Species that inhabit shrublands and pinyon-juniper are more likely to burn under climate change scenarios due to increased temperatures and increase in weedy understory (especially cheatgrass) (Grunau et al. 2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Somewhat Increase. Prefers Mancos Shale derived soils which are common in the species range (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Unknown.

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Physaria vicina* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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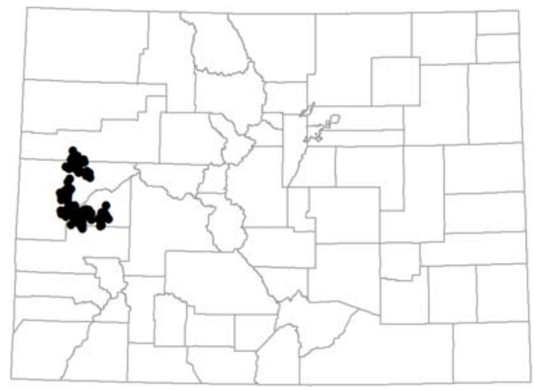
## *Sclerocactus glaucus*

**Colorado hookless cactus**
**G2G3/*S2S3***
**Listed Threatened**
**Family: Cactaceae**

Photo: Jill Handwerk



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on the following factors: 1) natural and anthropogenic barriers to movement; 2) likelihood of short seed dispersal distances; 3) lack of variation in annual precipitation in occupied habitat over last 50 years; 4) potential increase in climate influenced disturbances within its habitat, 5) potential for wind and solar energy development within its range, and; 5) pollinator specificity.

**Distribution*:*** Known from Delta, Garfield, Mesa, and Montrose counties in Colorado. **Habitat:** Populations occur primarily on alluvial benches along the Colorado and Gunnison Rivers and their tributaries. The soils are usually coarse, gravelly river alluvium above the river flood plains usually consisting of Mancos shale with volcanic cobbles and pebbles on the surface. It is also found on lower slopes of dry, rocky alkaline hills. The associated vegetation is typically desert scrub dominated by shadscale (*Atriplex confertifolia*), galleta (*Hilaria jamesii*), black-sage (*Artemisia nova*), and Indian rice grass (*Stipa hymenoides*). (Scheck 1994). Fire is not typically characteristic of *S. glaucus* habitat, but areas with large infestations of cheatgrass (*Bromus tectorum*) may build up sufficient fuel to carry fire into *S. glaucus* populations. **Elevation:** 4646-7126 feet.

**Ecological System:** Desert shrublands

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase-somewhat increase. The Grand Mesa and Roan Cliffs act as barriers to northward movement of the species.

**B2b) Distribution relative to anthropogenic barriers.** Somewhat increase-neutral. Agricultural, residential and commercial development in the Delta and Grand Junction areas may act as barriers to *S. glaucus* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Increase. Barren and shrubland habitats are rated Increase due to the potential for wind, solar, and bioenergy development (Grunau et al. 2011).

**C1) Dispersal and movements.** Increase. Seeds most likely fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Somewhat decrease. Considering the mean annual temperature variation of occupied cells, *S. glaucus* has experienced greater than average temperature variation (>77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *Sclerocactus glaucus* distribution is not likely to be significantly affected by climate change induced temperature changes in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *S. glaucus* has experienced small (4-10 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Somewhat Increase. Warmer temperatures due to climate change may increase evapotranspiration rates and decrease available soil moisture for *S. glaucus*.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Somewhat increase. Species that inhabit shrublands and pinyon-juniper are more likely to burn under climate change scenarios due to increased temperatures and increase in weedy understory (especially cheatgrass) (Grunau et al. 2011).

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Prefers Mancos shale with volcanic cobbles and surface pebbles which are common in the species range (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Somewhat increase. Pollinators are thought to be limited to several genera or species (Grunau et al. 2011).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Sclerocactus* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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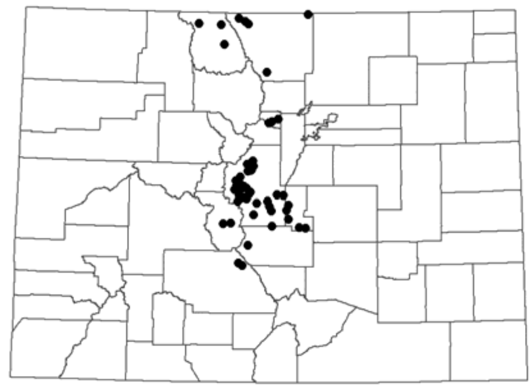
## *Sisyrinchium pallidum*

**Pale blue-eyed grass**
**G3/S2**
**Family: Iridaceae**

Photo: Denise Culver



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *Sisyrinchium pallidum's* preference for wet soils with early season moisture, its predicted sensitivity to changes in precipitation, the presence of natural barriers to range shift, and limited dispersal ability.

**Distribution***:* Regional endemic, known from Albany, Carbon and Sweetwater counties in Wyoming and Chaffee, Fremont, Gilpin, Jackson, Larimer, Park, and Saguache counties in Colorado. **Habitat:** Wet, poorly drained meadows, stream banks, roadside ditches, and irrigated hay meadows where standing water is available through the early growing season (June or early July). Plant communities in which *S. pallidum* is found are dominated by graminoids and forbs, such as *Pedicularis crenulata, Dodecatheon pulchellum*, and *Primula incana* (CNHP 2014). It grows especially on alkaline soils, often with *Juncus arcticus* and *Carex aquatilis* (pers. comm. Coles 1994). **Elevation:** 6322-9708 feet.

**Ecological System:** Wetlands.

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. Occurrences are limited to wet meadows.

**B2b) Distribution relative to anthropogenic barriers.** Neutral. There are no significant anthropogenic barriers to range shift for *S. pallidum* in Colorado.

**B3) Impact of land use changes resulting from human responses to climate change.** Neutral. Solar and wind energy development are unlikely to occur in wet meadow habitats (NRDC 2011),

**C1) Dispersal and movements.** Increase. No information is available on dispersal, but seeds likely fall close to parent plants.

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *S. pallidum* has experienced average to temperature variation (57.1 to 77°F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. This species is not limited to cool or cold habitats that are likely to be lost to climate change.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Neutral. Considering the range of mean annual precipitation across occupied cells in Colorado, *S. pallidum* has experienced average (21-40 inches) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Greatly increase. This species occurs in wet meadows with early growing season moisture. These micro-habitats may be vulnerable drying with climate change.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Neutral. Most of the populations of *S. pallidum* are found on alkaline soils, which are not uncommon in it range.

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. *Sisyrinchium pallidum* can be self-pollinated (Moore and Friedley 2004).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *Sisyrinchium pallidum* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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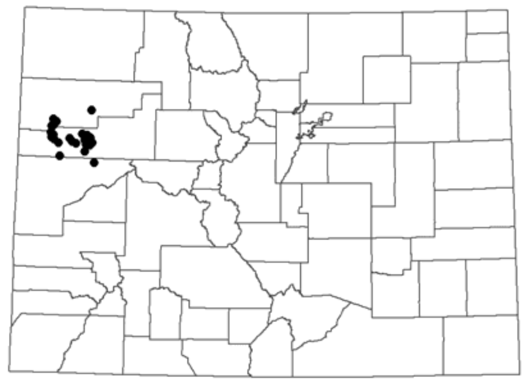
## *Thalictrum heliophilum*

**Sun-loving meadow rue**
**G2/S2**
**BLM Sensitive**
**Family: Ranunculaceae**

Photo: Janis Huggins



## Climate Vulnerability Rank: Extremely Vulnerable

This Colorado state-wide rank is based on *Thalictrum heliophilum's* preference for soils derived from shale of the Green River Formation, its predicted sensitivity to changes in precipitation, and limited dispersal ability.

**Distribution:** *Thalictrum heliophilum* is endemic to Colorado. It is known only from northwestern Colorado in Garfield, Rio Blanco, and Mesa counties (Panjabi and Anderson 2007). **Habitat:** Found in open sunny sites on steep talus slopes with soils derived from the Green River Shale Formation. Associated vegetation is usually very sparse, but may consist of rabbitbrush, snowberry, *Astragalus lutosus, Mentzelia rhizomata* and *Festuca dasyclada* (Scheck 1994). (Spackman et al. 1997). **Elevation:** 5951-8894 feet.

**Ecological System:** Barrens

## CCVI Scoring

**B1) Exposure to sea level rise.** Neutral.

**B2a) Distribution relative to natural barriers.** Increase. All species found on barrens habitat are ranked increase, as the edge of these substrates will function as barrier to plant movement (Grunau et al. 2011).

**B2b) Distribution relative to anthropogenic barriers.** Neutral. With the exception of oil and gas development on the Roan Plateau, there are few anthropogenic barriers to *T. heliophilum* range shift (CNHP 2014).

**B3) Impact of land use changes resulting from human responses to climate change.** Increase. Shale barrens have high potential for natural gas extraction, and solar and wind energy development (Grunau et al. 2011; NRDC 2011).

**C1) Dispersal and movements.** Increase. Seeds are thought to fall close to the parent plant (Grunau et al. 2011).

**C2ai) Predicted sensitivity to temperature: historic thermal niche.** Neutral. Considering the mean annual temperature variation of occupied cells, *T. heliophilum* has experienced average temperature variation (57.1 to 77$^{o}$F) in the past 50 years (NatureServe 2012).

**C2aii) Predicted sensitivity to temperature: physiological thermal niche.** Neutral. *T. heliophilum* distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

**C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche.** Increase. Considering the range of mean annual precipitation across occupied cells in Colorado, *T. heliophilum* has experienced small (4-10 inches/100-254 mm) precipitation variation in the past 50 years (NatureServe 2012).

**C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche.** Increase. Predicted decreases in precipitation of 7-8 percent during this species flowering period (NatureServe 2012) are likely to diminish reproductive success and consequently this species' abundance and distribution.

**C2c) Dependence on a specific disturbance regime likely to be impacted by climate change.** Neutral. The species is not known to be dependent on a specific disturbance regime, nor does it occur in habitat likely to be exposed to altered disturbance regimes in a way that would affect the range or abundance of the species.

**C2d) Dependence on ice, ice-edge, or snow cover habitats.** Neutral. This species is not restricted to or dependent on ice or snow cover habitats.

**C3) Restriction to uncommon geological features or derivatives.** Increase. *T. heliophilum* has a preference for soils derived from the Green River Formation found in west-central Colorado (CNHP 2014).

**C4a) Dependence on other species to generate habitat.** Neutral. There is no evidence that this species is dependent on other species to generate habitat.

**C4c) Pollinator Versatility.** Neutral. Species of *Thalictrum* have been reported to be both wind and insect pollenated (Kaplan and Mulcahy 1979).

**C4d) Dependence on other species for propagule dispersal.** Neutral. *T. heliophilum* is not dependent on other species for propagule dispersal.

**C4e) Forms part of an interspecific interaction not covered by C4a-d**. Unknown.

**C5a) Measured genetic variation.** Unknown.

**C5b) Occurrence of bottlenecks in recent evolutionary history.** Unknown.

**C6) Phenological response to changing seasonal temperature and precipitation dynamics.** Unknown.

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# Appendix A: Climate Models Used in the Analysis

Ecosystem analysis used an ensemble average of 34 CMIP5 models for the Continental US obtained from NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30).

*We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed in Table A.1) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.*

Table A1. Models included in NEX-DCP30 ensemble average.

| Model | Modeling Center | Institution |
|---|---|---|
| ACCESS1-0 | CSIRO-BOM | CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia), and BOM (Bureau of Meteorology, Australia) |
| BCC-CSM1-1<br>BCC-CSM1-1-M | BCC | Beijing Climate Center, China Meteorological Administration |
| BNU-ESM | GCESS | College of Global Change and Earth System Science, Beijing Normal University |
| CanESM2 | CCCma | Canadian Centre for Climate Modelling and Analysis |
| CCSM4 | NCAR | National Center for Atmospheric Research |
| CESM1-BGC<br>CESM1-CAM5 | NSF-DOE-NCAR | National Science Foundation, Department of Energy, National Center for Atmospheric Research |
| CMCC-CM | CMCC | Centro Euro-Mediterraneo per I Cambiamenti Climatici |
| CNRM-CM5 | CNRM-CERFACS | Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique |
| CSIRO-MK3-6-0 | CSIRO-QCCCE | Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence |
| EC-EARTH | EC-EARTH | EC-EARTH consortium |
| FGOALS-g2 | LASG-CESS | LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University |
| FIO-ESM | FIO | The First Institute of Oceanography, SOA, China |
| GFDL-CM3<br>GFDL-ESM2G<br>GFDL-ESM2M | NOAA GFDL | Geophysical Fluid Dynamics Laboratory |
| GISS-E2-H-CC<br>GISS-E2-R<br>GISS-E2-R-CC | NASA GISS | NASA Goddard Institute for Space Studies |
| HadGEM2-AO<br>HadGEM2-CC<br>HadGEM2-ES | MOHC (additional realizations by INPE | Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais) |
| INMCM4 | INM | Institute for Numerical Mathematics |
| IPSL-CM5A-LR<br>IPSL-CM5A-MR<br>IPSL-CM5B-LR | IPSL | Institut Pierre-Simon Laplace |

| Model | Modeling Center | Institution |
|---|---|---|
| MIROC-ESM<br>MIROC-ESM-CHEM | MIROC | Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies |
| MIROC5 | MIROC | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology |
| MPI-ESM-LR<br>MPI-ESM-MR | MPI-M | Max Planck Institute for Meteorology (MPI-M) |
| MRI-CGCM3 | MRI | Meteorological Research Institute |
| NorESM1-M | NCC | Norwegian Climate Centre |

Species analysis used an ensemble average of 16 CMIP3 models obtained from Climate Wizard (www.climatewizard.org). Models were downscaled 12km translations of contemporary climate projections over the contiguous United States. The original projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report.

*We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.*

Table A2. Models included in Climate Wizard ensemble average.

| Model | Country | Institution |
|---|---|---|
| BCCR-BCM2.0 | Norway | Bjerknes Centre for Climate Research |
| CGCM3.1(T47) | Canada | Canadian Centre for Climate Modelling & Analysis |
| CNRM-CM3 | France | Météo-France / Centre National de Recherches Météorologiques |
| CSIRO-Mk3.0 | Australia | CSIRO Atmospheric Research |
| GFDL-CM2.0<br>GFDL-CM2.1 | USA | US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory |
| GISS-ER | USA | NASA / Goddard Institute for Space Studies |
| INM-CM3.0 | Russia | Institute for Numerical Mathematics |
| IPSL-CM4 | France | Institut Pierre Simon Laplace |
| MIROC3.2(medres) | Japan | Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC) |
| ECHO-G | Germany / Korea | Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group. |
| ECHAM5/MPI-OM | Germany | Max Planck Institute for Meteorology |
| MRI-CGCM2.3.2 | Japan | Meteorological Research Institute |
| CCSM3<br>PCM | USA | National Center for Atmospheric Research |
| UKMO-HadCM3 | UK | Hadley Centre for Climate Prediction and Research / Met Office |

# APPENDIX B: CCVI SCORING CATEGORY DEFINITIONS

**<u>Section A – Exposure to Local Climate Change</u>**

**Temperature**: percent of species known range/distribution that is expected to experience temperature increase, in categories defined by the CCVI. All of Colorado falls within the top 2 categories: >5 degrees warmer and 5.1-5.5 degrees warmer.

**AET:PET Moisture Metric**: This index integrates projected temperature and precipitation changes to indicate how much drying will take place. This metric was created by NatureServe as part of the CCVI. Categories are:

| |
|---|
| < -0.119 |
| -0.097 - -0.119 |
| -0.074 - -0.096 |
| -0.051 - -0.073 |
| -0.028 - -0.050 |
| >-0.028 |

**<u>Section B – Indirect Exposure to Climate Change</u>**

1. **Exposure to sea level rise:** not applicable to Colorado.

2a. **Distribution relative to natural barriers**: degree to which species' vulnerability is influenced by its ability to shift range/distribution in response to climate change.

2b. **Distribution relative to anthropogenic barriers**:

Scoring categories ***for both natural barriers and anthropogenic barriers*** are:

| | |
|---|---|
| *Greatly Increase Vulnerability:* | Barriers completely OR almost completely surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly with climate change, or the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. See *Neutral* for species in habitats not vulnerable to climate change. |
| | *Examples for natural barriers:* lowland terrestrial species completely surrounded by high mountains (or bordered closely and completely on the north side by high mountains); cool-water stream fishes for which barriers would completely prevent access to other cool-water areas if the present occupied habitat became too warm as a result of climate change; most nonvolant species that exist only on the south side of a very large lake in an area where habitats are expected to shift northward with foreseeable climate change. |
| | *Examples for anthropogenic barriers:* species limited to small habitats within intensively developed urban or agricultural landscapes through which the species cannot pass, A specific example of this category is provided by the quino checkerspot butterfly (*Euphydryas editha quino*), a resident of northern Baja California and southern California; warming climates are forcing this butterfly northward, but urbanization in San Diego blocks its movement (Parmesan 1996, Nature 382:765). |
| *Increase Vulnerability:* | Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired. |

| | |
|---|---|
| | *Examples for natural barriers:* certain lowland plant or small mammal species whose ranges are mostly (50-90%) bordered by high mountains or a large lake. |
| | *Examples for anthropogenic barriers:* most streams inhabited by a fish species have dams that would prevent access to suitable habitat if the present occupied habitat became too warm as a result of climate change; intensive urbanization surrounds 75% of the range of a salamander species. |
| *Somewhat Increase Vulnerability:* | Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired. |
| | *Examples for natural barriers:* certain lowland plant or small mammal species whose ranges are partially but not mostly bordered by high mountains or a large lake. |
| | *Examples for anthropogenic barriers:* 10-50% of the margin of a plant species' range is bordered by intensive urban development; 25% of the streams occupied by a fish species include dams that are likely to impede range shifts driven by climate change. |
| *Neutral:* | Significant barriers do not exist for this species, OR small barriers exist in the assessment area but likely would not significantly impair distributional shifts with climate change, OR substantial barriers exist but are not likely to contribute significantly to a reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area. |
| | *Examples of species in this category:* most birds (for which barriers do not exist); terrestrial snakes in extensive plains or deserts that may have small barriers that would not impede distributional shifts with climate change; small alpine-subalpine mammal (e.g., ermine, snowshoe hare) in extensive mountainous wilderness area lacking major rivers or lakes; fishes in large deep lakes or large main-stem rivers that are basically invulnerable to projected climate change and lack dams, waterfalls, and significant pollution; a plant whose climate envelope is shifting northward and range is bordered on the west by a barrier but for which no barriers exist to the north. |

3. **Impact of land use changes resulting from human responses to climate change**: This factor is intended to identify species that might be further threatened by strategies designed to mitigate or adapt to climate change (e.g., renewable energy projects such as wind-farms, solar arrays, biofuels production, hydro-power; tree-planting for carbon offsets).

Definitions of scoring categories are:

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| *Increase Vulnerability:* | The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that are likely to very likely to occur within its current and/or potential future range. This includes (but is not limited to) the following:<br><br>✓ Species requiring open habitats within landscapes likely to be reforested or afforested. If the species requires openings within forests that are created/maintained by natural processes (e.g., fire), and if those processes have a reasonable likelihood of continuing to operate within its range, a lesser impact category may be appropriate.<br><br>✓ Bird and bat species whose migratory routes, foraging territory, or lekking sites include existing and/or suitable wind farm sites. If numerous wind farms already exist along the species' migratory route, negative impacts have been found in relevant studies; if such studies exist but negative impacts have not been found, a lesser impact category may be appropriate.<br><br>✓ Greater than 20% of the species' range within the assessment area occurs on marginal agricultural land, such as CRP land or other open areas with suitable soils for agriculture ("prime farmland", etc.) that are not currently in agricultural production OR > 50% of the species' range within the assessment area occurs on any non-urbanized land with suitable soils, where there is a reasonable expectation that such land may be converted to biofuel production.<br><br>✓ The species occurs in one or more river/stream reaches not yet developed for hydropower, but with the potential to be so developed.<br><br>✓ Species of deserts or other permanently open, flat lands with potential for placement of solar arrays.<br><br>✓ Species dependent on dynamic shoreline habitats (e.g., active dunes or salt marshes) likely to be destroyed by human fortifications against rising sea levels. |
| *Somewhat Increase Vulnerability:* | The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that *may possibly* occur within its current and/or potential future range, including any of the above (under Increase). |
| *Neutral:* | The species is unlikely to be significantly affected by mitigation-related land use changes that may occur within its current and/or potential future range, including any of the above; OR it is unlikely that any mitigation-related land use changes will occur within the species' current and/or potential future range. |
| *Somewhat Decrease Vulnerability:* | The species is likely to benefit from mitigation-related land use changes that may occur within its current and/or potential future range. This includes (but is not limited to) the following:<br><br>✓ Forest-associated species currently found within a landscape with < 40% forest cover, where increases in forest cover may occur as a result of reforestation or afforestation projects.<br><br>✓ Species currently subject to a higher frequency of fires than experienced historically, where there may now be greater incentive to control such fires.<br><br>✓ Species occurring on unprotected lands which may be protected and managed for conservation due to their carbon storage and/or sequestration ability. |

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| *Decrease Vulnerability:* | The species is likely to benefit from mitigation-related land use changes that are likely to very likely to occur within its current and/or potential future range, including any of the above (under Somewhat Decrease). |

## Section C - Sensitivity

### 1. Dispersal and movement

Definitions of scoring categories are:

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| *Greatly Increase Vulnerability:* | Species is characterized by severely restricted dispersal or movement capability. This category includes species represented by sessile organisms that almost never disperse more than a few meters per dispersal event. Examples include: plants with large or heavy propagules for which the disperser is extinct or so rare as to be ineffective; species with dispersal limited to vegetative shoots, buds, or similar structures that do not survive (at least initially) if detached from the parent. |
| *Increase Vulnerability:* | Species is characterized by highly restricted dispersal or movement capability. This category includes species that rarely disperse through unsuitable habitat more than about 10 meters per dispersal event, and species in which dispersal beyond a very limited distance (or outside a small isolated patch of suitable habitat) periodically or irregularly occurs but is dependent on highly fortuitous or rare events. Examples include: plants dispersed ballisticly; plant or animal species with free-living propagules or individuals that may be carried more than 10 meters by a tornado or unusually strong hurricane or large flood but that otherwise rarely disperse more than 10 meters; plants that do not fit criteria for Greatly Increase but lack obvious dispersal adaptations (i.e., propagules lack any known method for moving more than 10 meters away from the source plant). |
| *Somewhat Increase Vulnerability:* | Species is characterized by limited but not severely or highly restricted dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 10-100 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include; species that exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are up to 100 meters (rarely farther) apart; many ant-dispersed plant species; plants whose propagules are dispersed primarily by small animals (e.g., some rodents) that typically move propagules approximately 10-100 meters from the source (propagules may be cached or transported incidentally on fur or feathers); plants dispersed by wind with low efficiency (e.g., species with inefficiently plumed seeds and/or that occur predominantly in forests). |
| *Neutral:* | Species is characterized by moderate dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 100-1,000 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: species whose individuals exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are 100-1,000 meters (rarely farther) apart; many plant species dispersed by wind with high efficiency (e.g., species with efficiently plumed seeds or very small propagules that occur predominantly in open areas); plant and animal species whose propagules or individuals are dispersed by small animals (e.g., rodents, grouse) that regularly but perhaps infrequently move propagules approximately 100-1,000 meters from the source). |

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| *Somewhat Decrease Vulnerability:* | Species is characterized by good dispersal or movement capability. Species has propagules or dispersing individuals that readily move 1-10 kilometers from natal or source areas (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: plant species regularly dispersed up to 10 km (rarely farther) by large or mobile animals (e.g., plant has seeds that are cached, regurgitated, or defecated 1-10 kilometers from the source by birds [e.g., corvids, songbirds that eat small fleshy fruits] or mammals or that are transported on fur of large mobile animals such as most Carnivora or ungulates). |
| *Decrease Vulnerability:* | Species is characterized by excellent dispersal or movement capability. Species has propagules or dispersing individuals that readily move more than 10 kilometers from natal or source areas, or dispersal capability likely is consistent with one of the following examples. |
| | Examples include: plant or animal species whose individuals often or regularly are dispersed more than 10 kilometers by migratory or otherwise highly mobile animals, air or ocean currents, or humans, including species that readily become established outside their native ranges as a result of intentional or unintentional translocations by humans. |

2. **Sensitivity to temperature and moisture changes**: This factor pertains to the breadth of temperature and precipitation conditions, at both broad and local scales, within which a species is known to be capable of reproducing, growing, or otherwise existing. Species with narrow environmental tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.

   (a.i.) **historical thermal niche**: This factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature). It is a proxy for species' temperature tolerance at a broad scale.

Definitions of scoring categories are:

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| *Greatly Increase Vulnerability:* | Considering the mean seasonal temperature variation for occupied cells, the species has experienced **very small (< 37° F/20.8° C)** temperature variation in the past 50 years. Includes cave obligates and species occurring in thermally stable groundwater habitats. |
| *Increase Vulnerability:* | Considering the mean seasonal temperature variation for occupied cells, the species has experienced **small (37 - 47° F/20.8 - 26.3° C)** temperature variation in the past 50 years. |
| *Somewhat Increase Vulnerability:* | Considering the mean seasonal temperature variation for occupied cells, the species has experienced **slightly lower than average (47.1 - 57° F/26.3 - 31.8° C)** temperature variation in the past 50 years. |
| *Neutral:* | Considering the mean seasonal temperature variation for occupied cells, the species has experienced **average (57.1 - 77° F/31.8 - 44.0° C)** temperature variation in the past 50 years. |
| *Somewhat Decrease Vulnerability:* | Considering the mean seasonal temperature variation for occupied cells, the species has experienced **greater than average (> 77° F/43.0° C)** temperature variation in the past 50 years. |

(a.ii.) **physiological thermal niche**: This factor assesses the degree to which a species is restricted to relatively cool or cold environments that are thought to be vulnerable to loss or significant reduction as a result of climate change.

Definitions of scoring categories are:

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|---|---|
| *Greatly Increase Vulnerability:* | Species is completely or almost completely (> 90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. |
| *Increase Vulnerability:* | Species is moderately (50-90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. |
| *Somewhat Increase Vulnerability:* | Species is somewhat (10-50% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change. |
| *Neutral:* | Species distribution is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are thought to be not vulnerable to projected climate change. |
| *Somewhat Decrease Vulnerability:* | Species shows a preference for environments toward the warmer end of the spectrum. |

(b.i.) **historical hydrological niche**: This factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area.

Definitions of scoring categories are:

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| *Greatly Increase Vulnerability:* | Considering the range of mean annual precipitation across occupied cells, the species has experienced **very small (< 4 inches/100 mm)** precipitation variation in the past 50 years. |
| *Increase Vulnerability:* | Considering the range of mean annual precipitation across occupied cells, the species has experienced **small (4 - 10 inches/100 - 254 mm)** precipitation variation in the past 50 years. |
| *Somewhat Increase Vulnerability:* | Considering the range of mean annual precipitation across occupied cells, the species has experienced **slightly lower than average (11 - 20 inches/255 - 508 mm)** precipitation variation in the past 50 years. |
| *Neutral:* | Considering the range of mean annual precipitation across occupied cells, the species has experienced **average (21 - 40 inches/509 - 1,016 mm)** precipitation variation in the past 50 years. |
| *Somewhat Decrease Vulnerability:* | Considering the range of mean annual precipitation across occupied cells, the species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years. |

(b.ii.) **physiological hydrological niche**: This factor pertains to a species' dependence on a narrowly defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats (e.g., certain springs, vernal pools, seeps, seasonal standing or flowing water) or localized moisture conditions that may be highly vulnerable to loss or reduction with climate change.

Definitions of scoring categories are:

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|---|---|
| *Greatly Increase Vulnerability:* | Completely or almost completely (>90% of occurrences or range) dependent on a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met (e.g., species dependent on springs tied to a regional aquifer that would not be expected to change significantly with climate change), the species should be scored as Neutral. Examples for Greatly Increase include plants that are exclusively or very strongly associated with localized moist microsites (e.g., "hanging gardens" in arid landscapes). |
| *Increase Vulnerability:* | Moderately (50-90% of occurrences or range) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples for Increase include certain plants whose life cycles are highly synchronized with Mediterranean precipitation patterns in areas vulnerable to large changes in the amount and seasonal distribution of precipitation. Also included are desert or semidesert plants that frequently occur in but are not restricted to or almost restricted to moisture-accumulating microsites, as well as plants (and animals that depend on these species) for which >50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation. |
| *Somewhat Increase Vulnerability:* | Somewhat (10-50%) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples: plants (and animals that depend on these species) for which 10-50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation; certain plants with ranges restricted to seasonal precipitation environments (e.g., summer rainfall deserts) and which have a moderate degree of adaptation to that seasonality. |
| *Neutral:* | Species has little or no dependence on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change OR hydrological requirements are not likely to be significantly disrupted in major portion of the range. |
| *Somewhat Decrease Vulnerability:* | Species has very broad moisture regime tolerances OR would benefit by the predicted change in hydrologic regime. Examples include water-limited species that could increase with increasing precipitation or arid-adapted species that could increase in areas with decreasing moisture availability. |

(c .) **dependence on specific disturbance regime**: This factor pertains to a species' response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

Definitions of scoring categories are:

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|---|---|
| *Increase Vulnerability:* | Strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality. For example, many sagebrush-associated species in regions predicted to experience increased fire frequency/intensity would be scored here due to the anticipated deleterious effects of increased fire on their habitat. |
| *Somewhat Increase Vulnerability:* | Moderately affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality, OR strongly affected by specific disturbance regime, and climate change is likely to change that regime in a way that causes minor disruption to the species' distribution, abundance, or habitat quality. For example, plants in a riverscour community that are strongly tied to natural erosion and deposition flood cycles, which may shift position within the channel rather than disappear as a result of climate change. |
| *Neutral:* | Little or no response to a specific disturbance regime, or climate change is unlikely to change the frequency, severity, or extent of that disturbance regime in a way that affects the range or abundance of the species. |
| *Somewhat Decrease Vulnerability:* | Moderately affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that increases the species' distribution, abundance, or habitat quality. Many fire-adapted plants can be scored here if a predicted increase in fire frequency/intensity is anticipated to be beneficial. |
| *Decrease Vulnerability:* | Strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that increases the species' distribution, abundance, or habitat quality (e.g.,in areas predicted to experience increased fire frequency, invasive grasses that have a strong positive response to fire (e.g., ecosystem function-altering) could be scored here. |

(d.) **dependence on ice, ice-edge, or snow covered habitats**: Definitions of scoring factors are:

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| Greatly Increase Vulnerability: | Highly dependent (>80% of subpopulations or range) on ice- or snow-associated habitats; or found almost exclusively on or near ice or snow during at least one stage of the life cycle. |
| Increase Vulnerability: | Moderately dependent (50-80% of subpopulations or range) on ice- or snow-associated habitats; or often found most abundantly on or near ice or snow but also regularly occurs away from such areas. |
| Somewhat Increase Vulnerability: | Somewhat (10-49% of subpopulations or range) dependent on ice- or snow-associated habitats, or may respond positively to snow or ice but is not dependent on it. For example, certain alpine plants are often associated with long-lasting snowbeds but also commonly occur away from such areas; certain small mammals experience increased survival and may develop relatively large populations under winter snow cover but do not depend on snow cover. Species that benefit from a minimum thickness of ice or snowpack for winter insulation should also be scored here. |
| Neutral: | Little dependence on ice- or snow-associated habitats (may be highly dependent in up to 10% of the range). |

3. **Restriction to uncommon geological features or derivatives** - This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical

feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle (e.g., normal growth, shelter, reproduction, seedling establishment). It focuses on the commonness of suitable conditions for the species on the landscape, as indicated by the commonness of the features themselves combined with the degree of the species' restriction to them. Climate envelopes may shift away from the locations of fixed (within at least a 50 year timeframe) geological features or their derivatives, making species tied to these uncommon features potentially more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.

Definitions of scoring categories are:

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|---|---|
| *Increase Vulnerability:* | **Very highly dependent** upon, i.e., more or less endemic to (> 85% of occurrences found on) a particular highly uncommon geological feature or derivative (e.g., soil, water chemistry). Such features often have their own endemics. Examples include serpentine (broad and strict) endemic plants, plants of calcareous substrates where such substrates are uncommon (e.g., California, southeastern U.S.), plants restricted to one or a few specific rock strata, organisms more or less restricted to inland sand dunes or shale barrens, obligate cave-dwelling organisms, and springsnails restricted to springs with high dissolved $CO_2$. This category could also include fish species that require a highly uncommon substrate particle size for their stream bottoms, such as the Colorado pikeminnow (*Ptychocheilus lucius*) that spawns only on rare cobble bars cleared of debris by strong upstream currents. |
| *Somewhat Increase Vulnerability:* | **Moderately to highly dependent** upon a particular geological feature or derivative, i.e., (1) an indicator of but not an endemic to (65-85% of occurrences found on) the types of features described under Increase, OR (2) more or less restricted to a geological feature or derivative that is not highly uncommon within the species' range, but is not one of the dominant types. Examples of the latter include species more or less restricted to active coastal sand dunes, cliffs, salt flats (including shorebirds that require sodic soils), inland waters within a particular salinity range, and non-dominant rock types such as occasional igneous rock intrusions within a landscape mostly dominated by sedimentary and/or metamorphic rocks. This category could also include fish species that require a specific substrate particle size for their stream bottoms, if that type of stream bottom is not one of the dominant types within the species' range. |
| *Neutral:* | Having a **clear preference** for (> 85% of occurrences found on) a certain geological feature or derivative, where the feature is among the dominant types within the species' range. For example, red spruce prefers acidic, organic soils (not uncommon within its range), although it is occasionally found on other soil types. Many species whose habitat descriptions specify one pH category (acidic, neutral, or basic) and/or one soil particle size (e.g., rocky, sandy, or loamy) will probably fall here, upon confirmation that the substrate type is not particularly uncommon within the species' range. |
| *Somewhat Decrease Vulnerability:* | **Somewhat flexible but not highly generalized** in dependence upon geological features or derivatives, i.e., found on a subset of the dominant substrate/water chemistry types within its range. Most habitat descriptions that mention more than one type of relatively widespread geological feature should probably go here; however, if all types mentioned are uncommon within the species' range, Somewhat Increase may be appropriate. This category also encompasses species not strongly tied to any specific geological feature or derivative, such as many birds and mammals. |
| *Decrease Vulnerability:* | **Highly generalized** relative to dependence upon geological features or derivatives, i.e., the species is described as a generalist and/or a significant proportion of its occurrences have been documented on substrates or in waters that represent opposite ends of the spectrum of types within the assessment region (e.g., many occurrences |

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| | known from both acidic and basic soils or waters, or from both sandy and clay soils). Species such as common yarrow (*Achillea millefolium*) and coyote (*Canis latrans*) should be assigned to this category. |

4. **Reliance on specific interactions -** The primary impact of climate change on many species may occur via effects on synchrony with other species on which they depend, rather than through direct physiological stress.

(a) **Dependence on other species to generate habitat**: Definitions of scoring categories are:

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|---|---|
| Greatly Increase Vulnerability: | Required habitat generated primarily by one species, and that species is highly to extremely vulnerable to climate change within the assessment area. |
| Increase Vulnerability: | Required habitat generated primarily by one species, and that species is at most moderately vulnerable to climate change within the assessment area. See examples of species requiring other species to generate habitat under Greatly Increase Vulnerability. If the climate change vulnerability of the habitat-generating species is unknown, check both Greatly Increase and Increase Vulnerability. |
| Somewhat Increase Vulnerability: | Required habitat generated primarily by one or more of not more than a few species. For example, a certain degree of specificity exists between particular cactus species and certain nurse plants; burrowing owls (Athene cunicularia) depend on excavations made by relatively few species of burrowing mammals; certain plant species depend on large grazing animals to generate disturbance required for establishment and early growth. |
| Neutral: | Required habitat generated by more than a few species, or does not involve species-specific processes. |

(b) **Dietary versatility**: applicable only to animals.

Definitions of scoring categories are:

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| Increase Vulnerability: | Completely or almost completely (>90%) dependent on one species during any part of the year. For example, Clark's nutcracker (Nucifraga columbiana) depends heavily on the seeds of whitebark pine (Pinus albicaulis). |
| Somewhat Increase Vulnerability: | Completely or almost completely (>90%) dependent during any part of the year on a few species from a single guild that may respond similarly to climate change. For example, the larvae of various fritillary butterflies rely heavily on a few species of violets; the great purple hairstreak is dependent on a few mistletoe species. |
| Neutral: | Diet flexible; not dependent on one or a few species. For example, the diet of the great horned owl (Bubo virginianus) is flexible and not strongly dependent on one or a few species (although its diet may be dominated by one or a few species in a particular location). |
| Somewhat Decrease Vulnerability: | Omnivorous diet including numerous species of both plants and animals. |

(c) **Pollinator versatility**: applicable only to plants.

Definitions of scoring categories are:

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| Increase Vulnerability: | Completely or almost completely dependent on one species for pollination (> 90% of effective pollination accomplished by 1 species) or, if no observations exist, morphology suggests very significant limitation of potential pollinators (e.g., very long corolla tube). |
| Somewhat Increase Vulnerability: | Completely or almost completely dependent on 2-4 species for pollination (> 90% of effective pollination accomplished by 2-4 species) or, if no observations exist, morphology suggests conformation to a specific "pollination syndrome" (e.g., van der Pijl 1961, Evolution 15: 44-59, http://www.fs.fed.us/wildflowers/pollinators/syndromes.shtml). |
| Neutral: | Pollination apparently flexible; five or more species make significant contributions to pollination or, if no observations exist, morphology does not suggest pollinator limitation or pollination syndrome. |

(d) **Dependence on other species for propagule dispersal**: Definitions for scoring categories are:

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| Increase Vulnerability: | Completely or almost completely (roughly > 90%) dependent on a single species for propagule dispersal. For example, whitebark pine would fit here because Clark's nutcracker is the primary dispersal agent. |
| Somewhat Increase Vulnerability: | Completely or almost completely (roughly > 90%) dependent on a small number of species for propagule dispersal. For example, a freshwater mussel for which only a few species of fish can disperse larvae. |
| Neutral: | Disperses on its own (most animals) OR propagules can be dispersed by more than a few species. |

(e) **Other inter-specific interactions**: This factor refers to interactions unrelated to habitat, seedling establishment, diet, pollination, or propagule dispersal. Here an inter-specific interaction can include mutualism, parasitism, commensalism, or predator-prey relationship.

Definitions for scoring categories are:

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|---|---|
| Increase Vulnerability: | Requires an interaction with a single other species for persistence. |
| Somewhat Increase Vulnerability: | Requires an interaction with a one member of a small group of taxonomically related species for persistence. Could also include cases where specificity is not known for certain, but is suspected. Many Orchidaceae will be in this category because of their requirement for a specific fungal partner for germination (Tupac Otero and Flanagan 2006, TREE 21: 64-65). |
| Neutral: | Does not require an interspecific interaction or, if it does, many potential candidates for partners are available. |

5. **Genetic factors**

**(a) Measured genetic variation**: Species with less standing genetic variation will be less able to adapt because the appearance of beneficial mutations is not expected to keep pace with the rate of 21st Century climate change.

Definitions for scoring categories are:

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|---|---|
| Increase Vulnerability: | Genetic variation reported as "very low" compared to findings using similar techniques on related taxa (i.e., lack of genetic variation has been identified as a conservation issue for the species). |
| Somewhat Increase Vulnerability: | Genetic variation reported as "low" compared to findings using similar techniques on related taxa. |
| Neutral: | Genetic variation reported as "average" compared to findings using similar techniques on related taxa. |
| Somewhat Decrease Vulnerability: | Genetic variation reported as "high" compared to findings using similar techniques on related taxa. |

**(b) Occurrences of bottlenecks in recent evolutionary history** (use only if C5a is "unknown"): In the absence of rangewide genetic variation information, this factor can be used to infer whether reductions in species-level genetic variation that would potentially impede its adaptation to climate change may have occurred. Only species that suffered population reductions and then subsequently rebounded qualify for the Somewhat Increase or Increase Vulnerability categories.

Definitions for scoring categories are:

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|---|---|
| Increase Vulnerability: | Evidence that total population was reduced to < 250 mature individuals, to one occurrence, and/or that occupied area was reduced by >70% at some point in the past 500 years. |
| Somewhat Increase Vulnerability: | Evidence that total population was reduced to 251-1000 mature individuals, to less than 10 occurrences, and/or that occupied area was reduced by 30-70% at some point in the past 500 years. |
| Neutral: | No evidence that total population was reduced to < 1000 mature individuals and/or that occupied area was reduced by >30% at some point in the past 500 years. |

6. **Phenological response to changing seasonal temperature or precipitation dynamics**: Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (e.g., earlier onset of growing season, longer growing season).

Definitions for scoring categories are:

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| Increase Vulnerability: | Seasonal temperature or precipitation dynamics within the species' range show detectable change, but phenological variables measured for the species show no detectable change |

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| Somewhat Increase Vulnerability: | Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show some detectable change, but the change is significantly less than that of other species in similar habitats or taxonomic groups. |
| Neutral: | Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change which is average compared to other species in similar habitats or taxonomic groups, OR seasonal dynamics within the species' range show no detectable change. |
| Somewhat Decrease Vunlerability: | Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change which is significantly greater than that of other species in similar habitats or taxonomic groups. |

**Section D – Documented or modeled response to climate change** (optional)

**1. Documented response to recent climate change** (e.g., range contraction or phenology mismatch with critical resources): This factor pertains to the degree to which a species is known to have responded to recent climate change based on published accounts in the peer-reviewed literature. Time frame for the reduction or increase is 10 years or 3 generations, whichever is longer. Examples include population declines due to phenology mismatches between species and critical food or pollinator resources. Note that not all responses to climate change necessarily indicate vulnerability. Species that respond to climate change by shifting (but not contracting) their range, for example, show adaptability to climate change and should be scored as Neutral for this factor. Similarly, species that respond by changing their phenology (without a related decline in population) should also be scored as Neutral.

Definitions of scoring factors are:

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|---|---|
| Greatly Increase Vulnerability: | Distribution or abundance undergoing major reduction (>70% over 10 years or three generations) believed to be associated with climate change. |
| Increase Vulnerability: | Distribution or abundance undergoing moderate reduction (30-70% over 10 years or three generations) believed to be associated with climate change. |
| Somewhat Increase Vulnerability: | Distribution or abundance undergoing small but measureable (10-30% over 10 years or three generations) believed to be associated with climate change. |
| Neutral: | Distribution and abundance not known to be increasing or decreasing with climate change. Includes species undergoing range shifts without significant change in distributional area or species undergoing changes in phenology but no change in net range size or population size. |
| Somewhat Decrease Vulnerability: | Distribution or abundance undergoing small but measureable increase (10-30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts. |
| Decrease Vulnerability: | Distribution or abundance undergoing moderate or major increase (>30% over 10 years or three generations) believed to be associated with climate change. Distribution changes must be true increases in area, not range shifts. |

2. **Modeled future (2050) change in range or population size:** This factor can include both distribution models and population models. Models should be developed based on reasonably accurate locality data (error < 5km) using algorithms that are supported by peer-reviewed literature. Areas of obvious over-prediction should be removed from current and predicted future distributions. Projections should be based on "middle of the road" climate scenarios for the year 2050. Range size should be based on "extent of occurrence" sensu IUCN Red List. Population models should be based on known processes as described in peer-reviewed literature. If necessary, check multiple boxes to reflect variation in model output.

Definitions of scoring factors are:

| | |
|---|---|
| Greatly Increase Vulnerability: | Predicted future range disappears entirely from the assessment area OR predicted future abundance declines to zero as a result of climate change processes. |
| Increase Vulnerability: | Predicted future range represents 50-99% decrease relative to current range within the assessment area OR predicted future abundance represents 50-99% decrease associated with climate change processes. |
| Somewhat Increase Vulnerability: | Predicted future range represents a 20-50% decrease relative to current range within the assessment area OR predicted future abundance represents 20-50% decrease associated with climate change processes. |
| Neutral: | Predicted future range represents no greater than a 20% change relative to current range within the assessment area OR predicted future abundance represents increases or decreases < 20% associated with climate change processes. |
| Somewhat Decrease Vulnerability: | Predicted future range represents a 20-50% increase relative to current range within the assessment area OR predicted future abundance represents 20-50% increase associated with climate change processes. |
| Decrease Vulnerability: | Predicted future range represents a > 50% increase relative to current range within the assessment area OR predicted future abundance represents > 50% increase associated with climate change processes. |

3. **Overlap of modeled future (2050) range with current range**: Distribution models of current and projected future ranges should meet standards described in the notes for D2. Overlap is calculated as the percent of the current range represented by an intersection of the predicted future and current ranges. If the range disappears or declines > 70% within the assessment area, such that factor D2 is coded as "Greatly Increase Vulnerability," this factor should be skipped to avoid double-counting model results.

Definitions of scoring factors are:

| | |
|---|---|
| Greatly Increase Vulnerability: | There is no overlap between the current and predicted future range within the assessment area. |

| | |
|---|---|
| Increase Vulnerability: | Predicted future range overlaps the current range by 30% or less within the assessment area. |
| Somewhat Increase Vulnerability: | Predicted future range overlaps the current range by 30-60% within the assessment area. |
| Neutral: | Predicted future range overlaps the current range by > 60% within the assessment area. |

4. **Occurrence of protected areas in modeled future (2050) distribution**: "Protected area" refers to existing parks, refuges, wilderness areas, and other designated conservation areas that are relatively invulnerable to outright habitat destruction from human activities and that are likely to provide suitable conditions for the existence of viable populations of the species. Models of current and projected future ranges should meet standards described in the notes for D2. Modeled future distribution may refer to a single season (e.g., breeding season distribution or winter distribution) for migratory species. This factor considers ranges and protected areas within the assessment area only.

Definitions of scoring factors are:

| | |
|---|---|
| Increase Vulnerability: | < 5% of the modeled future distribution within the assessment area is encompassed by one or more protected areas. |
| Somewhat Increase Vulnerability: | 5-30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas. |
| Neutral: | >30% of the modeled future distribution within the assessment area is encompassed by one or more protected areas. |

# APPENDIX C: FULL CCVI SCORING RESULTS

Values in columns with pink headers (degree of projected future warming), and blue headers (projected future changes in moisture availablitiy) are percentages of species range within Colorado.
Ranks for indirect climate factors that affect the vulnerability of a species (columns with light brown headings) are: GI = Greatly Increase vulnerability, Inc = Increase vulnerability, SI = Somewhat Increase vulnerability, N = Neutral, SD = Somewhat Decrease vulnerability, Dec = Decrease vulnerability, N/A = Not applicable, U = Unknown. The overall vulnerability rank is given in the Index column as EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely. Confidence levels are shown in the last column as VH = Very High, H = High, M = Moderate, L = Low.

Table c1. Animal results, sorted alphabetically by common name within taxanomic group.

| | | Percent of range in each category | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature Scope Change in °F | | | Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| English Name | Species | >5.5 | 4.5 to 5.1 | <4.5 | < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | >-0.028 | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
| Amphibians | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Boreal Toad | *Anaxyrus boreas boreas* | | 100 | | 17 | 49 | 32 | 2 | 0 | | N | Inc | N | SI-N | N-SD | N | SI | SD | Inc | N | SI | N | Inc | N | N/A | N | N | SD | N/A | N | U | U | U | U | HV | M |
| Canyon Treefrog | *Hyla arenicolor* | | 100 | | 12.1 | 43.2 | 31.3 | 13 | 0.4 | | N | SI | N | N | N-SD | N | SD | N | Inc | N | N | SI | N | N | N/A | N | N | SI | N/A | N | U | U | U | U | MV | VH |
| Great Basin Spadefoot | *Spea intermontana* | | 100 | | 9.1 | 55.1 | 22.6 | 12.7 | 0.5 | | N | N | N | N | N | N | N | N | Inc | N | N | N | N | N | N/A | N | N | N | N/A | N | U | U | U | U | PS | VH |
| Northern Leopard Frog | *Lithobates pipiens* | | 100 | | 12.6 | 52.8 | 29.1 | 5.4 | 0.1 | | N | N | SI | SI-N | N-SD | N | SI | SD | Inc | N | N | N | SI-N | N | N/A | N | N | SD | N/A | N | U | U | U | U | MV | L |
| Birds | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| American Peregrine Falcon | *Falco peregrinus anatum* | | 100 | | 11 | 52 | 30 | 7 | | | N | N | N | N | Dec | N | N | SD | GI | N | N | Inc-SI | N | N | N/A | N | SI | U | U | U | U | Dec | U | U | IL | L |
| Black Swift | *Cypseloides niger* | | 100 | | 18.6 | 46.2 | 29.9 | 5.3 | | | N | N | N | N | Dec | N | N | N | Inc | N | N | SI | N | N | N/A | N | N | U | N | U | U | U | U | U | PS | VH |
| Brewer's Sparrow | *Spizella breweri* | | 100 | | 6.5 | 57.5 | 31.2 | 4.6 | 0.2 | | N | N | N | SI | Dec | N | N | SD | N | N | SI | N | GI | N | N/A | N | N | N | N/A | U | U | U | U | U | PS | VH |
| Burrowing Owl | *Athene cunicularia hypuguaea* | | 100 | | 2.2 | 61.4 | 31.8 | 4.3 | 0.3 | | N | N | N | SI | Dec | N | N | SD | N | N | N | N | SI | N | N/A | U | N | Inc | N/A | U | U | Inc | U | Inc | MV | VH |

| English Name | Species | Percent of range in each category | | | | | | | | | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature Scope Change in °F | | | Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | >5.5 | 4.5 to 5.1 | <4.5 | < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | >-0.028 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Golden eagle | *Aquila chrysaetos* | | 100 | | 9 | 52 | 32 | 7 | | | N | N | N | SI | Dec | N | N | SD | N | N | N | N | N | SI | N/A | N | N | N | N/A | U | U | Inc | U | U | MV | VH |
| Greater sage-grouse | *Centrocercus urophasianus* | | 100 | | 8.4 | 75.5 | 15 | 1.1 | | | N | N | N | SI | Dec | N | N | SD | GI | SI | N | SD | GI | SI | N/A | N | U | N | N/A | U | U | U | U | U | HV | VH |
| Gunnison sage-grouse | *Centrocercus minimus* | | 100 | | 60 | 27 | 12 | 1 | | | N | SI | Inc-SI | SI | SD | N | SI | N | GI | SI | N | N | GI | Inc | N/A | N | U | Inc-SI | N/A | U | U | U | U | N | HV | VH |
| Long-billed curlew | *Numenius americanus* | | 99.85 | 0.15 | 0.1 | 67 | 29.6 | 3.2 | 0.1 | | N | SI | SI | SI | Dec | N | N | N | Inc | SI | N | SI | N | N | N/A | N | U | U | U | U | U | U | U | U | HV | VH |
| Mountain Plover | *Charadrius montanus* | | 99.91 | 0.09 | 3 | 56 | 38 | 3 | | | N | N | N | Inc | Dec | N | SI | SD | SD | SD | N | N | SI | N | N/A | N | N | SD | N/A | U | U | Inc | U | U | PS | VH |
| Norhern goshawk | *Accipiter gentilis* | | 100 | | 13 | 50.7 | 29 | 7.2 | 0.1 | | N | N | N | SI | Dec | N | SI | SD | SD | N | N | N | N | SI | N/A | N | N | SI | N/A | U | U | Inc | U | U | MV | VH |
| Western snowy plover | *Charadrius alexandrinus nivosus* | 0.14 | 99.86 | | 6.1 | 46.5 | 41.6 | 5.7 | 0.1 | | N | SI | N | SI | Dec | N | N | SD | GI | SI | SI | SI | N | N | N/A | N | U | SI | N/A | U | U | U | U | U | HV | VH |
| Western yellow-billed cuckoo | *Coccyzus americanus occidentalis* | | 100 | | 13 | 49 | 28 | 10 | | | N | N | Inc-SI | U | SD-Dec | N | Inc-SI | SD | GI | SI | N | N | N | SI-N | N/A | N | SI | U | U | U | U | U | U | U | HV | M |
| White-faced Ibis | *Plegadis chihi* | | 100 | | 12.7 | 41 | 40.3 | 5.8 | 0.2 | | N | N | SI | SI | Dec | N | N | SD | Inc | SI | SI | N | N | N | N/A | N | U | U | U | U | U | U | U | U | MV | VH |
| Fish | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bluehead sucker | *Catostomus discolobus* | | 100 | | | 9 | 54.6 | 27.2 | 8.7 | 0.5 | N | Inc | Inc | N | SD-Dec | N | SI-N | SD | SI | N | N | N | U | N | N/A | N | U | Inc | N/A | U | U | U | U | U | HV | M |
| Bonytail Chub | *Gila elegans* | | 100 | | | 51 | 27 | 22 | | | N | SI-N | Inc | N | Dec | N | N | Inc | SI | Inc | N | Inc | N | N | N/A | N | U | Inc | N/A | U | U | U | U | U | EV | VH |
| Colorado pikeminnow | *Ptychocheilus lucius* | | 100 | | | 31 | 28 | 40 | 1 | | N | SI-N | Inc | N | Dec | N | N | SI | SI | Inc | N | Inc | N | N | N/A | N | U | Inc | N/A | U | U | U | U | U | EV | VH |
| Colorado River Cutthroat Trout | *Oncorhynchus clarki pleuriticus* | 100 | | | 16.2 | 53.4 | 24.5 | 5.9 | | | N | SI-N | SI-N | N | SD | N | SI-N | SI | Inc | SI-N | N | SI-N | N | N | N/A | N | U | Inc | N/A | U | U | U | U | U | EV | H |
| Flannelmouth Sucker | *Catostomus latipinnis* | | 100 | | 9 | 54.6 | 27.2 | 8.7 | 0.5 | | N | Inc | Inc | N | Dec | N | SI-N | SD | SI | N | N | SI-N | U | N | N/A | U | U | Inc | N/A | U | U | U | U | U | HV | M |
| Humpback Chub | *Gila cypha* | | 100 | | | 50 | 27 | 23 | | | N | SI-N | Inc | N | N-SD | N | N | Inc | SI | Inc | U | U | N | N | N/A | N | U | SI | N/A | U | U | U | U | U | EV | VH |
| Razorback sucker | *Xyrauchen texanus* | | 100 | | | 31 | 28 | 40 | 1 | | N | SI-N | Inc | N | Dec | N | N | SI | SI | Inc-SI | SI | SI | N | N | N/A | N | U | N | N/A | U | U | U | U | U | HV | M |
| Rio Grande cutthroat trout | *Onchorhynchus clarkii virginalis* | | 100 | | 4 | 33 | 45 | 17 | 1 | | N | Inc | SI | N | SD | N | GI | SD | GI | N | N | SI-N | U | N | N/A | N | N | Inc | N/A | U | U | U | U | U | EV | VH |
| Roundtail Chub | *Gila robusta* | | 100 | | | 9 | 54.6 | 27.2 | 8.7 | 0.5 | N | SI-N | Inc | N | N | N | N | SD | SI | Inc | N | U | U | N | N/A | N | U | SI | N/A | U | U | U | U | U | HV | VH |

| English Name | Species | Percent of range in each category: Temperature Scope Change in °F >5.5 | 4.5 to 5.1 | <4.5 | Hamon AET:PET Moisture Metric Scope Percent change in moisture availability < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | >-0.028 | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Insects | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Great Basin silverspot | *Speyeria Nokomis Nokomis* | | 100 | | 4 | 52 | 39 | 5 | | | N | Inc | N | Inc | N | N | GI | SD | SD | Inc | N | N | N | Inc | N/A | N | N | Inc | N/A | U | U | Inc | U | U | HV | VH |
| Mammals | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| American beaver | *Castor canadensis* | | 100 | | 7 | 55 | 33 | 5 | | | N | N | N | N | SD | N | Inc | SD | GI | SI | N | N | N | N | N/A | U | U | N | N/A | N | N | U | U | N | MV | VH |
| Desert bighorn sheep | *Ovis canadensis* | | 100 | | | 8 | 53 | 39 | | | N | N | Inc | N | Dec | N | SD | SI | N-SD | SI | N | N | N | N | N/A | N | N | N | N/A | N-SD | N | SI | U | SI | MV | VH |
| Fringed Myotis | *Myotis thysanodes* | | 100 | | 2.7 | 46 | 42.3 | 8.4 | 0.6 | | N | N | N | N | Dec | N | N | N | SI | N | N | SI | N | N | N/A | N | N | U | U | U | U | U | U | U | PS | VH |
| Gunnison's Prairie Dog | *Cynomys gunnisoni* | | 100 | | 18 | 43 | 27 | 11 | 1 | | N | SI-N | N | SI-N | SD | N | SI-N | SD | N-SD | Inc-SI | N | N | N | N | N/A | N | N | SI-N | N/A | N | N | U | U | N | PS | H |
| Townsend's Big-eared Bat | *Corynorhinus townsendii* | | 100 | | 10.8 | 49.8 | 32.2 | 7 | 0.2 | | N | N | N | N | Dec | N | N | N | SI-N | N | N | SI | N | N | N/A | N | N | N-SD | N/A | N | U | U | U | U | PS | M |
| White-tailed prairie dog | *Cynomys leucurus* | | 100 | | 5 | 60 | 20 | 14 | 1 | | N | N | N | N | SD | N | SI-N | SD | N-SD | Inc-SI | N | N | N | N | N/A | N | N | SI-N | N/A | N | N | U | U | N | PS | VH |
| Reptiles | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Desert Spiny Lizard | *Sceloporus magister* | | 100 | | | | 1.1 | 53.6 | 45.3 | | N | N | N | N | N-SD | N | SD | Inc | N-SD | N | N | Inc | N | N | N/A | N | N | N | N/A | U | U | N | U | U | PS | VH |
| Longnose leopard lizard | *Gambelia wislizenii* | | 100 | | 2 | 21 | 43 | 30 | 4 | | N | SI-N | N | N | N | N | SD | N | N-SD | SI-N | N | N | N | N | N/A | U | U | N | N/A | N | N | U | U | N | PS | H |
| Midget Faded Rattlesnake | *Crotalus oreganus concolor* | | 100 | | 10 | 42 | 32 | 15 | 1 | | N | SI-N | N | N | N-SD | N | Inc | N | SI-N | N | N | Inc | N | N | N/A | N | N | SI-N | N/A | U | U | U | U | U | HV | M |

Table C2. Plant results, sorted alphabetically by scientific name.

| Species | English Name | Percent of range in each category: Temperature Scope Change in °F | | Percent of range in each category: Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | >5.5 | 4.5 to 5.1 | < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Aletes latilobus (Lomatium latilobum)* | Canyonlands aletes | 100 | | | | | 100 | | N | Inc | Inc | Inc | Inc | N | Inc | GI | Inc | N | N | SI | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Aletes lithophilus (Neoparrya lithophila)* | Rock-loving neoparrya | 100 | | 6 | 34 | 28 | 31 | 1 | N | Inc | SI | SI | SD | N | N | N | SI | Inc | N | U | N | N/A | N | N | N | U | U | U | U | U | U | U | EV | VH |
| *Amsonia jonesii* | Jones' bluestar | 100 | | | 20 | 58 | 20 | 2 | N | SI | SI | N | SI | N | SD | N | SI | Inc | N | SD | N | N/A | N | N | U | U | U | U | U | SI | N | SI | MV | VH |
| *Aquilegia chrysantha var. rydbergii* | Golden columbine | 100 | | | 100 | | | | N | N | N | N | Inc | SI | Inc | Inc | GI | N | N | SD | N | N/A | SI | N | N | U | U | U | U | U | U | U | EV | VH |
| *Asclepias uncialis ssp. uncialis* | Dwarf milkweed | 23 | 77 | | 71 | 29 | | | N | N | SI | Inc | SI | SD | N | Inc | Inc | N | N | N | N | N/A | N | N | N | U | U | U | U | U | U | U | EV | VH |
| *Astragalus anisus* | Gunnison milkvetch | 100 | | 45 | 55 | | | | N | SI | SI | Inc | Inc | SD | N | Inc | SI | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus debequaeus* | DeBeque milkvetch | 100 | | | | 99 | 1 | | N | Inc | SI | Inc | Inc | SD | N | Inc | Inc | N | N | SI | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus equisolensis* | Horseshoe milkvetch | 100 | | | | 100 | | | N | SI-N | N | SI | Inc | N | N | Inc | Inc | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus microcymbus* | Skiff milkvetch | 100 | | 97 | 3 | | | | N | SI-N | SI-N | Inc | Inc | SD | SI | Inc | SI | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus naturitensis* | Naturita milkvetch | 100 | | | | 98 | 2 | | N | Inc-SI-N | SI-N | N | Inc | SD | Inc | Inc | Inc | SI | N | SI | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus osterhoutii* | Kremmling milkvetch | 100 | | | 100 | | | | N | SI | N | SI | Inc | SD | N | Inc | SI | SI | N | SI | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus piscator* | Fisher Towers milkvetch | 100 | | | | 100 | | | N | N | N | Inc | Inc | N | N | GI | SI | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus rafaelensis* | San Rafael milkvetch | 100 | | | | 91 | 9 | | N | Inc | N | N | Inc | N | N | GI | Inc | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Astragalus ripleyi* | Ripley milkvetch | 100 | | | 76 | 24 | | | N | SI | SI | N | SI | N | N | N | Inc | Inc | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Astragalus tortipes* | Sleeping Ute milkvetch | 100 | | | | | 100 | | N | Inc-SI | Inc-SI | Inc | Inc | N | N | GI | SI | SI | N | N | N | N/A | N | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Bolophyta ligulata (Parthenium ligulatum)* | Ligulate feverfew | 100 | | | 2 | 13 | 71 | 14 | N | SI | Inc | SI | SI | N | SI | GI | SI | U | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Camissonia eastwoodiae* | Eastwood evening primrose | 100 | | | | 42 | 50 | 8 | N | N | N | Inc | Inc | SD | N | Inc | SI | SI | N | N | N | N/A | U | N | U | U | U | U | U | U | U | U | HV | VH |
| *Cleome multicaulis* | Slender spiderflower | 2 | 98 | | | 46 | 54 | | N | GI | N | Inc | Inc | SD | N | GI | GI | N | N | N | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Corispermum navicula* | Boat-shaped bugseed | 100 | | | 33 | 67 | | | N | Inc | N | N | Inc | N | N | GI | Inc | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |

| Species | English Name | Percent of range in each category: Temperature Scope Change in °F | | Percent of range in each category: Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | >5.5 | 4.5 to 5.1 | < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Cryptogramma stelleri* | Slender rock-brake | 100 | | 28 | 38 | 30 | 4 | | N | SI | N | N | N | N | SI | SD | GI | N | N | Inc | N | N/A | N | U | U | U | U | U | U | U | U | U | EV | VH |
| *Erigeron kachinensis* | Kachina daisy | 100 | | | | 100 | | | N | Inc | N | N | SI | N | Inc | GI | GI | N | N | SI | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Eriogonum brandegei* | Brandegee wild buckwheat | 100 | | 86 | 14 | | | | N | Inc | N | N | SI-N | N | N | Inc | Inc | N | N | Inc | N | N/A | N | N | N | U | U | U | U | U | U | U | EV | VH |
| *Eriogonum clavellatum* | Comb Wash buckwheat | 100 | | | | | 99.5 | 0.5 | N | N | SI | Inc | Inc | N | N | GI | SI | SI | N | N | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Eriogonum coloradense* | Colorado wild buckwheat | 100 | | 33 | 27 | 15 | 25 | | N | Inc | N | N | SI-N | N | Inc | N | Inc | N | SI | N | N | N/A | N | N | N | U | U | U | U | U | U | U | EV | VH |
| *Eriogonum contortum* | Twisted Buckwheat | 100 | | | 2 | 13 | 71 | 14 | N | GI | Inc | SI | SI | SD | SI | Inc | Inc | Inc | N | SI | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Eriogonum pelinophilum* | Clay-loving wild buckwheat | 100 | | | | 48 | 52 | | N | Inc | Inc | Inc | Inc | SD | N | Inc | SI | SI | N | SI | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Eriogoum ephedroides* | Ephedra buckwheat | 100 | | | 21 | 19 | 60 | | N | Inc | Inc | SI | SI | N | SI | Inc | SI | Inc | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Eutrema penlandii* | Penland alpine fen mustard | 100 | | | 28 | 72 | | | N | Inc | N | N | Inc | N | Inc | N | GI | N | SI | N | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Gentianella tortuosa* | Utah gentian | 100 | | 100 | | | | | N | Inc | SI | SI | SD | N | SI | GI | SI | Inc | N | SI | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Gilia (Aliciella) stenothyrsa* | Narrow-stem Gilia | 100 | | 30 | 42 | 24 | 4 | | N | SI | GI | SI | SI | N | SD | SI | Inc | Inc | N | N | N | N/A | SI | N | U | U | U | U | U | Inc | Inc | SI | EV | VH |
| *Gutierrezia elegans* | Lone Mesa snakeweed | 100 | | | 100 | | | | N | Inc | SI | Inc | Inc | N | N | GI | SI | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Ipomopsis polyantha* | Pagosa skyrocket | | 100 | | 100 | | | | N | Inc | Inc | Inc | Inc | SD | N | GI | Inc | N | N | Inc | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Lomatium concinnum* | Coloado desert-parsley | 100 | | 42 | 9 | 49 | | | N | SI | Inc-SI | Inc | Inc | N | N | Inc | SI | SI | N | SI | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Lupinus crassus* | Payson lupine | 100 | | 3 | | 97 | | | N | SI | N | SI | Inc | SD | N | SI | Inc | SI | N | N | N | N/A | U | N | SI | U | U | U | U | U | U | U | EV | VH |
| *Mentzelia rhizomata* | Roan Cliffs blazing star | 100 | | 2 | 93 | 5 | | | N | Inc | N | Inc | Inc | N | N | Inc | Inc | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Mimulus eastwoodiae* | Eastwood's monkeyflower | 100 | | | 32 | 58 | 10 | | N | SI | SI | N | N | N | Inc | N | GI | N | N | SI | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Nuttallia (Mentzelia) chrysantha* | Golden blazing star | 71 | 29 | 10 | 28 | 62 | | | N | Inc | SI-N | Inc | Inc-SI | N | N | Inc | Inc | N | N | Inc | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Nuttallia (Mentzelia) densa* | Arkansas Canyon stickleaf | 100 | | 1.5 | 98.5 | | | | N | Inc-SI | SI-N | N | Inc | N | N | Inc | Inc | SI | N | N | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Oenothera acutissima* | Narrow-leaf evening primrose | 100 | | 4 | 70 | 26 | | | N | N | N | N | Inc | N | N | Inc | SI | N | N | N | N | N/A | U | N | U | U | U | U | U | U | U | U | HV | VH |

| Species | English Name | Percent of range in each category | | | | | | | Sea level | Natural barriers | Anthropogenic barriers | CC mitigation | Dispersal/Movement | Historical thermal niche | Physiological thermal niche | Historical hydrological niche | Physiological hydrological niche | Disturbance | Ice/snow | Phys habitat | Other spp for hab | Diet | Pollinators | Other spp disp | Other spp interaction | Genetic var | Gen bottleneck | Phenol response | Doc response | Modeled change | Modeled overlap | Protected Areas | Index | Confidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature Scope Change in °F | | Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | >5.5 | 4.5 to 5.1 | < -0.119 | -0.119 | -0.096 | -0.073 | -0.05 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Oreocarya (Cryptantha) caespitosa* | Tufted Cryptanth | 100 | | | 54 | 37 | 9 | | N | N | Inc | SI | SI | N | N | Inc | Inc | Inc | N | N | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Oreocarya (Cryptantha) rollinsii* | Rollins' Cats-eye | 100 | | 2 | 33 | 33 | 32 | | N | Inc | Inc | SI | Inc | N | N | SI | Inc | Inc | N | N | N | N/A | U | N | N | N | N/A | U | U | U | U | U | EV | VH |
| *Oreocarya osterhoutii (Cryptantha osterhoutii)* | Osterhout's cat's-eye | 100 | | | | 61 | 39 | | N | Inc | Inc-SI | Inc | Inc | SD | N | Inc | Inc | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Oroecarya revealii (Cryptantha gypsophila)* | Gypsum Valley cat's-eye | 100 | | | 8 | 84 | 8 | | N | Inc | N | SI | Inc | N | N | Inc | Inc | SI | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Pediomelum aromaticum* | Paradox breadroot | 100 | | | 33 | 59 | 8 | | N | SI | SI | N | Inc | N | N | N | SI | SI | N | N | N | N/A | SI | N | Inc | U | U | U | U | U | U | U | EV | VH |
| *Penstemon debilis* | Parachute penstemon | 100 | | | 92 | 8 | | | N | Inc | N | Inc | Inc | N | N | Inc | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon degeneri* | Degener beardtongue | 100 | | 29 | 71 | | | | N | N | N | N | Inc | N | N | Inc | Inc | SI | N | N | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon gibbensii* | Gibben's beardtongue | 100 | | | | 100 | | | N | Inc | N | Inc | Inc | SD | N | GI | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon grahamii* | Graham beardtonuge | 100 | | | | | 100 | | N | Inc | N | Inc | Inc | SD | N | GI | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon harringtonii* | Harrington's beardtongue | 100 | | 18 | 80 | 2 | | | N | N | SI | N | Inc | N | N | N | SI | SI | N | N | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon penlandii* | Penland penstemon | 100 | | | 100 | | | | N | SI | SI | SI | Inc | SD | N | GI | SI | SI | N | N | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Penstemon scariosus var. albifluvis* | White River penstemon | 100 | | | | | 100 | | N | Inc | N | Inc | Inc | SD | N | GI | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Phacelia formosula* | North Park phacelia | 100 | | | 99 | 1 | | | N | Inc | N | Inc | Inc | N | N | Inc | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Phacelia submutica* | DeBeque phacelia | 100 | | | 4 | 95 | 1 | | N | Inc | Inc-SI | Inc | Inc | SD | N | GI | Inc | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Physaria (Lesquerella) congesta* | Dudley Bluffs bladderpod | 100 | | | 100 | | | | N | Inc | Inc | Inc | Inc | N-SD | N | GI | Inc | N | N | Inc | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Physaria (Lesquerella) parviflora* | Piceance bladderpod | 100 | | 75 | 24 | 1 | | | N | Inc | N | Inc | Inc | N | N | Inc | Inc | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Physaria (Lesquerella) pruinosa* | Pagosa bladderpod | | 100 | 1 | 95 | 4 | | | N | Inc | SI | Inc | Inc | SD | N | Inc | Inc | N | N | Inc | N | N/A | N | N | N | U | U | U | U | U | U | U | EV | VH |
| *Physaria (Lesquerella) vicina* | Good-neighbor bladderpod | 100 | | 6 | 49 | 42 | 3 | | N | Inc | Inc | N | Inc | N | N | Inc | Inc | SI | N | SI | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |
| *Physaria obcordata* | Piceance twinpod | 100 | | | 100 | | | | N | Inc | N | Inc | Inc | SD | N | Inc | Inc | N | N | Inc | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Physaria pulvinata* | Cushion bladderpod | 100 | | | 100 | | | | N | Inc | SI-N | Inc | Inc | N | N | Inc | SI | N | N | Inc | N | N/A | U | N | U | U | U | U | U | U | U | U | EV | VH |

| | | Percent of range in each category | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature Scope Change in °F | | Hamon AET:PET Moisture Metric Scope Percent change in moisture availability | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Species** | **English Name** | **>5.5** | **4.5 to 5.1** | **< -0.119** | **-0.119** | **-0.096** | **-0.073** | **-0.05** | **Sea level** | **Natural barriers** | **Anthropogenic barriers** | **CC mitigation** | **Dispersal/Movement** | **Historical thermal niche** | **Physiological thermal niche** | **Historical hydrological niche** | **Physiological hydrological niche** | **Disturbance** | **Ice/snow** | **Phys habitat** | **Other spp for hab** | **Diet** | **Pollinators** | **Other spp disp** | **Other spp interaction** | **Genetic var** | **Gen bottleneck** | **Phenol response** | **Doc response** | **Modeled change** | **Modeled overlap** | **Protected Areas** | **Index** | **Confidence** |
| *Sclerocactus glaucus* | Colorado hookless cactus | 100 | | 0.5 | 1 | 12 | 86.5 | | N | Inc-SI | SI-N | Inc | Inc | SD | N | Inc | SI | SI | N | N | N | N/A | SI | N | U | U | U | U | U | U | U | U | EV | VH |
| *Sisyrinchium pallidum* | Pale blue-eyed grass | 100 | | 26 | 74 | | | | N | Inc | N | N | Inc | N | N | N | GI | N | N | N | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |
| *Thalictrum heliophilum* | Sun-loving meadow rue | 100 | | 72 | 28 | | | | N | Inc | N | Inc | Inc | N | N | Inc | Inc | N | N | Inc | N | N/A | N | N | U | U | U | U | U | U | U | U | EV | VH |