Colorado Bureau of Land Management
MODELING ECOLOGICAL RESPONSE TO SUPPORT ADAPTATION STRATEGIES

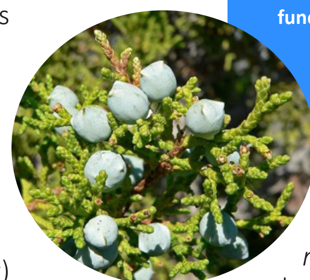
SUMMARY OF FINDINGS

Overview
In 2015, the Colorado Natural Heritage Program (CNHP) completed a statewide vulnerability assessment for Colorado BLM. In that assessment, we determined that the pinyon-juniper ecosystem was the highest priority for additional analysis and adaptation strategy development. Of the ecosystems that make up the majority of BLM lands, pinyon-juniper ranked as most vulnerable, primarily due to potential for significant impacts to two-needle pinyon pine (CNHP 2015).

RESEARCH QUESTIONS:

- ***How might different climate scenarios influence future distribution of vulnerable ecosystems?***
- ***What strategies might improve the ability of species and ecosystems to adapt to changing conditions, and where should we employ those strategies?***

Adaptation = management strategies that promote ecological resilience, maintain ecological function, and support sustainable ecosystem services in the face of a changing climate.



In order to develop adaptation strategies for addressing ecosystem vulnerability, we need to know how and where climate might change, as well as how and where ecosystems might respond. Building on previous and ongoing work (e.g., Rondeau et al. 2017), we developed rangewide models for two-needle pinyon pine (*Pinus edulis*) and the two juniper species primarily associated with pinyon pine in Colorado— Utah juniper (*Juniperus osteosperma*) and one-seed juniper (*J. monosperma*) (current distributions shown in Figure 1). The purpose of the models was to determine where habitat suitability for those species may improve or deteriorate, based on our best understanding of how each species may respond to projected future climate variables. The models will support our ongoing collaboration with BLM and other partners on identification of adaptation strategies.

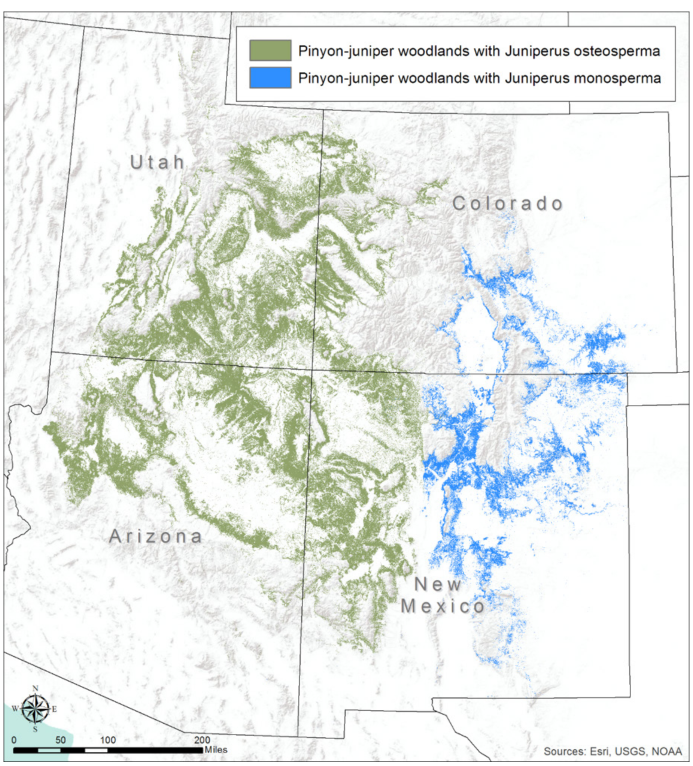


Figure 1. Current distribution of pinyon pine (*Pinus edulis*) with Utah juniper (green) and one-seed juniper (blue).

Potential Future Climate Scenarios
To accommodate uncertainty in climate projections, we developed our models using four scenarios representing the variety of future conditions we might expect. Each scenario was developed using one Global Circulation Model/emission scenario combination, selected in collaboration with a climate scientist. The four climate models capture the basic range of wetter to drier and warmer to hotter projected for the southwestern U.S. (Figure 2) by mid-century (i.e., 30-year period around 2050). We called these scenarios “Hot & Dry,” “Hot & Wet,” “Warm & Wet,” and “Feast or Famine.”

For each climate scenario, we interpreted how changes in projected temperature and precipitation may translate into climate and weather patterns, and what those changes might mean for pinyon pine and the two juniper species. Examples include changes in amount, seasonality, and form of precipitation (e.g., rain v. snow), timing and seasonality of temperature changes, and ecological consequences

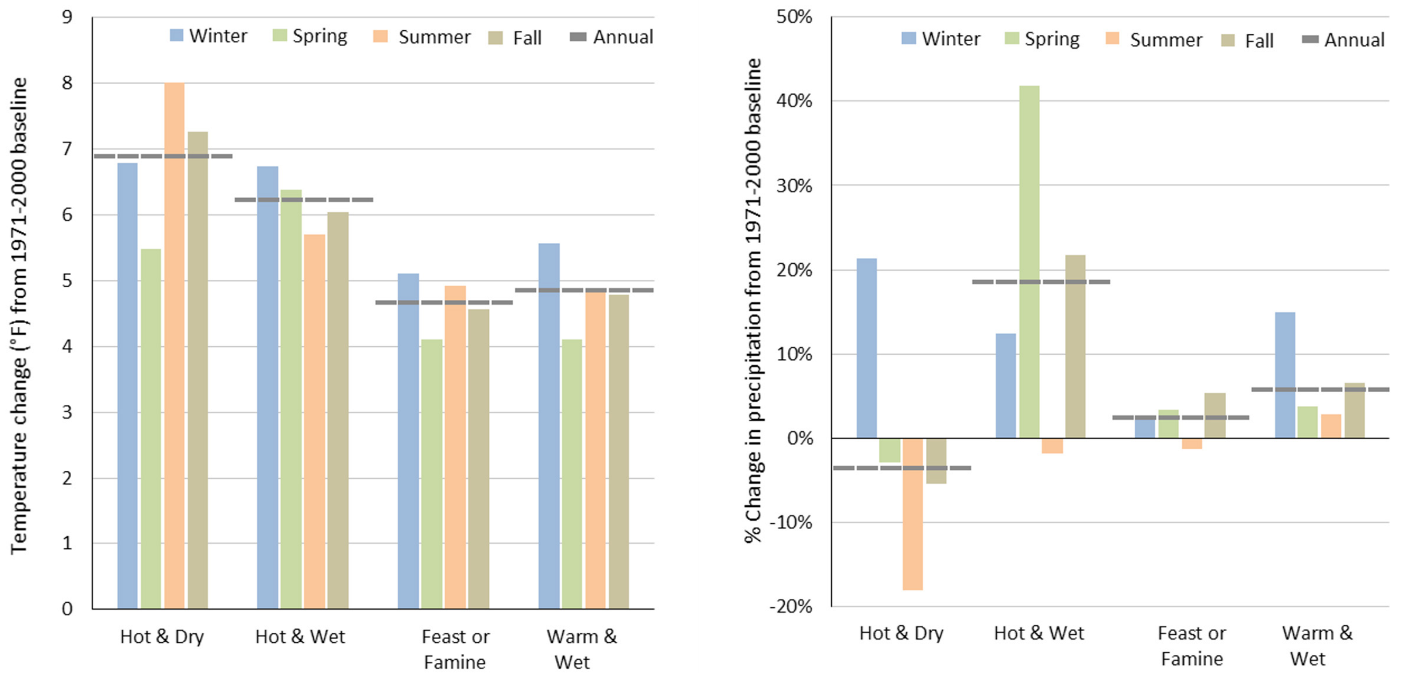


Figure 2. Projected seasonal changes under each future climate scenario for temperature (left) and precipitation (right). Dashed lines represent projected annual mean for each scenario. Zero (x-axis) represents current mean. Note that increased precipitation may not result in increased moisture availability due to higher temperatures (e.g., Nash and Gleick 1991).

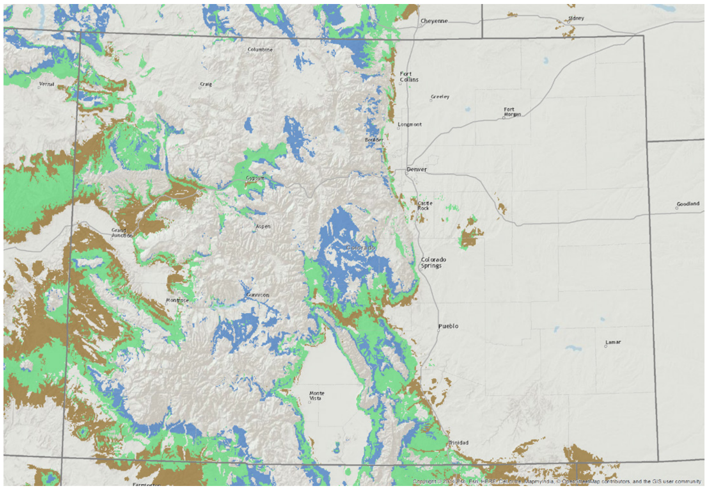
(e.g., length of growing season, requirements for successful reproduction) (Table 1).

Ecological Response Models

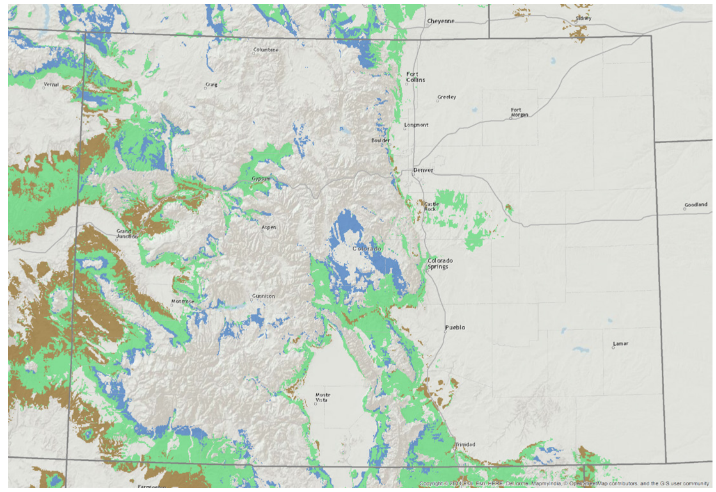
We developed spatial ecological response models based on distribution modeling of the dominant tree species (pinyon pine and the two juniper species), and projected those models out to a mid-century time frame under the four climate scenarios. These models (e.g., Figure 3) depict areas where suitable climate is likely to persist, likely to be emergent (i.e., new areas where climate will become suitable), or unlikely to remain in place. The most important variables influencing the model for each species are presented in Table 2.

Table 1. Summary of estimated impacts of projected changes in temperature and precipitation for each future climate scenario.

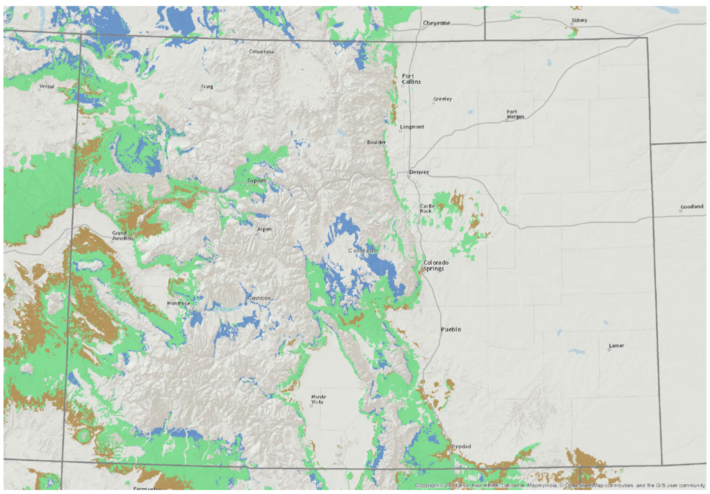
Scenario	Statewide Effects (compared to 1971-2000 baseline)
Hot and Dry	Annual mean temperature increase of >6°F, with temperatures warming most in summer and fall. This, combined with a decrease in annual precipitation, results in snowline moving up in elevation by about 1500 ft, as well as frequent severe multi-year droughts. Winters are >20% wetter, but other seasons 3-18% drier, and summer monsoon decreases by 20%. Runoff peak flows are 2 weeks earlier, and volume decreases substantially (>15%).
Hot and Wet	Annual mean temperature increase of >6°F, with temperatures warming at similar levels across all seasons, combined with a 18% increase in annual precipitation. Even with increased winter precipitation, permanent snow lines are likely to be more than 1200 ft higher, and rain on snow events more frequent. Spring precipitation is 30% higher, and higher temperatures mean that peak runoff will be 2 weeks earlier. Summer monsoon decreases by almost 10%.
Feast or Famine	Annual mean temperature increase of over 4°F, with temperatures warming most in winter may lead to a +900 ft elevation change for permanent snow lines and frequent severe droughts. Annual precipitation shows little overall change (2%) but with large year-to-year variation. Winter and spring are likely to be wetter (11% and 3%), but other seasons drier, including a 5% reduction in monsoon moisture. Peak runoff may be 1-2 weeks earlier, with reduced volume (5-10%).
Warm and Wet	Annual mean temperature increase about 5°F with temperatures warming most in winter, combined with a 6% increase in annual precipitation results in a +600 ft elevation change for permanent snow lines. Drought frequency is similar to the recent past. Peak runoff is 1-2 weeks earlier, but with volumes generally unchanged. Summer monsoon remains similar to historic levels.



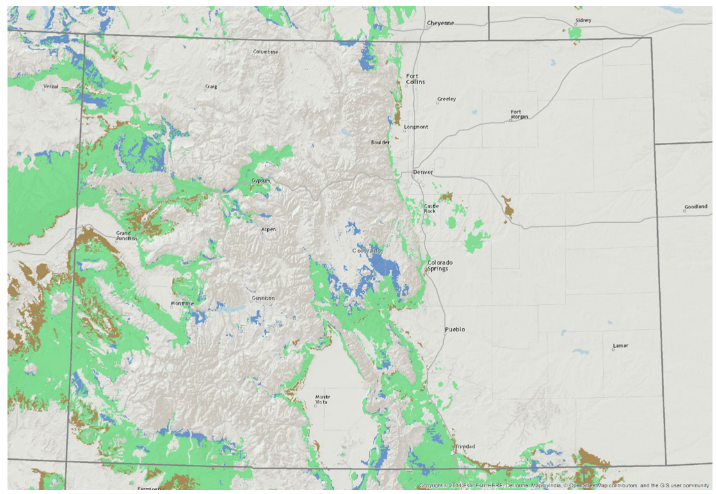
a) Hot & Dry Scenario



b) Hot & Wet Scenario



c) Feast or Famine Scenario



d) Warm & Wet Scenario

Threatened/Lost
Persistent
Emergent

Figure 3. Projected climate suitability for pinyon pine (*Pinus edulis*) at mid-Century under four scenarios (a-d), and degree of agreement among models (e). In map 3e, the more saturated each color, the higher the agreement between climate models on projected suitability. Comparable models were also created for the juniper species.

All Models = Threatened
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All Models = Persistent
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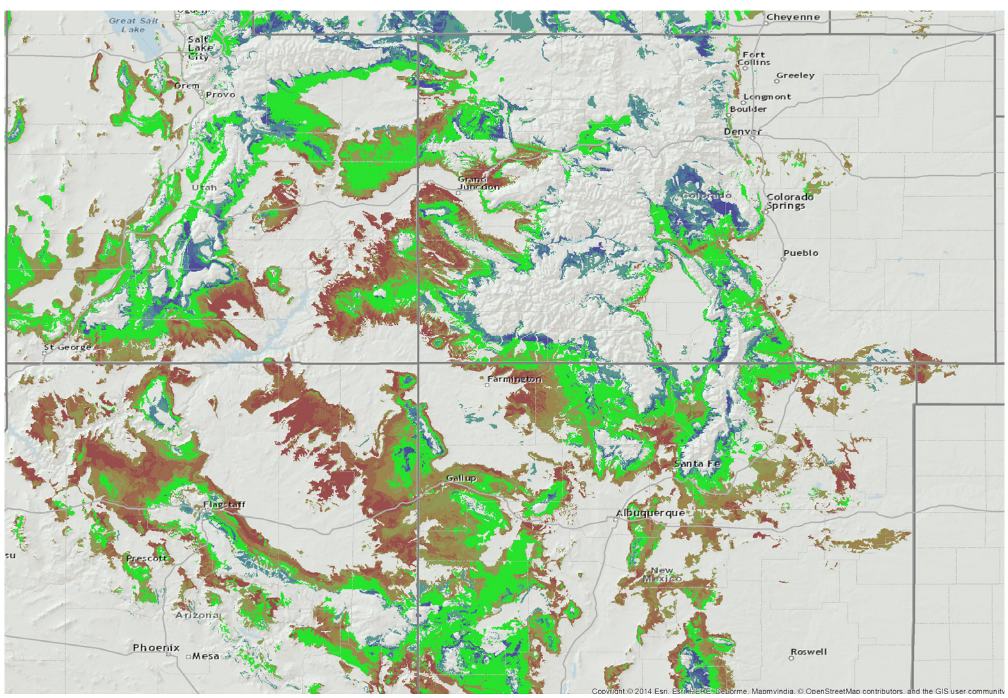
All Models = Emergent



e) degree of agreement among climate models

Table 2. Most important environmental variables influencing the models for pinyon pine, Utah juniper, and one-seed juniper.

	Top 3 variables influencing the model			Other variables with some influence
Species	1	2	3	
Pinyon Pine	Summer mean temp	Winter precip	Summer precip	Available water supply, soil pH, % organic matter, percent sand.
Utah Juniper	Winter precip	Summer precip	Summer mean temp	Winter max temp, % organic matter, pH, % silt, available water supply, slope.
One-seed Juniper	Summer precip	Winter max temp	Summer max temp	Spring precip, autumn precip, % organic matter, % clay, pH, and % silt.

Future habitat categories for two-needle-pinyon and Utah juniper were originally developed by considering all possible combinations of a variety of factors, including current suitability, current occupation, direction of change, and proximity to source of seed. These combinations were simplified and rolled up into three final primary future habitat categories (Figure 3).

It is important to note that both pinyon and juniper are long-lived species reaching reproductive age only after many decades. Therefore, the lag time between when an area becomes suitable or unsuitable, and the presence or absence of these species on a site may be considerable. In addition, myriad physical and ecological factors other than climate may influence the actual distribution of any species. Thus, the proper interpretation of these maps is that *climate may be suitable* for species establishment and persistence, *not* that the species *will be there*.

Adaptation Strategies

Ecological response models can be used to identify potential intervention points, where management actions may facilitate increased ecosystem resilience and enhanced adaptive capacity under future climate conditions. The next steps in our ongoing work will include convening BLM managers to further explore the general adaptation strategies presented in Table 3, and to partner with social scientists in co-development of adaptation strategies that address both ecological and human livelihood concerns.

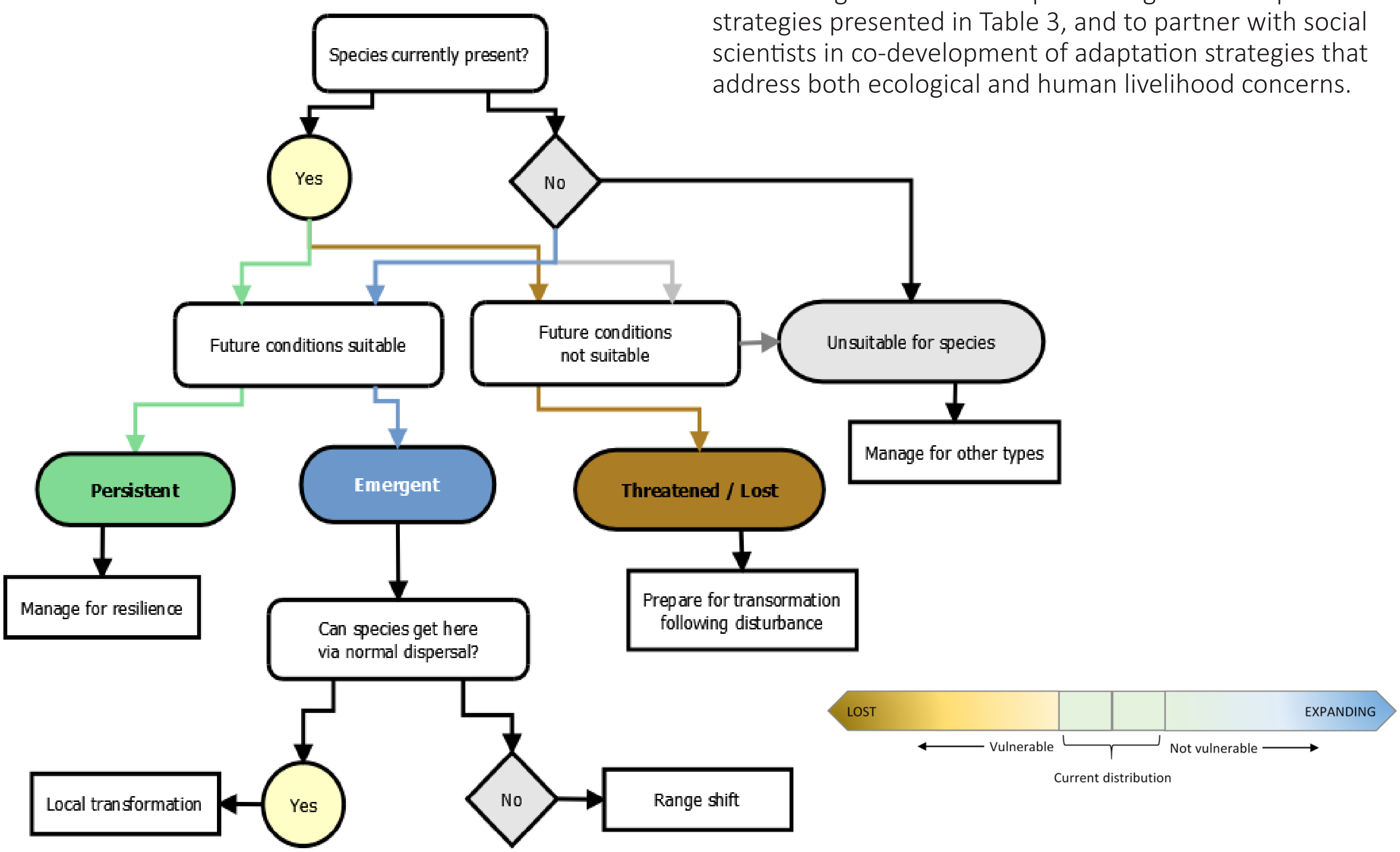


Figure 4. Decision support tool for using ecosystem response models to guide adaptation strategy selection.

Table 3. General adaptation strategies by ecological response categories.

Map Category	Description	General Adaptive Strategy	Details
Persistent	Areas where each species (*P. edulis*, *J. osteosperma*, and *J. monosperma*) and the pinyon-juniper assemblage is currently present, and where future bioclimatic conditions (e.g., climate, soils) will remain suitable for the persistence of the species through mid-century.	Manage for ecological resilience (e.g., to disturbance).	Map and identify the persistent areas, where climatic conditions are likely to remain stable under all future scenarios.
Emergent (areas not currently occupied, but likely to be suitable in the future).	Local transformation: improving, stable, or newly suitable habitat near existing seed sources, such that the species should be able to establish in emergent areas under normal migration rates.	Allow transformation, with assistance (planting) as needed.	For pinyon pine, incorporate presence of seed dispersers. Identify areas where the transformation may be in conflict with other ecosystems of concern (e.g., juniper into sagebrush).
	Range shift: future suitable habitat not within a likely distance to be colonized naturally under normal migration rates.	Consider assisted migration, unless there are conflicting resource issues.	Assisted migration means planting seedlings in areas where the species would not naturally disperse within the time frame under consideration. Genetic considerations may be important.
Threatened / Lost	Areas where the species is currently present, but where future climate conditions are not likely to be suitable for the species. High likelihood of eventual loss, or failure to re-establish following disturbance events.	Reduce management actions that disturb soils; consider allowing post-disturbance transformation.	Develop management plans that move toward expected future conditions (e.g., using a climate-smart seed mix—one that contains species expected to thrive in the area under future conditions—for restoration projects). Map and identify areas that potentially will be lost under all future scenarios vs. areas lost only under certain future conditions.
Not suitable	Areas that are not and will not be suitable for the species.	Manage for other types.	

Funding generously provided by Colorado Bureau of Land Management. Because this work is ongoing, a technical report is not yet available. In the interim, for additional information please contact Lee Grunau (CNHP), lee.grunau@colostate.edu, or Bruce Rittenhouse (BLM), brittenh@blm.gov.

Photo: Pinyon-juniper in Dominguez Canyon, Colorado. Renee Rondeau

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COLORADO NATURAL HERITAGE PROGRAM

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