



Vegetation and Soil Trends, Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, 2011–2022



National Park Service employees monitor vegetation and soils at Black Canyon of the Gunnison National Park.
NPS / WASHUTA

Vegetation and soil trends, Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, 2011–2022

Science Report NPS/SR—2025/254

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Please cite this publication as:

Livensperger, C. 2025. Vegetation and soil trends, Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, 2011–2022. Science Report NPS/SR—2025/254. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2309325>

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Abstract

In 2011, the Northern Colorado Plateau Network (NCPN) began long-term monitoring of vegetation and soils in upland communities at Black Canyon of the Gunnison National Park (BLCA) and Curecanti National Recreation Area (CURE). Managers wanted to understand conditions in sagebrush shrublands, aspen forests, pinyon-juniper woodlands, and Gambel oak shrublands. These four vegetation types are associated with a range of management concerns. These include suitable habitat conditions for the threatened Gunnison sage-grouse, planning for livestock grazing management, responses to disturbances (e.g., fire, plant diseases, and insect pests), wild ungulate usage and community responses to different climate conditions. The primary goals of monitoring are to track the status of these vegetation types and identify trends that describe changes over time. Status and trend of vegetation and soil indicators were analyzed for the 2011 – 2022 monitoring period. Key findings from this analysis are: 1) In both grazed and ungrazed sagebrush shrublands, total grass cover was stable. However, in grazed sagebrush, native perennial grasses decreased over time while non-native perennial grasses increased. 2) Most elements of Gunnison sage-grouse structural habitat guidelines were within recommended ranges in both grazed and ungrazed sagebrush shrublands; however, forb cover was lower than recommended. 3) Native perennial grass cover, primarily cool-season grasses, decreased in three of four vegetation types. Aspen forests were the only vegetation type with stable grass cover. 4) Pinyon-juniper woodlands maintained stable density and cover of overstory trees, saplings, and seedlings. Non-native plant cover was low and non-native plant frequency decreased. However, native perennial grass cover also decreased. 5) Aspen forests are in decline. Overstory trees and saplings experienced mortality and decreased canopy closure. Non-native plants, primarily perennial species, had high but stable cover. 6) Gambel oak shrublands show resistance to change. Gambel oak and other shrub cover and density remained stable over time but native perennial grasses decreased. 7) Actual evapotranspiration and water deficit predicted vegetation and soil response well. Water deficit or actual evapotranspiration in June, the month with lowest precipitation, was associated with declines in native perennial grasses in sagebrush shrublands, Gambel oak shrublands, and pinyon-juniper woodlands. Future changes in these water balance variables will influence conditions in all vegetation types.

Executive Summary

In 2011, the Northern Colorado Plateau Network (NCPN) began long-term monitoring of vegetation and soils in upland communities at Black Canyon of the Gunnison National Park (BLCA) and Curecanti National Recreation Area (CURE). Managers wanted to understand conditions in sagebrush shrublands, aspen forests, pinyon-juniper woodlands, and Gambel oak shrublands. These four vegetation types are associated with a range of management concerns, including suitable habitat conditions for the threatened Gunnison sage-grouse, planning for livestock grazing management, response to disturbances (e.g., fire, plant diseases and insect pests), wild ungulate usage, and community responses to different climate conditions. The primary goals of monitoring are to track the status of these vegetation types and determine trends that describe changes over time. The status and trends of vegetation and soil indicators were analyzed for the 2011 – 2022 monitoring period. This report addresses the following questions:

1. What are the status and trends of vegetation and soil indicators for sagebrush shrubland, pinyon-juniper woodland, aspen forest, and Gambel oak shrubland vegetation types?
2. How do grazed and ungrazed sagebrush shrublands differ in status and trends?
3. How do climate variables affect observed status and trends?

Table 1 summarizes directional trends over time for all vegetation types and indicators. Specific indicators evaluated in this report include plant cover (total, grass, native and non-native perennial grass, non-native annual, shrub, tree, forb, big sagebrush, and Gambel oak), surface cover (biological soil crust and bare soil), soil stability, density (big sagebrush, total shrub, tree seedling, tree sapling, and overstory tree), non-native plant frequency, and canopy closure. Key findings from this analysis are:

1. In both grazed and ungrazed sagebrush shrublands, total grass cover was stable. However, in grazed sagebrush, native perennial grasses decreased over time while non-native perennial grasses increased.
2. Most elements of Gunnison sage-grouse structural habitat guidelines were within recommended ranges in both grazed and ungrazed sagebrush shrublands; however, forb cover was lower than recommended.
3. Native perennial grass cover, which includes primarily cool-season grasses, decreased in three of four vegetation types. Aspen forests were the only vegetation type with stable grass cover.
4. Pinyon-juniper woodlands maintained stable density and cover of overstory trees, saplings, and seedlings. Non-native plant cover was low and non-native plant frequency decreased. However, native perennial grass cover also decreased.
5. Aspen forests are in decline. Overstory trees and saplings experienced mortality and decreased canopy closure. Non-native plants, primarily perennial species, had high but stable cover.

6. Gambel oak shrublands show resistance to change. Gambel oak and other shrub cover and density remained stable over time, but native perennial grasses decreased.
7. Actual evapotranspiration and water deficit predicted vegetation and soil response well. Water deficit or actual evapotranspiration in June, the month with lowest precipitation, was associated with declines in native perennial grasses in sagebrush shrublands, Gambel oak shrublands, and pinyon-juniper woodlands. Future changes in these water balance variables will influence conditions in all vegetation types.

Table 1. Summary of directional trends over time by vegetation type for all indicators. A dash indicates no trend analysis was conducted for that parameter.

Indicator	Sagebrush Shrublands – Grazed	Sagebrush Shrublands – Ungrazed	Pinyon-Juniper Woodlands	Aspen Forest	Gambel Oak Shrublands
Total Cover	None	None	None	None	None
Total Grass Cover	None	None	–	–	–
Perennial Grass Cover ^A	Decreasing	None	Decreasing	None	Decreasing
Non-native Plant Cover ^B	Increasing	None	None	None	None
Non-native Plant Frequency	None	None	Decreasing	None	None
Total shrub cover	None	None	None	None	None
Total shrub density	None	None	None	–	–
Big sagebrush cover	None	None	–	–	–
Big sagebrush density	None	None	–	–	–
Gambel oak cover	–	–	–	–	None
Overstory tree cover	–	–	None	–	None
Overstory tree density	–	–	None	Decreasing	–
Sapling density	–	–	None	Decreasing	–
Seedling density	–	–	None	None	–
Canopy closure	–	–	–	Decreasing	–
Forb cover	None	None	–	None	Increasing
Biological soil crust cover	Increasing	None	None	–	–
Bare ground cover	None	None	None	None	None
Soil stability	None	Decreasing	None	–	–

^A In sagebrush shrublands, Gambel oak shrublands, and aspen forests, perennial grass cover includes only native species.

^B In sagebrush shrublands, non-native plant cover includes only non-native perennial grasses.

Based on the results presented in this report, the NCPN recommends the following actions for managing sagebrush shrublands, pinyon-juniper woodlands, aspen forests, and Gambel oak shrublands at BLCA and CURE:

1. Maintain sagebrush and monitor grazing impacts from livestock and native ungulates. Maintain and monitor allotment boundary fences to limit trespass livestock. Prioritize protection of resilient sagebrush systems with low non-native plant cover.
2. Protect high-value, e.g., old-growth, pinyon-juniper woodlands from fire and continue to monitor and control for cheatgrass which could increase surface fuels.
3. Consider acceptance of aspen forest decline as these communities are unlikely to persist.
4. The consistent decline in cool-season native perennial grasses across vegetation types warrants concern, and continued monitoring is critical. Managers should consider this functional group as vulnerable when making decisions regarding livestock grazing and wildlife management.
5. Actual evapotranspiration and water deficit are important predictors of vegetation and soil response, and June may be a critical month for determining native perennial grass cover. Managers should consider future changes in these water balance variables for future management plans.

1 Introduction

1.1 Purpose and Scope

Long-term monitoring of vegetation and soils in upland communities at Black Canyon of the Gunnison National Park (BLCA) and Curecanti National Recreation Area (CURE) began in 2011 by the Northern Colorado Plateau Network (NCPN). Monitoring upland vegetation and soil indicators is one of the protocols selected by the NPS Inventory & Monitoring Division because they provide insight into the overall health or condition of the park's natural resources. More specifically, the upland vegetation and soils protocol monitors "vital signs" that include plant communities, soil stability, biological soil crusts, and hydrologic function to understand long-term change and the impact of selected drivers and stressors. The NPS Organic Act (16 U.S.C. 1, 2, 3, and 4; 39 Stat. 535) directs park managers to preserve these ecosystems "unimpaired for the enjoyment of future generations", requiring information on their current status and long-term trends. This report provides the first 10-year status and trend analysis for upland vegetation and soil indicators at BLCA and CURE.

When establishing the long-term monitoring program at BLCA and CURE, resource managers identified four priority ecosystems: big sagebrush (*Artemisia tridentata*) shrublands (referred to hereafter as sagebrush), pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) woodlands (referred to hereafter as pinyon-juniper), Gambel oak (*Quercus gambelii*)/mixed montane shrublands (referred to hereafter as Gambel oak), and aspen (*Populus tremuloides*) forest communities. These four ecosystems were prioritized for different reasons. Sagebrush shrublands comprise most of the plant community at CURE and provide critical habitat for the threatened Gunnison sage-grouse (*Centrocercus minimus*). Managers were interested in comparing areas of grazed and ungrazed sagebrush. Pinyon-juniper woodlands are widespread at BLCA and include areas of highly valuable, relatively undisturbed old-growth woodlands. Aspen forests are limited in range but provide unique habitat that is under threat from insect pests, aridification, and ungulate browsing. Finally, Gambel oak shrublands are a dominant vegetation type at BLCA.

The purpose of this report is to address the following questions:

1. What are the status and trend of vegetation and soil indicators for sagebrush shrubland, pinyon-juniper woodland, aspen forest, and Gambel oak shrubland vegetation types?
2. How do grazed and ungrazed sagebrush shrublands differ in status and trend?
3. How do climate variables affect observed status and trends?

Specific indicators evaluated in this report include plant cover (total, grass, native and non-native perennial grass, non-native annual, shrub, tree, forb, big sagebrush, and Gambel oak), surface cover (biological soil crust and bare soil), soil stability, density (big sagebrush, total shrub, tree seedling, tree sapling, and overstory tree), non-native plant frequency, and canopy closure. Data used in this report come from the NCPN 2011–2022 upland vegetation and soils monitoring data. Pilot years (2008–2010) were excluded from analysis.

1.2 Study Area

While administratively managed as one unit, BLCA and CURE have distinct settings and vegetation types. Black Canyon of the Gunnison was designated as a national monument in 1933 and elevated to a national park in 1999. It protects the Black Canyon, one of the steepest, deepest, and narrowest canyons in North America, which was carved by the steeply descending Gunnison River (National Park Service 2013). Curecanti National Recreation Area was created when Blue Mesa Dam was completed in 1965, forming the largest reservoir in Colorado. The two units are located on the eastern edge of the Colorado Plateau (Figure 1, Figure 2).

At BLCA, elevations range from 1,645 meters (5,400 ft) at the bottom of Black Canyon to 2,743 meters (9,000 ft). Sagebrush, pinyon-juniper, and Gambel oak vegetation types occur at the higher elevations along the rim of the canyon (Coles et al. 2010). At CURE, elevations range from 1,981 meters (6,500 ft) to 2,896 meters (9,500 ft). Sagebrush shrublands occur on mesas surrounding Blue Mesa Reservoir. Aspen forests are limited in extent but tend to be found on higher elevation, north- and east-facing aspects (Tendick et al. 2010).

BLCA and CURE are situated along the northern edge of the North American monsoon, and thus experience widely variable summer precipitation (Miller 2005). Climate records from the weather station at Cimarron (38.444, -107.559) date back to 1951. Annual average precipitation during this period has ranged from 210–509 millimeters (8 – 20 in). Winter precipitation, in the form of snow, averages 162 centimeters (54 in) annually (Tendick et al. 2010) with up to 117 centimeters (46 in) recorded on the ground. Winters are cold, with January average minimum temperature of -17°C (1°F) and average maximum temperature of 1°C (34°F). Summer temperatures peak in July and the average maximum temperature is 30°C (85°F), with cooler nights averaging a minimum temperature of 7°C (44°C).

Grazing by wildlife, cattle, sheep, and horses occurred before the establishment of BLCA and CURE, and although livestock grazing is reduced from historic levels it continues on permitted allotments in both park units. NCPN monitors areas impacted by grazing, either historically and/or presently, in sagebrush shrublands, pinyon-juniper woodlands, and oak shrublands. Management of livestock grazing has primarily been administered by the Bureau of Land Management (BLM) and U.S. Forest Service (USFS); however, the NPS will issue Special Use Permits for livestock grazing and trailing in BLCA and CURE upon completion of a Grazing Management Plan. There are 23 active allotments: 16 in CURE, 5 in BLCA, and 2 that share land between BLCA and CURE. Grazing intensity, timing, and duration varies among allotments but takes place between May and November and includes cattle and sheep. Most allotments span both NPS and BLM land.

Fire occurs in the landscape at BLCA and CURE but is infrequent. Historic fire regimes in pinyon-juniper woodlands were long, greater than 400 years, which has led to old-growth pinyon-juniper forests persisting on the landscape today (Romme et al. 2009, Kennard and Moore 2013, Floyd et al. 2017). In sagebrush shrublands of the Gunnison Basin, historic fire regimes were much shorter, with one recent study reporting a mean fire interval of 49.6 years, followed by limited to no fires over the past century (Simic et al. 2023).

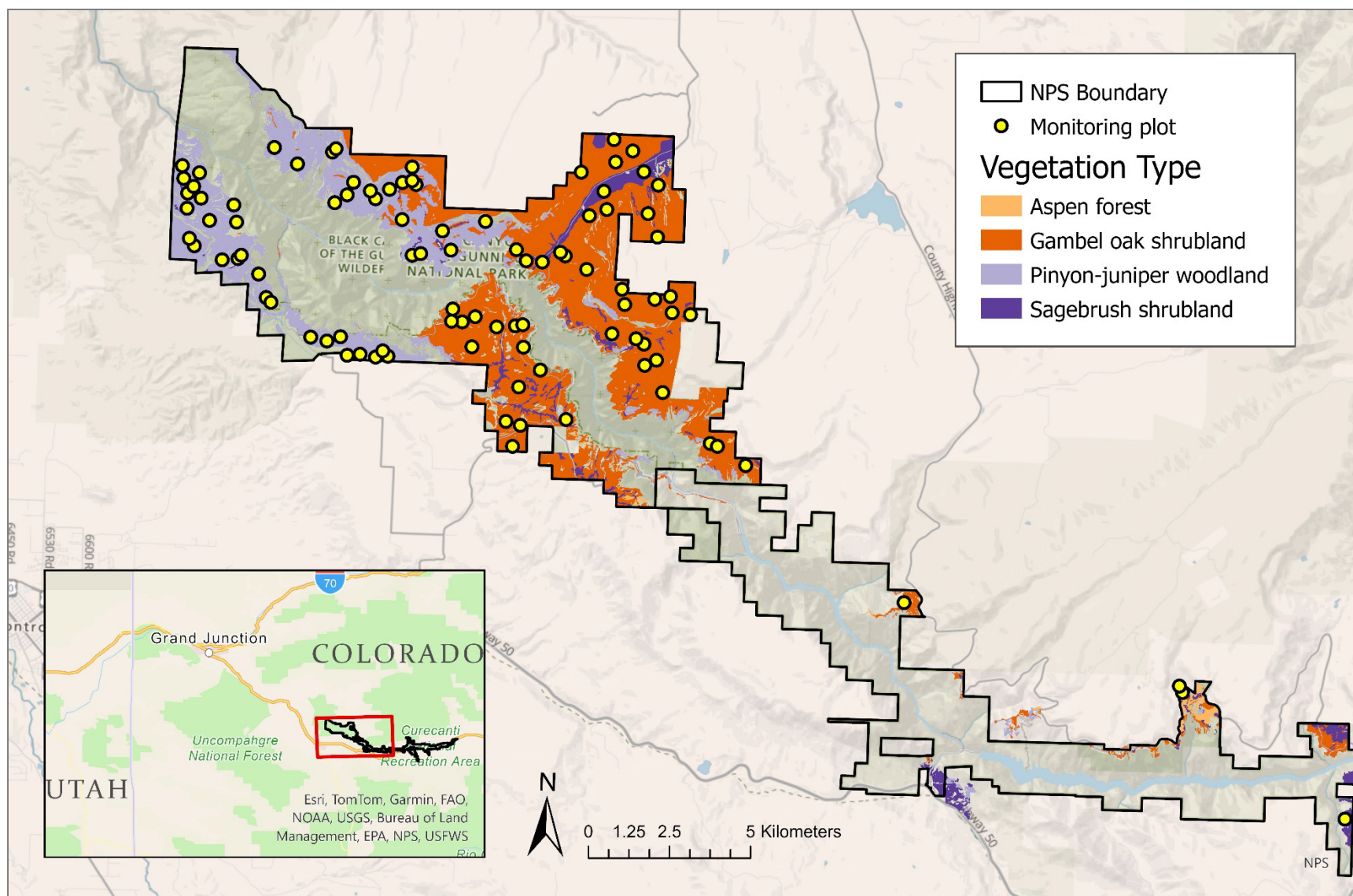


Figure 1. Western portion of upland monitoring at Black Canyon of the Gunnison NP and Curecanti NRA. NPS / CAROLYN LIVENSPIERGER

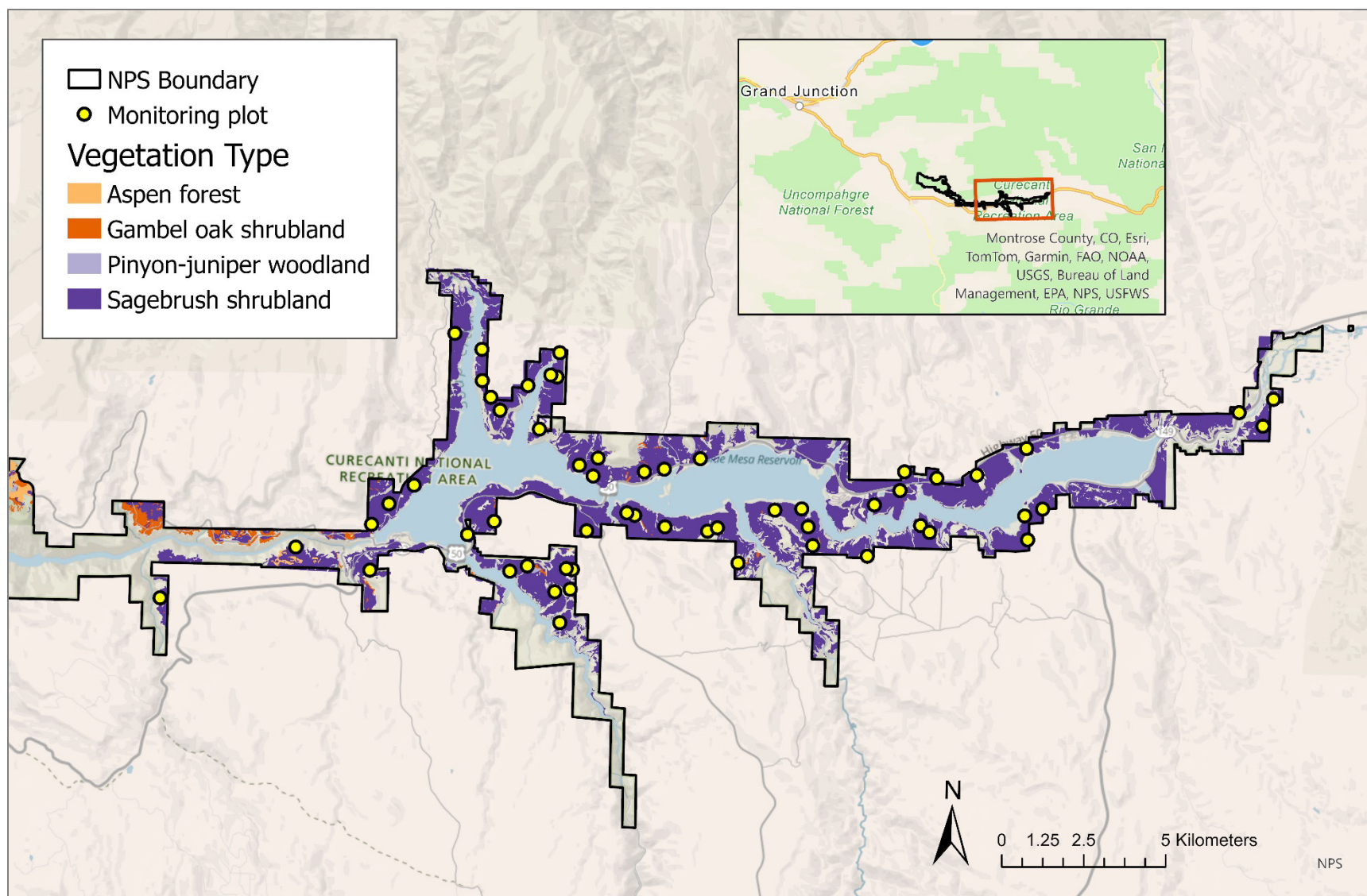


Figure 2. Eastern portion of upland monitoring at Curecanti NRA. NPS / CAROLYN LIVENSBERGER

2 Methods

2.1 Study Design

Monitoring design and selection of target populations and plot locations are thoroughly described in Witwicki (2012). Briefly, priority vegetation types for sampling were identified in consultation with park managers in 2008. The vegetation types selected for monitoring were pinyon-juniper woodlands, Gambel oak shrublands, aspen forests, and grazed and ungrazed sagebrush shrublands. Areas considered for monitoring were restricted by accessibility (excluding slopes $\geq 50\%$, hiking distances >4 kilometers, and privately owned land). Next, sampling frames for each vegetation type were generated based on suitable ecological sites. Since ecological site descriptions were not complete for all areas of interest, these were sometimes approximated by also incorporating information from range site descriptions, vegetation maps (Coles et al. 2010, Tendick et al. 2010), and field scouting. Target ecological sites for each vegetation type are described in Appendix A. The sampling frame area for grazed sagebrush shrubland was 2,309 hectares, ungrazed sagebrush shrubland was 2,790 hectares, pinyon-juniper woodland was 2,260 hectares, aspen forest was 122 hectares, and Gambel oak shrubland was 4,425 hectares. From the sampling frames, potential monitoring sites were selected at a 10 meter grid size using Reversed Randomized Quadrat-Recursive Raster (RRQRR) (Theobald et al. 2007), which ensured a spatially balanced sampling grid across the landscape. Plots were verified in the field before being accepted into the study.

Pilot monitoring took place from 2008–2010. A variance and power-for-trend assessment was completed following pilot data collection. The findings of this analysis led to the establishment of 153 plots: 59 sagebrush, 4 aspen, 45 pinyon-juniper, and 45 Gambel oak. A total of 42 or 45 plots were sampled each year, with a scheduled rotation through all plots over a 5-year period, beginning in 2011. Actual monitoring effort varied due to staffing limitations caused by funding inconsistencies and a flat budget (Table 2). Data from 2011–2022 were analyzed in this report.

Table 2. Annual monitoring effort by vegetation type at Black Canyon of the Gunnison NP and Curecanti NM. Values are the number of plots monitored.

Year	Sagebrush Shrublands	Pinyon-Juniper Woodlands	Aspen Forest	Gambel Oak Shrublands
2011	17	11	1	12
2012	17	12	1	12
2013	15	12	1	12
2014	14	12	4	12
2015	14	12	4	12
2016	17	12	1	12
2017	17	12	1	12
2018	13	9	1	12
2019	14	12	4	12

Table 2 (continued). Annual monitoring effort by vegetation type at Black Canyon of the Gunnison NP and Curecanti NM. Values are the number of plots monitored.

Year	Sagebrush Shrublands	Pinyon-Juniper Woodlands	Aspen Forest	Gambel Oak Shrublands
2020	0	0	4	0
2021	15	12	1	12
2022	15	8	1	11

2.2 Vegetation and Soil Measurements

Witwicki et al. (2017) details the monitoring procedures for upland vegetation and soils in the NCPN. Each sagebrush shrubland, aspen forest, and pinyon-juniper woodland plot had three parallel, 50-meter-long transects spaced 25 meters apart (Figure 3). Transects ran across the slope and were permanently marked by rebar at the endpoints of each transect. Crew members avoided stepping on biological soil crusts as much as possible within plots and when traveling to plots. The field methods for upland monitoring in NCPN parks were based largely on the rangeland monitoring procedures recommended by Herrick et al. (2005).

A point-intercept method was used to record hits of plant species and ground cover attributes at 0.5-meter intervals along each transect (Figure 3). The frequency of exotic species was recorded using 1×1-meter quadrats placed every five meters along each transect. Counts of shrubs by species and height class, and counts of seedlings, were recorded in a one-meter belt along each transect. Counts of tree saplings were recorded in a five-meter belt centered on the middle transect. Six soil surface samples were collected along each of the transects to assess soil-aggregate stability. Samples were rated from 1 to 6 based on their structural integrity following immersion in water, with higher ratings corresponding to greater soil stability. Overstory trees greater than 15 centimeters in diameter were tagged in quadrant 1 of the plot (Figure 3) and diameter measured either at root crown (DRC; for pinyon pine or juniper trees) or breast height (DBH; all other trees). Canopy closure was measured every 10 meters along the transects using a densiometer. At each point, a reading was made in four directions oriented along and perpendicular to the transect.

At Gambel oak shrubland plots, methods were adjusted to accommodate the structural differences of this denser vegetation type. The three transects were 20 meters in length and spaced 10 meters apart. Point-intercept hits were recorded at 0.25-meter intervals. Exotic frequency quadrats were recorded every 2 meters. Overstory trees were measured throughout the entire 20 × 20-meter plot.

Quality assurance and quality control (QA/QC) procedures were performed for all vegetation and soil data and included checks for missing values, logic checks, and visual inspection of measurements.

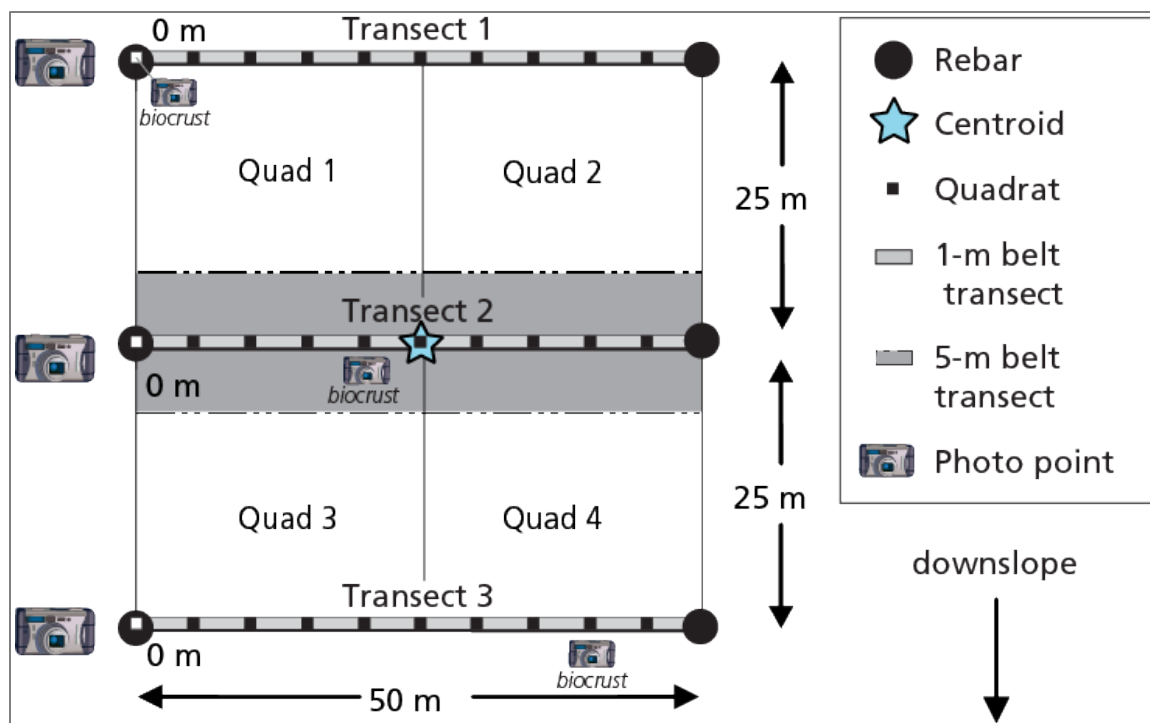


Figure 3. Locations of transects and monitoring measurements at upland plots, including 1-m² quadrats for sampling frequency of exotics and 1-meter-wide belt transects for measuring shrubs. Soil stability measurements were taken at six randomized locations along each transect. Sapling density data were collected in the 5-meter-wide belt centered on Transect 2. Repeat photos were taken of each transect (larger camera symbols show transect photo locations) and of the soil surface on each transect (smaller camera symbols labeled “biocrust” show soil surface photo locations). Overstory tree censuses were conducted in Quad 1. NPS / CAROLYN LIVENSPIRGER

2.3 Analysis

2.3.1 Data Summaries

2.3.1.1 Vegetation and Soil Data

To provide context for the Bayesian status and trend analysis, vegetation and surface percent cover were summarized across all plots and years. Point-intercept data for functional groups of vegetation and surface features were summarized as the number of hits along the 50-meter or 20-meter transect. Live cover included photosynthetic and live woody tissue. Hits of cyanobacteria, moss, and lichen at the soil surface were totaled and analyzed as biological soil crust. Bare ground was defined as undifferentiated crust and loose soil at the surface.

Exotic frequency was calculated as the number of 1-m² quadrats where any exotic species was detected, out of 10 quadrats along the 50-meter or 20-meter transect. Shrubs and seedlings from the 1-meter belt were summed for analysis of density and transformed post-hoc to the number of individuals per hectare. The smallest size class of shrubs was excluded to reduce noise in the data from large seedling recruitment events that did not result in established shrubs. Sapling counts from the 5-meter belt were summed for analysis of density and transformed post-hoc to number of

individuals per hectare. Soil stability data were modeled as counts of categorical class ratings from 1 to 6.

Overstory tree census data in pinyon-juniper woodlands were cleaned prior to analysis. Pinyon pine and juniper trees were particularly difficult to census because of their highly branching structure, where stems can be tagged as individual trees when they branch low to the ground. In some cases, individual trees or stems were added after the initial census but were too large to have naturally grown into the quadrat. For example, if a 40 cm DRC tree was added to the census five years after the initial visit, it is highly unlikely to have grown to that size over that time period. This occurred either because trees were missed in the initial visit, tagged in different locations on the tree in years after the initial visit, or were determined to be ‘rooted in’ the quadrat in later years. Trees that were added to the census at a DRC greater than 17 centimeters after the initial visit were presumed to be invalid entries and excluded from analysis. This approach removed 9% of the overstory tree data but prevented artificial inflation of tree density over time. To determine density, number of live trees per quadrat were summed and transformed to individuals per ha post-hoc.

Canopy closure measurements were averaged over the four directional readings taken at each point. Bayesian analysis was conducted with transect as the sampling unit.

2.3.1.2 Climate Data

There are cooperative observer weather stations at BLCA, at Cimarron (38.444, -107.559), and CURE, at Blue Mesa Reservoir (38.466, -107.167). Examination of these long-term datasets revealed significant data gaps during the monitoring period of 2011–2022. Therefore, to examine climate patterns during the monitoring period, climate data from the Daymet Daily Surface Weather Dataset (Thornton et al. 2020) were downloaded for the same point locations as the Cimarron and Blue Mesa Reservoir weather stations. These data were used to calculate the 30-year averages for maximum and minimum temperatures and average annual cumulative precipitation, defined as the period from 1980–2010. Then, departures from the long-term averages for the 2011–2020 monitoring period were calculated. A time series of the 5-year standardized precipitation evapotranspiration index (SPEI) was accessed from Climate Engine (app.climateengine.com) and used to identify wet and dry periods (Vicente-Serrano et al. 2010, Huntington et al. 2017). The SPEI incorporates the impact of temperature by using the difference between precipitation (P) and potential evapotranspiration (PET), while negative values indicate dry conditions and positive values indicate wet conditions. The SPEI is standardized relative to a reference period (1980–2020) and values are standard deviations away from the long-term average. Values greater or less than 2 standard deviations away from the long-term average are rare and are considered extremely wet or dry conditions.

2.3.2 Bayesian Hierarchical Models

2.3.2.1 Bayesian Models

Bayesian hierarchical modeling was used to analyze these data and determine the status and trend for the four vegetation types: sagebrush shrublands, pinyon-juniper woodlands, aspen forests, and Gambel oak shrublands. Appendix B provides additional background on Bayesian hierarchical modeling. Bayesian hierarchical modeling provides a flexible approach that addresses challenges in

long-term monitoring data, including: 1) complex revisit designs with data missing by design; 2) non-normally distributed response variables; and 3) censored or truncated data (Zachmann et al. 2021).

The general form for the Bayesian models is:

$$[\text{Model parameters} \mid \text{data}] \propto [\text{data} \mid \text{likelihood model}] [\text{priors}]$$

where “ $\mid$ ” is “conditional on” and $\propto$ is “proportional to.”

All models followed a general linear model that included a time slope (β_1), intercept (β_0), and ecologically informative covariates. Intercepts were allowed to vary among plots in all models (i.e., a plot-level random effect), but slopes were held constant. This accounted for within-plot variance because data were aggregated at the transect level for analysis. A deterministic model represented the ecological process under investigation. For example, change in plant cover over time is well represented by an inverse logit model. For each response, a likelihood model appropriate to the data distribution was chosen. In all models, vague priors were used because of limited comparable data in the literature.

All Bayesian analyses were run in R 4.3.2 (R Core Team 2023) using JAGS (Plummer 2019) as the Markov Chain Monte Carlo (MCMC) sampler. For each model, three chains with a variable burn-in period and number of iterations were used.

2.3.2.2 Covariates

Water availability is the primary limiting factor for plant growth on the Colorado Plateau. Different functional groups may respond to water inputs over differing time periods. For example, cool-season grasses generally benefit from increased winter and spring precipitation in the same year, but trees and shrubs may respond to precipitation over multiple years (Comstock and Ehleringer 1992; Witwicki et al. 2016). The influence of precipitation on plant growth is often mediated by soil properties, such as water-holding capacity or the timing and intensity of rainfall. Therefore, water balance covariates like actual evapotranspiration (AET) and water deficit (D) may better predict plant response than precipitation (P) alone (Thoma et al. 2019).

For Bayesian analysis, climate covariates were developed using the Daymet Daily Surface Weather Data (Thornton et al. 2020). Point data were downloaded at each upland plot location (Figure 1, Figure 2) to allow for site-specific covariates in the analysis. AET and D at the plot level were calculated using a modified Thornthwaite Water Balance Model (Tercek et al. 2021).

P, AET, and D were summarized over four different time periods prior to sampling, which took place in July–September. The time periods were June (the month of June prior to sampling), cool season (October–April in the year prior to sampling), monsoon season (July–September in the year prior to sampling), and 2-year lag (the 24 months prior to sampling). For example, if sampling took place in August 2021, the cool-season water balance summary would include data from October 2020 to April 2021. These water balance summaries were used as possible covariates in Bayesian models,

individually and in combination. Water balance covariates were checked for correlation with each other and with year prior to use in models, and covariates with a Pearson's r value ≥ 0.8 or ≤ -0.8 were excluded from use in the same model. No water balance variable was strongly correlated with year.

Across all years, timing of monitoring occurred between July 17 and September 13 to measure plant cover after full green-up and before senescence. However, plant phenology is strongly influenced by heat accumulation, and a cool or warm spring could lead to phenological differences that were not accounted for by the water balance covariates. Therefore, cumulative growing degree-days (CGDD) from January to April were also included in the models. CGDD were calculated following McMaster and Wilhelm (1997):

$$cumGDD_{month\ hly} = \sum_1^d \frac{T_{max} + T_{min}}{2} - T_{base}$$

where $cumGDD_{monthly}$ is the cumulative GDD over a single month, d is the number of days in a month, T_{max} is the maximum temperature on a given day, T_{min} is the minimum temperature on a given day, and $T_{base} = 4.4^{\circ}\text{C}$, the temperature below which grass physiological activity ceases (Wang 1960).

All covariates were centered and standardized so that the relative effects of the coefficients could be directly compared in the models.

2.3.2.3 Annual Status

To model the annual status of each indicator, standardized values of covariates were used in the Bayesian hierarchical model to create a figure showing the year-to-year variation of the indicator due to the covariate(s). When CGDD was included in the model, it was held at its mean across all years of sampling to remove variation associated with differences in timing of plot visits. The annual status figures used data from all plots sampled in all years of monitoring, with modeled predictions (i.e., imputations) of values for plots that were not sampled in a particular year. Status was reported as the model-predicted mean value of an indicator for each year. Values within the 95% credible intervals (CI) should also be considered as plausible values for the mean when evaluating these results. Credible intervals are probabilities and can be interpreted as having 95% confidence that the true value of the mean of the indicator falls within the lower and upper values for the given interval. These status figures highlight shorter-term variation caused by differences in weather and represent conditions on the ground during the monitoring period.

2.3.2.4 Trend

In this report, trend is defined as the “directional change in an indicator over time apart from year-to-year [stochastic] variation that is caused by changes in weather, observers, instrumentation, disturbances, or other short-term influences on status” (Zachmann et al. 2021, pg. 3). Results figures show trend over time as the posterior distribution of the coefficient of the time covariate in the Bayesian hierarchical model, β_t . If the distribution of β_t contained zero, there was no evidence of trend over time. If the distribution of β_t was centered on a value greater or less than zero, with the 95% credible interval (CI) not containing zero, this is reported as a significant positive or negative

trend. Climate covariates are interpreted similarly, with significant effects reported if the 95% CI of the coefficient of the covariate did not contain zero.

Trend is interpreted as directional change over time under the average conditions of the monitoring period, since other covariates (e.g., cool-season P) in the model are held at their mean to examine the time covariate. This controls for interannual variation in the indicator to observe the remaining trend. When results showed a significant trend, this indicated that the climate covariates in the model did not fully explain the directional change over time. For example, a water balance covariate like cool-season AET might be a large source of variation in perennial grass cover and explain the change in status over the period of monitoring. When cool-season AET is held at its mean and there is still a significant trend, this suggests that an underlying mechanism not included in the model is driving the observed trend (e.g., competition with an invasive species or longer-term responses to aridification). When a climate covariate is largely responsible for shorter-term changes in status over the period of monitoring, this information can be used to guide management and to understand how the indicator may respond to climate in the future.

2.3.2.5 Model Evaluation and Selection

Model evaluation proceeded by first checking convergence using the Gelman-Rubin diagnostic with a threshold of 1.1 (Gelman and Rubin 1992), as well as visual examination of trace plots. In addition, models were required to pass posterior predictive checks for Bayesian P-values (P_B), which describe the ability of the model to predict the data. Following Hobbs and Hooten (2015), when the P_B of the test statistic is either ≤ 0.1 or ≥ 0.9 the chosen model does not adequately represent the data. Models not meeting these criteria were rejected. A visual examination of observed vs. predicted data was also performed. Of the models converging and passing posterior predictive checks, the best fit model was chosen by minimizing posterior predictive loss (PPL) (Hobbs and Hooten 2015).

Following these guidelines, combinations of climate covariates were tested in a stepwise fashion. First, a climate covariate (P, AET, or D) was selected by creating a model set with additive models of all time period summaries (cool season, June, and monsoon season) for each climate covariate. Two-year lag summaries were tested in models where the indicator was expected to respond to longer-term water inputs, such as trees and shrubs. The best fit model from the first model set was determined by lowest PPL. Next, a model set using individual and all combinations of the selected climate covariate was run to select a final model. An example of this process is shown in Table 3.

All data summaries and figures were created in R 4.3.2 (R Core Team 2023).

Table 3. Example of model selection process for Bayesian analysis. The example shown here is for total grass cover in sagebrush shrublands. Model Set 1 is compared first to determine the best climate covariate. Model Set 2 is compared next to determine the best fit climate covariate and time period combination. The best fit model from Model Set 2 is the final model. PPL is posterior predictive loss, CGDD is cumulative growing degree-days, AET is actual evapotranspiration, D is deficit, and P is precipitation.

Model Set	Model Covariates	Gelman Diagnostic	PPL
Model Set 1	Year, CGDD, cool-season AET, June AET, monsoon-season AET ^A	1.03	17201
	Year, CGDD, cool-season P, June P, monsoon-season P	1.03	17250
	Year, CGDD, cool-season D, June D, monsoon-season D	1.03	17232
Model Set 2	Year, CGDD, cool-season AET	1.03	17214
	Year, CGDD, June AET ^A	1.03	17153
	Year, CGDD, monsoon-season AET	1.08	17176
	Year, CGDD, cool-season AET, June AET	1.03	17215
	Year, CGDD, cool-season AET, monsoon-season AET	1.02	17189
	Year, CGDD, June AET, monsoon-season AET	1.01	17199
	Year, CGDD, cool-season AET, June AET, monsoon-season AET	1.03	17221

^A Best fit model for the model set.

3 Results

3.1 Vegetation and Soil Summary

3.1.1 Sagebrush Shrublands

Grazed and ungrazed sagebrush shrublands were similar in overall composition of functional groups for both vegetative and surface components (Figure 4, Figure 5). Sagebrush shrublands had around 30% cover of total shrubs, with big sagebrush being the dominant shrub. Other common shrub species included green rabbitbrush (*Chrysothamnus viscidiflorus*), mountain snowberry (*Symphoricarpos oreophilus*), and antelope bitterbrush (*Purshia tridentata*). Perennial grass cover was also high, around 25%, with some differences in species between grazed and ungrazed sagebrush. The three perennial grasses with the highest percent cover in grazed sagebrush were the native muttongrass (*Poa fendleriana*) and non-natives bulbous bluegrass (*Poa bulbosa*) and Kentucky bluegrass (*Poa pratensis*); however, the non-native species were found in only a small number of visits (Appendix C). Ungrazed sagebrush had the natives muttongrass and junegrass (*Koeleria macrantha*) along with non-native Kentucky bluegrass as the species with the highest mean cover, but again the non-native was recorded at a much smaller number of visits (Appendix C). The native Letterman's needlegrass (*Achnatherum lettermanii*) and squirreltail (*Elymus elymoides*) had < 5% cover on average but were detected in most visits. Trees and annual grasses had very low cover, although there were slightly more trees in ungrazed sagebrush. Trees detected were Rocky Mountain juniper (*Juniperus scopulorum*) and Douglas fir (*Pseudotsuga menziesii*). Ungrazed sagebrush had slightly lower overall cover of shrubs and slightly higher cover of perennial grasses, compared to grazed sagebrush.

At the surface, litter had the highest percent cover in both grazed and ungrazed shrublands, about 40% (Figure 4). There was also a relatively high percent cover of rock. Bare ground, which includes undifferentiated crust and soil, was about 20%. Biological soil crust cover in this vegetation type is low, less than 5%. Biological soil crust includes cyanobacteria, lichen crusts, and moss.

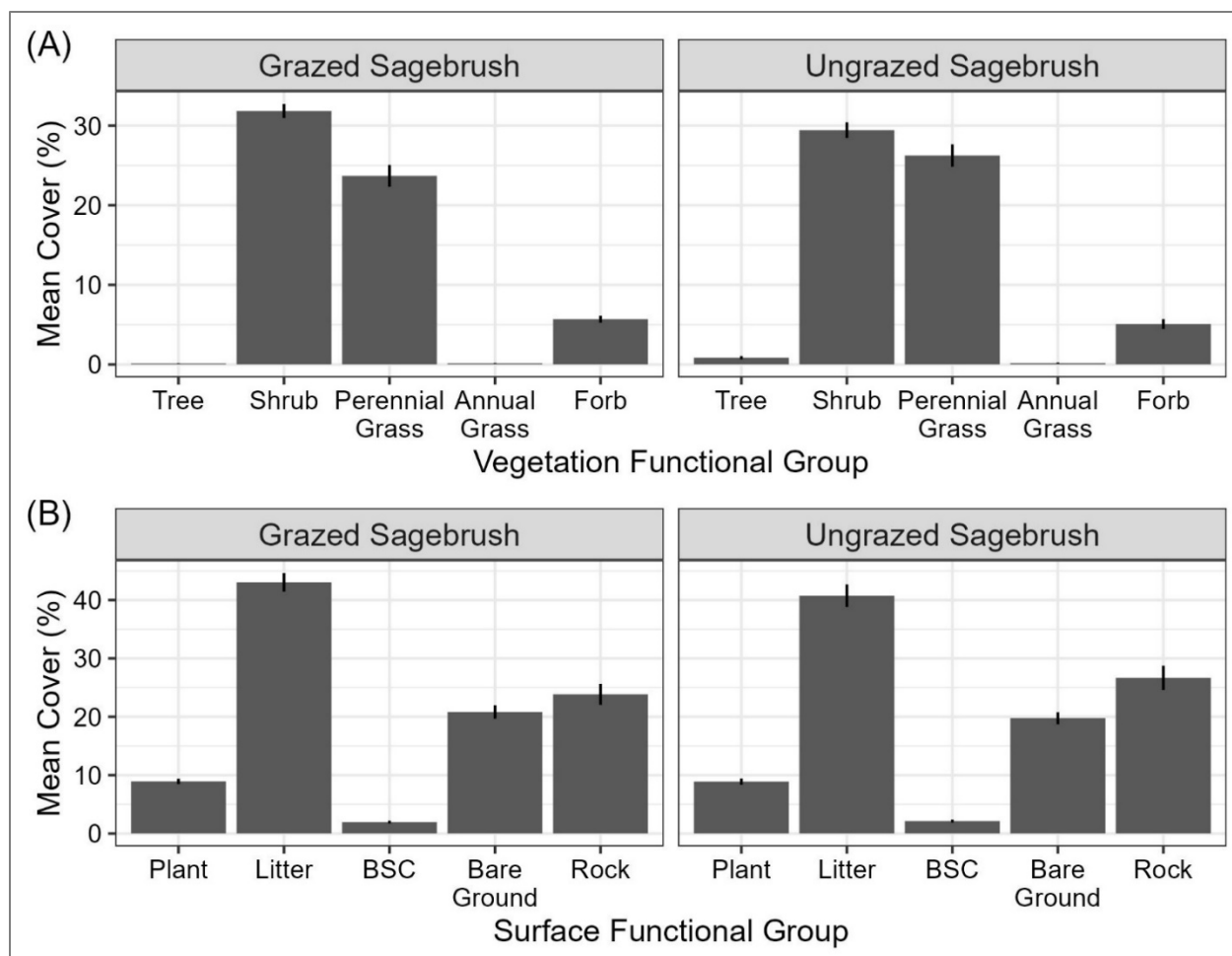


Figure 4. (A) Percent cover of vegetation functional groups for grazed and ungrazed sagebrush. (B) Percent cover of surface functional groups for grazed and ungrazed sagebrush. In (B), BSC is biological soil crust. In both (A) and (B), percent cover is the mean of all plots across all years of monitoring, ± 1 standard error of the mean. NPS / CAROLYN LIVENSPEGER



Figure 5. Sagebrush shrublands at Curecanti National Recreation Area. NPS / WASHUTA

3.1.2 Pinyon-Juniper Woodlands

Trees dominate pinyon-juniper woodlands, with over 30% cover (Figure 6, Figure 7). Mean cover of Utah juniper was 19% and two-needle pinyon was 16%. Understory shrubs and perennial grasses are the other major components, with about 10% and 5% cover, respectively. Common shrubs in this vegetation type include Gambel oak, Utah serviceberry (*Amelanchier utahensis*), and alder-leaf mountain mahogany (*Cercocarpus montanus*). Common perennial grasses include the natives muttongrass and squirreltail.

At the surface, litter dominates with over 45% cover (Figure 6). Rock is the next largest component. The low percent cover of plants at the surface (<5%) reflects the greater proportion of vegetation in the canopy in this vegetation type.

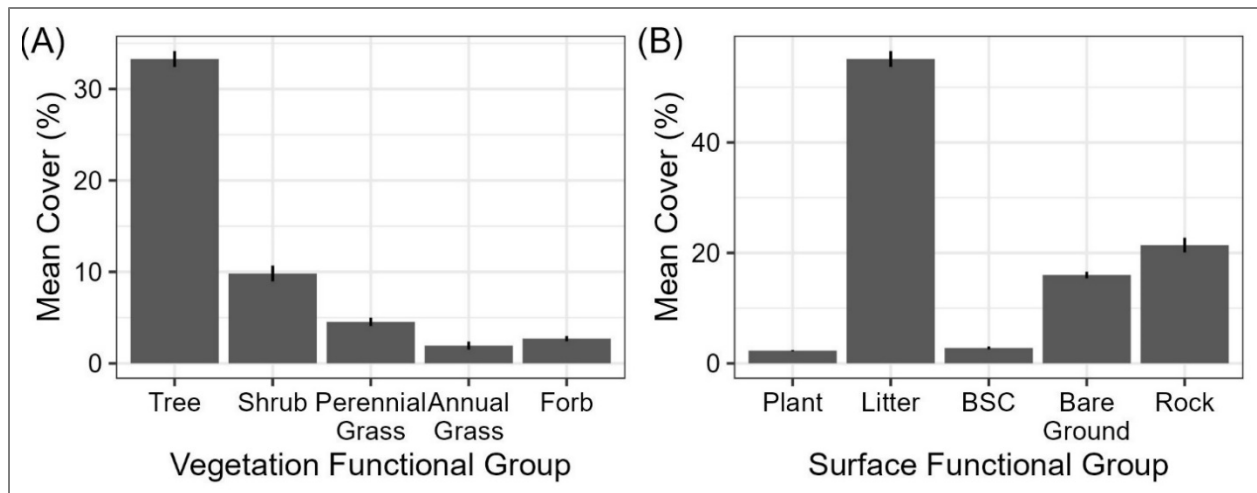


Figure 6. (A) Percent cover of vegetation functional groups for pinyon-juniper woodlands. (B) Percent cover of surface functional groups for pinyon-juniper woodlands. In (B), BSC is biological soil crust. In both (A) and (B), percent cover is the mean of all plots across all years of monitoring, ± 1 standard error of the mean. NPS / CAROLYN LIVENSPPERGER



Figure 7. Pinyon-juniper woodlands at Black Canyon of the Gunnison National Park. NPS / WASHUTA

3.1.3 Aspen Forest

Point-intercept measurements in aspen forest show surprisingly low tree cover because tree hits are only counted up to 2 meters in height. Since much of the aspen canopy is higher than 2 meters, it is not counted, and tree cover appears artificially low (Figure 8, Figure 9). In the understory, perennial grasses were dominant, with close to 65% cover. Kentucky bluegrass was detected in all visits and had high mean cover, 37%. Forbs had a much greater percent cover in aspen forests, about 40%, than any other vegetation type.

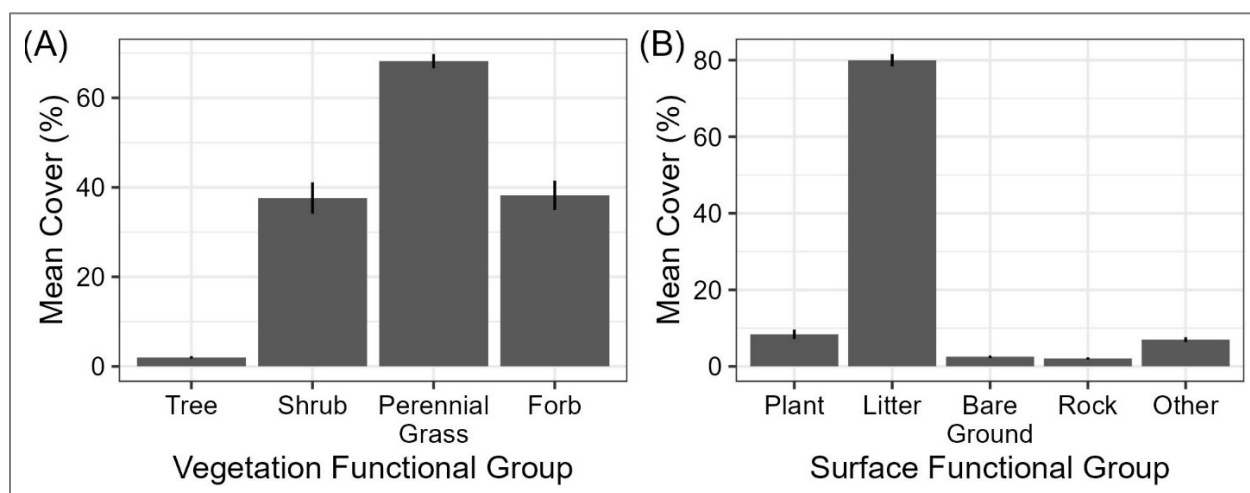


Figure 8. (A) Percent cover of vegetation functional groups for aspen forests. (B) Percent cover of surface functional groups for aspen forests. In both (A) and (B), percent cover is the mean of all plots across all years of monitoring, ± 1 standard error of the mean. NPS / CAROLYN LIVENSPPERGER

Litter was very high on the surface, close to 80% (Figure 8). The “other” category shown in Figure 8 includes wildlife or livestock scat and woody debris.



Figure 9. Aspen forest at Curecanti National Recreation Area. NPS

3.1.4 Gambel Oak Shrublands

Gambel oak shrublands have close to 20% cover of Gambel oak, but even greater cover of other shrubs and perennial grasses (Figure 10, Figure 11). Utah serviceberry, mountain snowberry, and big sagebrush are all common shrubs in this vegetation type. The native muttongrass and non-native Kentucky bluegrass are the most common perennial grasses. Trees and annual grasses are less common, but there is a relatively large forb component, greater than 5%.

At the surface, litter is the dominant functional group, and all other categories are 10% cover or less (Figure 10). There is very little biological soil crust in this vegetation type.

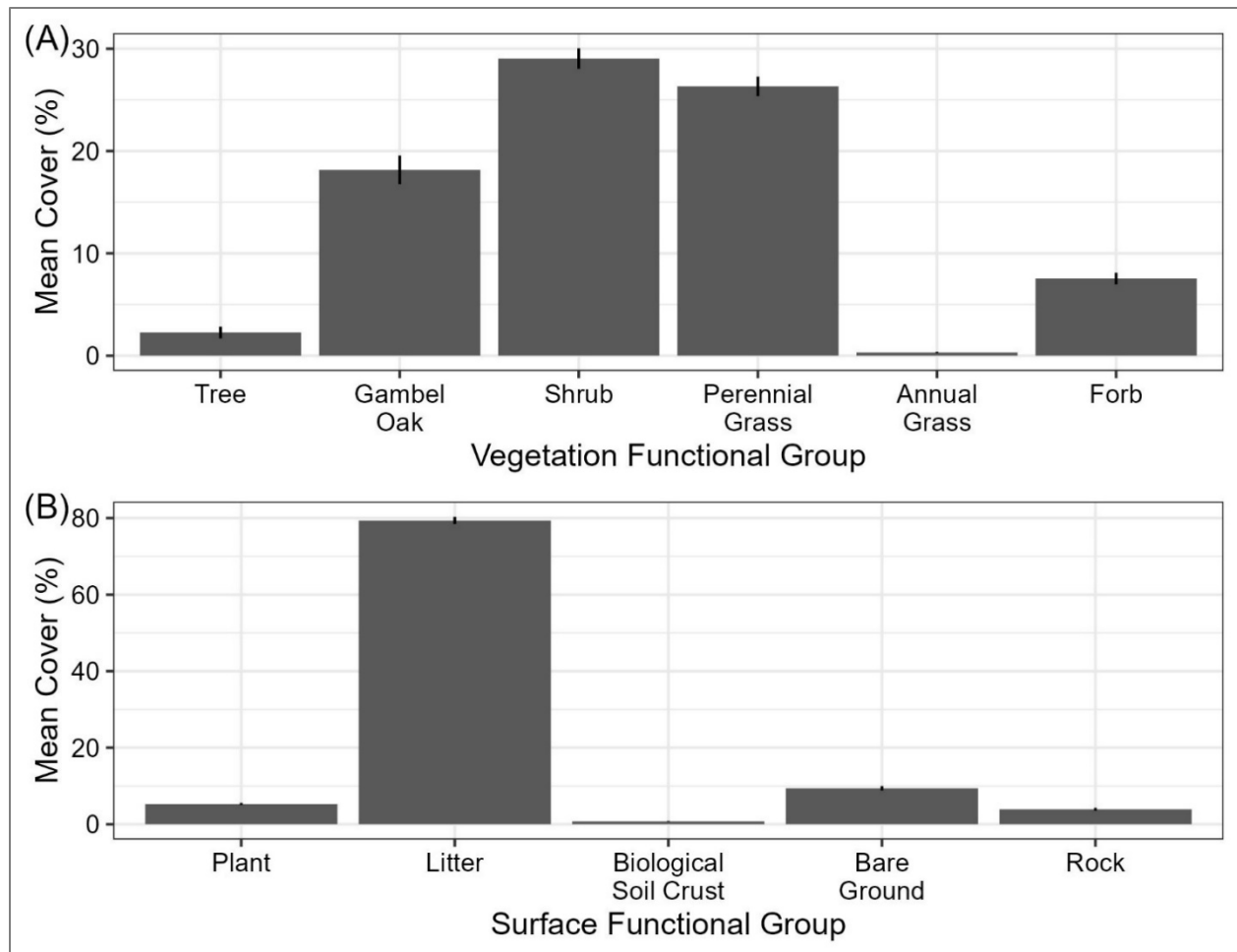


Figure 10. (A) Percent cover of vegetation functional groups for Gambel oak shrublands. (B) Percent cover of surface functional groups for Gambel oak shrublands. In both (A) and (B), percent cover is the mean of all plots across all years of monitoring, ± 1 standard error of the mean.

NPS / CAROLYN LIVENSPEGER



Figure 11. Gambel oak shrublands at Black Canyon of the Gunnison National Park. NPS

3.2 Climate Summary

Comparison of minimum and maximum temperatures to 30-year averages at Blue Mesa Reservoir (CURE) and Cimarron (BLCA) weather station locations shows that most years during the monitoring period had temperatures greater than average (Figure 12). The Blue Mesa Reservoir 30-year average annual maximum temperature was 14.0°C and minimum temperature was -3.8°C. At Cimarron, 30-year average maximum temperature was 15.2°C, and the minimum temperature was -1.8°C. Average annual precipitation was 302 mm at Blue Mesa Reservoir and 375 mm at Cimarron. Maximum temperatures in 2012 were close to 2°C greater than average, while 2013 and 2019 were cooler at both locations for both maximum and minimum temperatures. Most years were also wetter than normal, with precipitation greater than 100% of the 30-year average. Cimarron had greater deviations from average than Blue Mesa Reservoir, with multiple years having more than

125% of normal precipitation. The years 2012, 2018, and 2020 were hotter and drier at both locations.

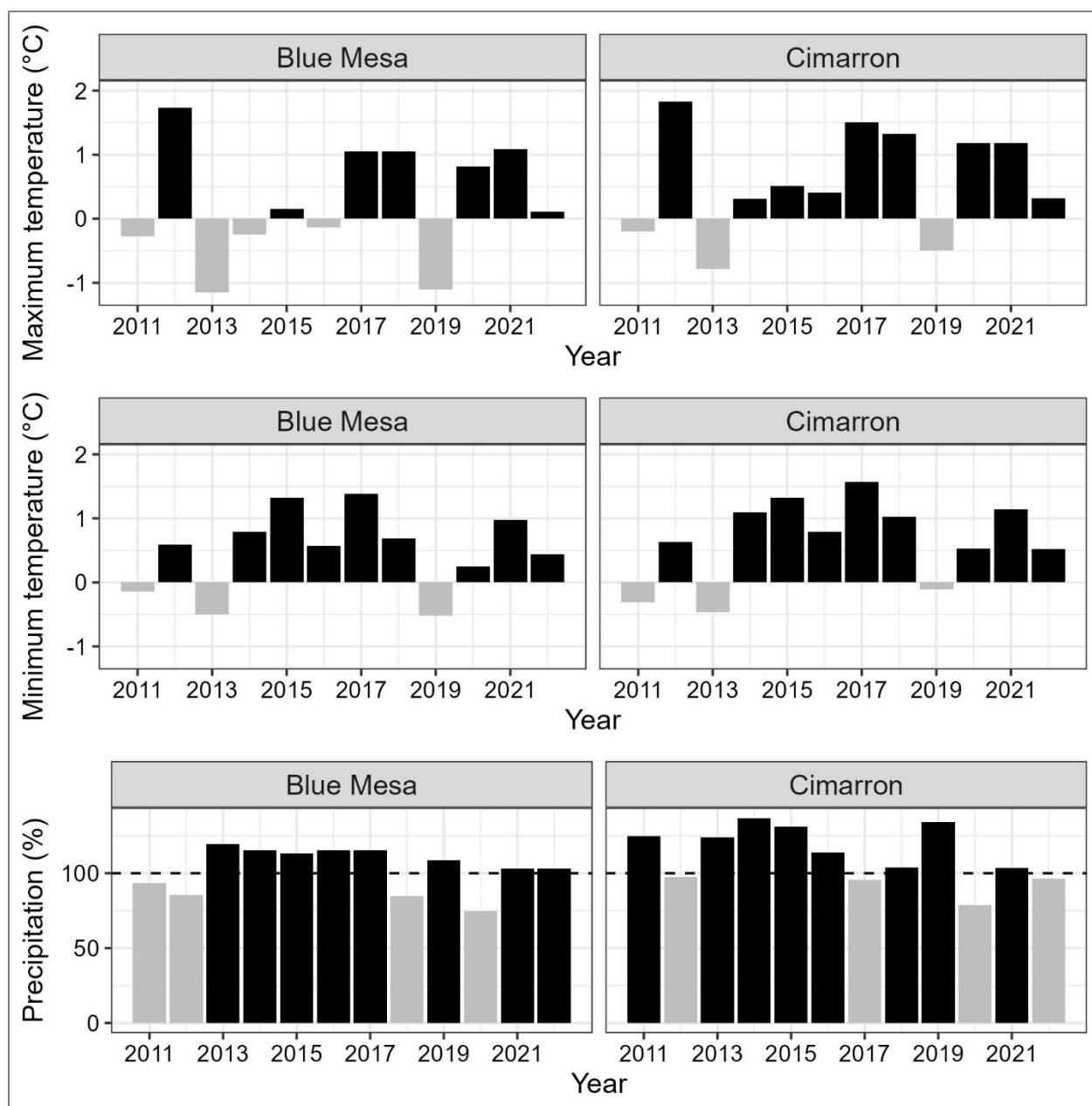


Figure 12. Temperature and precipitation departures from the 30-year average. (A) Maximum temperature difference from the 1980 – 2010 mean annual maximum temperature. (B) Minimum temperature difference from the 1980 – 2010 mean annual minimum temperature. (C) Precipitation percentage of the 1980 – 2010 mean annual precipitation. NPS / CAROLYN LIVENSPIERGER

A summary of the 5-year SPEI over the monitoring period shows alternating wet and dry periods, but much more dry than wet, particularly at BLCA (Figure 13). The SPEI showed that BLCA was in drought for most of the monitoring period, with extreme drought since 2020. While CURE also was

in drought for a majority of the monitoring period, there was a slightly wetter period from approximately 2016 to 2018.

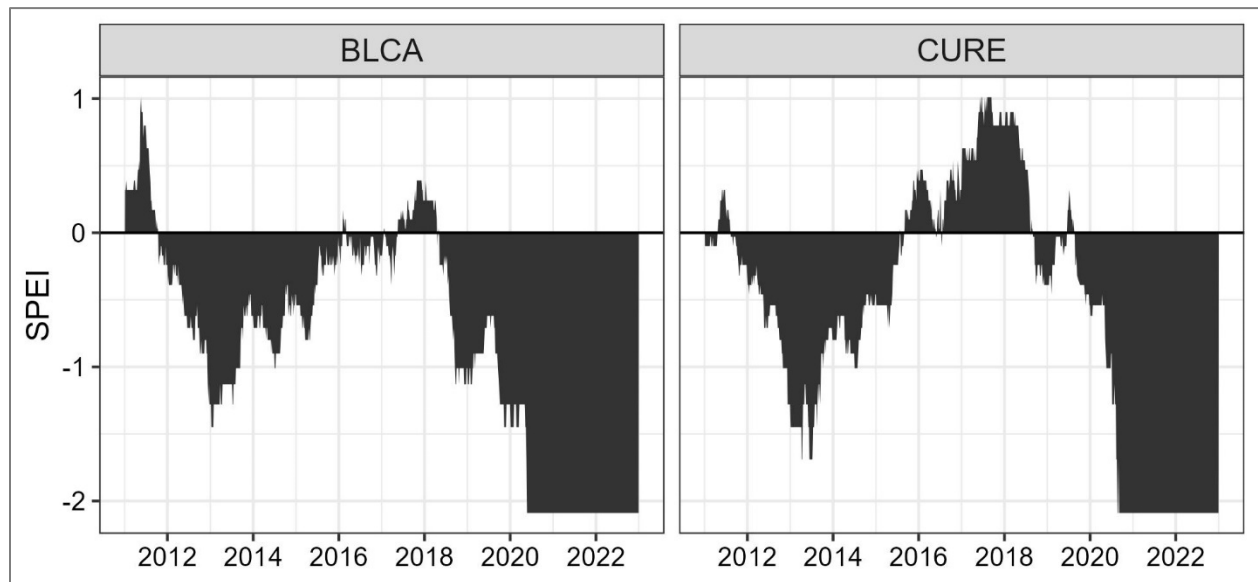


Figure 13. Five-year Standardized Precipitation Evapotranspiration Index (SPEI) for Black Canyon of the Gunnison National Park and Curecanti National Recreation Area from 2011 to 2022. The SPEI is the standardized index of precipitation (P) minus potential evapotranspiration (PET) accumulated over 5 years and is presented on the y-axis as a Z-score (the number of standard deviations from the mean), which compares to the distribution of values from the 1980 to 2020 reference period. An SPEI value of 2 or more is considered extremely wet, and -2 or less indicates extreme drought. Data were accessed from Climate Engine (app.climateengine.com, accessed 8 February 2024, Abatzoglou, 2013).
NPS / CAROLYN LIVENSPIERGER

AET, D, and P had differing patterns over the monitoring period (Figure 14). In general, P was more variable between years than AET or D, which reflects the buffering influence of soil properties on AET and D. While patterns were similar at BLCA and CURE, BLCA generally had higher cumulative water. Low monsoon-season P from 2019 to 2022 was reflected in higher D and lower AET over the same time period. D was lowest and varied little in the cool season. CGDD were consistently greater at BLCA, but the interannual pattern was similar between BLCA and CURE (Figure 15). The years 2012 and 2018 had particularly high CGDD, while 2011, 2013, and 2019 were low, consistent with patterns of minimum temperature (Figure 12). BLCA and CURE are shown individually in Figures 14 and 15 for comparison, but analysis was performed on vegetation types, which included plots in both parks.

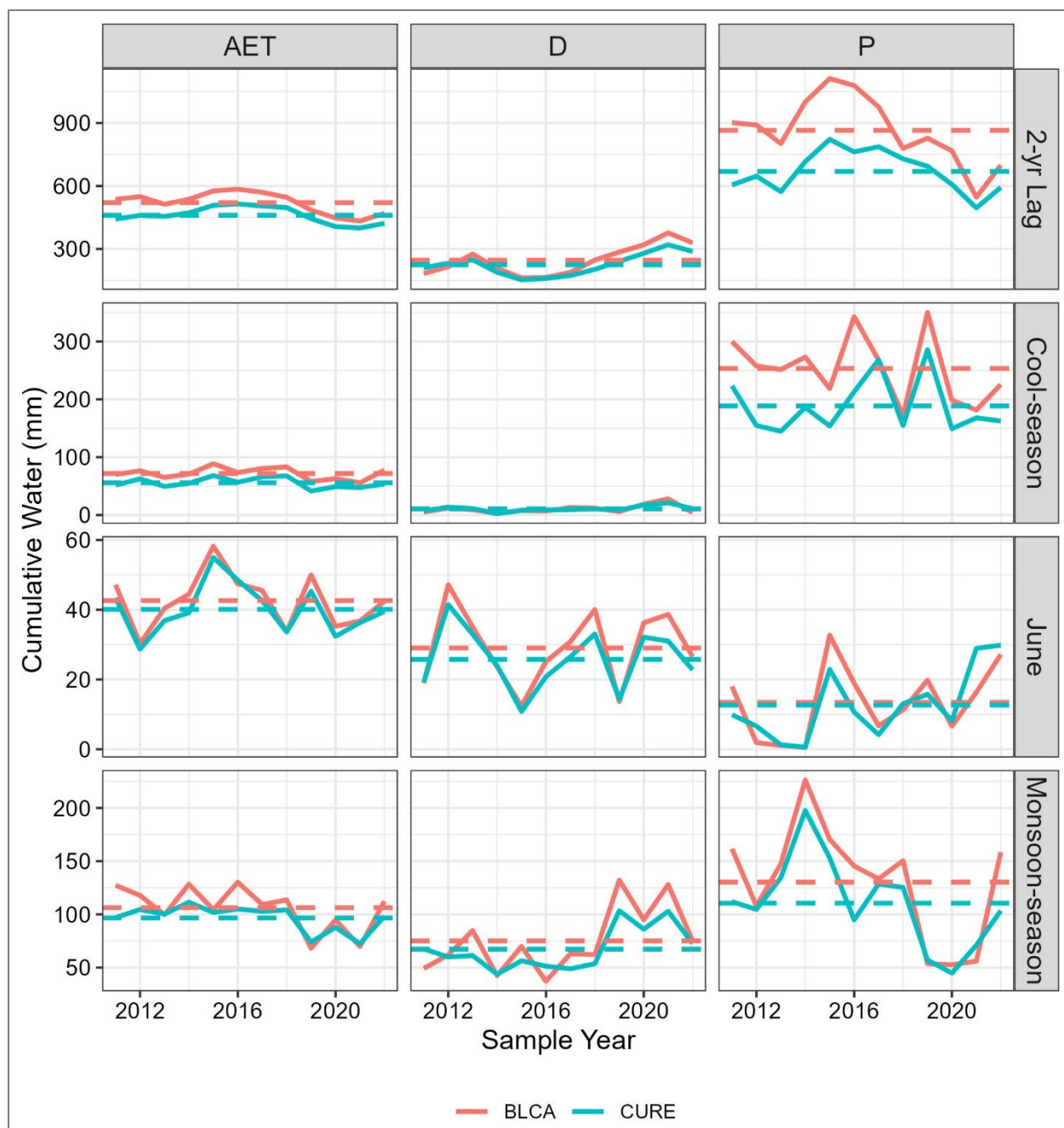


Figure 14. Annual patterns of water balance covariates used in Bayesian modeling. Columns show the water balance variable (AET, actual evapotranspiration; D, deficit; and P, precipitation) and rows are the time period over which the variable is summarized. Sample year on the x-axis denotes the year in which sampling took place. Note that rows have different scales on the y-axis. Dashed lines denote the mean over the monitoring period. NPS / CAROLYN LIVENSBERGER

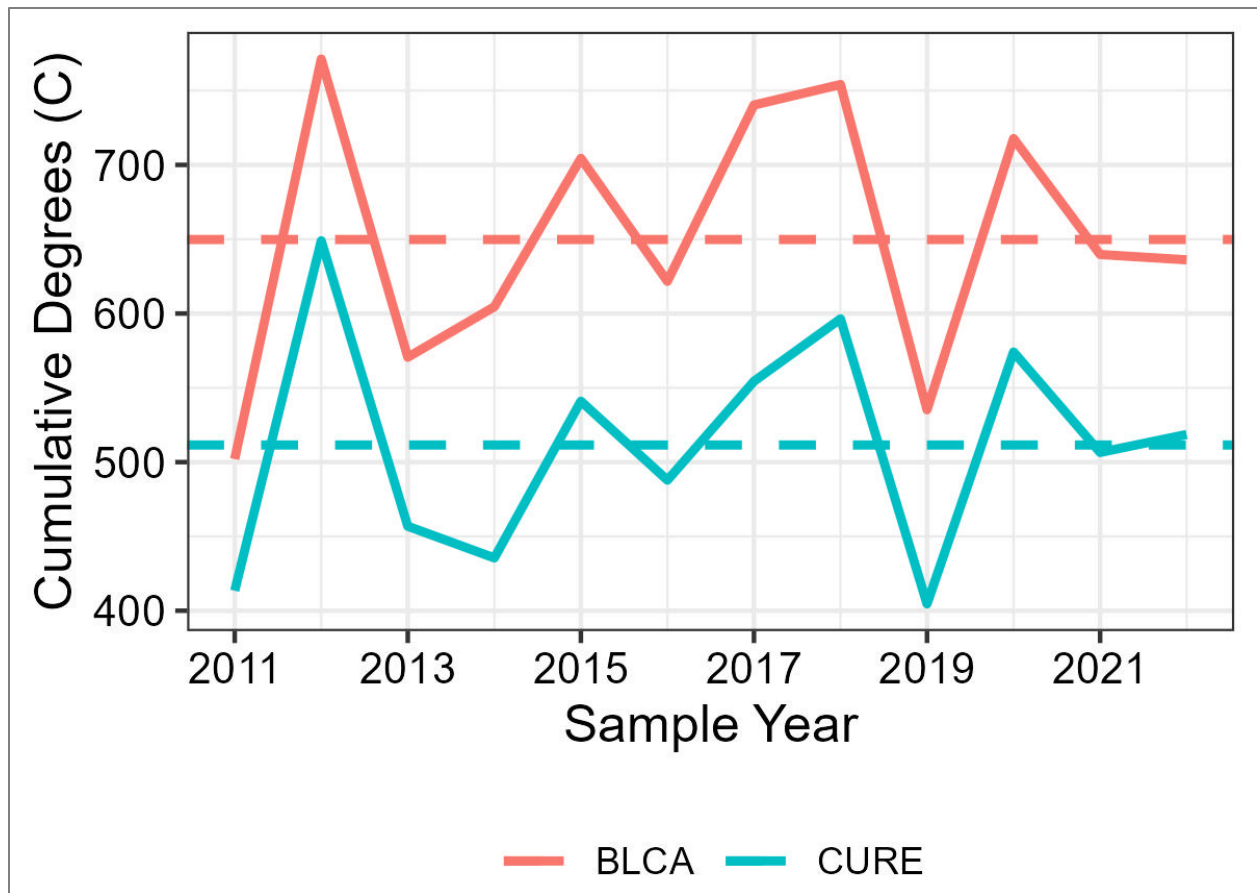


Figure 15. Annual pattern of cumulative growing degree-days covariate used in Bayesian modeling.
NPS / CAROLYN LIVENSPIERGER

3.3 Sagebrush Status and Trend

All models presented here passed posterior predictive checks for model convergence and fit (Table 4). A Gelman diagnostic, which evaluates model convergence, with a cutoff of less than 1.12 was used for model testing but all final sagebrush shrubland models had a value of 1.09 or less. Final models were run with a minimum of 20,000 burn-in and 10,000 iterations using the MCMC sampler. Bayesian p-values (B_p) describe the ability of the model to reproduce the observed data, with values close to 0.5 meaning that observed data were well predicted by the model. Bayesian p-values for predicting the observed mean for all but one of the sagebrush models were within 0.1 of 0.5, indicating a very good model fit. The exotic annual cover model had a B_p for the mean of 0.68, indicating that the model slightly overpredicted the mean. Values for B_p for the variance tended to be farther from 0.5, indicating that it was more difficult for models to reproduce the observed variance.

A model for tree cover did not achieve convergence, so results are not presented. Tree cover was very low in sagebrush shrublands (<1%), which likely contributed to difficulty in modeling this indicator.

Table 4. Bayesian model specifications for sagebrush shrublands. All models take the form of a general linear model with a site-level random effect, meaning intercepts in the model were allowed to vary by site. The likelihood describes the form of the response variable. The deterministic model represents the ecological process being modeled. In addition to having varying site means, the variance of sites could either be fixed or variable, as indicated by a hierarchical variance structure. The Gelman diagnostic indicates model convergence and B_P (Bayesian p-value for the model mean and variance) evaluates model fit.

Indicator	Likelihood	Deterministic Model	Variance Structure	Gelman Diagnostic	B_P mean, B_P Variance
Total cover	Beta binomial	Inverse logit	Fixed	1.00	0.5, 0.57
Total grass cover	Beta binomial	Inverse logit	Fixed	1.02	0.49, 0.51
Native perennial grass cover	Beta binomial	Inverse logit	Fixed	1.00	0.51, 0.51
Non-native perennial grass cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.09	0.55, 0.57
Non-native plant frequency	Zero-inflated beta binomial	Inverse logit	Fixed	1.04	0.57, 0.47
Total shrub cover	Beta binomial	Inverse logit	Fixed	1.01	0.5, 0.51
Big sagebrush cover	Beta binomial	Inverse logit	Fixed	1.03	0.51, 0.59
Total shrub density	Negative binomial simple	Linear	Hierarchical	1.00	0.41, 0.26
Big sagebrush density	Negative binomial simple	Linear	Hierarchical	1.03	0.53, 0.64
Forb cover	Beta binomial	Inverse logit	Fixed	1.03	0.52, 0.53
Biological soil crust cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.01	0.54, 0.62
Bare ground cover	Beta binomial	Inverse logit	Fixed	1.01	0.51, 0.54
Soil stability	Ordinal latent normal	Linear	Fixed	1.00	0.4, 0.66

Most models had fixed slopes, except for the density models for big sagebrush and total shrubs. These models used a hierarchical variance structure.

Total cover was very similar in grazed and ungrazed sagebrush shrublands (Figure 16). The effect of year was not significant, and no trend was found for either grazed or ungrazed sagebrush. Cool-season precipitation had a significant positive effect on total cover. Model-predicted mean total cover was around 50% for both vegetation types, with a credible interval range between 33% and 79% (Table 5).

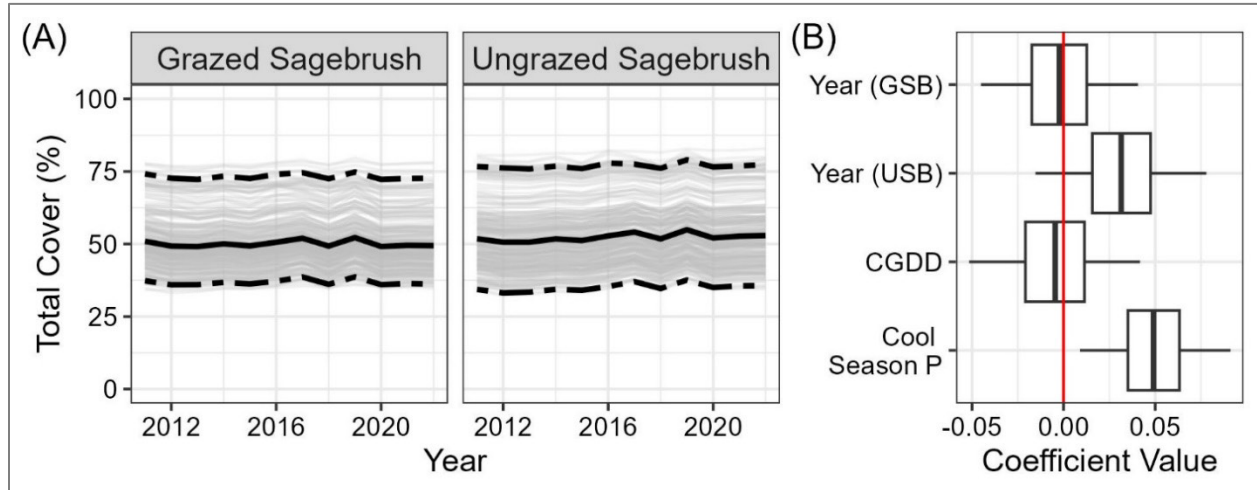


Figure 16. Total cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of total cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIERGER

Table 5. Status and trend of all indicators for sagebrush shrublands. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; “None” means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	Stratum	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Total cover (%)	Grazed sagebrush	50 (36, 72)	53 (39, 75)	None	-0.02 (-0.12, 0.29)
	Ungrazed sagebrush	51 (33, 76)	56 (38, 79)	None	0.21 (0.11, 0.54)
Total grass cover (%)	Grazed sagebrush	20 (7, 48)	25 (9, 54)	None	0.02 (-0.01, 0.26)
	Ungrazed sagebrush	21 (8, 49)	26 (11, 54)	None	0.08 (-0.02, 0.39)
Native perennial grass cover (%)	Grazed sagebrush	17 (7, 40)	22 (9, 49)	Decreasing	-0.33 (-0.43, -0.06)
	Ungrazed sagebrush	21 (8, 42)	26 (10, 47)	None	-0.18 (-0.27, 0.1)
Non-native perennial grass cover (%)	Grazed sagebrush	0.4 (0, 5)	1 (0, 19)	Increasing	0.05 (0, 0.8)
	Ungrazed sagebrush	0.7 (0, 5)	1.4 (0, 10)	None	0.03 (0, 0.3)
Non-native plant frequency	Grazed sagebrush	0.06 (0, 0.90)	0.08 (0, 0.95)	None	0.002 (0, 0.017)
	Ungrazed sagebrush	0.06 (0, 0.83)	0.08 (0, 0.90)	None	0.002 (0, 0.015)
Total shrub cover (%)	Grazed sagebrush	31 (18, 47)	32 (18, 47)	None	-0.04 (-0.17, 0.35)
	Ungrazed sagebrush	30 (16, 49)	31 (16, 50)	None	-0.01 (-0.13, 0.34)
Total shrub density (shrubs/ha)	Grazed sagebrush	7142 (2959, 19074)	7793 (3649, 19705)	None	53.6 (27.9, 127.8)
	Ungrazed sagebrush	8817 (2998, 19157)	9416 (3616, 19729)	None	-1.4 (-32.1, 89.7)
Big sagebrush cover (%)	Grazed sagebrush	14 (6, 24)	16 (7, 26)	None	-0.14 (-0.2, 0.04)
	Ungrazed sagebrush	14 (7, 24)	15 (8, 26)	None	-0.13 (-0.2, 0.06)
Big sagebrush density (shrubs/ha)	Grazed sagebrush	3612 (1235, 5692)	4261 (1790, 6322)	None	-2.1 (-17.9, 44.2)
	Ungrazed sagebrush	3411 (1132, 6384)	4030 (1775, 6980)	None	-19.4 (-33.2, 20.6)
Forb cover (%)	Grazed sagebrush	4 (1, 13)	6 (1, 18)	None	0.05 (0, 0.25)
	Ungrazed sagebrush	4 (1, 15)	6 (1, 25)	None	0.14 (0.04, 0.6)

Table 5 (continued). Status and trend of all indicators for sagebrush shrublands. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; “None” means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	Stratum	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Biological soil crust cover (%)	Grazed sagebrush	1 (0, 6)	2 (0, 9)	Increasing	0.08 (0.01, 0.38)
	Ungrazed sagebrush	2 (0, 5)	2 (0, 7)	None	-0.06 (-0.08, 0.01)
Bare ground cover (%)	Grazed sagebrush	20 (7, 40)	21 (7, 41)	None	-0.09 (-0.17, 0.19)
	Ungrazed sagebrush	19 (10, 45)	20 (11, 46)	None	-0.1, (-0.2, 0.2)
Soil stability	Grazed sagebrush	2.6 (1.6, 4.6)	3.2 (2.1, 5.1)	None	-0.01 (-0.01, 0.02)
	Ungrazed sagebrush	2.6 (1.6, 3.8)	3.5 (2.4, 4.6)	Decreasing	-0.04 (-0.05, -0.01)

Total grass cover includes both native and non-native, annual and perennial grasses. Total grass cover was very similar in grazed and ungrazed sagebrush, and there was no directional trend in either vegetation type (Figure 17). Model-predicted mean total grass cover was between 20% and 26%, comprising about half of total plant cover in sagebrush shrublands (Table 5). CGDD and June AET both had significant positive effects on total grass cover, indicating that warmer early spring temperatures and greater AET in the summer contributed to higher cover of grasses.

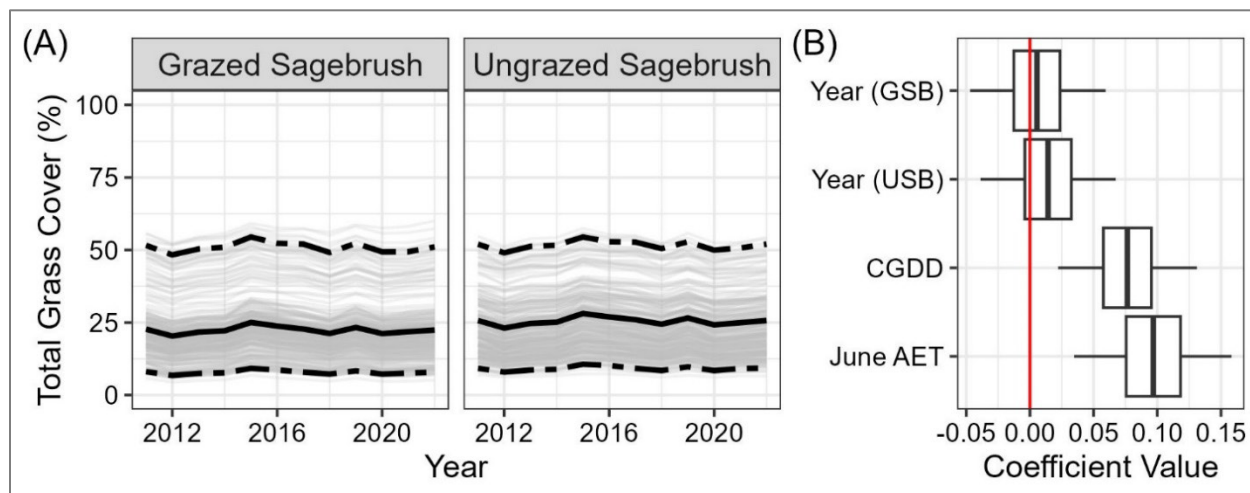


Figure 17. Total grass cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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Native perennial grass cover comprises most of the total grass cover in both grazed and ungrazed sagebrush shrublands. Model-predicted status shows that grazed and ungrazed sagebrush have a similar total range of cover as indicated by the credible intervals, but mean cover is slightly greater in ungrazed sagebrush (Table 5). Year had a significant negative effect in grazed sagebrush, indicating a decreasing trend in native perennial grass cover (Figure 18), with an annual average rate of change of -0.33% . Ungrazed sagebrush did not have a significant effect of year. June D had a significant negative effect, meaning that in both grazed and ungrazed sagebrush, higher D in June resulted in lower native perennial grass cover.

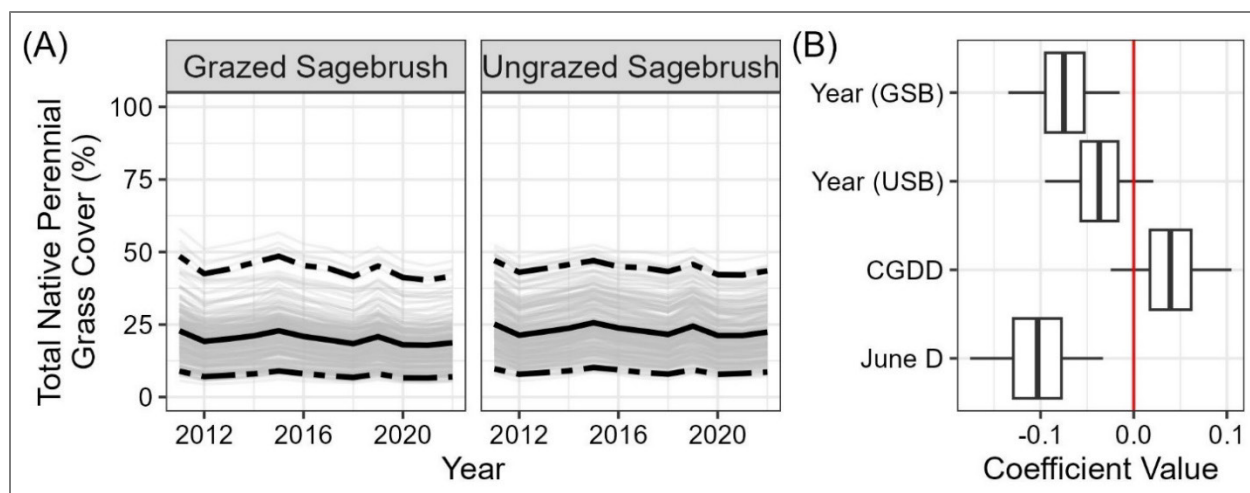


Figure 18. Total native perennial grass cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of native perennial grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total native perennial grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit.
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Non-native perennial grass cover included Kentucky bluegrass, crested wheatgrass, smooth brome, and bulbous bluegrass, and model-predicted mean cover was never greater than 2% throughout the monitoring period (Table 5). However, in grazed sagebrush, cover increased towards the end of the monitoring period, and the credible interval range had a maximum of 19% (Figure 19). Year had a significant positive effect for grazed sagebrush, meaning that non-native perennial grasses had an increasing trend over time at the rate of 0.05% per year. Ungrazed sagebrush did not have a significant effect of year.

Frequency of any non-native plant species was generally low, below 0.1 (Figure 20). However, the wide credible intervals and predictions of high frequency (light gray lines in Figure 20A) show that some plots, particularly in grazed sagebrush, did have high frequency of non-native species. While some annual non-natives were detected (*Bromus tectorum* and *Alyssum sp.*), non-native perennial grasses were more common (Appendix C). There was no significant effect of year, indicating no increasing or decreasing trend over time.

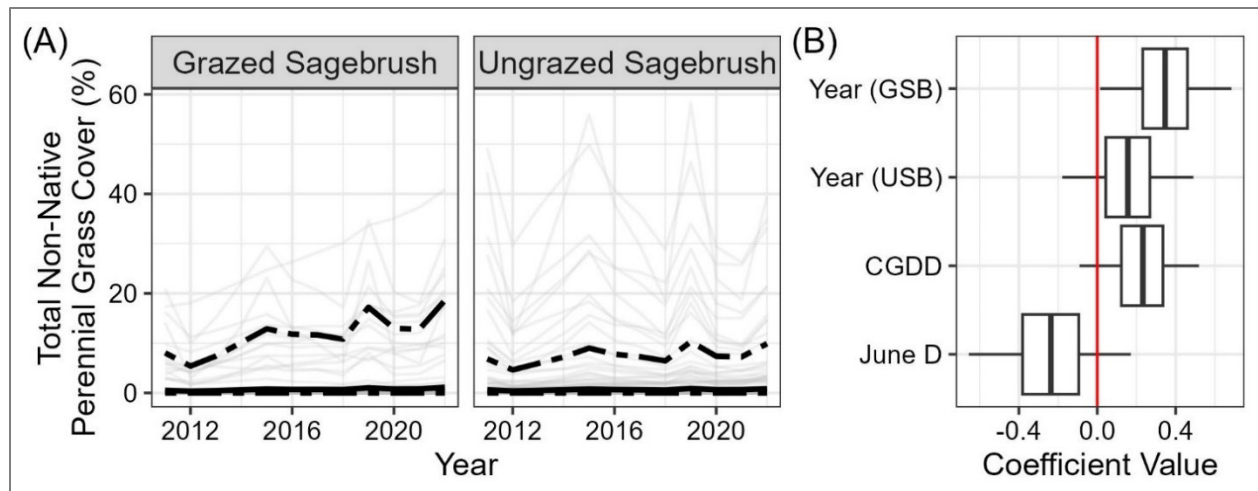


Figure 19. Total non-native perennial grass cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of non-native perennial grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total non-native perennial grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIERGER

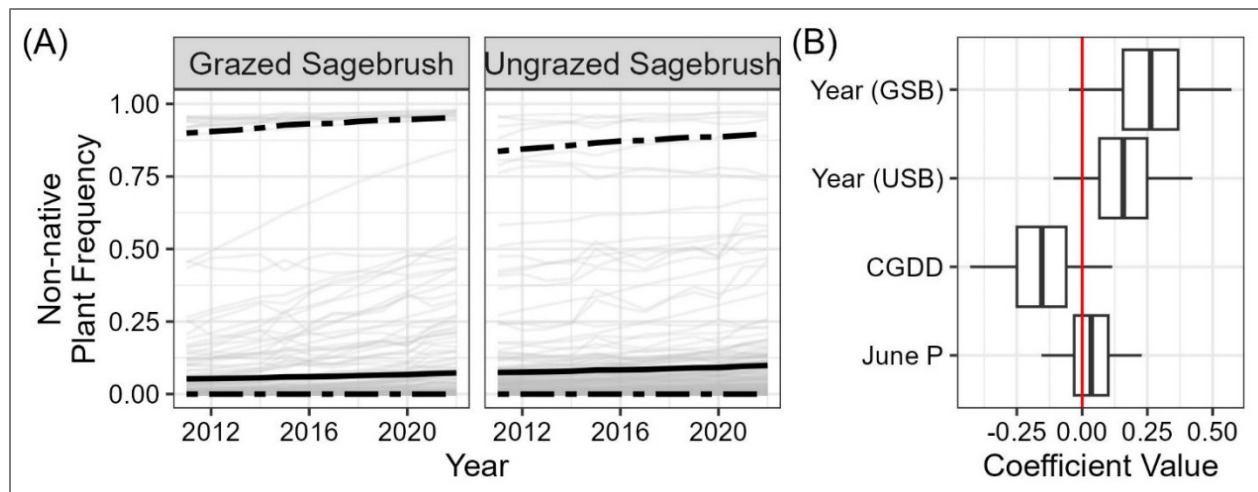


Figure 20. Non-native plant frequency status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of non-native plant frequency, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant frequency model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIERGER

Total shrub cover included big sagebrush along with many other shrub species, including green rabbitbrush, mountain snowberry, and antelope bitterbrush. Model-predicted mean total shrub cover was around 30%, with credible intervals ranging from 16% to 50%, and was very similar in grazed and ungrazed shrublands (Table 5). Total shrub cover was stable during the monitoring period, with no evidence of an increasing or decreasing trend (Figure 21). Covariates with 2-year lag effects were tested for total shrub cover, but June and monsoon-season precipitation were better predictors, although neither had a directional effect on the response variable.

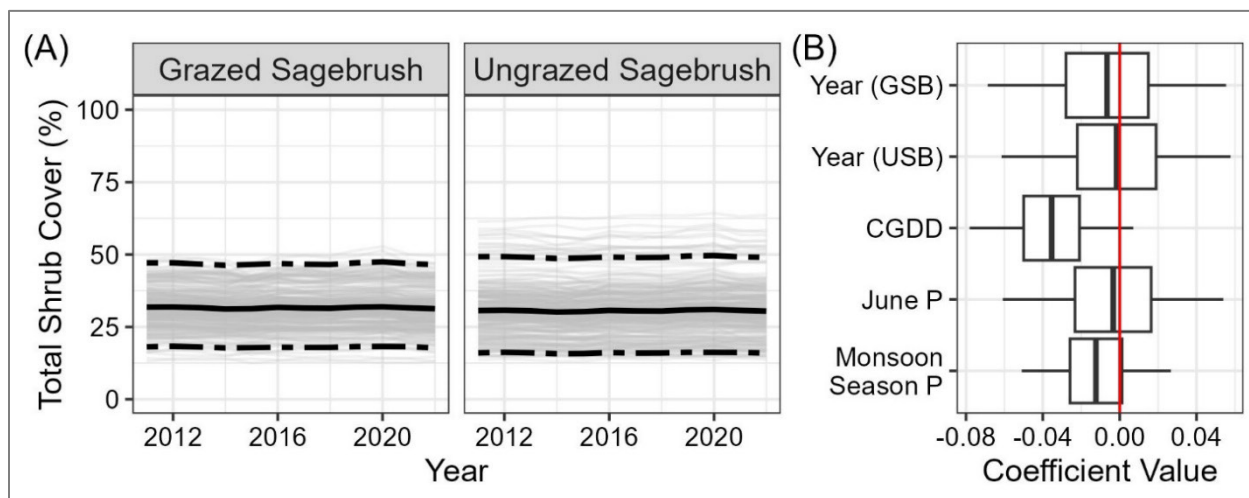


Figure 21. Total shrub cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of total shrub cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total shrub cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation.
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Shrub density, which includes all shrub species, ranged from 2,998 to 19,729 shrubs/ha (Table 5), with wide credible intervals (Figure 22). However, model-predicted mean shrub density was slightly higher in ungrazed sagebrush. There was no significant effect for year covariates, but there was a significant positive relationship with 2-year lag AET. This indicates that when AET was greater over the 2-year period prior to sampling, shrub density increased.

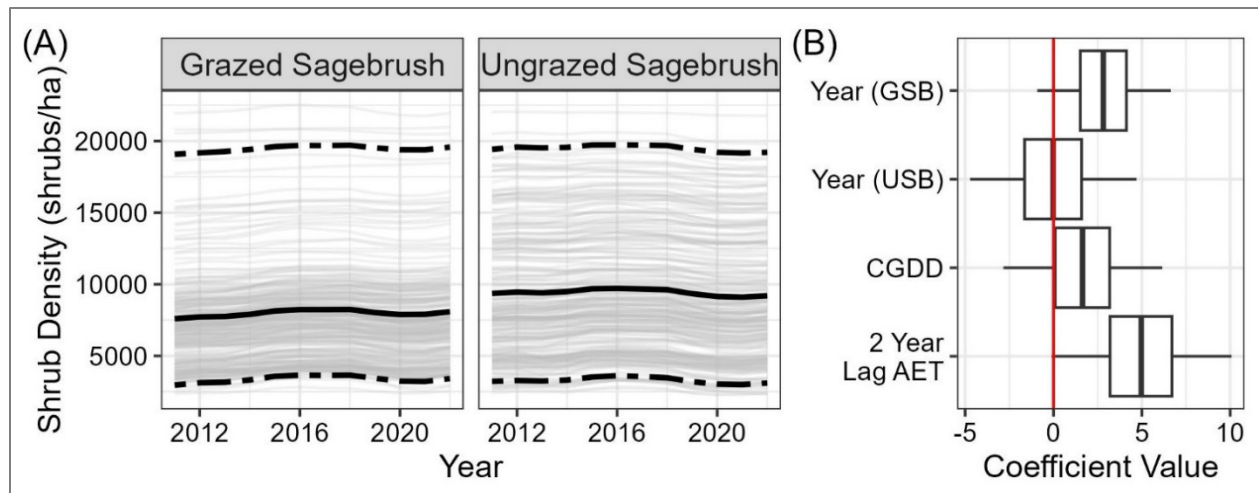


Figure 22. Shrub density status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of shrub density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for shrub density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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In addition to cover of all shrubs, big sagebrush cover alone was analyzed. Model-predicted mean big sagebrush cover was close to 15%, with credible intervals ranging from 6% to 26%, and like total shrubs was very similar in grazed and ungrazed sagebrush (Table 5, Figure 23). There was no significant effect of year. The climate covariates also did not have significant effects, but the 2-year lag precipitation covariate was included in the final model.

Density of big sagebrush was more variable between years than total shrub density (Figure 22, Figure 24). Density was very similar in grazed and ungrazed sagebrush and had a model-predicted credible interval ranging from 1,132 to 6,980 shrubs/ha (Table 5). There was no significant effect of year in either grazed or ungrazed sagebrush. CGDD had a significant positive relationship with big sagebrush density, but the water balance covariates showed no significant effects.

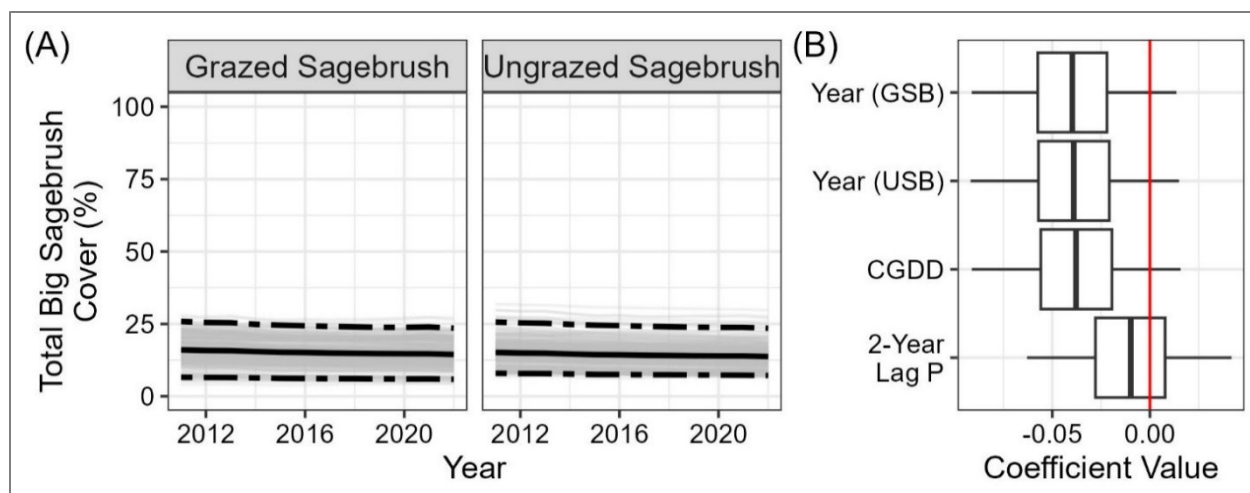


Figure 23. Total big sagebrush cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of big sagebrush cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total big sagebrush cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation.
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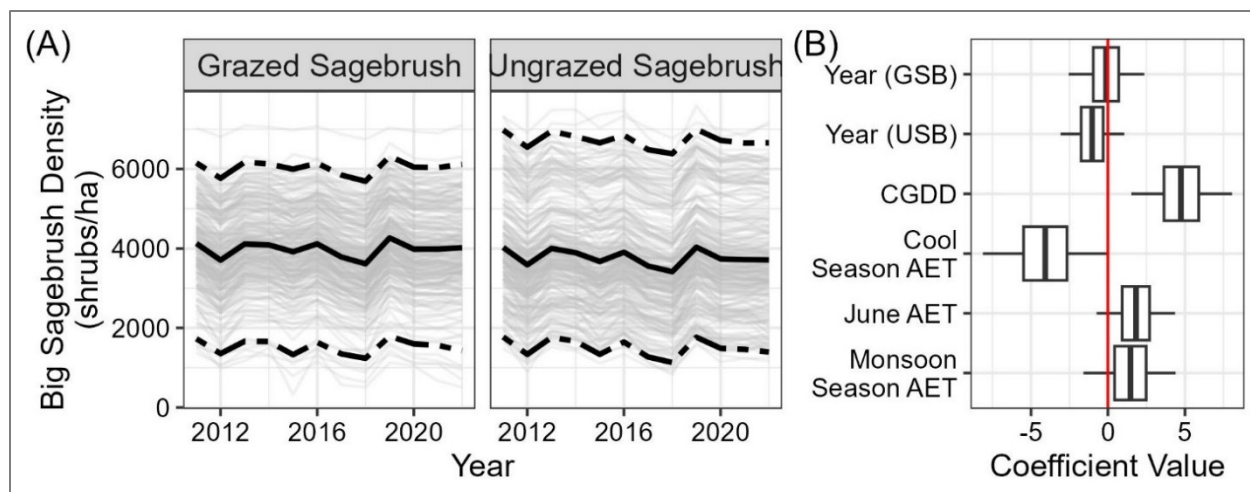


Figure 24. Big sagebrush density status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of big sagebrush density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for big sagebrush density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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Model-predicted mean forb cover was generally low in sagebrush shrublands (note scale on y-axis in Figure 25) but had a maximum credible interval range of 18% and 25% in grazed and ungrazed, respectively, indicating that years with favorable conditions could result in high forb cover (Table 5, Figure 25). Results show that cooler springs (low CGDD) with high AET and low monsoon season AET in the year prior contribute to higher forb cover. There was no significant effect of year, although in ungrazed sagebrush the annual average rate of change was positive (Table 5), and the covariate effect was close to being significant.

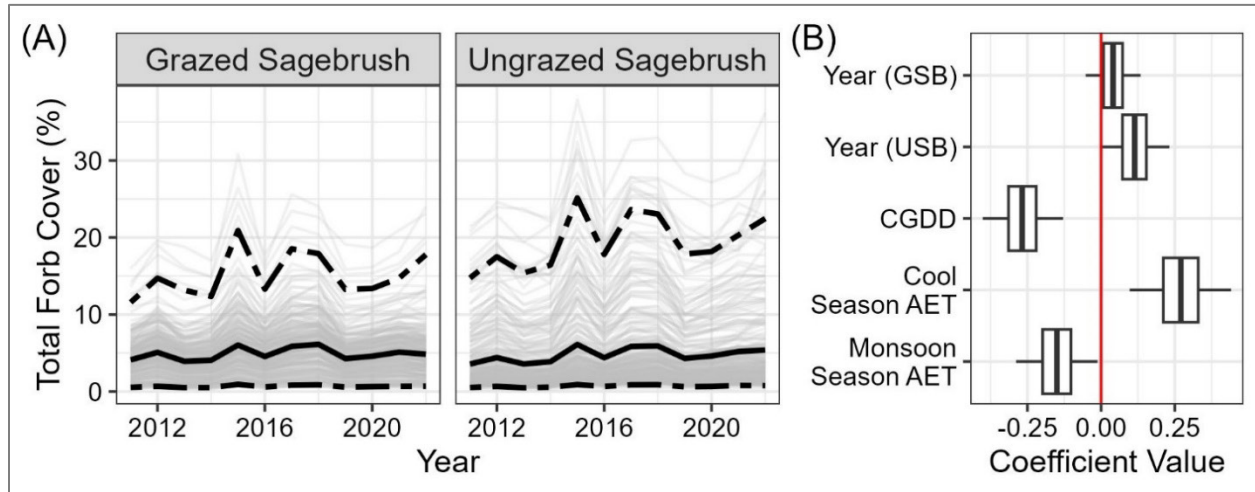


Figure 25. Total forb cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of forb cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total forb cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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Model-predicted mean biological soil crust cover was very low (1%–2%) in sagebrush shrublands, which have greater cover of litter and bare ground (Table 5, Figure 4). However, biological soil crust cover was significantly increasing over time in grazed sagebrush (Figure 26). Biological soil crust cover was lower at the end of the monitoring period in ungrazed sagebrush, but there was no significant effect of year. The effect of CGDD on biological soil crust cover was positive.

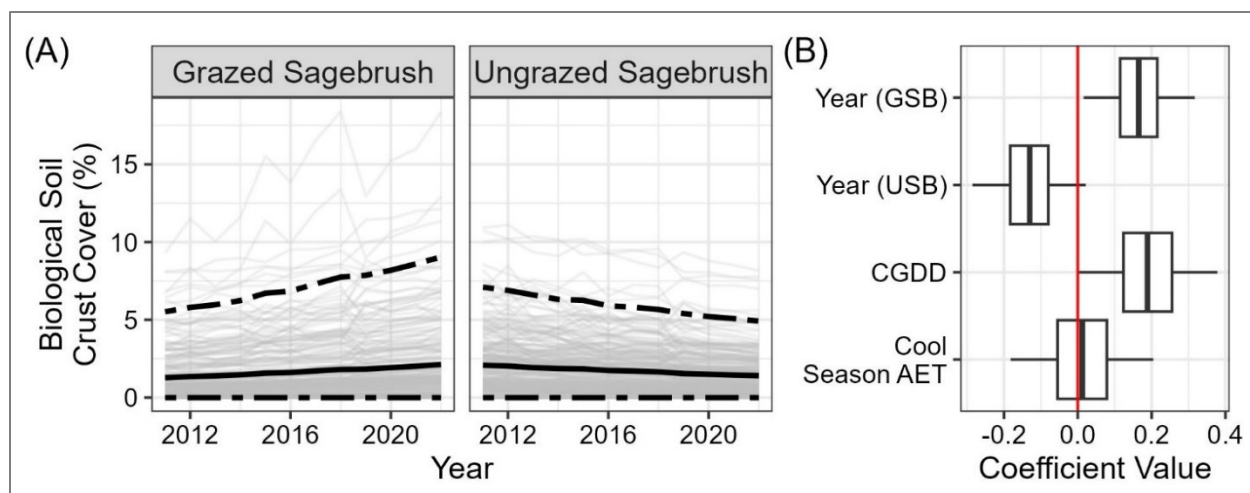


Figure 26. Total biological soil crust cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of biological soil crust cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total biological soil crust cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPIERGER

Bare ground was the largest surface functional group analyzed for trend in sagebrush. Model-predicted mean bare ground was about 20%, with a credible interval ranging from 7% to 46% (Table 5). Bare ground, which included both undifferentiated crust and loose soil, varied little between years (Figure 27). Year covariates for grazed and ungrazed sagebrush were not significant, indicating there was no directional trend over time. CGDD had a significant negative effect, indicating that cooler springs resulted in greater bare ground.

Soil stability is measured on a categorical scale of 1–6, with higher values indicating more stable soil. Model-predicted soil stability was similar in grazed and ungrazed sagebrush, with mean values from 2.6 to 3.5 (Table 5, Figure 28). Soil stability was responsive to climate covariates, varying significantly in response to CGDD, cool-season D, and June D. The climate relationships show that warmer, wetter springs and early summers resulted in greater soil stability. Over the monitoring period, ungrazed sagebrush soil stability decreased significantly, at a rate of -0.04 scale units per year.

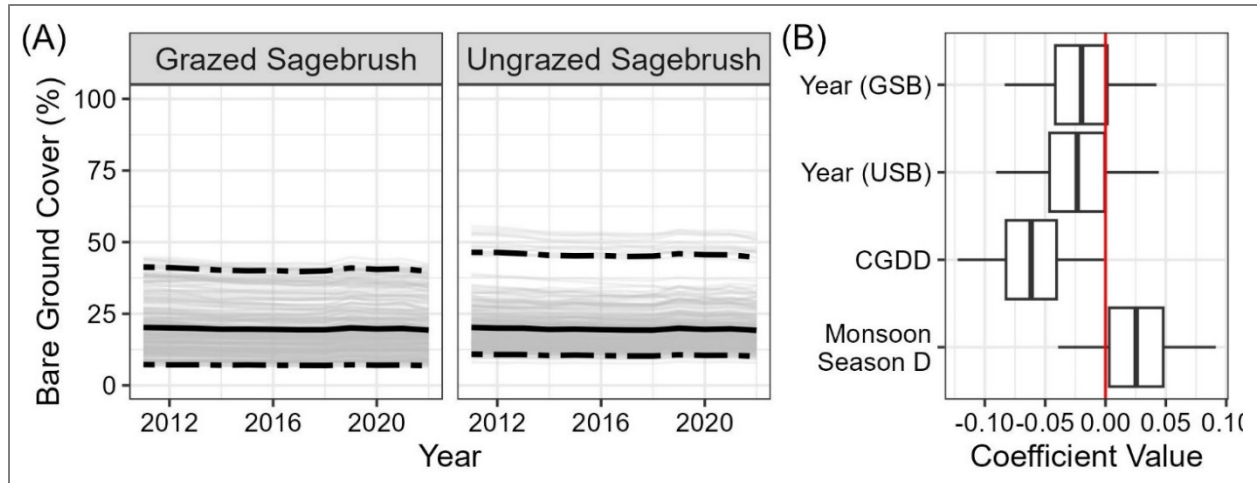


Figure 27. Bare ground cover status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of bare ground cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for bare ground cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

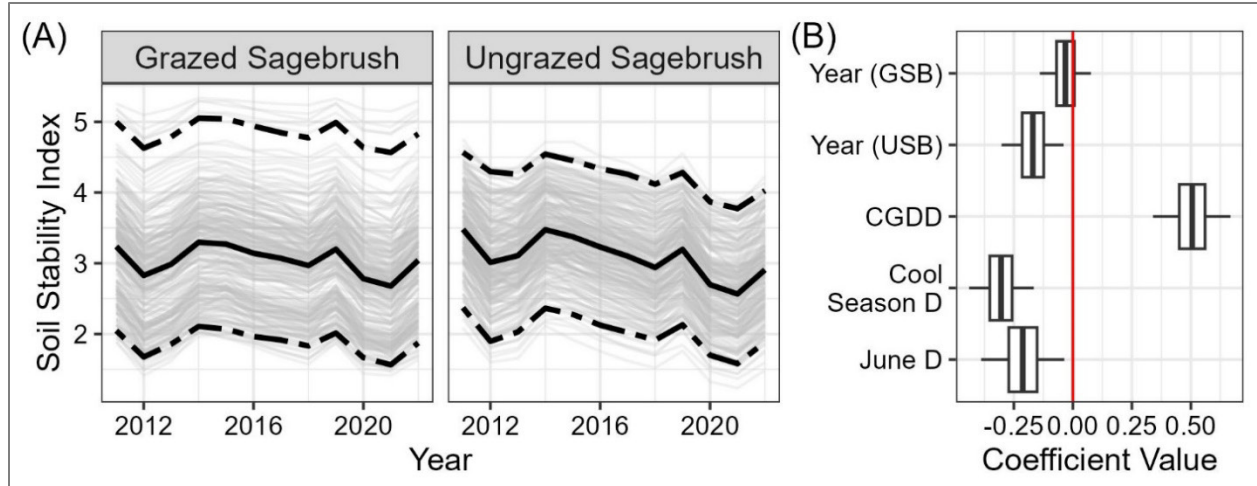


Figure 28. Soil stability status and covariate effects for grazed (GSB) and ungrazed sagebrush (USB). (A) Model-predicted status of soil stability, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for soil stability model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

3.4 Pinyon-Juniper Woodlands Status and Trend

All models presented here passed posterior predictive checks for model convergence and fit (Table 6). A Gelman diagnostic, which evaluates model convergence, with a cutoff of less than 1.12 was used for model testing, but all final pinyon-juniper woodland models had a value of 1.06 or less. Final models were run with a minimum of 20,000 burn-in and 10,000 iterations in the MCMC sampler. Bayesian p-values (B_P) describe the ability of the model to reproduce the observed data, with values close to 0.5 meaning that observed data was well predicted by the model. Bayesian p-values for predicting the observed mean for all but one of the pinyon-juniper models were within 0.1 of 0.5, indicating very good model fit. The total shrub density model had a B_P for the mean of 0.63, indicating that the model slightly overpredicted the mean. Values for B_P for the variance tended to be farther away from 0.5, indicating that it was more difficult for models to reproduce the observed variance.

A model for overstory tree basal area did not achieve convergence and results are not presented.

Most models had fixed slopes, except for overstory tree density, sapling density, and seedling density, which used a hierarchical variance structure (Table 6).

Model-predicted mean total cover in pinyon-juniper woodlands was close to 50% (Table 7, Figure 29). There was no significant trend over time. Total cover varied little from year to year, which is expected in a coniferous tree-dominated woodland. CGDD had a significant negative relationship with total cover, but the water balance variables cool-season and monsoon-season D did not.

Live tree cover and total tree cover were both analyzed; however, results were nearly identical and therefore only live tree cover is reported here. Model-predicted mean live tree cover was around 30% and varied little between years during the monitoring period (Figure 30). There was no significant effect of year. The 2-year lag AET covariate was selected for the top model, reflecting the longer-term water balance dynamics driving tree cover, but did not have a significant directional relationship. CGDD had a significant negative effect on live tree cover.

Table 6. Bayesian model specifications for pinyon-juniper woodlands. All models take the form of a general linear model with a site-level random effect, i.e., intercepts in the model were allowed to vary by site. The likelihood describes the form of the response variable. The deterministic model represents the ecological process being modeled. In addition to having varying site means, the variance of sites could either be fixed or variable, indicated by a hierarchical variance structure. The Gelman diagnostic indicates model convergence and B_p (Bayesian p-value for the model mean and variance) is an evaluation of model fit.

Indicator	Likelihood	Deterministic Model	Variance Structure	Gelman Diagnostic	B_p mean, B_p Variance
Total cover	Beta binomial	Inverse logit	Fixed	1.04	0.51, 0.55
Live tree cover	Beta binomial	Inverse logit	Fixed	1.00	0.5, 0.62
Overstory tree density	Negative binomial simple	Linear	Hierarchical	1.00	0.58, 0.77
Sapling density	Poisson	Linear	Hierarchical	1.02	0.56, 0.41
Seedling density	Negative binomial simple	Exponential	Hierarchical	1.06	0.58, 0.67
Perennial grass cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.01	0.51, 0.63
Total shrub cover	Beta binomial	Inverse logit	Fixed	1.05	0.51, 0.55
Total shrub density	Zero-inflated negative binomial	Exponential	Fixed	1.01	0.63, 0.67
Non-native plant cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.01	0.52, 0.53
Non-native plant frequency	Zero-inflated beta binomial	Inverse logit	Fixed	1.04	0.57, 0.47
Biological soil crust cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.02	0.52, 0.59
Bare ground cover	Beta binomial	Inverse logit	Fixed	1.03	0.5, 0.57
Soil stability	Ordinal latent normal	Linear	Fixed	1.00	0.4, 0.66

Table 7. Status and trend of all indicators for pinyon-juniper woodlands. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; “None” means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Total cover (%)	45 (25, 63)	49 (29, 67)	None	-0.37 (-0.5, 0.02)
Live tree cover (%)	28 (14, 41)	31 (17, 44)	None	-0.04 (-0.18, 0.38)
Overstory tree density (trees/ha)	303 (105, 568)	310 (113, 576)	None	0.15 (-0.23, 1.29)
Sapling density (trees/ha)	291 (0, 895)	341 (0, 950)	None	0.43 (-0.99, 4.9)
Seedling density (trees/ha)	292 (46, 683)	375 (62, 871)	None	3.6 (0.4, 17)
Perennial grass cover (%)	3.2 (0, 14)	6.7 (0, 27)	Decreasing	-0.24 (-0.38, 0)
Total shrub cover (%)	8 (0.3, 28)	9.3 (0.4, 33)	None	-0.1 (-0.2, 0.1)
Total shrub density (shrubs/ha)	368 (3, 1409)	417 (3, 1561)	None	-3.2 (-5.1, 14.9)
Non-native plant cover (%)	1.2 (0, 12)	2.7 (0, 23)	None	-0.01 (0, 0.27)
Non-native plant frequency	0.18 (0, 0.99)	0.26 (0, 0.99)	Decreasing	-0.01 (-0.01, 0)
Biological soil crust cover (%)	1.4 (0, 5)	2.6 (0, 9)	None	-0.06 (-0.08, 0.03)
Bare ground cover (%)	14 (3.1, 26)	16 (3.9, 31)	None	0.07 (-0.01, 0.35)
Soil stability	2.6 (1.6, 3.7)	3.5 (2.5, 4.6)	None	-0.02 (-0.02, 0.01)

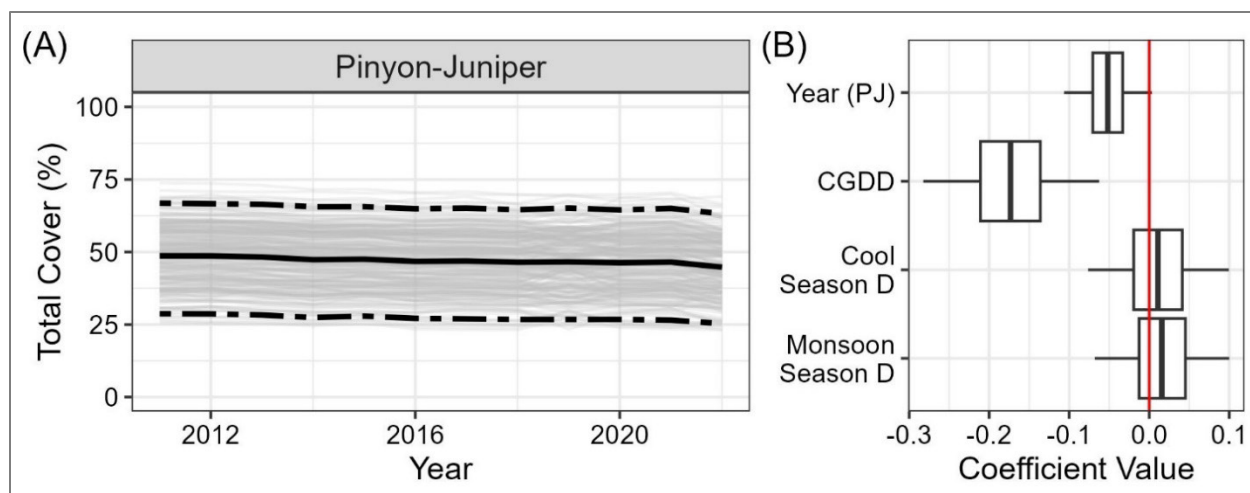


Figure 29. Total cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of total cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

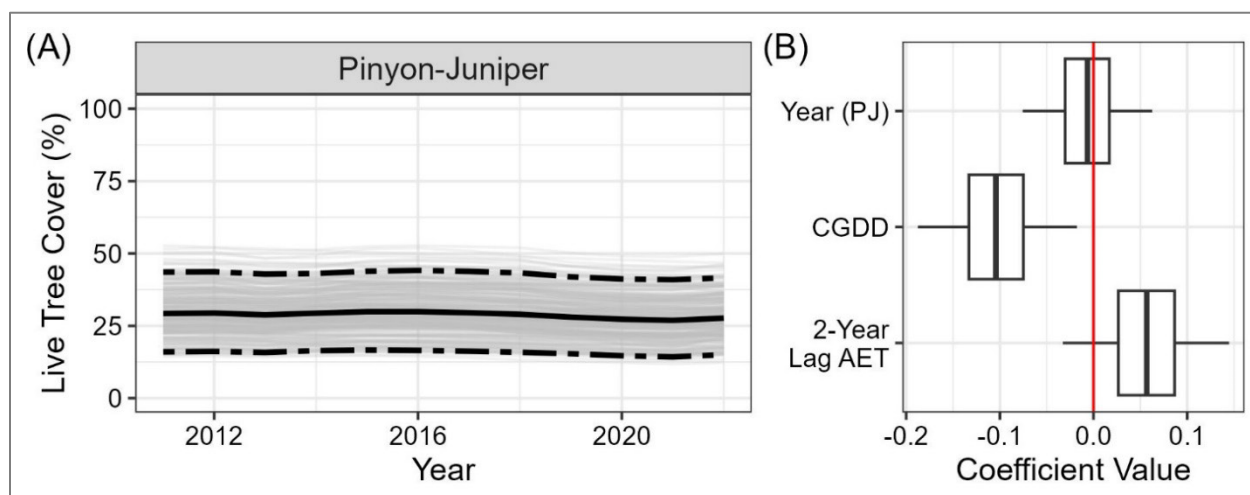


Figure 30. Live tree cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of live tree cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for live tree cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPPERGER

Overstory trees included almost entirely two-needle pinyon and Utah juniper in pinyon-juniper woodlands. Tree density of these species had a model-predicted mean of 303 to 310 trees/ha during the monitoring period, with the credible interval ranging from 105 to 576 trees/ha (Table 7). Because pinyon and juniper have complex branching structures, multiple stems on the same individual may be counted as “trees”, which should be considered when interpreting density values for overstory trees. Overstory tree density varied little during the monitoring period, and variation would usually be attributed to trees dying or smaller trees growing into the overstory tree size class (>15 cm DRC) (Figure 31). There was no significant effect of year or 2-year lag P, but higher CGDD was positively correlated with greater tree density.

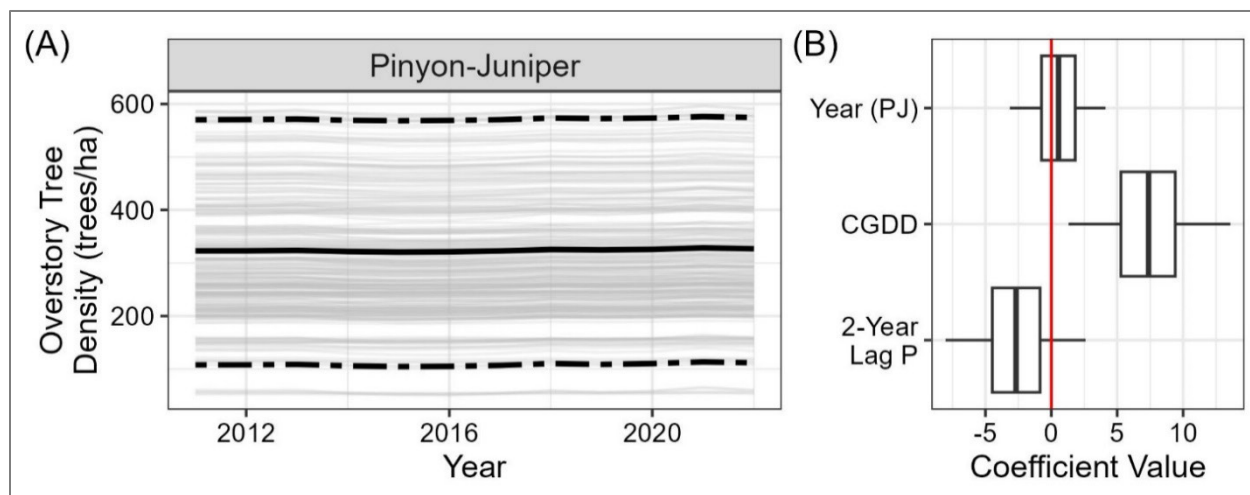


Figure 31. Overstory tree density status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of overstory tree density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for overstory tree density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIRGER

Similarly to overstory trees, saplings measured were primarily two-needle pinyon pine and Utah juniper. Density of saplings had a model-predicted mean between 291 to 341 trees/ha, with a wide credible interval ranging from 0 to 950 trees/ha (Table 7). There was no significant trend over time, and none of the water balance covariates in the final model had significant relationships with sapling density (Figure 32).

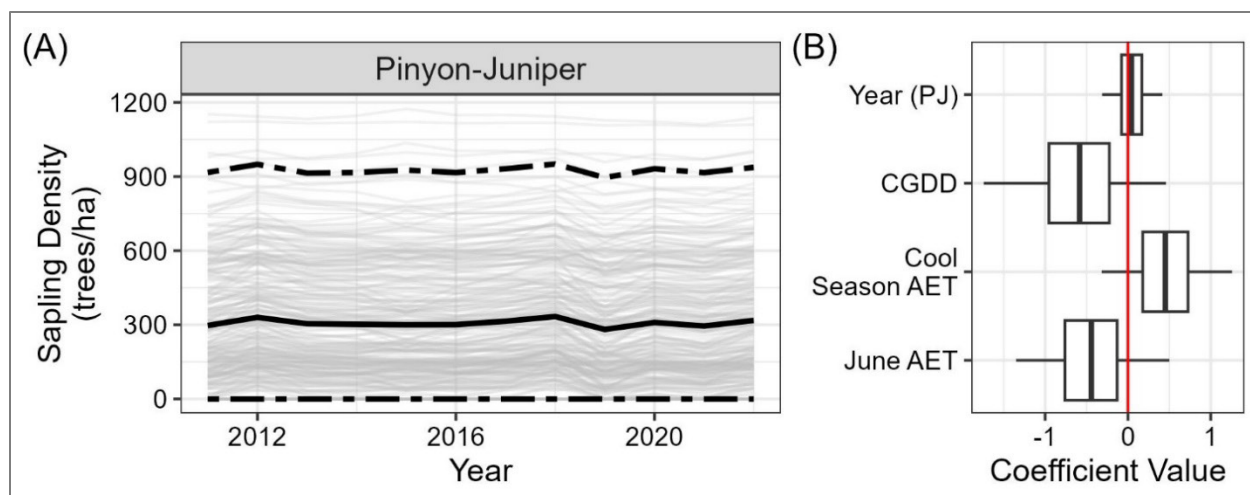


Figure 32. Sapling density status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of sapling density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for sapling density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPIRGER

Model-predicted mean of pinyon-juniper seedling density was between 292 and 375 trees/ha, with a wide credible interval ranging from 46 to 871 trees/ha (Table 7). Density increased slightly at the end of the monitoring period in 2022 (Figure 33). Seedling density was more variable between years than sapling or tree density. There was no significant trend over time or significant relationships with water balance covariates.

Perennial grass cover in pinyon-juniper woodlands was low, particularly compared to perennial grass cover in sagebrush shrublands. Model-predicted mean perennial grass cover was between 3.2 and 6.7% during the monitoring period (Table 7). As in grazed sagebrush shrublands, there was a significant negative effect of year, indicating a negative trend over time (Figure 34), at the annual average rate of -0.24%. There was also a significant negative relationship with CGDD.

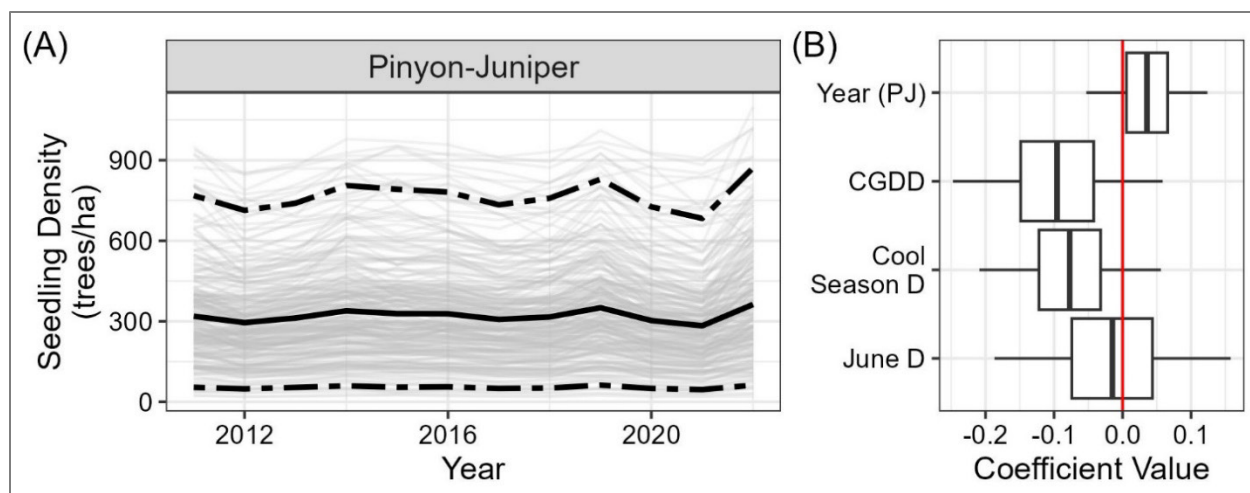


Figure 33. Seedling density status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of seedling density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for seedling density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIRGER

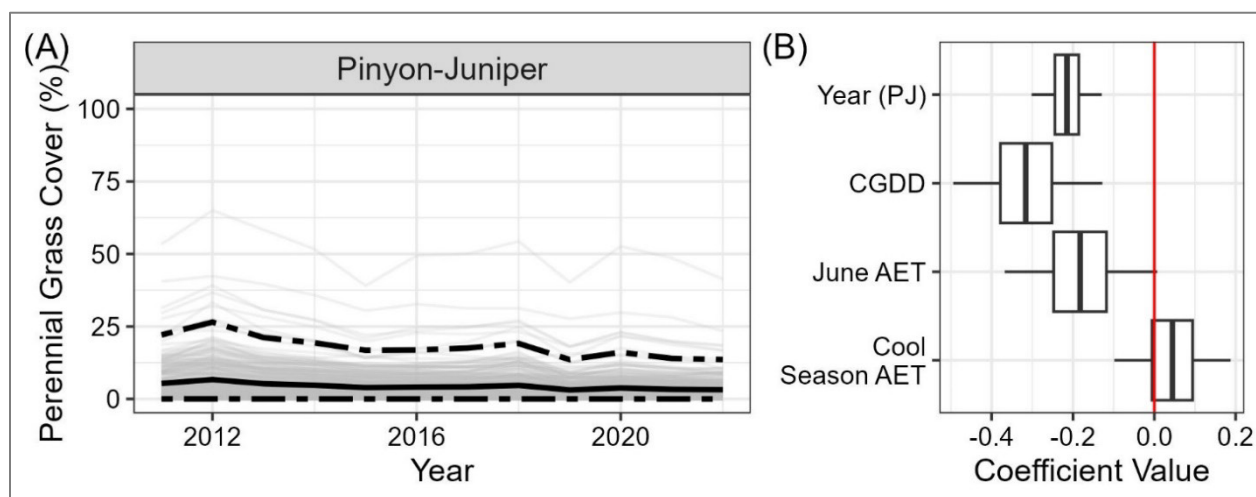


Figure 34. Perennial grass cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of perennial grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for perennial grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPIRGER

Total shrub cover in pinyon-juniper woodlands included the common understory shrubs Gambel oak, Utah serviceberry, and alder-leaf mountain mahogany. Total mean shrub cover varied little over the monitoring period, from 8% to 9.3%, and there was no significant trend over time (Table 7, Figure 35). A 2-year lag deficit covariate was informative in the final model but did not have a directional effect on the response. This indicates that shrubs in pinyon-juniper woodlands are responding to water balance over longer time periods, however.

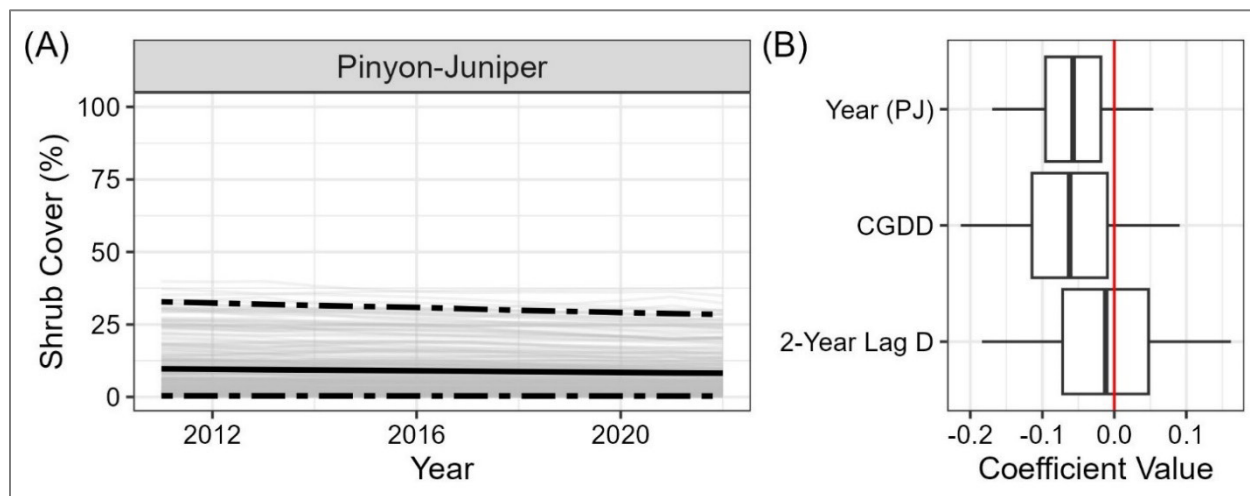


Figure 35. Total shrub cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of total shrub cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total shrub cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPEGER

Shrub density also responded to longer-term water balance conditions, with 2-year lag P chosen for the final model. Although shrub density was slightly lower at the end of the monitoring period, there was not a significant decrease (Figure 36). Light gray lines in Figure 36 (individual draws from the posterior distribution of the mean) showed greater variation among years; this is likely due to recruitment events in individual years that did not impact the overall trend.

Cover of non-native plants, which was primarily annual forbs and cheatgrass (*B. tectorum*), was variable among years in pinyon-juniper woodlands (Figure 37). The model-predicted mean cover during the monitoring period ranged from 1.2% to 2.7%, but credible intervals were as high as 23% (Table 7). CGDD had a strong negative relationship with non-native plant cover, meaning that cover increased with cooler spring weather. Cool-season D did not have a significant effect.

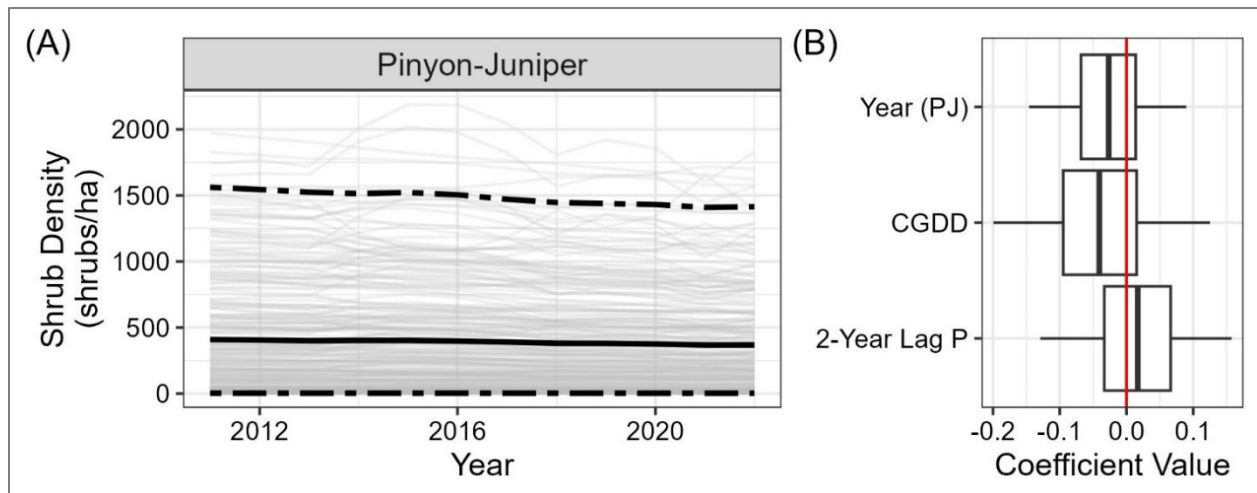


Figure 36. Shrub density status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of shrub density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for shrub density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIERGER

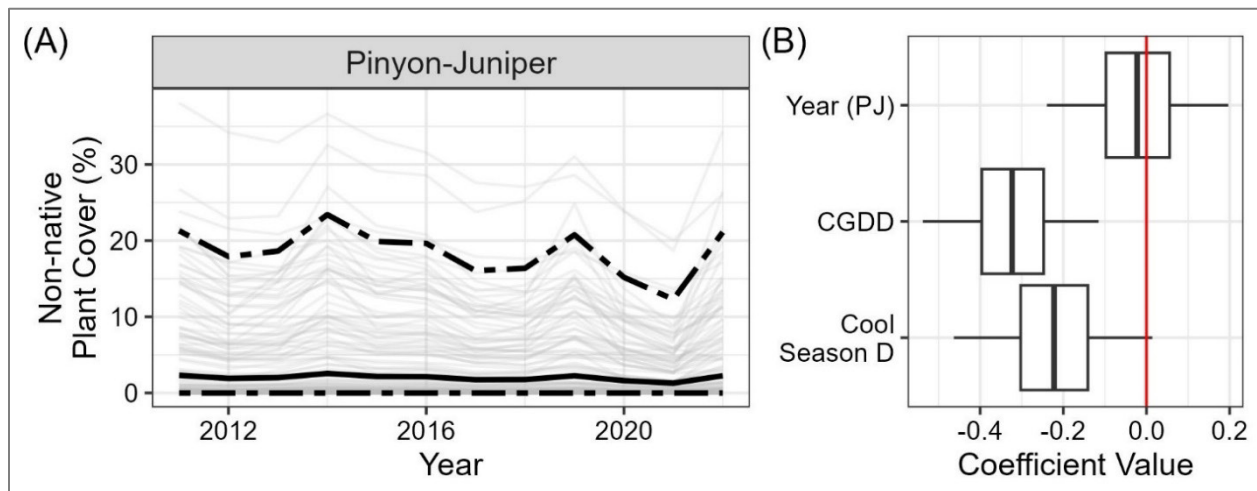


Figure 37. Non-native plant cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of non-native plant cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIERGER

Non-native plant frequency differs from cover in that it is more sensitive to change but a less precise measure. In pinyon-juniper woodlands, non-native plant cover had no trend over time, but non-native plant frequency showed a significant decline (Figure 38). Model-predicted mean frequency was between 0.18 and 0.26 but had credible intervals spanning the entire range of values from 0 to 0.99 (Table 7). There was no significant relationship with either CGDD or June P, although these informed the final model.

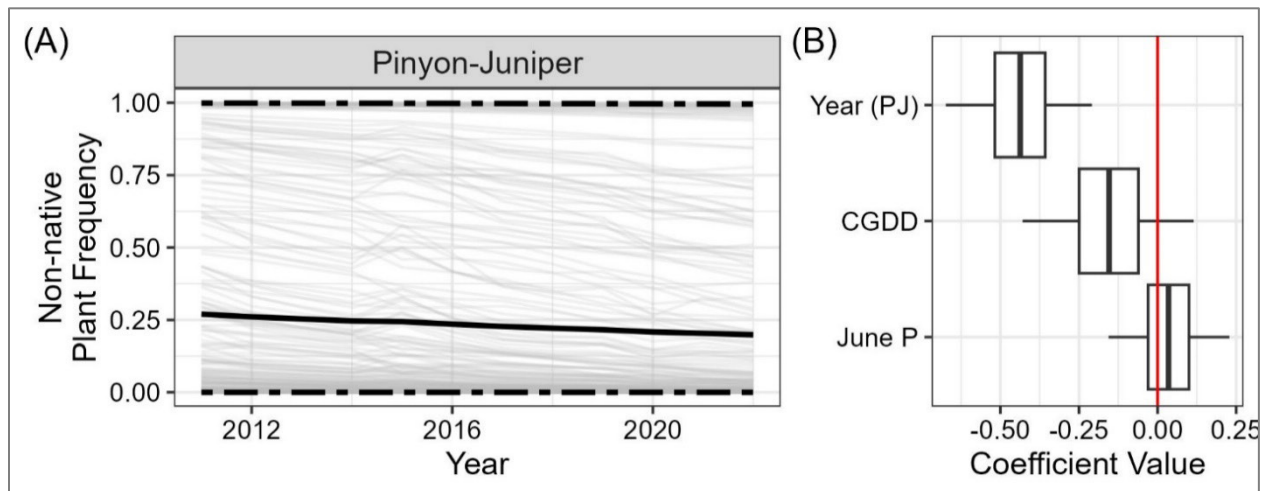


Figure 38. Non-native plant frequency status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of non-native plant frequency, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant frequency model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation.
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Like sagebrush shrublands, biological soil crust cover was low and had a narrow credible interval in pinyon-juniper woodlands, with a model-predicted mean ranging from 1.4% to 2.6% over the monitoring period (Figure 39, Table 7). There was a little variation among years, but no significant relationship with either year or water balance covariates (Figure 39). CGDD, June P, and monsoon-season P were informative in the final model.

Model-predicted bare ground cover had a mean of 14% to 16% during the monitoring period (Table 7). Bare ground includes undifferentiated crust as well as loose soil. There was no significant effect of year (Figure 40). Bare ground cover was the only model where CGDD did not help predict the response and was removed from the model. Cool-season D was informative in the final model but did not have a significant effect.

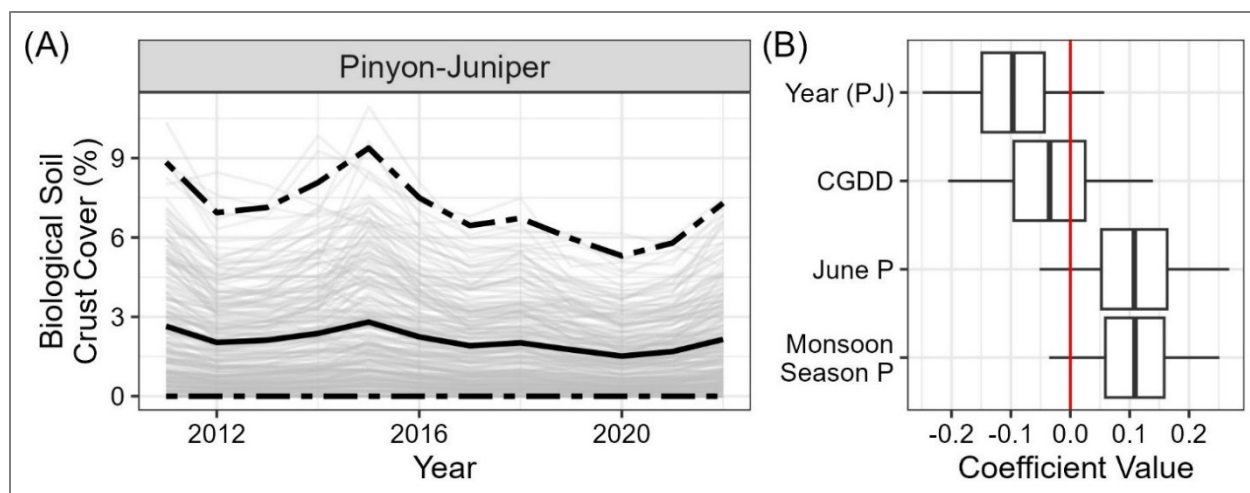


Figure 39. Biological soil crust cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of biological soil crust cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total biological soil crust cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation.
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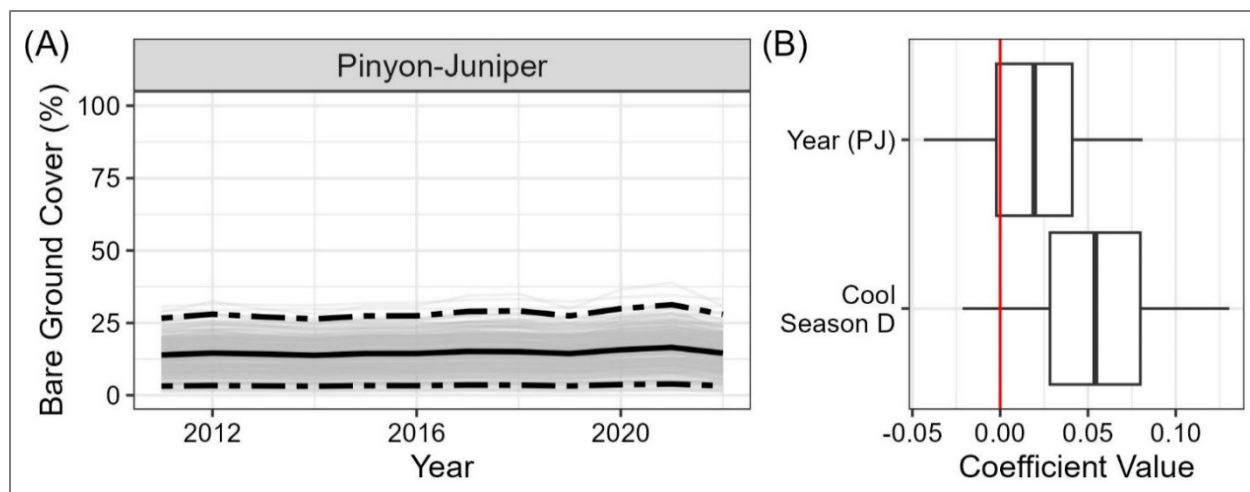


Figure 40. Bare ground cover status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of bare ground cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for bare ground cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). D is water deficit.
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Model-predicted soil stability was variable among years and had a relatively wide range with a predicted minimum and maximum from 1.6 to 4.6, where the scale is 1 to 6 (Table 7). The range may be wide in part due to the categorical nature of these data. There was no significant trend over time for soil stability (Figure 41). However, there was a significant positive effect of CGDD, and significant negative effects of cool-season D and June D.

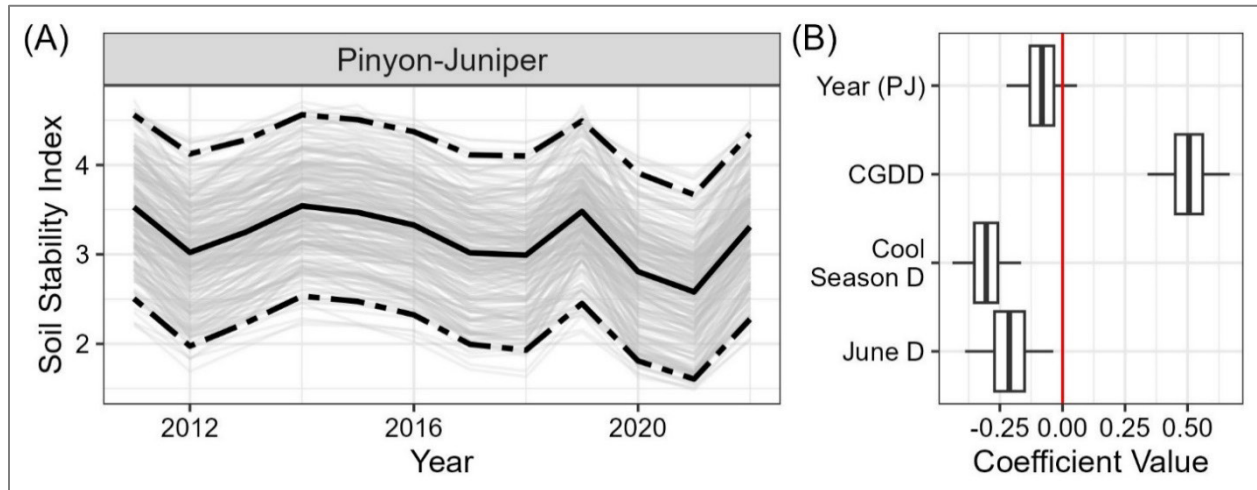


Figure 41. Soil stability status and covariate effects for pinyon-juniper woodlands. (A) Model-predicted status of soil stability, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for soil stability model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIERGER

3.5 Aspen Forest Status and Trend

All models presented here passed posterior predictive checks for model convergence and fit (Table 8). A Gelman diagnostic, which evaluates model convergence, with a cutoff of less than 1.12 was used for model testing but all final aspen forest models had a value of 1.09 or less. Final models were run with a minimum of 20,000 burn-in and 10,000 iterations in the MCMC sampler. Bayesian p-values (B_P) describe the ability of the model to reproduce the observed data, with values close to 0.5 meaning that observed data was well predicted by the model. Bayesian p-values for predicting the observed mean for all aspen forest models were within 0.1 of 0.5, indicating good model fit. Values for B_P for the variance tended to be farther away from 0.5, indicating that it was more difficult for models to reproduce the observed variance.

Most models had fixed slopes, except for overstory tree density, sapling density, and seedling density, which used a hierarchical variance structure (Table 8).

Table 8. Bayesian model specifications for aspen forests. All models take the form of a general linear model with a site-level random effect, i.e., intercepts in the model were allowed to vary by site. The likelihood describes the form of the response variable. The deterministic model represents the ecological process being modeled. In addition to having varying site means, the variance of sites could either be fixed or variable, indicated by a hierarchical variance structure. The Gelman diagnostic indicates model convergence and B_P (Bayesian p-value for the model mean and variance) is an evaluation of model fit.

Indicator	Likelihood	Deterministic Model	Variance Structure	Gelman Diagnostic	B_P mean, B_P Variance
Overstory tree density	Negative binomial simple	Linear	Hierarchical	1.00	0.58, 0.77
Sapling density	Poisson	Linear	Hierarchical	1.02	0.56, 0.41
Seedling density	Negative binomial simple	Exponential	Hierarchical	1.06	0.58, 0.67
Canopy closure	Zero-inflated beta binomial	Inverse logit	Fixed	1.09	0.5, 0.53
Total cover	Beta binomial	Inverse logit	Fixed	1.04	0.51, 0.55
Total shrub cover	Beta binomial	Inverse logit	Fixed	1.05	0.51, 0.55
Native perennial grass cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.08	0.5, 0.54
Forb cover	Beta binomial	Inverse logit	Fixed	1.04	0.51, 0.53
Non-native plant cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.01	0.52, 0.53
Non-native plant frequency	Zero-inflated beta binomial	Inverse logit	Fixed	1.04	0.57, 0.47
Bare ground cover	Beta binomial	Inverse logit	Fixed	1.03	0.5, 0.57

Line-point intercept methods for forests exclude tree measurements above 2 meters. Therefore, tree cover was not modeled in aspen forests since cover of the tall aspen trees would appear artificially low. Canopy closure, overstory tree density, sapling density, and seedling density indicate conditions for aspen trees.

There are only four aspen forest plots at Curecanti NRA. While the small sample size did not preclude successful models for most indicators, some were modeled in combination with pinyon-juniper and/or sagebrush shrublands. The hierarchical approach takes advantage of the larger sample size while still allowing for inference to aspen forests. Models that were run in combination with pinyon-juniper woodlands were total cover, total shrub cover, non-native plant cover, bare ground cover, overstory tree density, seedling density, and sapling density. The exotic frequency model was run in combination with pinyon-juniper woodlands and sagebrush shrublands.

Model-predicted mean overstory tree density of aspens decreased from 305 to 225 trees/ha over the monitoring period, and the effect of year was significant (Table 9). Modeled density included only live trees, so density decreased when trees died or fell down and were not replaced by saplings growing into the larger size class. CGDD had a significant positive effect on overstory tree density, and 2-year lag P was included in the model but did not have a significant directional effect (Figure 42).

Saplings were primarily aspen (*P. tremuloides*), although a few individuals of Rocky Mountain juniper (*J. scopulorum*) were detected. Model-predicted mean sapling density decreased from 460 trees/ha in 2012 to 289 trees/ha at the end of the monitoring period in 2022, a rate of -16 trees/year (Table 9). The negative effect of year shows that there was a significant trend over time (Figure 43). Cool-season and June AET were informative in the final model but did not have significant effects.

Table 9. Status and trend of all indicators for aspen forests. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; 'None' means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Overstory tree density (trees/ha)	225 (21, 420)	305 (102, 507)	Decreasing	-7.6 (-9.8, -0.4)
Sapling density (trees/ha)	289 (0, 589)	460 (135, 758)	Decreasing	-16 (-21, -1)
Seedling density (trees/ha)	296 (176, 462)	514 (278, 893)	None	-16 (-24, 8)
Canopy closure (%)	38 (27, 49)	58 (45, 68)	Decreasing	-1.6 (-2, -0.1)
Total cover (%)	86 (67, 95)	88 (70, 96)	None	-0.16 (-0.3, 0.38)
Total shrub cover (%)	32 (9.7, 67.6)	40 (14.7, 75.7)	None	0.7 (0.4, 1.8)
Native perennial grass cover (%)	36 (19, 58)	46 (26, 68)	None	0.47 (0.02, 1.77)
Forb cover (%)	31 (12, 54)	41 (20, 65)	None	-0.85 (-1.2, 0.2)
Non-native plant cover (%)	20 (0.7, 45)	29 (1.2, 60)	None	-0.51 (-0.87, 0.25)
Non-native plant frequency	0.7 (0.04, 0.98)	0.73 (0.06, 0.99)	None	-0.003 (-0.01, 0.003)
Bare ground cover (%)	2 (0.3, 4.1)	3.5 (0.6, 6.9)	None	0.14 (0.06, 0.38)

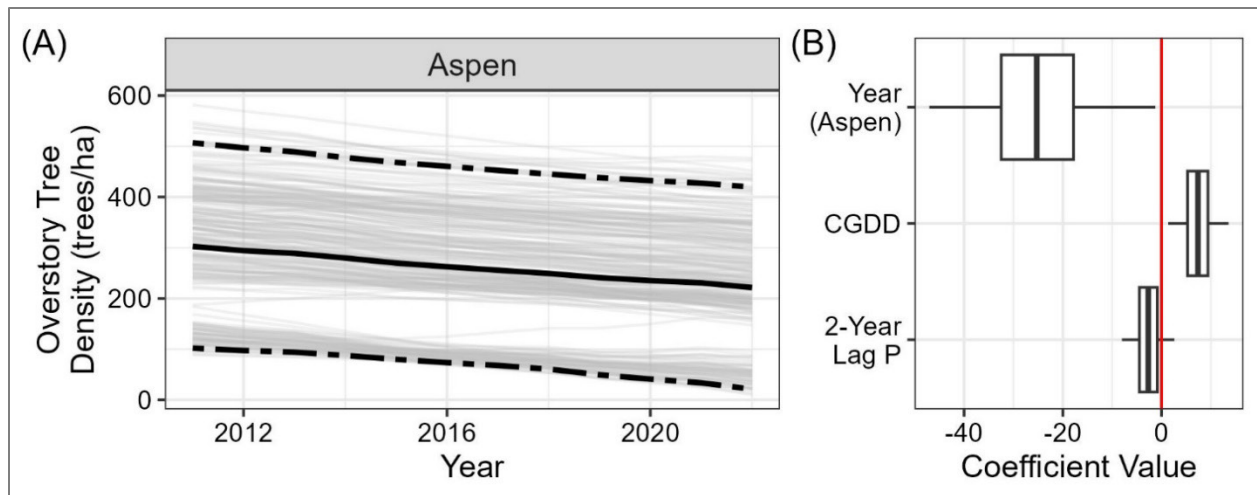


Figure 42. Overstory tree density status and covariate effects for aspen forests. (A) Model-predicted status of overstory tree density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for overstory tree density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIRGER

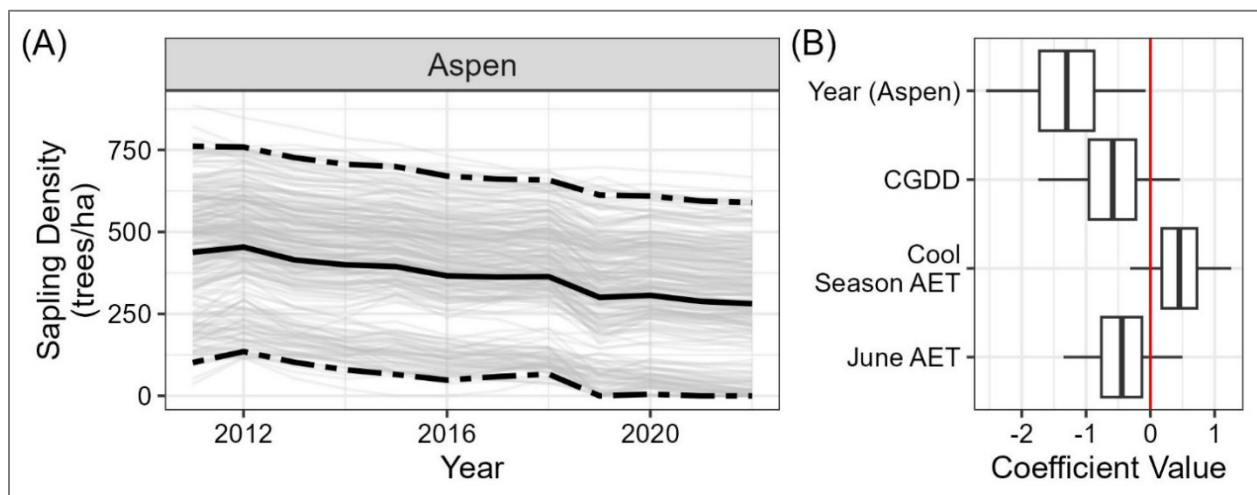


Figure 43. Sapling density status and covariate effects for aspen forests. (A) Model-predicted status of sapling density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for sapling density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPIRGER

Seedling density was similar in magnitude to sapling density in aspen forests, with a model-predicted mean ranging from 296 to 514 trees/ha (Table 9). While seedling density was lower at the end of the monitoring period, the effect of year was not significant (Figure 44). The status plot indicates high variability in seedling density earlier in the monitoring period. Cool-season and June D were informative in the final model but did not have significant effects.

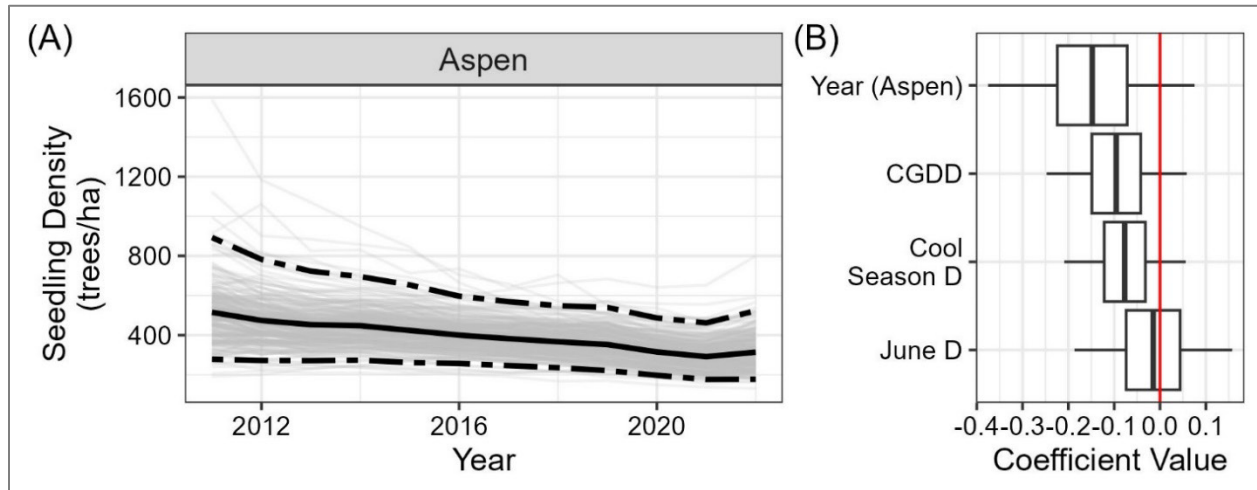


Figure 44. Seedling density status and covariate effects for aspen forests. (A) Model-predicted status of seedling density, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for seedling density model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIERGER

Canopy closure was more variable between years than other indicators in aspen forests (Figure 45). The model-predicted mean was between 38% and 58% during the monitoring period (Table 9). The effect of year was significant, showing a decreasing trend over time at a rate of -1.6%. Cool-season, June, and monsoon-season AET were all included in the final model.

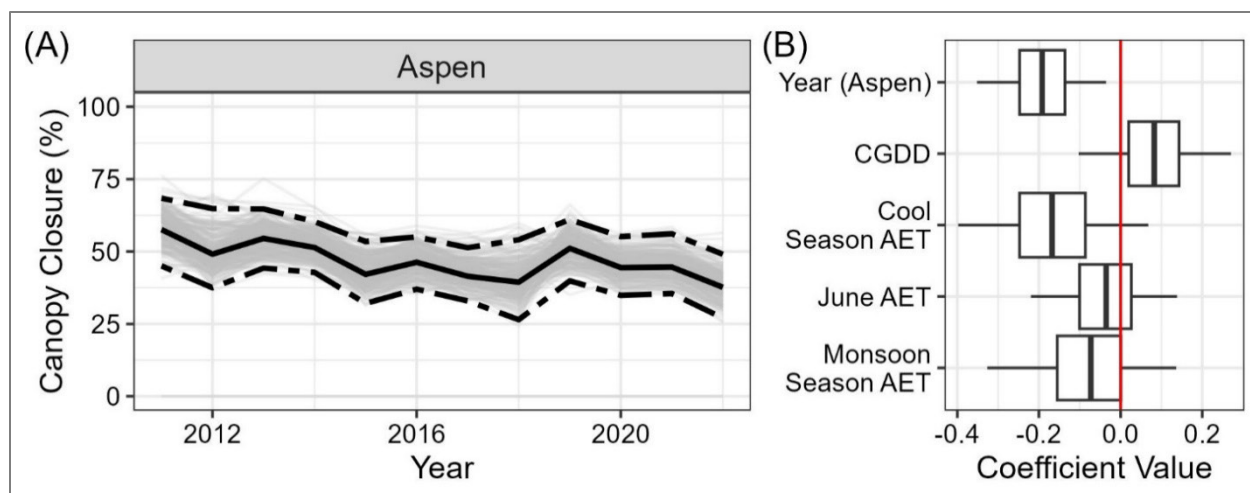


Figure 45. Canopy closure status and covariate effects for aspen forests. (A) Model-predicted status of canopy closure, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for canopy closure model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration. NPS / CAROLYN LIVENSPIERGER

Model-predicted mean total cover was very high in aspen forests, up to 88% (Table 9). Total cover was consistent between years, and there was no significant trend over time (Figure 46). Total cover had a strong negative relationship with CGDD, with cover increasing in years with lower CGDD. Cool- and monsoon-season D were informative in the model but did not have a significant effect.

Model-predicted mean total shrub cover was 32% in 2011 and rose to 40% in 2022, and the average annual rate of change over time was positive (Table 9, Figure 47). However, there was no significant trend over time. Wide credible intervals indicate high variability among the four aspen plots. The 2-year lag D was informative in the final model.

Model-predicted mean native perennial grass cover in aspen forests was between 36% and 46%, with credible intervals ranging from 19% to 68% (Table 9). Native perennial grass cover varied among years in response to June, cool-season, and monsoon-season D, although none of the water balance covariates had a significant relationship (Figure 48). There was no significant trend over time.

Forbs are prominent in the aspen understory, as shown by the relatively high model-predicted mean forb cover, which ranged from 31%–41% during the monitoring period (Table 9). Cover was lower at the end of the monitoring period, but there was no significant effect of year (Figure 49). CGDD had a significant negative relationship with forb cover, indicating that warmer temperatures in early spring resulted in lower forb cover.

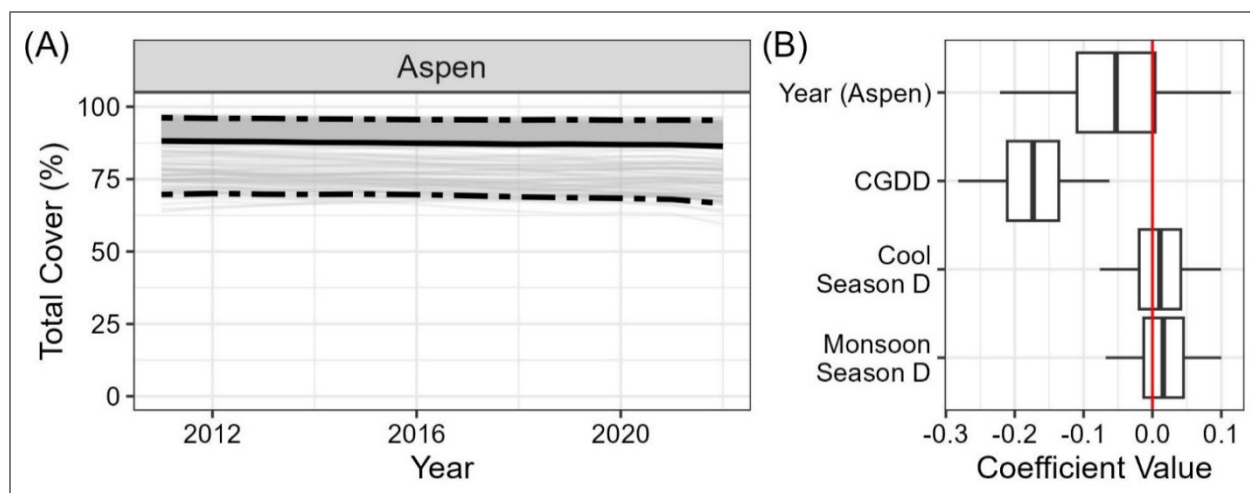


Figure 46. Total cover status and covariate effects for aspen forests. (A) Model-predicted status of total plant cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

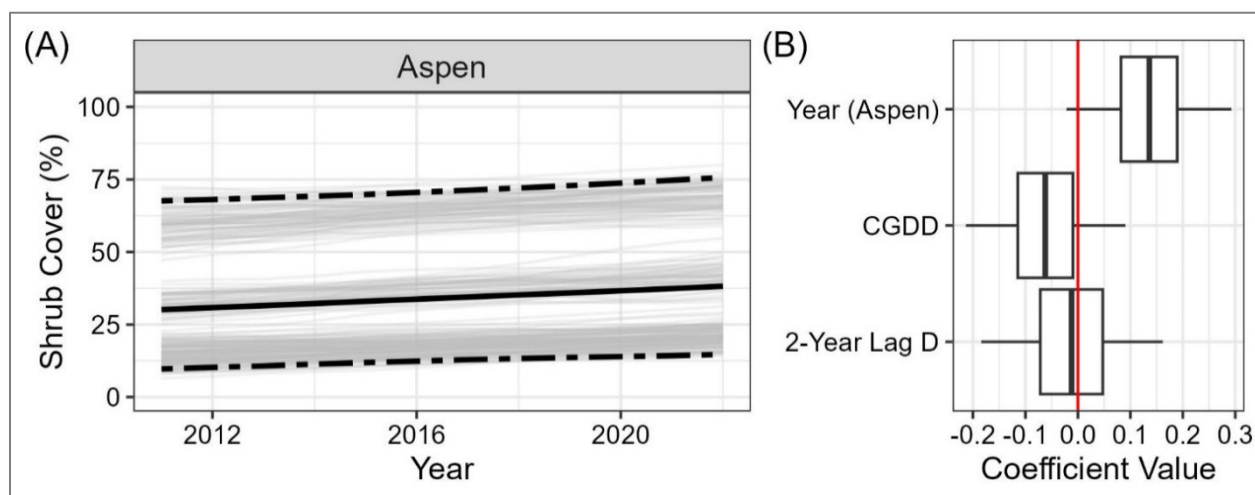


Figure 47. Total shrub cover status and covariate effects for aspen forests. (A) Model-predicted status of total shrub cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total shrub cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

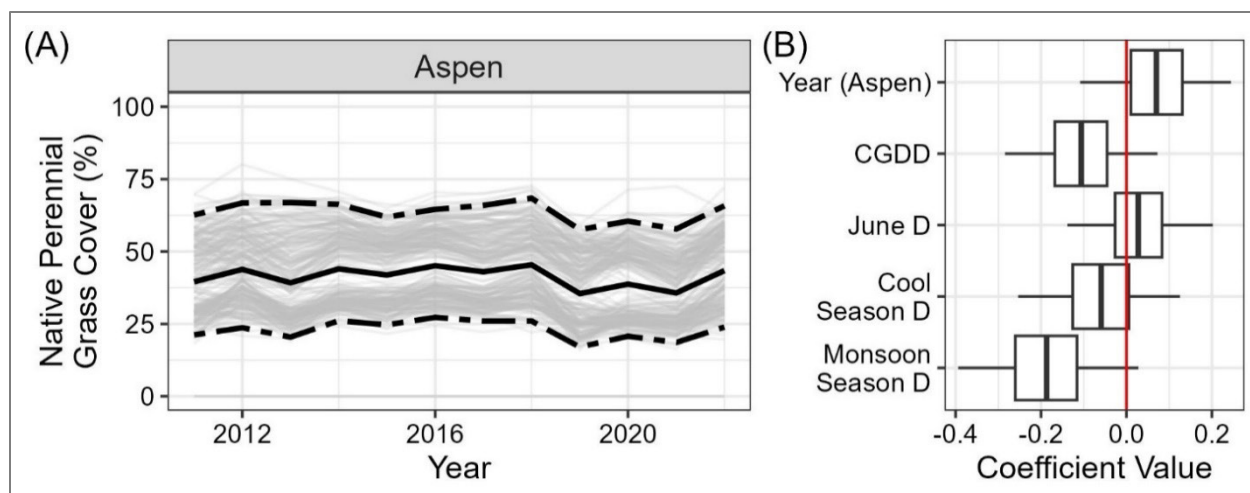


Figure 48. Native perennial grass cover status and covariate effects for aspen forests. (A) Model-predicted status of native perennial grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for native perennial grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

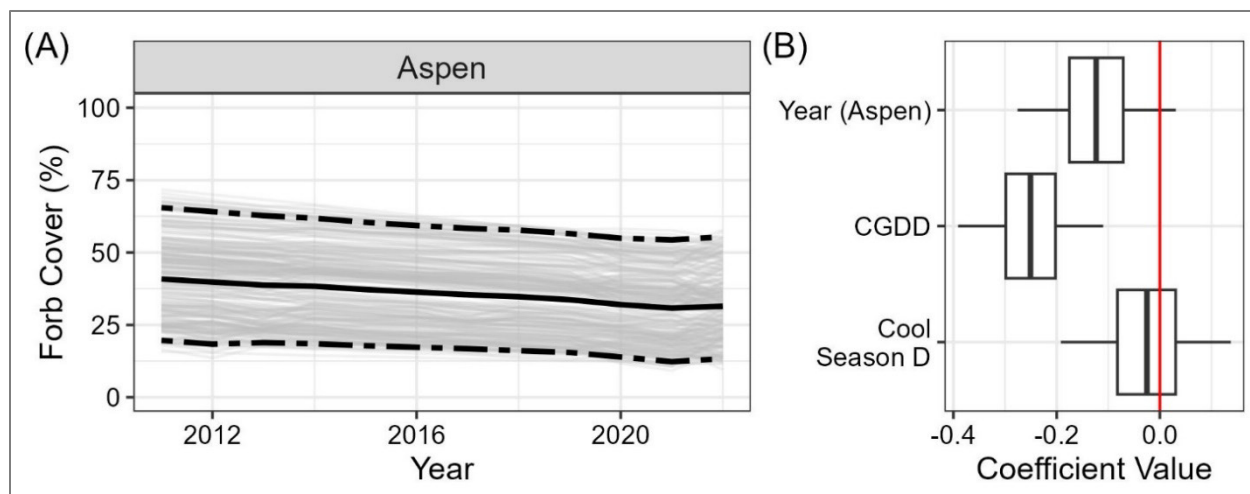


Figure 49. Total forb cover status and covariate effects for aspen forests. (A) Model-predicted status of total forb cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total forb cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

Model-predicted mean non-native plant cover in aspen forests ranged from 20% to 29% but had wide credible intervals ranging from less than 1% to 60% (Table 9, Figure 50). A large proportion of non-native plant cover is contributed by the non-native perennial Kentucky bluegrass (*Poa pratensis*). Non-native plant cover reached its lowest point in 2021. There was no significant trend over time.

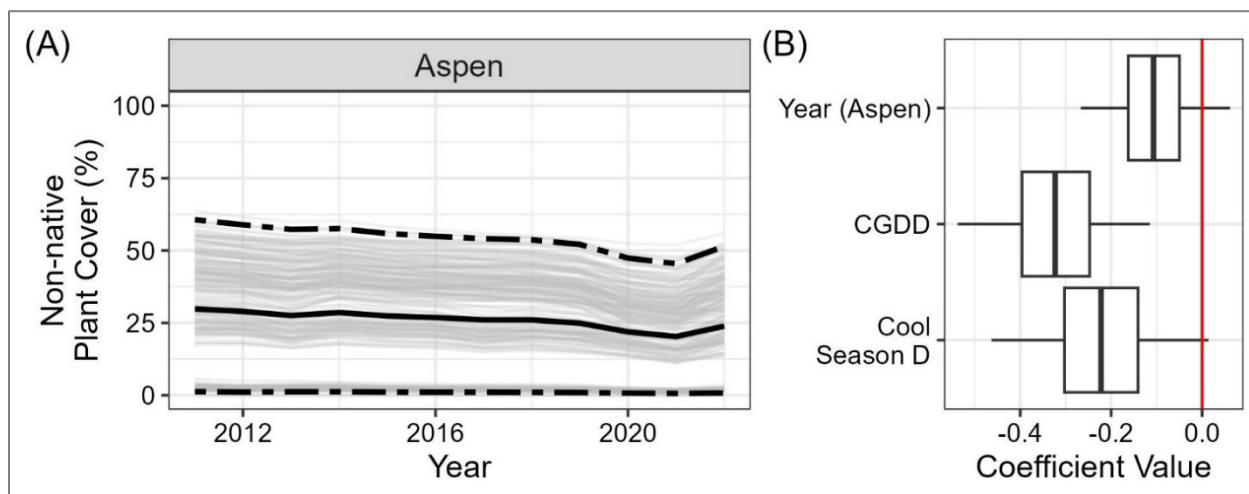


Figure 50. Non-native plant cover status and covariate effects for aspen forests. (A) Model-predicted status of non-native plant cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPPERGER

In aspen forests, frequency of non-native plants had a strongly bimodal distribution, with plots having either very high or very low cover, indicated by the light gray lines in Figure 51. Overall, model-predicted mean non-native plant frequency was high, between 0.7 and 0.73 (Table 9). The effect of year was not significant. CGDD and June P were included in the model but did not have significant relationships with non-native frequency.

Model-predicted bare ground cover in aspen forests was very low, ranging from 2% to 3.5% (Table 9). Cover was slightly greater at the end of the monitoring period, but the effect of year in the model was not significant (Figure 52). Cool-season D was the only climate covariate included in this model, and there was no significant effect.

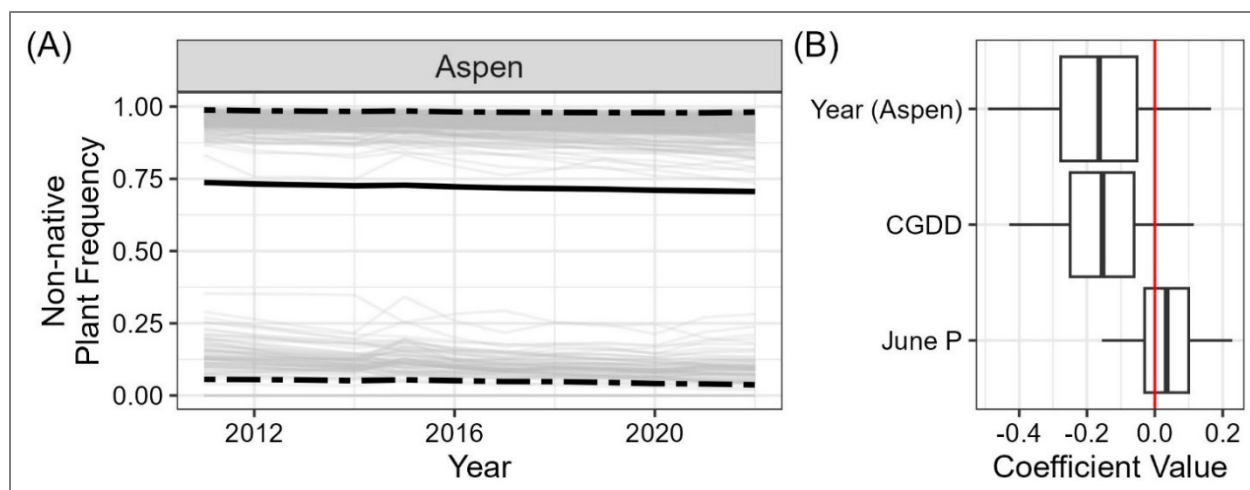


Figure 51. Non-native plant frequency status and covariate effects for aspen forests. (A) Model-predicted status of non-native plant frequency, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant frequency model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days, and P is precipitation. NPS / CAROLYN LIVENSPIRGER

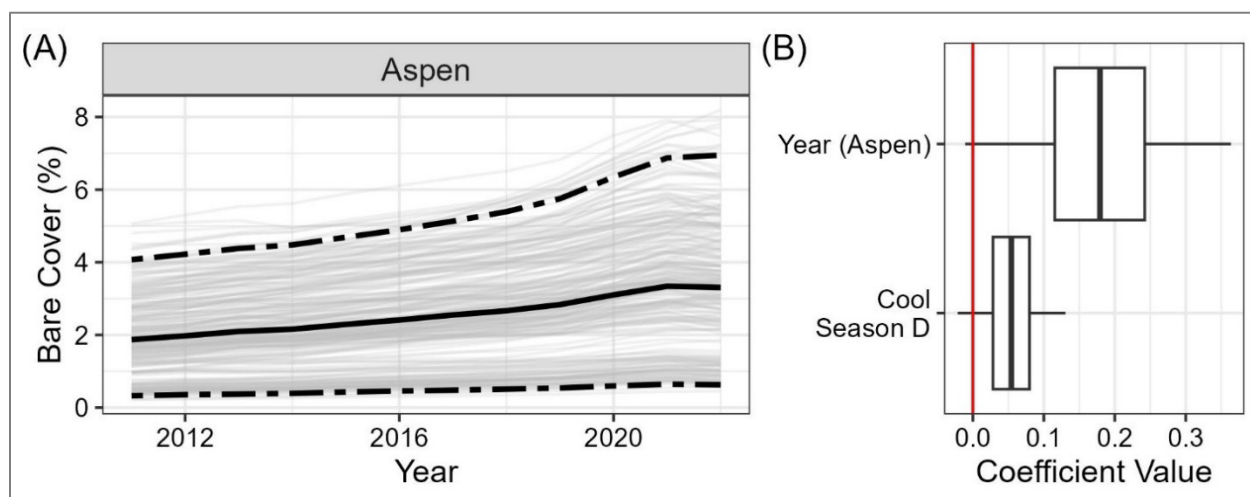


Figure 52. Bare ground cover status and covariate effects for aspen forests. (A) Model-predicted status of bare ground cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for bare ground cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days, and D is water deficit. NPS / CAROLYN LIVENSPIRGER

3.6 Gambel Oak Shrublands Status and Trend

All models presented here passed posterior predictive checks for model convergence and fit (Table 10). A Gelman diagnostic, which evaluates model convergence, with a cutoff of less than 1.12 was used for model testing but all final oak shrubland models had a value of 1.05 or less. Final models were run with a minimum of 20,000 burn-in and 10,000 iterations in the MCMC sampler. Bayesian p-values (B_p) describe the ability of the model to reproduce the observed data, with values close to 0.5 meaning that observed data was well predicted by the model. Bayesian p-values for predicting the observed mean for all oak shrubland models were within 0.1 of 0.5, indicating good model fit. Values for B_p for the variance tended to be farther away from 0.5, indicating that it was more difficult for models to reproduce the observed variance.

All models for Gambel oak shrublands had fixed slopes (Table 10).

Because of the different vegetation composition and structure, Gambel oak shrubland plots are monitored using slightly different methods than the other strata, including shorter transects and different spacing of samples (see Methods). Therefore, oak shrubland indicators were not modeled in combination with any other strata.

Model-predicted mean total cover in Gambel oak shrublands was relatively high, ranging from 72% to 80% during the monitoring period (Table 11). Cover was variable between years and had a positive relationship with cool-season P (Figure 53). The effect of year was nearly positive, but not statistically significant.

Model-predicted mean live Gambel oak cover was 23% to 24%, varying little during the monitoring period (Table 11, Figure 54). The credible intervals were wide, however, ranging from 0% to 67%. This indicates that Gambel oak cover is not homogenous across the sampled area, and some plots may be dominated by other shrubs. There was no effect of year, and no significant relationship with CGDD or monsoon-season P.

Table 10. Bayesian model specifications for Gambel oak shrublands. All models take the form of a general linear model with a site-level random effect, i.e., intercepts in the model were allowed to vary by site. The likelihood describes the form of the response variable. The deterministic model represents the ecological process being modeled. In addition to having varying site means, the variance of sites could either be fixed or variable, indicated by a hierarchical variance structure. The Gelman diagnostic indicates model convergence and B_p (Bayesian p-value for the model mean and variance) is an evaluation of model fit.

Indicator	Likelihood	Deterministic Model	Variance Structure	Gelman Diagnostic	B_p mean, B_p Variance
Total cover	Beta binomial	Inverse logit	Fixed	1.00	0.5, 0.66
Gambel oak cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.01	0.5, 0.68
Shrub cover	Beta binomial	Inverse logit	Fixed	1.00	0.51, 0.62
Tree cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.05	0.54, 0.54
Native perennial grass cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.00	0.5, 0.58
Forb cover	Beta binomial	Inverse logit	Fixed	1.01	0.51, 0.51
Non-native plant cover	Zero-inflated beta binomial	Inverse logit	Fixed	1.02	0.57, 0.61
Non-native plant frequency	Zero-inflated beta binomial	Inverse logit	Fixed	1.00	0.5, 0.58
Bare ground cover	Beta binomial	Inverse logit	Fixed	1.00	0.51, 0.68

Table 11. Status and trend of all indicators for Gambel oak shrublands. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; 'None' means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Total cover (%)	72 (50, 92)	80 (60, 95)	None	0.27 (0.15, 0.65)
Gambel oak cover (%)	23 (0, 66)	24 (0, 67)	None	-0.02 (-0.13, 0.54)
Shrub cover (%)	36 (12, 63)	38 (13, 65)	None	0.3 (0.12, 0.85)

Table 11 (continued). Status and trend of all indicators for Gambel oak shrublands. Ten-year minimum and maximum status are the model-predicted mean values of the indicator with the 95% credible interval for the year with the lowest and highest values. Direction of trend over time indicates whether a significant increase or decrease occurred while holding climate covariates at their mean; 'None' means that no significant trend was detected. A trend is considered significant if the 95% credible interval of the posterior distribution of the time slope coefficient (β_1) does not include zero. Annual average rate of change is the slope of significant trend lines in the same units as the indicator, shown with the 95% credible interval.

Indicator	10-year Minimum Status (95% CI)	10-year Maximum Status (95% CI)	Direction of Trend over Time	Annual Average Rate of Change (95% CI)
Tree cover (%)	1.8 (0, 23)	2.8 (0, 35)	None	0.06 (0, 0.9)
Native perennial grass cover (%)	21 (6, 41)	26 (8, 49)	Decreasing	-0.51 (-0.65, -0.14)
Forb cover (%)	7.2 (1.5, 23)	16 (3.8, 45)	Increasing	0.5 (0.3, 1.3)
Non-native plant cover (%)	0.2 (0, 3.6)	0.4 (0, 5.7)	None	0.003 (0, 0.08)
Non-native plant frequency	0.39 (0, 0.96)	0.48 (0, 0.98)	None	0.14 (-0.07, 1.1)
Bare ground cover (%)	7 (1.1, 21)	8.2 (1.4, 24)	None	0.18 (0.06, 0.61)

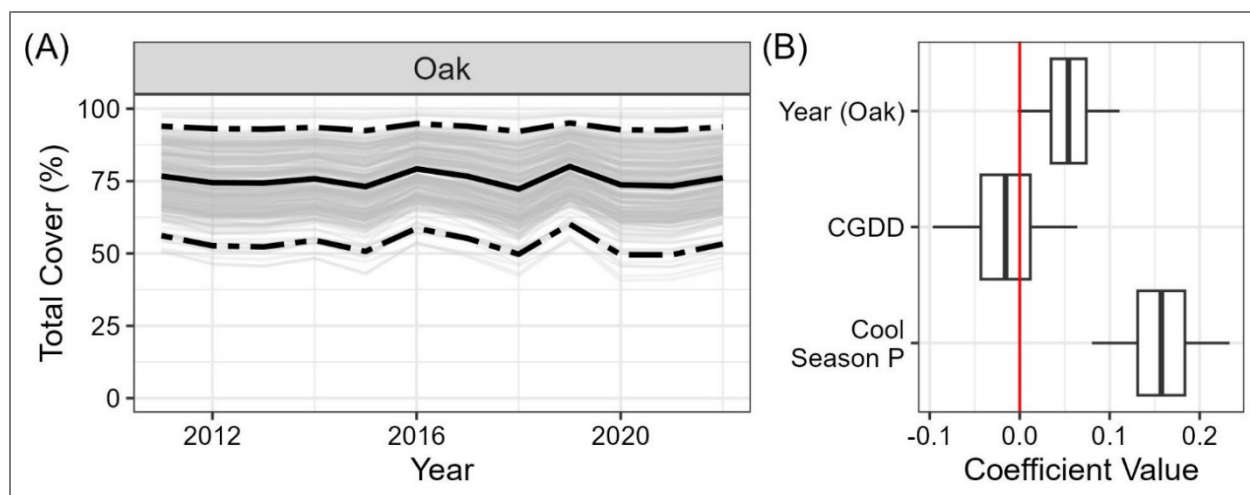


Figure 53. Total plant cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of total cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for total cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIRGER

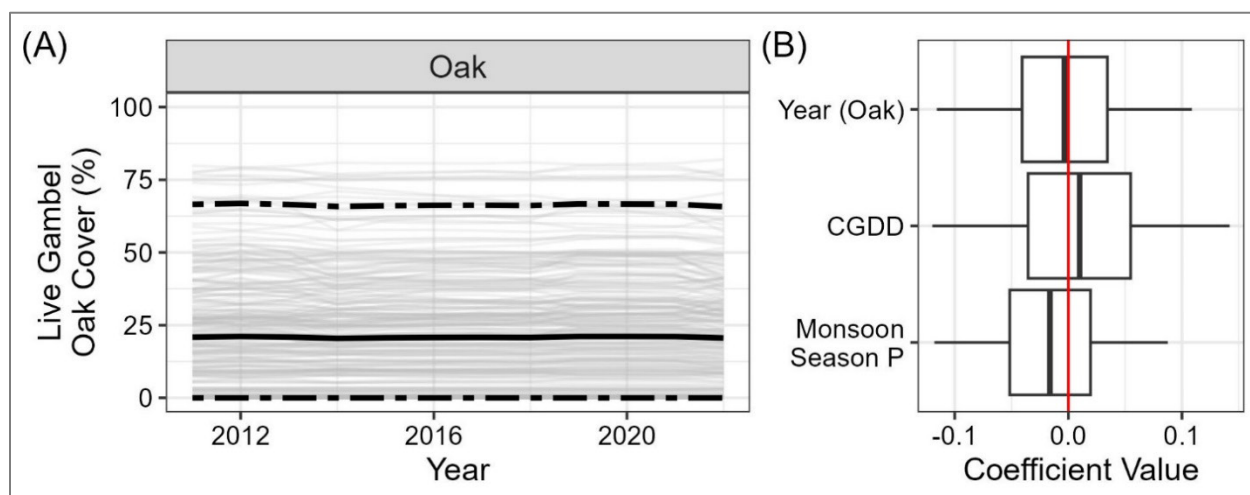


Figure 54. Live Gambel oak cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of live Gambel oak cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for live Gambel oak cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPIRGER

Other large shrubs, including Utah serviceberry, mountain snowberry, and big sagebrush, comprise a significant portion of cover in Gambel oak shrublands. Combined, these other shrubs have greater percent cover than Gambel oak alone, with the model-predicted mean between 36% and 38% (Table 9). Shrub cover was stable between years during the monitoring period (Figure 55). There was no significant effect of year, CGDD, or 2-year lag D.

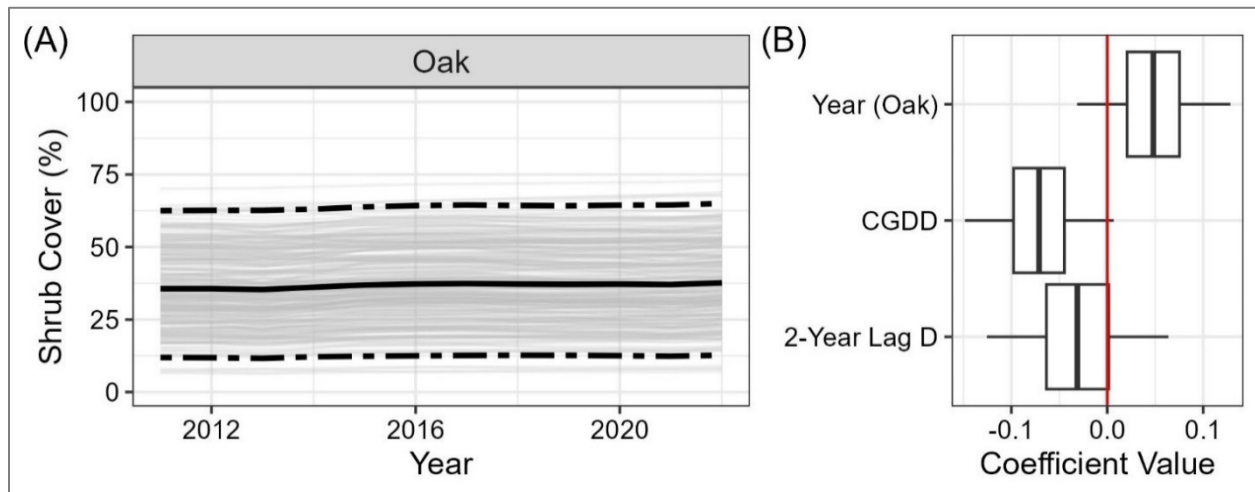


Figure 55. Shrub cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of shrub cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for shrub cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIERGER

Model-predicted mean tree cover, consisting primarily of pinyon pine and Utah juniper trees, was low in Gambel oak shrublands, ranging from 1.8% to 2.8% (Table 11). Tree cover varied little between years, and there was no effect of year (Figure 56). The 2-year lag D was the only additional covariate included in the model, and it did not have a significant effect on the response.

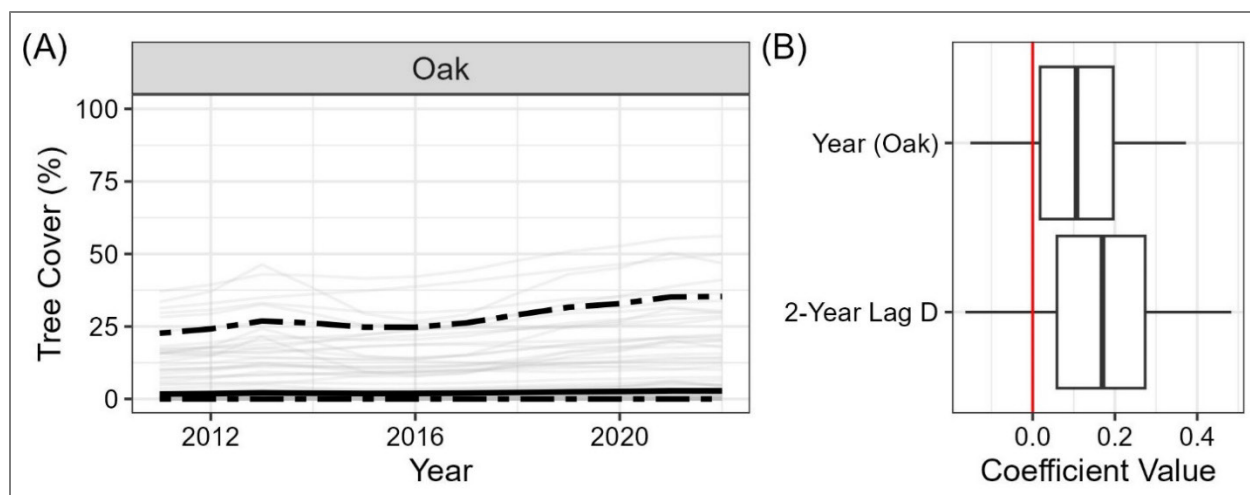


Figure 56. Tree cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of tree cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for tree cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIRGER

Model-predicted mean native perennial grass cover varied little during the monitoring period, but slowly declined from a maximum status of 26% in 2011 to 21% in 2022 (Table 11, Figure 57). The effect of year was significant, indicating a decreasing trend over time at an annual rate of -0.51%. CGDD had a significant negative effect, but June AET did not.

Patterns of yearly forb cover status reflected those of total cover, with peaks in 2016 and 2019 (Figure 58). Model-predicted mean forb cover ranged from 7.2% to 16% (Table 11). There was a significant positive effect of year, indicating that forb cover increased over time. There was also a significant positive effect of cool-season P, which was the same as modeled total cover.

Non-native plant cover was very low in Gambel oak shrublands, with a model-predicted mean of < 1% and the credible intervals ranging from 0% to 5.7% (Table 11). Cover was somewhat variable and was at its greatest in 2019 (Figure 59). There was no significant effect of year, CGDD, or water balance covariates.

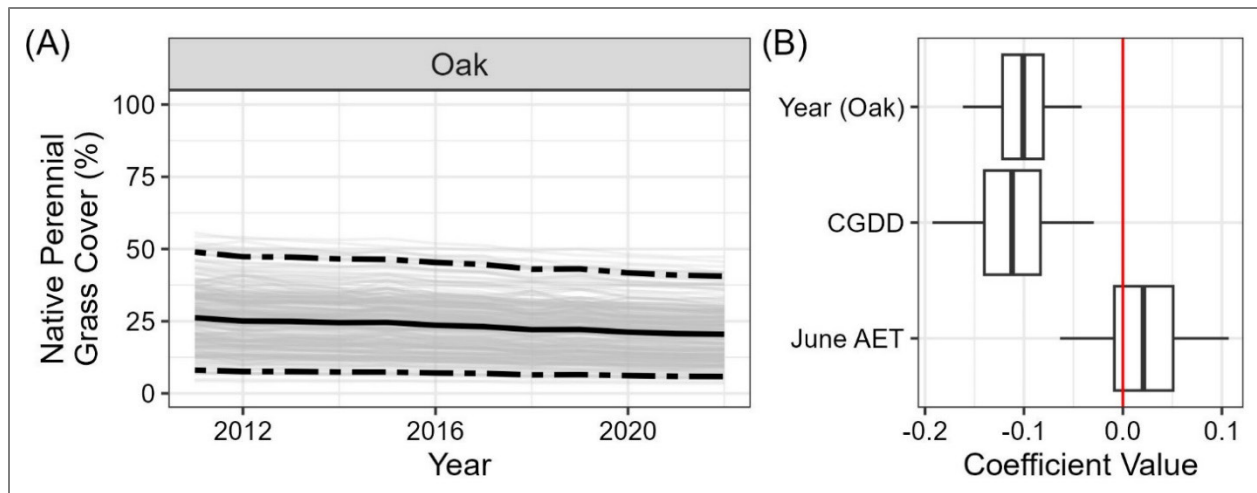


Figure 57. Native perennial grass cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of native perennial grass cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for native perennial grass cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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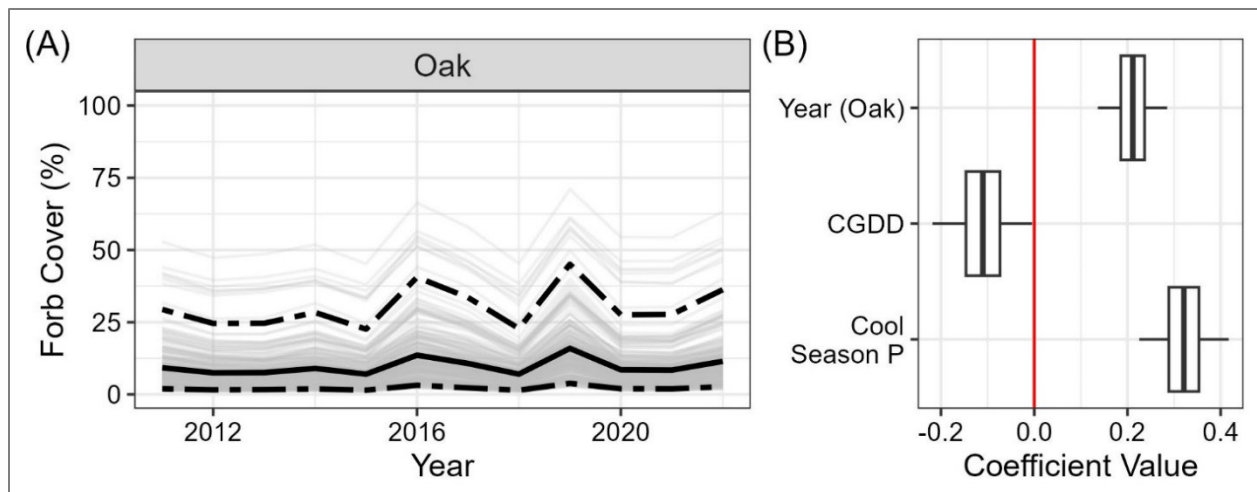


Figure 58. Forb cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of forb cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for forb cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and P is precipitation. NPS / CAROLYN LIVENSPPERGER

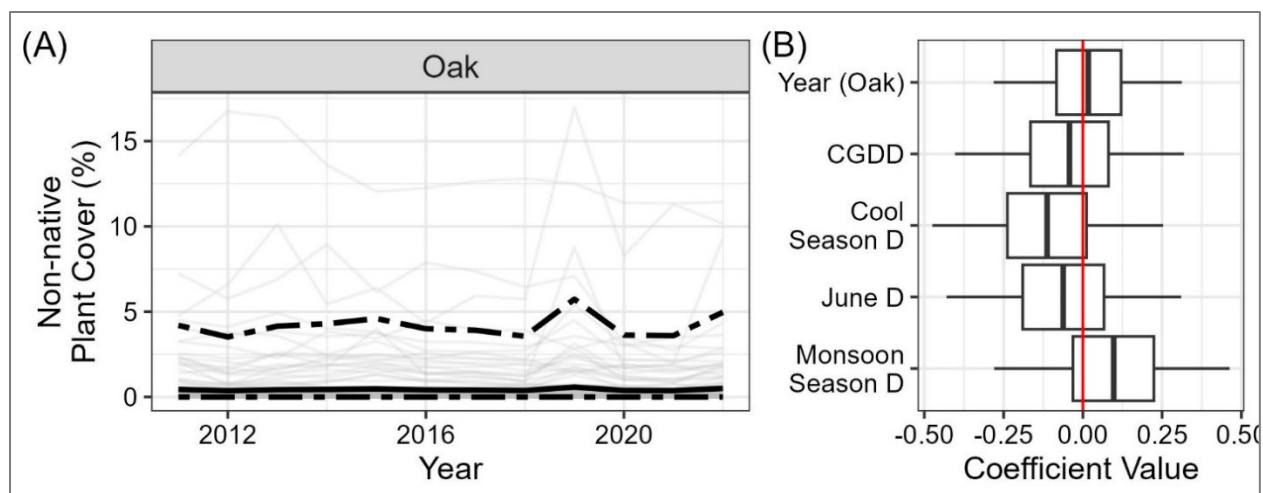


Figure 59. Non-native plant cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of non-native plant cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit. NPS / CAROLYN LIVENSPIRGER

In contrast to non-native plant cover, non-native plant frequency had a much greater model-predicted mean, ranging from 0.39 to 0.48 (Table 11). It also had very wide credible intervals, spanning the range of possible values from 0 to 1. The light gray lines of the posterior distribution in Figure 60 show that non-native plant frequency was distributed across the entire range of values. There was no significant effect of year or cool-season D, but non-native plant frequency did increase with greater CGDD.

Model-predicted mean bare ground cover ranged from 7% to 8.2% during the monitoring period (Table 11). Although it increased slightly over the monitoring period and was at its highest in 2022, there was no significant effect of year, indicating no trend over time (Figure 61). The 2-year lag AET was included in the final model, but there was not a significant relationship with this water balance covariate.

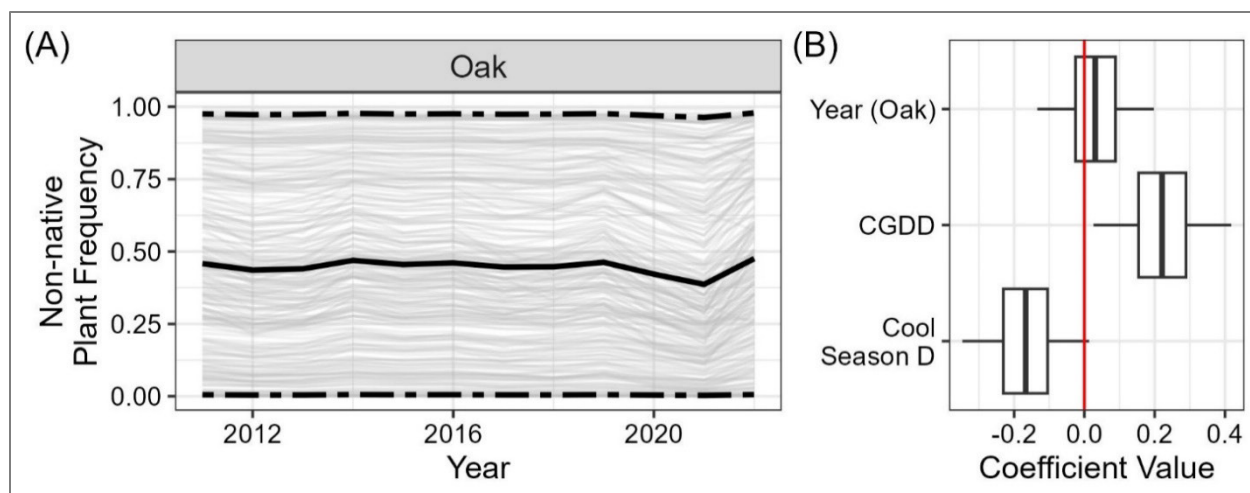


Figure 60. Non-native plant frequency and covariate effects for Gambel oak shrublands. (A) Model-predicted status of non-native plant frequency, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for non-native plant frequency model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and D is water deficit.
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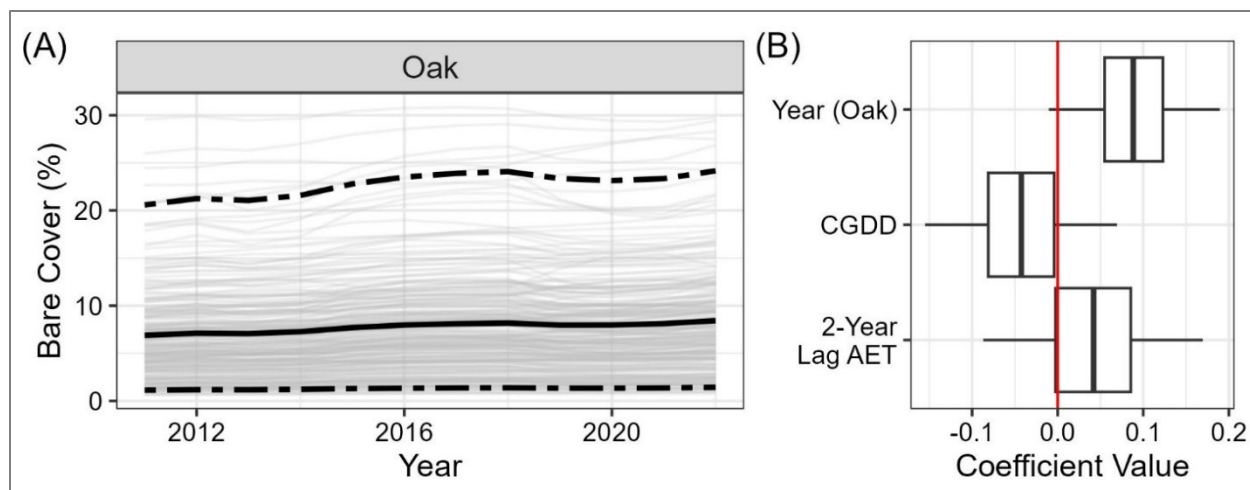


Figure 61. Bare ground cover status and covariate effects for Gambel oak shrublands. (A) Model-predicted status of bare ground cover, where the solid black line is the median, dashed black lines are the upper and lower 95% credible intervals, and gray lines are draws from the posterior distribution of model-predicted means. (B) Standardized coefficient values for bare ground cover model parameters. Boxplots show values for the 2.5% (left end of horizontal line), 25% (left vertical line), 50% (middle vertical line), 75% (right vertical line), and 97.5% (right end of horizontal line) quantiles. Coefficient effects are considered significant if the 95% credible interval does not overlap 0 (vertical red line). CGDD is cumulative growing degree-days and AET is actual evapotranspiration.
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3.7 Climate Covariates

We tested P, D, and AET as predictors for all vegetation and soil indicators analyzed in this report and found that in 27 of 37 models, D or AET were chosen over P as the best fit model using a stepwise model selection process (Table 12). D was selected in 16, AET selected in 11, and P selected in 10 of the final models. D and AET are water balance variables that consider soil properties, slope, and aspect along with temperature and water inputs. CGDD was included in all model sets to help account for differences in timing of sampling. However, the models for bare ground cover in pinyon-juniper woodlands and aspen forests, and tree cover in Gambel oak shrublands, would not converge with CGDD and therefore it was excluded from these models.

No single time period (cool-season, June, or monsoon-season) was strongly favored in the models. However, cool-season summaries were chosen most frequently, occurring 19 times, either with CGDD alone or in combination with other covariates (Table 12). June was the next most frequent time-period summary, occurring 16 times, followed by monsoon-season (10 times) and 2-year lag (9 times). BLCA and CURE are at the edge of the northern boundary for the North American monsoon and do not have a strong monsoonal signal (Miller 2005).

Table 12. Summary of climate covariates. An ‘X’ indicates that the variable was selected for the final best fit model for the given indicator. An endash indicates that the variable was not selected in the final model. PJ is pinyon-juniper; CGDD is cumulative growing degree-days.

Model	CGDD	Actual Evapotranspiration				Deficit				Precipitation			
		Cool-Season	June	Monsoon-Season	2-Year Lag	Cool-Season	June	Monsoon-Season	2-Year Lag	Cool-Season	June	Monsoon-Season	2-Year Lag
Aspen – Canopy Closure	X	X	X	X	–	–	–	–	–	–	–	–	–
Aspen – Perennial Grass Cover	X	–	–	–	–	X	X	X	–	–	–	–	–
Aspen – Forb Cover	X	–	–	–	–	X	–	–	–	–	–	–	–
Oak – Bare Ground Cover	X	–	–	–	X	–	–	–	–	–	–	–	–
Oak – Non-native Plant Cover	X	–	–	–	–	X	X	X	–	–	–	–	–
Oak – Non-native Plant Frequency	X	–	–	–	–	X	–	–	–	–	–	–	–
Oak – Live Oak Cover	X	–	–	–	–	–	–	–	–	–	–	X	–
Oak – Shrub Cover	X	–	–	–	–	–	–	–	X	–	–	–	–
Oak – Perennial Grass Cover	X	–	X	–	–	–	–	–	–	–	–	–	–
Oak – Total Cover	X	–	–	–	–	–	–	–	–	X	–	–	–
Oak – Forb Cover	X	–	–	–	–	–	–	–	–	X	–	–	–
Oak – Tree Cover	–	–	–	–	–	–	–	–	X	–	–	–	–
PJ – Biological Soil Crust Cover	X	–	–	–	–	–	–	–	–	–	X	X	–
PJ – Live Tree Cover	X	–	–	–	X	–	–	–	–	–	–	–	–
PJ – Perennial Grass Cover	X	X	X	–	–	–	–	–	–	–	–	–	–
PJ – Shrub Density	X	–	–	–	–	–	–	–	–	–	–	–	X
PJ – Soil Stability	X	–	–	–	–	X	X	–	–	–	–	–	–
PJ/Aspen – Overstory Tree Density	X	–	–	–	–	–	–	–	–	–	–	–	X
PJ/Aspen – Bare Ground Cover	–	–	–	–	–	X	–	–	–	–	–	–	–
PJ/Aspen – Non-native Plant Cover	X	–	–	–	–	X	–	–	–	–	–	–	–
PJ/Aspen – Sapling Density	X	X	X	–	–	–	–	–	–	–	–	–	–
PJ/Aspen – Seedling Density	X	–	–	–	–	X	X	–	–	–	–	–	–
PJ/Aspen – Total Cover	X	–	–	–	–	X	–	X	–	–	–	–	–

Table 12 (continued). Summary of climate covariates. An ‘X’ indicates that the variable was selected for the final best fit model for the given indicator. An endash indicates that the variable was not selected in the final model. PJ is pinyon-juniper; CGDD is cumulative growing degree-days.

Model	CGDD	Actual Evapotranspiration				Deficit				Precipitation			
		Cool-Season	June	Monsoon-Season	2-Year Lag	Cool-Season	June	Monsoon-Season	2-Year Lag	Cool-Season	June	Monsoon-Season	2-Year Lag
PJ/Aspen –Shrub Cover	X	–	–	–	–	–	–	–	X	–	–	–	–
Sagebrush – Bare Ground Cover	X	–	–	–	–	–	–	X	–	–	–	–	–
Sagebrush – Big sagebrush Cover	X	–	–	–	–	–	–	–	–	–	–	–	X
Sagebrush – Big sagebrush Density	X	X	X	X	–	–	–	–	–	–	–	–	–
Sagebrush – Biological Soil Crust Cover	X	X	–	–	–	–	–	–	–	–	–	–	–
Sagebrush – Forb Cover	X	X	–	X	–	–	–	–	–	–	–	–	–
Sagebrush – Native Perennial Grass Cover	X	–	–	–	–	–	X	–	–	–	–	–	–
Sagebrush – Non-native Perennial Grass Cover	X	–	–	–	–	–	X	–	–	–	–	–	–
Sagebrush – Shrub Cover	X	–	–	–	–	–	–	–	–	–	X	X	–
Sagebrush – Shrub Density	X	–	–	–	X	–	–	–	–	–	–	–	–
Sagebrush – Soil Stability	X	–	–	–	–	X	X	–	–	–	–	–	–
Sagebrush – Total Cover	X	–	–	–	–	–	–	–	–	X	–	–	–
Sagebrush – Total Grass Cover	X	–	X	–	–	–	–	–	–	–	–	–	–
PJ/Aspen/Sagebrush – Non-native Plant Frequency	X	–	–	–	–	–	–	–	–	–	X	–	–

4 Discussion

4.1 Sagebrush

Sagebrush shrublands provide habitat for sensitive species, including the threatened Gunnison sage-grouse. Approximately 9,500 acres of sagebrush shrublands at BLCA and CURE are designated as critical habitat for Gunnison sage-grouse since the species was listed as threatened in 2014 (Colorado Parks & Wildlife et al. 2010). While the area of inference for sagebrush shrubland monitoring in this report does not coincide entirely with the boundaries of Gunnison sage-grouse priority habitat by design, there is significant overlap between the two. Results presented here inform an understanding of the current condition of sagebrush shrublands in general and of Gunnison sage-grouse habitat at BLCA and CURE. Indicators of sagebrush habitat from our monitoring that support Gunnison sage-grouse include total shrub, sagebrush, grass, and forb cover (Gunnison Sage-grouse Rangewide Steering Committee 2005). Comparison of structural habitat guidelines to our results show that model-predicted means for total shrub, sagebrush, and grass cover are within recommended ranges (Table 13). The upper credible intervals for total shrub, sagebrush, and grass cover were outside the recommended range, which suggests that some areas within the sampling frame may have greater cover than recommended. Model-predicted mean forb cover was lower than the recommended range; however, forb cover can vary greatly annually and can have large responses to water availability (Figure 25) (U.S. Natural Resources Conservation Service 2024a). Forbs are an important food source for Gunnison sage grouse in spring, summer, and fall, and are particularly nutritious for breeding females (U.S. Fish and Wildlife Service 2019).

Table 13. Comparison of NCPN upland vegetation monitoring results to Gunnison sage-grouse habitat guidelines. CI is the credible interval.

Indicator	Critical Habitat Guideline ^A	Grazed Sagebrush Mean Range (CI) ^B	Ungrazed Sagebrush Mean Range (CI) ^B
Total Shrub Cover (%)	10 – 35	31 – 32 (18, 47)	30 – 31 (16, 50)
Sagebrush Cover (%)	5 – 20	14 – 16 (6, 26)	14 -15 (7, 26)
Grass Cover (%)	10 – 35	20 – 25 (7, 54)	21 – 26 (8, 54)
Forb Cover (%)	15 – 35	4 – 6 (1, 18)	4 – 6 (1, 25)

^A Mesic, summer-fall habitat guidelines from Gunnison Sage-grouse Rangewide Steering Committee 2005.

^B Credible interval shows the lower limit of the 10-year minimum and upper limit of the 10-year maximum as reported in Table 5.

Trends in the Gunnison sage-grouse habitat cover indicators (Table 5) show that this habitat is generally stable in both grazed and ungrazed sagebrush shrublands. Additionally, density of total shrubs and big sagebrush was stable. Tree cover in sagebrush shrublands was too low to model trend over time, suggesting that there is little evidence of trees encroaching into sagebrush habitat at this time. However, in grazed sagebrush, native perennial grass cover was decreasing while non-native perennial grass cover increased (Figure 62). This could lead to a shift in species composition that

would reduce habitat quality if native species, including forbs, are outcompeted (U.S. Fish and Wildlife Service 2019).

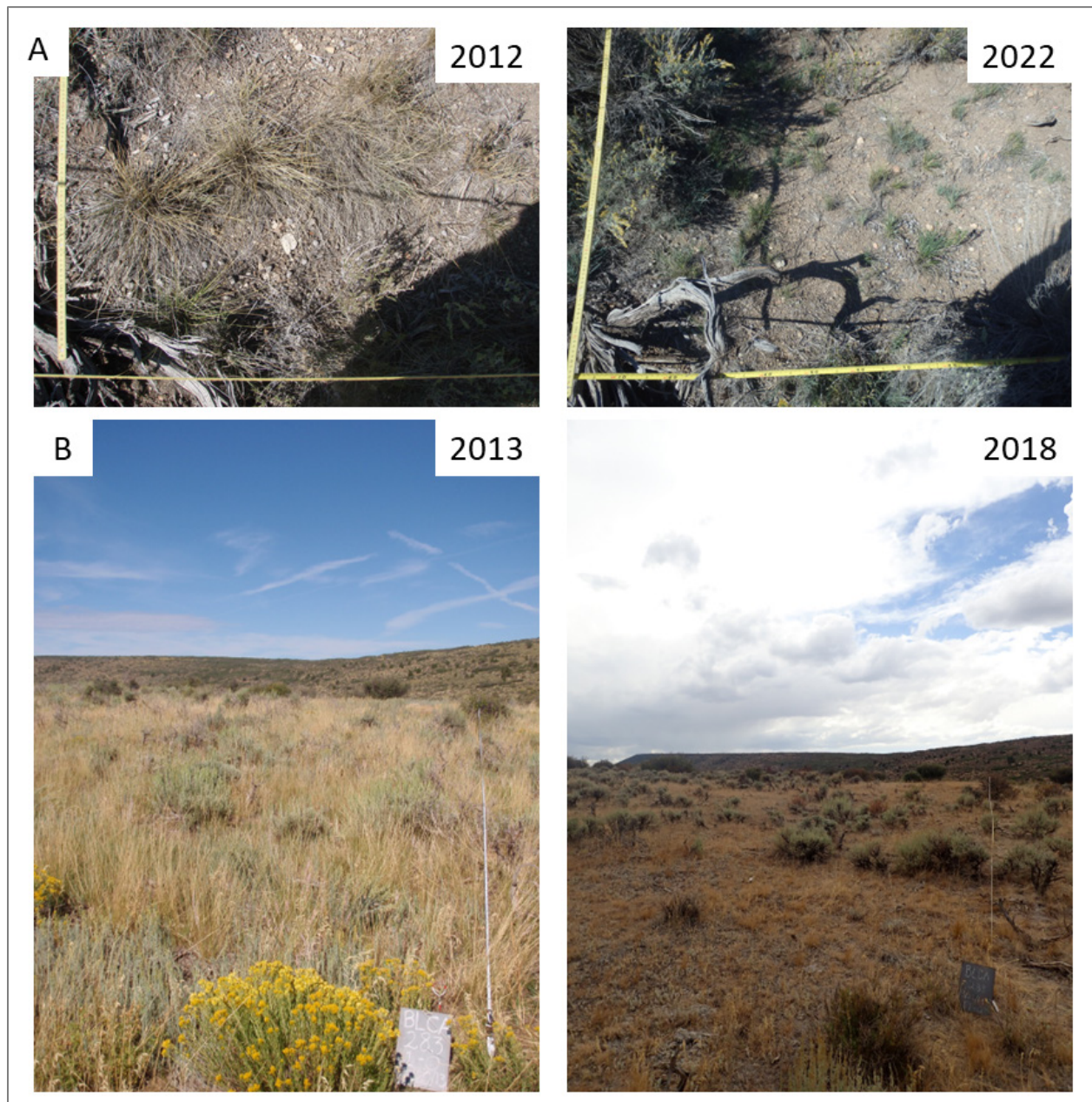


Figure 62. A) Repeat photograph of a grazed plot at CURE, showing a decrease in cover of native perennial grasses. The photo on the left was taken in 2012 and the photo on the right in 2022. B) Repeat photograph of a grazed plot at BLCA, showing a decrease in perennial grasses, increased bare ground, and increased cover of non-native grasses. The photo on the left was taken in 2013 and the photo on the right in 2018. NPS

Comparison of grazed and ungrazed sagebrush plots should be considered in the context of limited information on time, timing, and intensity of livestock grazing in BLCA and CURE allotments, as

well as the occurrence of trespass livestock and presence of native ungulates. Grazed and ungrazed sagebrush shrublands had similar results for most indicators (Table 5). An important exception is the noted decrease in native perennial grasses and increase in non-native perennial grasses in grazed sagebrush shrublands, but not ungrazed sagebrush shrublands. Current grazing as well as prior land history may play a role in these results. Although not directly comparable at an allotment level, these results are consistent with the 2018–2019 Interpreting Indicators of Rangeland Health assessments (Courkamp et al. 2022), which reported the loss of perennial bunchgrasses at most assessment sites.

Although non-native perennial grass cover was increasing in grazed sagebrush, model-predicted mean cover was very low, around 1% (Table 5). Non-native plant frequency (which includes annuals) was also very low in both grazed and ungrazed sagebrush (Table 5). This indicates that current conditions across the sample area are good, but there may be localized areas of high or increasing non-native cover in grazed sagebrush. The increase in non-native grasses may be driven in part by bulbous bluegrass, which is unpalatable to livestock and increases under grazing pressure (Gucker 2007). Bulbous bluegrass is currently only found in plots in the Grizzly Gulch allotment in BLCA. Courkamp et al. (2022) also note issues such as annual weeds in specific areas (e.g., Red Rock Canyon), but they conclude that rangeland health was generally good across the allotments visited. Ungrazed sagebrush had low cover of non-natives and it did not increase over time.

In addition to differences in native grass trends, biological soil crust was increasing in grazed sagebrush and soil stability was decreasing in ungrazed sagebrush. These results are somewhat surprising, since we would expect greater disturbance in grazed sagebrush to decrease biological soil crust cover. Similarly, less disturbance in ungrazed sagebrush should lead to improved or stable soil stability. However, livestock grazing is only one factor influencing soil surface conditions and biological soil crust is generally low in the sagebrush vegetation types (U.S. Natural Resources Conservation Service 2024a). Grazing of wild ungulates, small mammal activity, climate, and changes in plant cover or litter also influence these results. In our models, soil stability had a strong negative relationship with spring and summer water deficit.

There was no disturbance by fire at NCPN plots during the monitoring period. Nevertheless, managers should consider potential impacts of fire in sagebrush shrublands, where state transitions to a grassland dominated by annual non-natives have occurred (Sherrill and Romme 2012, Livensperger and Witwicki 2024). This type conversion would negatively impact Gunnison sage-grouse habitat as well as resources for livestock and wildlife. In contrast, a recent study in the Gunnison Basin found that burned sagebrush sites had relatively low cover of non-native plants, with only one non-native species (crested wheatgrass [*Agropyron cristatum*]) having higher cover post-fire (Simic et al. 2023). Additionally, Ecological Site Descriptions for the study area (Mountain Loam and Dry Mountain Loam, Appendix A) note that periodic, naturally occurring fires may prevent sagebrush from becoming dominant and reducing cover of understory grasses (U.S. Natural Resources Conservation Service 2024a, 2024b). The current lack of cheatgrass or other non-native plants in sagebrush shrublands at BLCA and CURE suggests that they may be resilient to disturbance by fire and that managers should prioritize protection of this intact ecosystem (Rodhouse et al. 2021).

4.2 Pinyon-Juniper Woodlands

Structure of pinyon-juniper forests in western Colorado has a history of long-rotation, stand-replacing fires, resulting in the old-growth, stable forests found in parts of Black Canyon of the Gunnison NP (Shinneman and Baker 2009, Kennard and Moore 2013). However, over the past 20 years, die-off of pinyon pine (Shaw et al. 2005) and Utah juniper (Kannenberg et al. 2021) has been observed in the region. Die-off and mortality are generally linked to drought, sometimes in combination with insects and diseases (Mueller et al. 2005, Romme et al. 2009). In the context of these long-lived trees, our 11-year monitoring period is relatively short; however, there was no evidence of unexpected mortality or die-off. Future monitoring will analyze crown health to detect dieback more quickly. Both total and live tree cover were stable, along with density of overstory trees, saplings, and seedlings.

Tree seedling density was somewhat variable and increased in 2022, indicating that recruitment may be occurring in some years with favorable climate conditions. Mean overstory tree, sapling, and seedling density were similar, around 300 individuals/ha for each. However, overstory tree density is not directly comparable to sapling and seedling density since stems may be considered individuals in these many-branched tree growth forms. In comparison, Shinneman and Baker (2009) reported a higher mean overstory tree density of 589.6 trees/ha (411.7 trees/ha standard deviation), for pinyon-juniper woodlands on the nearby Uncompahgre Plateau; however, this study used a smaller cutoff (5 cm DRC) to define overstory trees. Kennard and Moore (2013) reported 827.4 trees/ha (588.3 trees/ha standard deviation) at Colorado National Monument and this density value included all size classes.

While trees and shrubs had stable cover in pinyon-juniper woodlands, perennial grass cover declined. A negative relationship with CGDD indicates that warmer winter and early spring temperatures resulted in lower perennial grass cover. Perennial grasses in pinyon-juniper woodlands include primarily cool-season grasses, like muttongrass (*P. fendleriana*) and squirreltail (*E. elymoides*), which may be more sensitive to warmer, drier conditions in the months or year preceding sampling (Munson et al. 2011, Witwicki et al. 2016). Declining cover of perennial cool-season (C3) grasses has been reported throughout the Colorado Plateau through observational (Munson et al. 2011, Livensperger and Witwicki 2024) and experimental (Wertin et al. 2015) studies.

Declines in perennial grass cover have previously been observed in combination with increasing non-native frequency or cover at Dinosaur NM (Livensperger and Witwicki 2024, Table 1). In contrast, we observed non-native frequency decreasing and non-native cover remaining stable in pinyon-juniper woodlands. One difference between sagebrush shrublands and pinyon-juniper woodlands in the monitored area is that the pinyon-juniper non-natives are almost all annual species (including cheatgrass [*B. tectorum*], alyssum [*Alyssum* sp.], and tumble-mustard [*Sisymbrium altissimum*]), while in sagebrush, non-natives have a greater proportion of perennial species (bulbous bluegrass [*Poa bulbosa*], Kentucky bluegrass [*Poa pratensis*]). Stable cover but declining frequency could indicate that cover of non-natives will also decline in the future. Model-predicted mean values for cover and frequency were both low, but with high maximum predicted values. This indicates that localized areas already have high cover and frequency.

While our monitoring suggests that conditions in pinyon-juniper woodlands are stable, a stand-replacing fire could have devastating impacts in these forests. Relatively recent large fires in pinyon-juniper woodlands at Mesa Verde NP and Bandelier NM have resulted in state transitions to non-forested ecosystems, often with a greater proportion of non-native species (Floyd et al. 2015, Coop et al. 2016, Prev  y et al. 2024). Continued monitoring of non-native annuals, like cheatgrass, is essential since these may create contiguous fuels on the surface and increase fire risk.

4.3 Aspen Forest

Only four plots were monitored in aspen forests, so there is lower power to detect trends over time. Despite this, decreases over time in overstory tree density, sapling density, and canopy closure were observed. Although seedling density was stable, the trends in larger size classes are concerning and suggest that seedlings are not growing into maturity. Field crews noted browsing by ungulates at all aspen plots, which results in shrubby growth forms for aspen trees and may explain lack of growth into larger size classes. These results implicate a decline in tree condition consistent with a 2020 report on aspen health at NCPN plots at Curecanti NRA (Marchetti 2020). This report identified multiple potential causes of decline, including deterioration of older aspen trees, insect and disease damage, intensive use by ungulates, and deterioration following the sudden aspen decline that occurred regionally in the 2000s. Aspen forests at Curecanti NRA are at the lower elevation range for the species in this region, and the U.S. Forest Service bioclimate models suggest that these stands will have an unfavorable future climate and may only persist if the site is resilient (Worrall et al. 2016, Marchetti 2020).

Non-native plant cover was highest in aspen forests, compared to sagebrush, pinyon-juniper, and Gambel oak vegetation types. Model-predicted mean non-native plant cover was at least 20% during the monitoring period. However, there was no evidence of an increase in non-native cover or frequency. In aspen forests, the predominant non-native is Kentucky bluegrass, which is a perennial grass. Although cover of this species is high, it does not appear to be preventing native perennial grasses from achieving high percent cover (36 – 46%) and a stable trend over time. Aspen forests were the only vegetation type in the study area where perennial grass cover was not declining.

As canopy closure and tree cover decline, more light may penetrate the understory of these forests and benefit native or non-native grasses, forbs, and shrubs. However, none of these groups showed significant increases during the monitoring period. Instead, shrubs and forbs had non-significant decreases over time, and at all plots, aspen seedlings were heavily browsed and converted to a shrubby form. As noted, the small sample size in this study limits the ability to detect trends over time in aspen forests. Continued monitoring should reveal how succession will proceed as aspen tree mortality continues.

4.4 Gambel Oak Shrublands

Regionally, Gambel oak shrublands are often a stable part of the landscape, regenerating readily following disturbance, including fire, and resisting control efforts for management actions (Engle et al. 1983, Kaufman et al. 2016). The traits that make Gambel oak communities well adapted to disturbance are expected to give them an advantage under changing climate conditions as well

(Kaufman et al. 2016). The relatively large percent cover of associated shrub species (Utah serviceberry, mountain snowberry, big sagebrush) shows that oak stands at BLCA and CURE are more often mixed shrub communities rather than pure Gambel oak stands. However, the percent cover of both Gambel oak and other shrubs was stable over time during our monitoring period, consistent with expectations for the region.

Like sagebrush shrublands and pinyon-juniper woodlands, Gambel oak communities also had declining native perennial grass cover. As in other vegetation types at BLCA and CURE, cool-season grasses dominate in Gambel oak communities, and declines observed in our study reflect regional patterns. Conversely, forb cover increased over time. Forb cover responded strongly to cool-season P, increasing in years with greater P like 2016 and 2019. Changes in total cover reflected the patterns of forb cover, indicating that other functional groups are relatively stable among years compared to forbs.

Non-native plant species in Gambel oak communities include Kentucky bluegrass, smooth brome, and crested wheatgrass, among others, which are a mix of annual and perennial species. While cover of non-natives was very low (model-predicted mean <1%), the frequency of non-natives was greater, and credible intervals spanned all possible values. This indicates that non-natives are sparse but occur frequently across the area of inference. Kentucky bluegrass is a perennial species and may compete strongly against native grasses as they decline (Uchytel 1993).

4.5 Climate Relationships

Understanding controls on vegetation and soil indicators provides managers with an indication of how they will respond to different climate scenarios in the future. Previous work has shown that water balance variables (D, AET) are often better predictors of plant responses than P or temperature alone (Thoma et al. 2019). Our results were consistent with this finding, and D was the most frequently used water balance variable (Table 12). However, P should still be considered as a possible predictor for vegetation and soil indicators, as it was selected in 10 of the final models.

Recent findings from the NPS show that BLCA and CURE have warmed rapidly over the past few decades and will continue to warm (National Park Service 2024a, 2024b). Changing temperature and precipitation requires managers to consider that conditions for vegetation and soil vital signs are likely to differ from what we have seen in the past. While projections for P are uncertain, climatic water D consistently increased under future scenarios, from 33 mm/yr to 150 mm/yr, meaning that plants will experience water D outside the range of past values. Given the importance of D in many of the vegetation and soil responses, managers should consider D a critical indicator of future ecosystem condition.

Native perennial grasses, which declined in 3 of 4 vegetation types, all had June D or AET as a predictor. In sagebrush shrublands, native perennial grasses had a significant negative response to June D. June is, on average, the month with the lowest precipitation at BLCA and CURE, and continued drying over this time period would negatively impact this important functional group.

Changes in aridity and seasonality across the western U.S. are occurring and will have widespread consequences for plant communities (Tercek et al. 2021, 2023).

5 Management Recommendations

- Maintain sagebrush and monitor grazing impacts from both livestock and native ungulates. Maintain and monitor allotment boundary fences to limit trespass livestock. Prioritize protection of resilient sagebrush systems with low non-native plant cover.
- Protect high-value, e.g., old-growth, pinyon-juniper woodlands from fire and continue to monitor and control for cheatgrass, which could increase surface fuels.
- Consider acceptance of aspen forest decline as these communities are unlikely to persist.
- The consistent decline in cool-season native perennial grasses across vegetation types warrants concern, and continued monitoring is critical. Managers should consider this functional group as vulnerable when making decisions regarding livestock grazing and wildlife management.
- Actual evapotranspiration and water deficit are important predictors of vegetation and soil response, and June may be a critical month for determining native perennial grass cover. As temperatures continue to warm, managers should consider future changes in these water balance variables to land management planning.

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Appendix A: Ecological Site Types

Figure 63 and Table 14 show descriptions of the five vegetation types used for upland monitoring at BLCA and CURE.

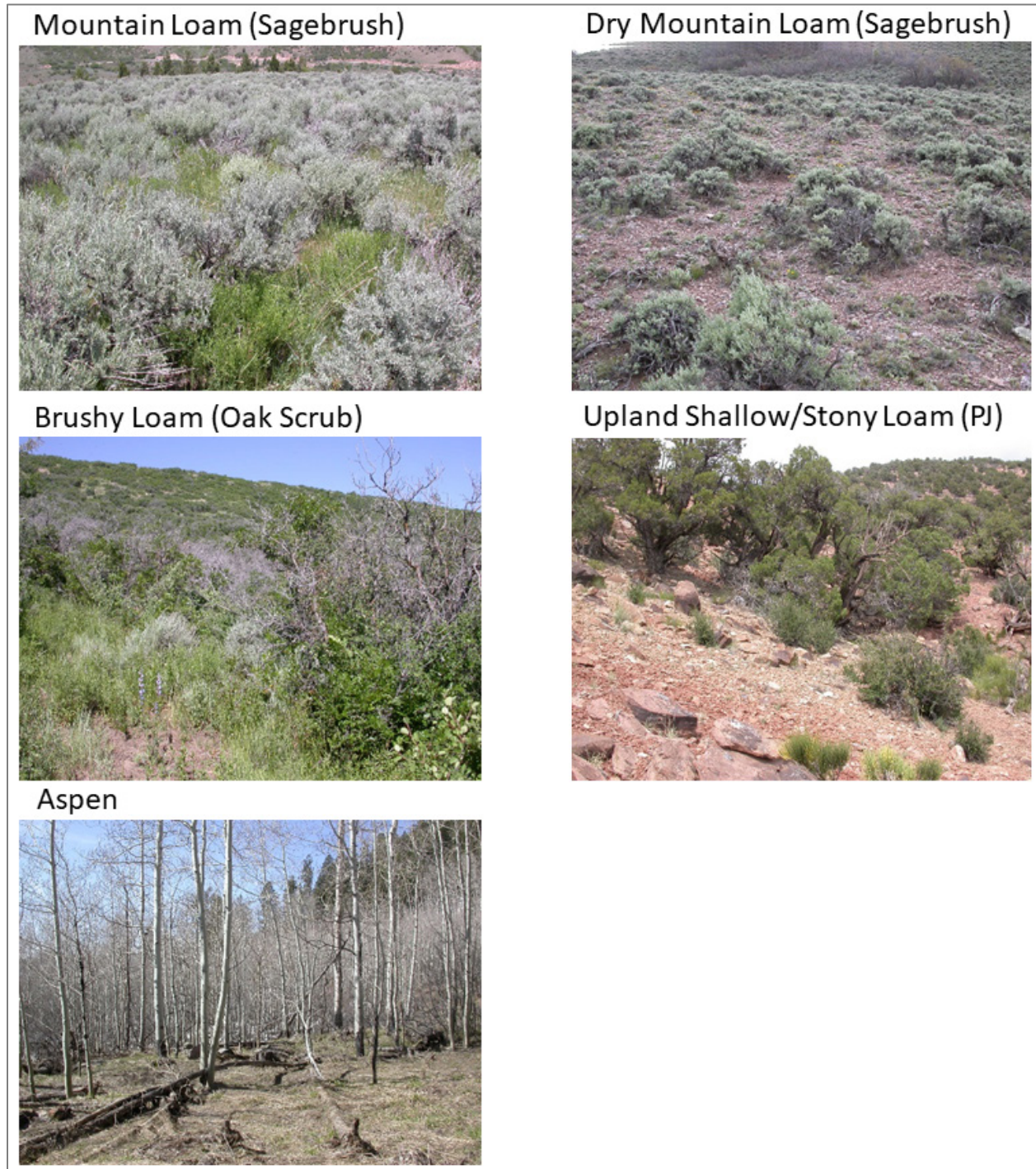


Figure 63. Examples of the five target vegetation/ecological site types for Upland Vegetation and Soil monitoring in Black Canyon of the Gunnison NP and Curecanti NRA. NPS

Table 14. Description of target vegetation and ecological site types selected for upland monitoring in Black Canyon of the Gunnison NP and Curecanti NRA.

Vegetation Type	Ecological Site Type	Soil Properties	Geological Properties	Vegetative Properties	Disturbance-mediated Alternative States
Aspen	no stratification	deep loams on mountain sides	alluvium, glacial till, or colluvium	Dominated by aspen, chokecherry, Saskatoon serviceberry, snowberry	Ranges from skeleton to climax forest.
Oak scrub/ mixed montane shrubs	Brushy Loam	deep loams on uplands and mountain sides	alluvium, slope alluvium, or glacial deposits	Dominated by Gamble oak, serviceberry, snowberry, mountain big sagebrush	<u>Grazing</u> : Decreased perennial grasses, increased woody shrubs. <u>Fire</u> : increased Gambel oak, snowberry, and rabbitbrush, decreased perennial grasses, forbs, and other shrubs.
Pinyon pine / Utah juniper	Upland Shallow / Stony Loam	shallow to moderately deep loams and stony loams on ridges and mountain sides	residuum or colluvium	Pinyon pine and Utah juniper with sparse to moderate understory cover of shrubs, grasses and forbs	<u>Grazing</u> : decreased understory plants, increased PJ. <u>Fire</u> : temporarily decreased PJ, increased perennial grasses and shrubs.
Sagebrush	Mountain Loam	deep loams on valleys, benches, and hillslopes	alluvium, slope alluvium, or glacial deposits	Tall big sagebrush with dense cover of grasses; may also include small amounts of mixed montane shrubs	<u>Grazing</u> : decreased perennial grasses, increased sagebrush. <u>Fire</u> : decreased sagebrush, increased rabbitbrush and snowberry.
	Dry Mountain Loam	shallow to moderately deep loams to stony loams on benches, ridges, and hills	residuum, alluvium, glacial deposits	Smaller big sagebrush with bunchgrasses and gravelly/stony interspaces	<u>Grazing</u> : decreased perennial grasses, increased sagebrush and snakeweed. <u>Fire</u> : decreased sagebrush.

Appendix B: Additional Information on Bayesian Trend Models

This appendix presents a brief overview of Bayesian data analysis. However, a thorough understanding of Bayesian data analysis is not needed to understand the results presented in this report.

B.1 Overview of Bayesian Data Analysis

According to Kruschke (2015), Bayesian data analysis involves the following steps:

1. *Define a descriptive model for the relevant data.* In this case, this means understanding changes in indicators of upland vegetation and soil condition over time, and understanding the relationships between these indicators and the climate conditions that drive changes. Linear models with slopes and intercepts were developed, like those used in frequentist statistics. However, there is often more random variation built into Bayesian models than into their frequentist counterparts. Bayesian models also contain a *likelihood*, which describes the distribution of the response data (e.g., normal, lognormal, binomial, Poisson, negative binomial). The *deterministic model* that describes the data is related to the distribution of the likelihood.
2. *Specify a prior distribution on the parameters. The prior must pass muster with skeptical scientists evaluating the analysis.* In some cases, previous analyses help to inform the values of priors. In the data analyzed in this report, vague priors were used that allow for equal credibility across a wide range of possible values for each parameter, meaning that there will be effectively no biasing of the resulting posterior distribution.
3. *Use Bayesian inference to re-allocate credibility across parameter values. Assuming that the model is a reasonable description of the data, interpret the posterior distribution with respect to the relevant issue.* The posterior distribution describes values of the slope, intercept, and other parameters that are credible, given the data. This range of values can be described through a 95% credible interval, which can be interpreted as a 95% confidence that the true value of the mean of the indicator falls within the lower and upper values of the interval.
4. *Check that the posterior predictions mimic the data with reasonable accuracy by conducting a posterior predictive check. If not, consider a different descriptive model.* To assess model fit, the field data were compared with data simulated from the Bayesian model, and test statistics were used to determine if they were sufficiently similar.

B.2 Bayesian Trend Modeling

Bayesian modeling provides an effective way to model the status and trends of data with complex sampling design features that are challenging with traditional frequentist statistical approaches (Hooten and Hobbs 2015). For example, hierarchical Bayesian models can easily accept data from the NCPN's five-year repeating sampling schedule and non-normally distributed data from categories, counts, proportions, and binomial distributions. In addition, Bayesian models provide a cohesive approach for determining status at a given point in time and trend over time using the same

model, unlike frequentist methods. This approach also allowed us to examine the influence of important covariates at any hierarchical level in the model (plot, strata, park) that influence vegetation and soils, such as climate (Zachmann et al. 2021).

These models are hierarchical because they allow parameters (slopes and intercepts) to vary at multiple levels—in this case, at the plot and stratum levels. Strata, in this analysis, correspond to vegetation type (sagebrush, aspen, oak, and pinyon-juniper). Inferences were made at the stratum scale based on the statistical distribution of slopes and intercepts at the plot scale. These models take into account that there can be wide variation in an indicator among plots. These differences were incorporated to inform stratum-level trends, rather than averaging over them.

Because these models are Bayesian, they predict the plot response for all years—even years when data were not collected. This means plots are modeled during years when they are not visited, thereby preventing the possibility that inferences on trends could be influenced by annual variation in the set of plots observed in a particular year. Additionally, plots observed more frequently have greater weight in inference than plots observed infrequently, a straightforward method to account for the difference in visitation frequency among plots due to the repeating five-year sampling schedule.

B.3 Equations

The general formula for Bayesian models is

$$[\text{Model parameters} \mid \text{data}] \propto [\text{data} \mid \text{likelihood model}] [\text{priors}]$$

where “ $\mid$ ” is “as conditional on” and $\propto$ is “is proportional to”.

For a simple model where intercepts are allowed to vary among sites within a single stratum and slopes are the same for all sites with no other covariates, the model can be written as

$$[\beta_0, \beta_1, \sigma_{\beta_0}^2, \mu_{\beta_0} \mid y] \propto [y_i \mid \beta_0 + \beta_1 x_i, \sigma^2] [\beta_0 \mid \mu, \sigma_{\beta_0}^2] [\beta_1] [\mu_{\beta_0}] [\sigma_{\beta_0}^2]$$

where β_0 is the intercept, β_1 is the common slope, $\sigma_{\beta_0}^2$ is the variance of the intercept, and μ_{β_0} is the mean of the intercepts. The expression $[y_i \mid \beta_0 + \beta_1 x_i, \sigma^2]$ reads the probability of the observation conditional on the model parameters and error variance. As such, it represents a general expression for the likelihood. Specific distributions (e.g., binomial, beta, Poisson) are chosen depending on the values of the observations (i.e., their “support”).

The likelihood model varies based on the distribution of the indicator. In the case of the shrub-density model, the simplified likelihood can be written as:

$$y \sim \text{Negative binomial}(e^{\beta_0 + \beta_1 x + \beta_2 x^2}) \backslash \kappa$$

where β_2 is the row vector of covariates in a covariance matrix, x_2 is the corresponding column vector of coefficients, and κ is a dispersion parameter.

B.4 Variance Structures

Hierarchical models were built with different variance structures to determine which best fit these data. The following three types of variance structures were examined:

1. **Hierarchical site:** The variance of observations at a given site is drawn from a hyperdistribution of variances shared by all the sites in the sample. In other words, there is an underlying distribution of the variances of observations within sites that gives rise to the variance of observations at a specific site.
2. **Fixed site:** As above, variances vary by site, but the variance of observations at each site is estimated completely independently of one another. There is not a shared hyperdistribution of variances.
3. **Fixed stratum:** Variance is forced to be the same for all sites within a stratum.

B.5 Model Checking and Selection

All models were checked for convergence using the Gelman-Rubin diagnostic (Gelman and Rubin 1992). A properly converged model will not meaningfully change the posterior distribution with more iterations in the Markov Chain Monte Carlo (MCMC) process, which ensures the model output provides reliable inference (Hooten and Hobbs 2015). In many cases, models would only converge under the most appropriate variance structure for the data.

To assess model fit, the field data were compared with data simulated from the Bayesian model to compute the probability that test statistics summarizing the real and simulated data were sufficiently similar. The Bayesian p value (P_B) tests whether the distribution of the data that would arise from the model is more extreme than the distribution of the observed data. Ideal values should be close to 0.5, with extremes of >0.9 or <0.1 indicating a poor fit (Hooten and Hobbs 2015).

To choose the “best” model among those with either varying intercepts (β_0), or varying slopes and intercepts ($\beta_0 \beta_1$), and with different combinations of covariates, the posterior predictive loss was minimized. Posterior predictive loss (Gelfand and Ghosh 1998) contains a goodness-of-fit term and a penalty term based on the number of model parameters. Its goal is to minimize loss by comparing replicated data created at each iteration of the MCMC chain with observed data. Generally, the results showed that models with random intercepts only (β_0) converged more often than models with random slopes and random intercepts ($\beta_0 \beta_1$), so these types of models were focused on for most of the trend analyses.

Appendix C: Species by Vegetation Type

The tables in this appendix show the percent cover by species observed on grazed sagebrush plots (Table 15), ungrazed sagebrush plots (Table 16), pinyon-juniper woodland plots (Table 17), Gambel oak shrubland plots (Table 18), and aspen forest plots (Table 19).

Table 15. Species list by total percent cover for grazed sagebrush plots. There are 30 grazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Artemisia tridentata</i>	big sagebrush	23.6	90	Perennial	Native
<i>Poa bulbosa</i>	bulbous bluegrass	12.8	4	Perennial	Non–native
<i>Poa fendleriana</i>	muttongrass	9.6	84	Perennial	Native
<i>Poa pratensis</i>	Kentucky bluegrass	9.3	9	Perennial	Non–native
<i>Artemisia carruthii</i>	Carruth's wormwood	6.2	5	Perennial	Native
<i>Quercus gambelii</i>	Gambel oak	5.5	33	Perennial	Native
<i>Lupinus sp.</i>	–	4.3	1	–	Native
<i>Achnatherum lettermanii</i>	Letterman's needlegrass	3.8	74	Perennial	Native
<i>Pascopyrum smithii</i>	Western wheatgrass	3.8	10	Perennial	Native
<i>Phlox hoodii</i>	spiny phlox	3.7	55	Perennial	Native
<i>Artemisia nova</i>	black sagebrush	3.5	29	Perennial	Native
<i>Vicia americana</i>	American vetch	3.2	3	Perennial	Native
<i>Lupinus caudatus</i>	tailcup lupine	3.2	2	Perennial	Native
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	3.0	68	Perennial	Native
<i>Bouteloua gracilis</i>	blue grama	2.8	27	Perennial	Native
<i>Symphoricarpos oreophilus</i>	mountain snowberry	2.8	38	Perennial	Native
<i>Ericameria parryi</i>	Parry's rabbitbrush	2.7	5	Perennial	Native
<i>Hesperostipa comata</i>	needle–and–thread	2.5	56	Perennial	Native
<i>Koeleria macrantha</i>	junegrass	2.3	23	Perennial	Native

Table 15 (continued). Species list by total percent cover for grazed sagebrush plots. There are 30 grazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Lupinus argenteus</i>	silvery lupine	2.3	22	Perennial	Native
<i>Carex</i> sp.	–	2.2	62	Perennial	Native
<i>Stipa</i> sp.	–	2.2	69	Perennial	Native
<i>Carex duriuscula</i>	narrowleaf sedge	2.1	6	Perennial	Native
<i>Festuca thurberi</i>	Thurber's fescue	2.0	8	Perennial	Native
<i>Chrysothamnus depressus</i>	dwarf rabbitbrush	2.0	37	Perennial	Native
<i>Arenaria congesta</i>	ballhead sandwort	1.9	5	Perennial	Native
<i>Elymus elymoides</i>	squirreltail	1.8	73	Perennial	Native
<i>Poa</i> sp.	–	1.7	12	–	–
<i>Polygonum douglasii</i>	Douglas' knotweed	1.7	2	Annual	Native
<i>Pyrrocoma</i> sp.	goldenweed	1.7	1	–	Native
<i>Phlox austromontana</i>	mountain phlox	1.7	20	Perennial	Native
<i>Purshia tridentata</i>	antelope bitterbrush	1.5	25	Perennial	Native
<i>Amelanchier utahensis</i>	Utah serviceberry	1.5	31	Perennial	Native
<i>Pseudotsuga menziesii</i>	Douglas–fir	1.4	3	Perennial	Native
<i>Achnatherum hymenoides</i>	Indian ricegrass	1.4	46	Perennial	Native
<i>Carex rossii</i>	Ross' sedge	1.2	6	Perennial	Native
<i>Sphaeralcea coccinea</i>	scarlet globe–mallow	1.2	15	Perennial	Native
<i>Achnatherum nelsonii</i>	Columbia needlegrass	1.2	2	Perennial	Native
<i>Androsace septentrionalis</i>	pygmy–flower rock–jasmine	1.2	2	Annual	Native
<i>Erysimum cheiranthoides</i>	worm–seed wallflower	1.2	2	Perennial	Native
<i>Elymus</i> sp.	–	1.2	19	Perennial	–
<i>Cercocarpus montanus</i>	alder–leaf mountain mahogany	1.1	14	Perennial	Native
<i>Antennaria</i> sp.	–	1.1	12	Perennial	Native

Table 15 (continued). Species list by total percent cover for grazed sagebrush plots. There are 30 grazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Artemisia sp.</i>	–	1.1	5	Perennial	–
<i>Antennaria microphylla</i>	small-leaf pussytoes	1.0	8	Perennial	Native
<i>Bromus tectorum</i>	cheatgrass	1.0	13	Annual	Non-native
<i>Poa secunda</i>	Sandberg's bluegrass	1.0	20	Perennial	Native
<i>Stenotus armerioides</i>	thrift goldenweed	1.0	9	Perennial	Native
<i>Peraphyllum ramosissimum</i>	squaw-apple	0.9	5	Perennial	Native
<i>Cryptantha sp.</i>	–	0.9	3	–	Native
<i>Selaginella densa</i>	dense spike-moss	0.9	6	Perennial	Native
<i>Artemisia frigida</i>	fringed sagebrush	0.9	16	Perennial	Native
<i>Tetraneuris acaulis</i>	stemless four-nerve daisy	0.9	8	Perennial	Native
<i>Leptodactylon pungens</i>	prickly-phlox	0.9	10	Perennial	Native
<i>Pleuraphis jamesii</i>	galleta	0.9	5	Perennial	Native
<i>Alyssum desertorum</i>	desert madwort	0.8	3	Annual	Non-native
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	0.7	9	Perennial	Native
<i>Penstemon caespitosus</i>	mat penstemon	0.7	26	Perennial	Native
<i>Gutierrezia sarothrae</i>	broom snakeweed	0.7	34	Perennial	Native
<i>Arabis glabra</i>	tower rockcress	0.7	1	Perennial	Native
<i>Aristida purpurea</i>	purple three-awn	0.7	1	Perennial	Native
<i>Astragalus convallarius</i>	lesser rushy milkvetch	0.7	14	Perennial	Native
<i>Chenopodium atrovirens</i>	mountain goosefoot	0.7	1	Annual	Native
<i>Draba sp.</i>	–	0.7	1	–	–
<i>Eriogonum racemosum</i>	redroot wild buckwheat	0.7	8	Perennial	Native
<i>Festuca ovina</i>	fescue	0.7	1	Perennial	Native
<i>Gayophytum ramosissimum</i>	branching groundsmoke	0.7	1	Annual	Native

Table 15 (continued). Species list by total percent cover for grazed sagebrush plots. There are 30 grazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Machaeranthera canescens</i>	hoary aster	0.7	1	Perennial	Native
<i>Opuntia fragilis</i>	brittle prickly-pear	0.7	2	Perennial	Native
<i>Orobanche fasciculata</i>	clustered broomrape	0.7	1	Perennial	Native
<i>Phlox longifolia</i>	long-leaf phlox	0.7	11	Perennial	Native
<i>Symphyotrichum ascendens</i>	Pacific aster	0.7	3	Perennial	Native
<i>Tetradymia canescens</i>	spineless horsebrush	0.6	14	Perennial	Native
<i>Castilleja linariifolia</i>	Wyoming paintbrush	0.5	5	Perennial	Native
<i>Schoenocrambe linifolia</i>	flax-leaved plainsmustard	0.5	10	Perennial	Native
<i>Erigeron engelmannii</i>	Engelmann's daisy	0.5	8	Perennial	Native
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat	0.5	4	Perennial	Native
<i>Galium boreale</i>	Northern bedstraw	0.5	2	Perennial	Native
<i>Arabis sp.</i>	–	0.5	18	Perennial	Native
<i>Erigeron sp.</i>	–	0.4	6	–	Native
<i>Eriogonum lonchophyllum</i>	spearleaf buckwheat	0.4	6	Perennial	Native
<i>Opuntia polyacantha</i>	plains prickly-pear	0.4	3	Perennial	Native
<i>Opuntia sp.</i>	–	0.4	10	Perennial	Native
<i>Achillea millefolium</i>	common yarrow	0.4	4	Perennial	Native
<i>Astragalus sp.</i>	–	0.4	8	–	–
<i>Cirsium arvense</i>	Canada thistle	0.4	4	Perennial	Non-native
<i>Rosa woodsii</i>	Woods' rose	0.4	4	Perennial	Native
<i>Sporobolus cryptandrus</i>	sand dropseed	0.4	4	Perennial	Native
<i>Yucca sp.</i>	–	0.4	4	Perennial	Native
<i>Antennaria parvifolia</i>	common pussytoes	0.4	6	Perennial	Native
<i>Mahonia repens</i>	Oregon-grape	0.4	6	Perennial	Native

Table 15 (continued). Species list by total percent cover for grazed sagebrush plots. There are 30 grazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Agropyron cristatum</i>	crested wheatgrass	0.3	1	Perennial	Non–native
<i>Arenaria fendleri</i>	Fendler's sandwort	0.3	1	Perennial	Native
<i>Arabis selbyi</i>	Selby's rockcress	0.3	1	Perennial	Native
<i>Bromus anomalus</i>	nodding brome	0.3	1	Perennial	Native
<i>Bromus ciliatus</i>	fringed brome	0.3	1	Perennial	Native
<i>Carex geyeri</i>	Elk sedge	0.3	1	Perennial	Native
<i>Chrysothamnus sp.</i>	–	0.3	1	Perennial	Native
<i>Crepis sp.</i>	–	0.3	2	Perennial	Native
<i>Erigeron flagellaris</i>	trailing daisy	0.3	1	Perennial	Native
<i>Ericameria nauseosa</i>	–	0.3	1	Perennial	Native
<i>Erigeron pumilus</i>	shaggy fleabane	0.3	1	Perennial	Native
<i>Heuchera parvifolia</i>	littleleaf alumroot	0.3	1	Perennial	Native
<i>Heterotheca villosa</i>	hairy false goldenaster	0.3	5	Perennial	Native
<i>Krascheninnikovia lanata</i>	winterfat	0.3	5	Perennial	Native
<i>Lactuca serriola</i>	prickly lettuce	0.3	1	Annual	Non-native
<i>Lithospermum ruderae</i>	Western stoneseed	0.3	2	Perennial	Native
<i>Machaeranthera sp.</i>	–	0.3	1	–	Native
<i>Machaeranthera grindelioides</i>	gumweed aster	0.3	1	Perennial	Native
<i>Packera multilobata</i>	basin groundsel	0.3	1	Perennial	Native
<i>Penstemon sp.</i>	–	0.3	1	Perennial	Native
<i>Potentilla gracilis</i>	slender cinquefoil	0.3	2	Perennial	Native
<i>Ribes cereum</i>	wax currant	0.3	3	Perennial	Native
<i>Taraxacum officinale</i>	common dandelion	0.3	2	Perennial	Non-native
<i>Trifolium gymnocarpon</i>	hollyleaf clover	0.3	1	Perennial	Native
<i>Yucca harrimaniae</i>	Spanish bayonet	0.3	2	Perennial	Native

Table 16. Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Artemisia tridentata</i>	big sagebrush	20.5	78	Perennial	Native
<i>Poa fendleriana</i>	muttongrass	10.4	75	Perennial	Native
<i>Quercus gambelii</i>	Gambel oak	7.6	20	Perennial	Native
<i>Artemisia nova</i>	black sagebrush	5.6	7	Perennial	Native
<i>Ericameria nauseosa</i>	–	4.7	3	Perennial	Native
<i>Phlox austromontana</i>	mountain phlox	4.7	7	Perennial	Native
<i>Poa pratensis</i>	Kentucky bluegrass	4.3	15	Perennial	Non–native
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	4.2	59	Perennial	Native
<i>Koeleria macrantha</i>	junegrass	3.7	50	Perennial	Native
<i>Carex rossii</i>	Ross' sedge	3.6	6	Perennial	Native
<i>Arenaria congesta</i>	ballhead sandwort	3.5	14	Perennial	Native
<i>Hesperostipa comata</i>	needle–and–thread	3.4	51	Perennial	Native
<i>Achnatherum lettermanii</i>	Letterman's needlegrass	3.3	65	Perennial	Native
<i>Carex sp.</i>	–	3.2	44	Perennial	Native
<i>Chrysothamnus depressus</i>	dwarf rabbitbrush	3.0	30	Perennial	Native
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	3.0	22	Perennial	Native
<i>Vicia americana</i>	American vetch	2.9	4	Perennial	Native
<i>Bouteloua gracilis</i>	blue grama	2.8	33	Perennial	Native
<i>Lupinus caudatus</i>	tailcup lupine	2.8	4	Perennial	Native
<i>Amelanchier utahensis</i>	Utah serviceberry	2.5	18	Perennial	Native
<i>Pascopyrum smithii</i>	Western wheatgrass	2.4	16	Perennial	Native
<i>Artemisia carruthii</i>	Carruth's wormwood	2.3	4	Perennial	Native
<i>Purshia tridentata</i>	antelope bitterbrush	2.2	32	Perennial	Native
<i>Stipa sp.</i>	–	1.9	46	Perennial	Native

Table 16 (continued). Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Pleuraphis jamesii</i>	galleta	1.8	14	Perennial	Native
<i>Lupinus argenteus</i>	silvery lupine	1.8	15	Perennial	Native
<i>Antennaria microphylla</i>	small-leaf pussytoes	1.7	14	Perennial	Native
<i>Krascheninnikovia lanata</i>	winterfat	1.7	2	Perennial	Native
<i>Elymus elymoides</i>	squirreltail	1.7	62	Perennial	Native
<i>Elymus sp.</i>	–	1.5	14	Perennial	–
<i>Antennaria rosea</i>	rosy pussytoes	1.5	2	Perennial	Native
<i>Phlox hoodii</i>	spiny phlox	1.5	31	Perennial	Native
<i>Selaginella densa</i>	dense spike-moss	1.5	5	Perennial	Native
<i>Cercocarpus montanus</i>	alder-leaf mountain mahogany	1.4	3	Perennial	Native
<i>Packera multilobata</i>	basin groundsel	1.4	3	Perennial	Native
<i>Mahonia repens</i>	Oregon-grape	1.4	9	Perennial	Native
<i>Achnatherum hymenoides</i>	Indian ricegrass	1.4	39	Perennial	Native
<i>Poa secunda</i>	Sandberg's bluegrass	1.4	14	Perennial	Native
<i>Carex duriuscula</i>	narrowleaf sedge	1.3	5	Perennial	Native
<i>Erigeron flagellaris</i>	trailing daisy	1.3	2	Perennial	Native
<i>Potentilla hippiana</i>	woolly cinquefoil	1.3	2	Perennial	Native
<i>Silene sp.</i>	–	1.3	1	–	Native
<i>Astragalus convallarius</i>	lesser rushy milkvetch	1.3	20	Perennial	Native
<i>Bromus tectorum</i>	cheatgrass	1.3	10	Annual	Non-native
<i>Tetranneuris acaulis</i>	stemless four-nerve daisy	1.3	4	Perennial	Native
<i>Heterotheca villosa</i>	hairy false goldenaster	1.1	8	Perennial	Native
<i>Bromus inermis</i>	smooth brome	1.1	3	Perennial	Non-native
<i>Symphoricarpos oreophilus</i>	mountain snowberry	1.1	34	Perennial	Native

Table 16 (continued). Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Ericameria parryi</i>	Parry's rabbitbrush	1.1	11	Perennial	Native
<i>Descurainia incana</i>	mountain tansymustard	1.0	1	Annual	Native
<i>Elymus lanceolatus</i>	thickspike wheatgrass	1.0	1	Perennial	Native
<i>Heliomeris multiflora</i>	showy goldeneye	1.0	1	Perennial	Native
<i>Leptodactylon pungens</i>	prickly-phlox	1.0	6	Perennial	Native
<i>Melilotus officinalis</i>	yellow sweet-clover	1.0	2	Biennial	Non-native
<i>Taraxacum officinale</i>	common dandelion	1.0	1	Perennial	Non-native
<i>Poa</i> sp.	–	0.9	6	–	–
<i>Artemisia frigida</i>	fringed sagebrush	0.9	9	Perennial	Native
<i>Artemisia</i> sp.	–	0.8	2	Perennial	–
<i>Symphyotrichum ascendens</i>	Pacific aster	0.8	2	Perennial	Native
<i>Gutierrezia sarothrae</i>	broom snakeweed	0.8	23	Perennial	Native
<i>Agropyron cristatum</i>	crested wheatgrass	0.8	4	Perennial	Non-native
<i>Antennaria</i> sp.	–	0.7	10	Perennial	Native
<i>Tetradymia canescens</i>	spineless horsebrush	0.7	11	Perennial	Native
<i>Sphaeralcea coccinea</i>	scarlet globe-mallow	0.7	14	Perennial	Native
<i>Achillea millefolium</i>	common yarrow	0.7	17	Perennial	Native
<i>Opuntia</i> sp.	–	0.7	23	Perennial	Native
<i>Eriogonum lonchophyllum</i>	spearleaf buckwheat	0.7	4	Perennial	Native
<i>Erigeron pumilus</i>	shaggy fleabane	0.7	1	Perennial	Native
<i>Eriogonum racemosum</i>	redroot wild buckwheat	0.7	7	Perennial	Native
<i>Erigeron speciosus</i>	aspen fleabane	0.7	1	Perennial	Native
<i>Gayophytum ramosissimum</i>	branching groundsmoke	0.7	2	Annual	Native
<i>Hordeum jubatum</i>	foxtail barley	0.7	1	Perennial	Native

Table 16 (continued). Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Lupinus sp.</i>	–	0.7	2	–	Native
<i>Peraphyllum ramosissimum</i>	squaw–apple	0.7	1	Perennial	Native
<i>Poa bulbosa</i>	bulbous bluegrass	0.7	2	Perennial	Non-native
<i>Penstemon caespitosus</i>	mat penstemon	0.6	36	Perennial	Native
<i>Phlox longifolia</i>	long–leaf phlox	0.6	14	Perennial	Native
<i>Eriogonum umbellatum</i>	sulphur–flower buckwheat	0.6	12	Perennial	Native
<i>Comandra umbellata</i>	bastard toadflax	0.6	12	Perennial	Native
<i>Lappula occidentalis</i>	Western stickseed	0.6	3	Annual	Native
<i>Schoenocrambe linifolia</i>	flax–leaved plainsmustard	0.5	5	Perennial	Native
<i>Pediocactus simpsonii</i>	Simpson's hedgehog cactus	0.5	2	Perennial	Native
<i>Polygonum douglasii</i>	Douglas' knotweed	0.5	2	Annual	Native
<i>Erigeron sp.</i>	–	0.5	13	–	Native
<i>Castilleja linariifolia</i>	Wyoming paintbrush	0.4	3	Perennial	Native
<i>Prunus virginiana</i>	chokecherry	0.4	3	Perennial	Native
<i>Arabis sp.</i>	–	0.4	19	Perennial	Native
<i>Antennaria parvifolia</i>	common pussytoes	0.4	4	Perennial	Native
<i>Opuntia fragilis</i>	brittle prickly–pear	0.4	4	Perennial	Native
<i>Sporobolus cryptandrus</i>	sand dropseed	0.4	4	Perennial	Native
<i>Astragalus drummondii</i>	Drummond's milkvetch	0.4	5	Perennial	Native
<i>Erigeron engelmannii</i>	Engelmann's daisy	0.4	5	Perennial	Native
<i>Alyssum desertorum</i>	desert madwort	0.3	1	Annual	Non–native
<i>Alyssum minus var. micranthum</i>	European madwort	0.3	1	Annual	Non–native
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	0.3	1	Perennial	Native
<i>Androsace septentrionalis</i>	pygmy–flower rock–jasmine	0.3	1	Annual	Native

Table 16 (continued). Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Arabis demissa</i>	nodding rock cress	0.3	1	Perennial	Native
<i>Astragalus sp.</i>	–	0.3	4	–	–
<i>Ceanothus fendleri</i>	Fendler's mountain-lilac	0.3	1	Perennial	Native
<i>Chaetopappa ericoides</i>	rose-heath	0.3	2	Perennial	Native
<i>Chenopodium fremontii</i>	Fremont's goosefoot	0.3	1	Annual	Native
<i>Chamaesyce glyptosperma</i>	ridge-seeded spurge	0.3	1	Annual	Native
<i>Cirsium sp.</i>	–	0.3	1	Perennial	–
<i>Cirsium undulatum</i>	wavyleaf thistle	0.3	2	Perennial	Native
<i>Clematis sp.</i>	–	0.3	1	Perennial	–
<i>Clematis hirsutissima</i>	sugar-bowls	0.3	1	Perennial	Native
<i>Collomia linearis</i>	small collomia	0.3	1	Annual	Native
<i>Crepis sp.</i>	hawksbeard	0.3	2	Perennial	Native
<i>Cryptantha flavoculata</i>	yellow-eye cryptanth	0.3	1	Perennial	Native
<i>Cryptantha sp.</i>	–	0.3	2	–	Native
<i>Erysimum capitatum</i>	sand-dune wallflower	0.3	1	Perennial	Native
<i>Erigeron eatonii</i>	Eaton's daisy	0.3	1	Perennial	Native
<i>Galium boreale</i>	Northern bedstraw	0.3	1	Perennial	Native
<i>Geum triflorum</i>	old man's whiskers	0.3	1	Perennial	Native
<i>Heuchera parvifolia</i>	littleleaf alumroot	0.3	1	Perennial	Native
<i>Hymenoxys sp.</i>	rubberweed	0.3	1	Perennial	Native
<i>Ipomopsis aggregata</i>	scarlet gilia	0.3	2	Perennial	Native
<i>Linum lewisii</i>	Lewis flax	0.3	1	Perennial	Native
<i>Lithospermum ruderales</i>	Western stoneseed	0.3	1	Perennial	Native
<i>Machaeranthera canescens</i>	hoary aster	0.3	1	Perennial	Native

Table 16 (continued). Species list by total percent cover for ungrazed sagebrush plots. There are 29 ungrazed sagebrush plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Penstemon sp.</i>	–	0.3	5	Perennial	Native
<i>Physaria acutifolia</i>	sharp-leaf twinpod	0.3	1	Perennial	Native
<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	0.3	1	Perennial	Native
<i>Ribes cereum</i>	wax currant	0.3	2	Perennial	Native
<i>Rosa woodsii</i>	Woods' rose	0.3	1	Perennial	Native
<i>Sedum lanceolatum</i>	lance-leaved stonecrop	0.3	1	Perennial	Native
<i>Stenotus armerioides</i>	thrift goldenweed	0.3	1	Perennial	Native
<i>Trifolium gymnocarpon</i>	hollyleaf clover	0.3	2	Perennial	Native
<i>Zigadenus paniculatus</i>	foothills death camas	0.3	1	Perennial	Native

Table 17. Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Juniperus osteosperma</i>	Utah juniper	18.7	124	Perennial	Native
<i>Pinus edulis</i>	two-needle pinyon	15.9	122	Perennial	Native
<i>Quercus gambelii</i>	Gambel oak	10.9	56	Perennial	Native
<i>Bromus tectorum</i>	cheatgrass	7.5	32	Annual	Non–native
<i>Poa fendleriana</i>	muttongrass	5.7	62	Perennial	Native
<i>Artemisia tridentata</i>	big sagebrush	4.4	19	Perennial	Native
<i>Alyssum alyssoides</i>	pale madwort	3.8	2	Annual	Non–native
<i>Amelanchier utahensis</i>	Utah serviceberry	3.8	35	Perennial	Native
<i>Alyssum minus</i> var. <i>micranthum</i>	European madwort	3.2	7	Annual	Non–native
<i>Cercocarpus montanus</i>	alder-leaf mountain mahogany	2.9	70	Perennial	Native

Table 17 (continued). Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Descurainia pinnata</i>	Western tansymustard	2.8	5	Annual	Native
<i>Purshia tridentata</i>	antelope bitterbrush	2.4	6	Perennial	Native
<i>Leymus salinus</i>	Salina wildrye	2.1	13	Perennial	Native
<i>Penstemon watsonii</i>	Watson's penstemon	2.1	3	Perennial	Native
<i>Stenotus armerioides</i>	thrift goldenweed	1.6	24	Perennial	Native
<i>Ephedra viridis</i>	green ephedra	1.4	47	Perennial	Native
<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot	1.4	16	Perennial	Native
<i>Allium</i> sp.	–	1.3	1	Perennial	Native
<i>Cryptantha flavoculata</i>	yellow–eye cryptanth	1.3	1	Perennial	Native
<i>Draba</i> sp.	–	1.3	1	–	–
<i>Elymus elymoides</i>	squirreltail	1.3	48	Perennial	Native
<i>Petradoria pumila</i>	rock goldenrod	1.3	33	Perennial	Native
<i>Opuntia fragilis</i>	brittle prickly–pear	1.2	33	Perennial	Native
<i>Koeleria macrantha</i>	junegrass	1.2	2	Perennial	Native
<i>Rhus trilobata</i>	skunkbush sumac	1.2	2	Perennial	Native
<i>Mahonia fremontii</i>	Fremont's mahonia	1.2	11	Perennial	Native
<i>Comandra umbellata</i>	bastard toadflax	1.1	15	Perennial	Native
<i>Sisymbrium altissimum</i>	tumble mustard	1.1	10	Annual	Non-native
<i>Carex</i> sp.	–	1.1	35	Perennial	Native
<i>Carex rossii</i>	Ross' sedge	1.1	4	Perennial	Native
<i>Symphoricarpos oreophilus</i>	mountain snowberry	1.1	24	Perennial	Native
<i>Artemisia nova</i>	black sagebrush	1.1	5	Perennial	Native
<i>Descurainia</i> sp.	–	1.1	5	Annual	–
<i>Draba cuneifolia</i>	wedgeleaf draba	1.0	20	Annual	Native

Table 17 (continued). Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Arabis pallidifolia</i>	Gunnison County rockcress	1.0	1	Perennial	Native
<i>Gutierrezia sarothrae</i>	broom snakeweed	1.0	12	Perennial	Native
<i>Hesperostipa comata</i>	needle–and–thread	1.0	9	Perennial	Native
<i>Opuntia sp.</i>	–	1.0	39	Perennial	Native
<i>Stipa sp.</i>	–	0.9	20	Perennial	Native
<i>Poa secunda</i>	Sandberg's bluegrass	0.9	16	Perennial	Native
<i>Lupinus caudatus</i>	tailcup lupine	0.9	6	Perennial	Native
<i>Lappula occidentalis</i>	Western stickseed	0.9	8	Annual	Native
<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	0.8	2	Perennial	Native
<i>Astragalus miser</i>	timber milkvetch	0.8	3	Perennial	Native
<i>Penstemon sp.</i>	–	0.8	3	Perennial	Native
<i>Gilia inconspicua</i>	shy gilia	0.8	4	Annual	Native
<i>Lupinus argenteus</i>	silvery lupine	0.8	4	Perennial	Native
<i>Achnatherum lettermanii</i>	Letterman's needlegrass	0.7	1	Perennial	Native
<i>Chenopodium atrovirens</i>	mountain goosefoot	0.7	1	Annual	Native
<i>Erodium cicutarium</i>	stork's–bill	0.7	3	Annual	Non–native
<i>Eriogonum sp.</i>	–	0.7	1	–	Native
<i>Eriogonum microthecum</i>	slender wild buckwheat	0.7	1	Perennial	Native
<i>Helianthella microcephala</i>	purpldisk sunflower	0.7	2	Perennial	Native
<i>Lupinus sp.</i>	–	0.7	1	–	Native
<i>Machaeranthera grindelioides</i>	gumweed aster	0.7	2	Perennial	Native
<i>Pedicularis centranthera</i>	dwarf lousewort	0.7	1	Perennial	Native
<i>Ribes sp.</i>	currant	0.7	2	Perennial	Native
<i>Yucca harrimaniae</i>	Spanish bayonet	0.7	5	Perennial	Native

Table 17 (continued). Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Achnatherum hymenoides</i>	Indian ricegrass	0.6	25	Perennial	Native
<i>Collinsia parviflora</i>	blue-eyed mary	0.6	14	Annual	Native
<i>Artemisia ludoviciana</i>	Louisiana wormwood	0.6	3	Perennial	Native
<i>Yucca sp.</i>	–	0.6	3	Perennial	Native
<i>Pleuraphis jamesii</i>	galleta	0.5	5	Perennial	Native
<i>Packera multilobata</i>	basin groundsel	0.5	7	Perennial	Native
<i>Sphaeralcea coccinea</i>	scarlet globe-mallow	0.5	7	Perennial	Native
<i>Atriplex canescens</i>	four-wing saltbush	0.5	6	Perennial	Native
<i>Glossopetalon spinescens</i>	spiny greaseweb	0.5	2	Perennial	Native
<i>Paxistima myrsinites</i>	mountain-lover	0.5	2	Perennial	Native
<i>Schoenocrambe linifolia</i>	flax-leaved plainsmustard	0.5	2	Perennial	Native
<i>Heterotheca villosa</i>	hairy false goldenaster	0.5	9	Perennial	Native
<i>Brickellia microphylla</i>	littleleaf brickellbush	0.4	3	Perennial	Native
<i>Chenopodium fremontii</i>	Fremont's goosefoot	0.4	3	Annual	Native
<i>Poa sp.</i>	–	0.4	3	–	–
<i>Phlox longifolia</i>	long-leaf phlox	0.4	13	Perennial	Native
<i>Elymus sp.</i>	–	0.4	7	Perennial	–
<i>Arabis sp.</i>	–	0.4	20	Perennial	Native
<i>Cryptantha sp.</i>	–	0.4	7	–	Native
<i>Alyssum desertorum</i>	desert madwort	0.3	1	Annual	Non-native
<i>Antennaria parvifolia</i>	common pussytoes	0.3	2	Perennial	Native
<i>Antennaria sp.</i>	–	0.3	1	Perennial	Native
<i>Arceuthobium divaricatum</i>	pinyon dwarf-mistletoe	0.3	2	Perennial	Native
<i>Arenaria fendleri</i>	Fendler's sandwort	0.3	1	Perennial	Native

Table 17 (continued). Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Arabis perennans</i>	perennial rockcress	0.3	1	Perennial	Native
<i>Astragalus oophorus</i>	egg milkvetch	0.3	4	Perennial	Native
<i>Astragalus sp.</i>	–	0.3	1	–	–
<i>Ceratocephala testiculata</i>	bur buttercup	0.3	3	Annual	Non–native
<i>Chrysothamnus depressus</i>	dwarf rabbitbrush	0.3	2	Perennial	Native
<i>Chaenactis douglasii</i>	hoary dusty–maiden	0.3	4	Perennial	Native
<i>Chenopodium sp.</i>	–	0.3	1	Annual	–
<i>Chenopodium leptophyllum</i>	narrow–leaf goosefoot	0.3	1	Annual	Native
<i>Crepis sp.</i>	–	0.3	1	Perennial	Native
<i>Descurainia incana</i>	mountain tansymustard	0.3	2	Annual	Native
<i>Descurainia sophia</i>	flixweed	0.3	2	Annual	Non–native
<i>Elymus lanceolatus</i>	thickspike wheatgrass	0.3	1	Perennial	Native
<i>Erysimum capitatum</i>	sanddune wallflower	0.3	1	Perennial	Native
<i>Erigeron sp.</i>	–	0.3	1	–	Native
<i>Eriogonum racemosum</i>	redroot wild buckwheat	0.3	4	Perennial	Native
<i>Fraxinus anomala</i>	singleleaf ash	0.3	1	Perennial	Native
<i>Heliomeris multiflora</i>	showy goldeneye	0.3	1	Perennial	Native
<i>Ipomopsis aggregata</i>	scarlet gilia	0.3	2	Perennial	Native
<i>Lappula sp.</i>	–	0.3	1	Annual	–
<i>Lithospermum incisum</i>	showy stoneseed	0.3	1	Perennial	Native
<i>Lithospermum rudrale</i>	Western stoneseed	0.3	4	Perennial	Native
<i>Lithospermum sp.</i>	–	0.3	2	–	–
<i>Machaeranthera canescens</i>	hoary aster	0.3	1	Perennial	Native
<i>Penstemon caespitosus</i>	mat penstemon	0.3	3	Perennial	Native

Table 17 (continued). Species list by total percent cover for pinyon–juniper woodland plots. There are 45 pinyon–juniper plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Pediocactus simpsonii</i>	Simpson's hedgehog cactus	0.3	1	Perennial	Native
<i>Physaria floribunda</i>	mesa twinpod	0.3	1	Perennial	Native
<i>Phoradendron juniperinum</i>	juniper mistletoe	0.3	2	Perennial	Native
<i>Physaria</i> sp.	–	0.3	2	–	Native
<i>Polygonum douglasii</i>	Douglas' knotweed	0.3	1	Annual	Native
<i>Poa pratensis</i>	Kentucky bluegrass	0.3	1	Perennial	Non–native
<i>Pseudostellaria jamesiana</i>	James' chickweed	0.3	1	Perennial	Native
<i>Ribes leptanthum</i>	trumpet gooseberry	0.3	3	Perennial	Native
<i>Streptanthus cordatus</i>	heart–leaf jewelflower	0.3	3	Perennial	Native
<i>Tetraneuris acaulis</i>	stemless four–nerve daisy	0.3	3	Perennial	Native
<i>Tetradymia canescens</i>	spineless horsebrush	0.3	1	Perennial	Native
<i>Townsendia incana</i>	hoary townsendia	0.3	1	Perennial	Native
<i>Vicia americana</i>	American vetch	0.3	1	Perennial	Native
<i>Wyethia arizonica</i>	Arizona mulesears	0.3	2	Perennial	Native

Table 18. Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Quercus gambelii</i>	Gambel oak	26.1	114	Perennial	Native
<i>Amelanchier utahensis</i>	Utah serviceberry	21.8	131	Perennial	Native
<i>Pinus edulis</i>	two–needle pinyon	15.9	22	Perennial	Native
<i>Carex</i> sp.	–	12.2	109	Perennial	Native
<i>Bromus inermis</i>	smooth brome	12.0	4	Perennial	Non–native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Poa fendleriana</i>	muttongrass	9.1	120	Perennial	Native
<i>Symphoricarpos oreophilus</i>	mountain snowberry	8.5	118	Perennial	Native
<i>Artemisia tridentata</i>	big sagebrush	7.8	115	Perennial	Native
<i>Poa pratensis</i>	Kentucky bluegrass	7.6	93	Perennial	Non–native
<i>Chenopodium atrovirens</i>	mountain goosefoot	5.4	1	Annual	Native
<i>Pseudotsuga menziesii</i>	Douglas–fir	5.4	1	Perennial	Native
<i>Peraphyllum ramosissimum</i>	squaw–apple	5.1	30	Perennial	Native
<i>Elymus lanceolatus</i>	thickspike wheatgrass	5.1	18	Perennial	Native
<i>Agropyron cristatum</i>	crested wheatgrass	4.9	6	Perennial	Non–native
<i>Galium boreale</i>	Northern bedstraw	4.4	4	Perennial	Native
<i>Carex rossii</i>	Ross' sedge	3.9	16	Perennial	Native
<i>Vicia americana</i>	American vetch	3.6	74	Perennial	Native
<i>Pascopyrum smithii</i>	Western wheatgrass	3.5	24	Perennial	Native
<i>Achnatherum nelsonii</i>	Columbia needlegrass	3.3	12	Perennial	Native
<i>Ligusticum porteri</i>	Southern ligusticum	3.3	8	Perennial	Native
<i>Bromus anomalus</i>	nodding brome	3.3	6	Perennial	Native
<i>Galium bifolium</i>	twin–leaf bedstraw	2.9	7	Annual	Native
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	2.9	5	Perennial	Native
<i>Lupinus argenteus</i>	silvery lupine	2.8	10	Perennial	Native
<i>Hesperostipa comata</i>	needle–and–thread	2.7	40	Perennial	Native
<i>Erigeron speciosus</i>	aspen fleabane	2.6	30	Perennial	Native
<i>Elymus</i> sp.	–	2.5	52	Perennial	–
<i>Mahonia repens</i>	Oregon–grape	2.5	43	Perennial	Native
<i>Alyssum minus</i> var. <i>micranthum</i>	European madwort	2.5	7	Annual	Non–native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Koeleria macrantha</i>	junegrass	2.3	75	Perennial	Native
<i>Erigeron flagellaris</i>	trailing daisy	2.3	14	Perennial	Native
<i>Elymus elymoides</i>	squirreltail	2.3	82	Perennial	Native
<i>Festuca thurberi</i>	Thurber's fescue	2.3	2	Perennial	Native
<i>Lomatium dissectum</i>	giant lomatium	2.1	1	Perennial	Native
<i>Achnatherum lettermanii</i>	Letterman's needlegrass	2.1	50	Perennial	Native
<i>Poa secunda</i>	Sandberg's bluegrass	2.0	18	Perennial	Native
<i>Arenaria congesta</i>	ballhead sandwort	2.0	18	Perennial	Native
<i>Paxistima myrsinites</i>	mountain-lover	2.0	6	Perennial	Native
<i>Chrysothamnus depressus</i>	dwarf rabbitbrush	2.0	14	Perennial	Native
<i>Thalictrum fendleri</i>	Fendler's meadow-rue	1.9	3	Perennial	Native
<i>Stipa sp.</i>	–	1.9	52	Perennial	Native
<i>Balsamorhiza sagittata</i>	arrowleaf balsamroot	1.7	48	Perennial	Native
<i>Petradoria pumila</i>	rock goldenrod	1.7	20	Perennial	Native
<i>Astragalus miser</i>	timber milkvetch	1.7	29	Perennial	Native
<i>Polygonum douglasii</i>	Douglas' knotweed	1.7	23	Annual	Native
<i>Alyssum desertorum</i>	desert madwort	1.7	3	Annual	Non–native
<i>Lathyrus sp.</i>	–	1.7	2	Perennial	–
<i>Lomatium triternatum</i>	nineleaf biscuitroot	1.7	1	Perennial	Native
<i>Poa bulbosa</i>	bulbous bluegrass	1.7	6	Perennial	Non–native
<i>Prunus virginiana</i>	chokecherry	1.7	4	Perennial	Native
<i>Bromus tectorum</i>	cheatgrass	1.7	31	Annual	Non–native
<i>Collomia linearis</i>	small collomia	1.6	14	Annual	Native
<i>Lupinus caudatus</i>	tailcup lupine	1.5	34	Perennial	Native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Cercocarpus montanus</i>	alder-leaf mountain mahogany	1.5	31	Perennial	Native
<i>Comandra umbellata</i>	bastard toadflax	1.4	34	Perennial	Native
<i>Artemisia nova</i>	black sagebrush	1.4	8	Perennial	Native
<i>Stellaria longifolia</i>	long-leaved starwort	1.4	4	Perennial	Native
<i>Collinsia parviflora</i>	blue-eyed mary	1.3	19	Annual	Native
<i>Achillea millefolium</i>	common yarrow	1.3	50	Perennial	Native
<i>Arabis perennans</i>	perennial rockcress	1.3	1	Perennial	Native
<i>Astragalus lentiginosus</i>	freckled milkvetch	1.3	4	Perennial	Native
<i>Gayophytum sp.</i>	groundsmoke	1.3	1	Annual	Native
<i>Lathyrus lanszwertii</i>	Nevada pea	1.3	4	Perennial	Native
<i>Poa sp.</i>	–	1.3	14	–	–
<i>Poa compressa</i>	Canada bluegrass	1.3	2	Perennial	Non-native
<i>Trifolium gymnocarpon</i>	hollyleaf clover	1.3	2	Perennial	Native
<i>Phlox longifolia</i>	long-leaf phlox	1.2	57	Perennial	Native
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	1.2	21	Perennial	Native
<i>Lupinus sp.</i>	–	1.2	18	–	Native
<i>Symphyotrichum ascendens</i>	Pacific aster	1.1	11	Perennial	Native
<i>Elymus trachycaulus</i>	slender wheatgrass	1.1	3	Perennial	Native
<i>Penstemon caespitosus</i>	mat penstemon	1.1	5	Perennial	Native
<i>Antennaria dimorpha</i>	low pussytoes	1.0	2	Perennial	Native
<i>Gayophytum ramosissimum</i>	branching groundsmoke	1.0	2	Annual	Native
<i>Rosa woodsii</i>	Woods' rose	1.0	7	Perennial	Native
<i>Bromus ciliatus</i>	fringed brome	0.9	4	Perennial	Native
<i>Artemisia carruthii</i>	Carruth's wormwood	0.9	6	Perennial	Native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Packera multilobata</i>	basin groundsel	0.9	6	Perennial	Native
<i>Antennaria sp.</i>	–	0.9	16	Perennial	Native
<i>Antennaria microphylla</i>	small-leaf pussytoes	0.9	12	Perennial	Native
<i>Pseudostellaria jamesiana</i>	James' chickweed	0.9	15	Perennial	Native
<i>Agrostis stolonifera</i>	redtop	0.8	1	Perennial	Non-native
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	0.8	1	Perennial	Native
<i>Antennaria rosea</i>	rosy pussytoes	0.8	4	Perennial	Native
<i>Artemisia sp.</i>	–	0.8	1	Perennial	–
<i>Bromus carinatus</i>	mountain brome	0.8	1	Perennial	Native
<i>Carex geyeri</i>	elk sedge	0.8	1	Perennial	Native
<i>Erigeron eatonii</i>	Eaton's daisy	0.8	1	Perennial	Native
<i>Juniperus osteosperma</i>	Utah juniper	0.8	2	Perennial	Native
<i>Lomatium sp.</i>	–	0.8	2	Perennial	Native
<i>Penstemon barbatus</i>	beardlip penstemon	0.8	2	Perennial	Native
<i>Wyethia arizonica</i>	Arizona mulesears	0.8	3	Perennial	Native
<i>Astragalus sp.</i>	–	0.8	21	–	–
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat	0.8	17	Perennial	Native
<i>Tetradymia canescens</i>	spineless horsebrush	0.7	9	Perennial	Native
<i>Allium sp.</i>	–	0.7	8	Perennial	Native
<i>Antennaria parvifolia</i>	common pussytoes	0.7	8	Perennial	Native
<i>Helimeris multiflora</i>	showy goldeneye	0.7	8	Perennial	Native
<i>Machaeranthera canescens</i>	hoary aster	0.7	3	Perennial	Native
<i>Potentilla gracilis</i>	slender cinquefoil	0.7	3	Perennial	Native
<i>Opuntia fragilis</i>	brittle prickly-pear	0.7	31	Perennial	Native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Heterotheca villosa</i>	hairy false goldenaster	0.7	5	Perennial	Native
<i>Pseudoroegneria spicata</i>	bluebunch wheatgrass	0.6	2	Perennial	Native
<i>Taraxacum officinale</i>	common dandelion	0.6	8	Perennial	Non–native
<i>Erigeron sp.</i>	–	0.6	5	–	Native
<i>Achnatherum hymenoides</i>	Indian ricegrass	0.6	3	Perennial	Native
<i>Draba cuneifolia</i>	wedgeleaf draba	0.6	3	Annual	Native
<i>Opuntia sp.</i>	–	0.6	3	Perennial	Native
<i>Crepis sp.</i>	hawksbeard	0.5	8	Perennial	Native
<i>Artemisia ludoviciana</i>	Louisiana wormwood	0.5	6	Perennial	Native
<i>Eriogonum racemosum</i>	redroot wild buckwheat	0.5	12	Perennial	Native
<i>Gutierrezia sarothrae</i>	broom snakeweed	0.5	6	Perennial	Native
<i>Agoseris sp.</i>	–	0.4	3	–	Native
<i>Arabis sp.</i>	–	0.4	5	Perennial	Native
<i>Arabis selbyi</i>	Selby's rockcress	0.4	2	Perennial	Native
<i>Astragalus megacarpus</i>	great bladdery milkvetch	0.4	1	Perennial	Native
<i>Astragalus tenellus</i>	pulse milkvetch	0.4	1	Perennial	Native
<i>Bromus sp.</i>	–	0.4	1	–	–
<i>Castilleja linariifolia</i>	Wyoming paintbrush	0.4	3	Perennial	Native
<i>Carduus nutans</i>	musk thistle	0.4	1	Perennial	Non–native
<i>Castilleja sp.</i>	–	0.4	1	–	Native
<i>Ceanothus fendleri</i>	Fendler's mountain–lilac	0.4	1	Perennial	Native
<i>Ceratocephala testiculata</i>	bur buttercup	0.4	1	Annual	Non–native
<i>Chenopodium sp.</i>	–	0.4	1	Annual	–
<i>Chenopodium fremontii</i>	Fremont's goosefoot	0.4	1	Annual	Native

Table 18 (continued). Species list by total percent cover for Gambel oak shrubland plots. There are 45 oak plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Clematis hirsutissima</i>	sugar–bowls	0.4	1	Perennial	Native
<i>Clematis ligusticifolia</i>	white virgin's–bower	0.4	1	Perennial	Native
<i>Eriogonum alatum</i>	winged wild buckwheat	0.4	1	Perennial	Native
<i>Erigeron divergens</i>	spreading daisy	0.4	1	Perennial	Native
<i>Eriogonum lonchophyllum</i>	spearleaf buckwheat	0.4	1	Perennial	Native
<i>Ericameria parryi</i>	Parry's rabbitbrush	0.4	1	Perennial	Native
<i>Ipomopsis aggregata</i>	scarlet gilia	0.4	2	Perennial	Native
<i>Iris missouriensis</i>	Rocky Mountain iris	0.4	2	Perennial	Native
<i>Lappula occidentalis</i>	Western stickseed	0.4	2	Annual	Native
<i>Linum lewisii</i>	Lewis flax	0.4	1	Perennial	Native
<i>Machaeranthera bigelovii</i>	Bigelow's aster	0.4	1	Perennial	Native
<i>Mirabilis linearis</i>	narrow–leaf four–o'clock	0.4	1	Perennial	Native
<i>Orthocarpus luteus</i>	yellow owl–clover	0.4	2	Annual	Native
<i>Penstemon sp.</i>	–	0.4	3	Perennial	Native
<i>Phlox gracilis</i>	slender phlox	0.4	2	Annual	Native
<i>Polygonum aviculare</i>	yard knotweed	0.4	1	Annual	Non–native
<i>Schoenocrambe linifolia</i>	flax–leaved plainsmustard	0.4	1	Perennial	Native
<i>Senecio sp.</i>	–	0.4	1	–	–
<i>Sphaeralcea coccinea</i>	scarlet globe–mallow	0.4	4	Perennial	Native
<i>Stellaria sp.</i>	–	0.4	3	–	–
<i>Tragopogon dubius</i>	yellow salsify	0.4	5	Biennial	Non–native
<i>Viola sp.</i>	–	0.4	1	–	–
<i>Wyethia sp.</i>	–	0.4	1	Perennial	Native
<i>Yucca harrimaniae</i>	Spanish bayonet	0.4	4	Perennial	Native

Table 19. Species list by total percent cover for aspen forest plots. There are 45 aspen plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Poa pratensis</i>	Kentucky bluegrass	37.2	24	Perennial	Non–native
<i>Symphoricarpos oreophilus</i>	mountain snowberry	26.2	24	Perennial	Native
<i>Poa fendleriana</i>	muttongrass	17.8	4	Perennial	Native
<i>Vicia americana</i>	American vetch	16.3	20	Perennial	Native
<i>Carex sp.</i>	–	11.4	24	Perennial	Native
<i>Poa palustris</i>	fowl bluegrass	9.6	6	Perennial	Native
<i>Lupinus argenteus</i>	silvery lupine	9.2	6	Perennial	Native
<i>Veratrum californicum</i>	false hellebore	9.0	4	Perennial	Native
<i>Amelanchier utahensis</i>	Utah serviceberry	8.2	5	Perennial	Native
<i>Prunus virginiana</i>	chokecherry	7.4	20	Perennial	Native
<i>Quercus gambelii</i>	Gambel oak	7.4	8	Perennial	Native
<i>Bromus carinatus</i>	mountain brome	6.6	17	Perennial	Native
<i>Achnatherum nelsonii</i>	Columbia needlegrass	6.1	17	Perennial	Native
<i>Achillea millefolium</i>	common yarrow	5.7	24	Perennial	Native
<i>Bromus ciliatus</i>	fringed brome	4.8	16	Perennial	Native
<i>Stipa sp.</i>	–	4.8	6	Perennial	Native
<i>Astragalus convallarius</i>	lesser rushy milkvetch	4.7	2	Perennial	Native
<i>Mahonia repens</i>	Oregon–grape	4.7	11	Perennial	Native
<i>Cirsium arvense</i>	Canada thistle	4.6	4	Perennial	Non–native
<i>Salix scouleriana</i>	Scouler's willow	4.5	12	Perennial	Native
<i>Elymus glaucus</i>	blue wildrye	4.4	22	Perennial	Native
<i>Astragalus miser</i>	timber milkvetch	4.3	1	Perennial	Native
<i>Symphyotrichum foliaceum</i>	alpine leafybract aster	4.0	1	Perennial	Native
<i>Elymus trachycaulus</i>	slender wheatgrass	3.8	20	Perennial	Native

Table 19 (continued). Species list by total percent cover for aspen forest plots. There are 45 aspen plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Taraxacum officinale</i>	common dandelion	3.4	20	Perennial	Non–native
<i>Carex geyeri</i>	elk sedge	3.3	3	Perennial	Native
<i>Bromus anomalus</i>	nodding brome	3.2	8	Perennial	Native
<i>Achnatherum lettermanii</i>	Letterman's needlegrass	3.2	12	Perennial	Native
<i>Viola</i> sp.	–	3.0	1	–	–
<i>Galium boreale</i>	Northern bedstraw	3.0	24	Perennial	Native
<i>Carex douglasii</i>	Douglas' sedge	2.7	1	Perennial	Native
<i>Viola adunca</i>	hook–spur violet	2.5	17	Perennial	Native
<i>Elymus</i> sp.	–	2.5	10	Perennial	–
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	2.4	11	Perennial	Native
<i>Ligusticum porteri</i>	Southern ligusticum	2.4	14	Perennial	Native
<i>Pseudostellaria jamesiana</i>	James' chickweed	2.3	1	Perennial	Native
<i>Erigeron speciosus</i>	aspen fleabane	2.3	17	Perennial	Native
<i>Stellaria longifolia</i>	long–leaved starwort	2.1	4	Perennial	Native
<i>Symphyotrichum lanceolatum</i>	white panicle aster	2.1	6	Perennial	Native
<i>Festuca thurberi</i>	Thurber's fescue	2.0	16	Perennial	Native
<i>Astragalus</i> sp.	–	2.0	1	–	–
<i>Cirsium remotifolium</i> ssp. <i>oregonense</i>	fringed thistle	2.0	15	Perennial	Native
<i>Urtica dioica</i>	stinging nettle	2.0	14	Perennial	Native
<i>Thalictrum fendleri</i>	Fendler's meadow–rue	1.9	18	Perennial	Native
<i>Populus tremuloides</i>	quaking aspen	1.9	24	Perennial	Native
<i>Maianthemum stellatum</i>	starry false Solomon's–seal	1.7	14	Perennial	Native
<i>Geranium richardsonii</i>	Richardson's crane's–bill	1.6	19	Perennial	Native
<i>Senecio serra</i>	tall ragwort	1.2	12	Perennial	Native

Table 19 (continued). Species list by total percent cover for aspen forest plots. There are 45 aspen plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Dactylis glomerata</i>	orchard grass	1.2	2	Perennial	Non–native
<i>Koeleria macrantha</i>	junegrass	1.2	4	Perennial	Native
<i>Maianthemum racemosum</i>	feathery false lily of the valley	1.2	2	Perennial	Native
<i>Osmorhiza occidentalis</i>	Western sweet–cicely	1.2	8	Perennial	Native
<i>Paxistima myrsinites</i>	mountain–lover	1.2	4	Perennial	Native
<i>Elymus elymoides</i>	squirreltail	1.1	4	Perennial	Native
<i>Rosa woodsii</i>	Woods' rose	1.1	16	Perennial	Native
<i>Hackelia floribunda</i>	showy stickseed	1.1	13	Perennial	Native
<i>Carex occidentalis</i>	Western sedge	1.0	1	Perennial	Native
<i>Delphinium glaucum</i>	tower larkspur	1.0	2	Perennial	Native
<i>Potentilla gracilis</i>	slender cinquefoil	1.0	7	Perennial	Native
<i>Senecio bigelovii</i>	nodding ragwort	0.9	4	Perennial	Native
<i>Cirsium</i> sp.	–	0.9	7	Perennial	–
<i>Chenopodium atrovirens</i>	mountain goosefoot	0.8	6	Annual	Native
<i>Heliomeris multiflora</i>	showy goldeneye	0.8	4	Perennial	Native
<i>Disporum trachycarpum</i>	rough–fruited fairy–bells	0.7	1	Perennial	Native
<i>Frasera speciosa</i>	elkweed	0.7	3	Perennial	Native
<i>Rumex crispus</i>	curly dock	0.7	2	Perennial	Non–native
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	0.6	5	Perennial	Native
<i>Bromus</i> sp.	–	0.6	6	–	–
<i>Sidalcea candida</i>	white checker–mallow	0.6	3	Perennial	Native
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	0.5	2	Perennial	Native
<i>Cirsium undulatum</i>	wavyleaf thistle	0.5	6	Perennial	Native
<i>Poa</i> sp.	–	0.5	2	–	–

Table 19 (continued). Species list by total percent cover for aspen forest plots. There are 45 aspen plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Silene menziesii</i>	Menzies' campion	0.5	2	Perennial	Native
<i>Osmorhiza depauperata</i>	blunt sweet-cicely	0.5	10	Perennial	Native
<i>Juniperus communis</i>	common juniper	0.4	3	Perennial	Native
<i>Pedicularis procera</i>	Gray's lousewort	0.4	3	Perennial	Native
<i>Phacelia heterophylla</i>	wand phacelia	0.4	6	Perennial	Native
<i>Polemonium foliosissimum</i>	towering Jacob's-ladder	0.4	4	Perennial	Native
<i>Hydrophyllum fendleri</i>	Fendler's waterleaf	0.4	7	Perennial	Native
<i>Artemisia tridentata</i>	big sagebrush	0.3	4	Perennial	Native
<i>Aster sp.</i>	–	0.3	1	–	Native
<i>Carduus nutans</i>	musk thistle	0.3	3	Perennial	Non-native
<i>Campanula parryi</i>	Parry's harebell	0.3	1	Perennial	Native
<i>Corydalis aurea</i>	golden smoke	0.3	2	Perennial	Native
<i>Collomia linearis</i>	small collomia	0.3	4	Annual	Native
<i>Descurainia californica</i>	California tansy-mustard	0.3	1	Annual	Native
<i>Descurainia incana</i>	mountain tansymustard	0.3	1	Annual	Native
<i>Epilobium ciliatum</i>	fringed willowherb	0.3	1	Perennial	Native
<i>Ericameria parryi</i>	Parry's rabbitbrush	0.3	5	Perennial	Native
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat	0.3	1	Perennial	Native
<i>Fragaria virginiana</i>	Virginia strawberry	0.3	2	Perennial	Native
<i>Geum macrophyllum</i>	largeleaf avens	0.3	2	Perennial	Native
<i>Hesperostipa comata</i>	needle-and-thread	0.3	1	Perennial	Native
<i>Heracleum maximum</i>	cow parsnip	0.3	2	Perennial	Native
<i>Juncus tenuis</i>	poverty rush	0.3	1	Perennial	Native
<i>Lomatium sp.</i>	–	0.3	1	Perennial	Native

Table 19 (continued). Species list by total percent cover for aspen forest plots. There are 45 aspen plots.

Species Scientific Name	Species Common Name	Mean Cover (%)	Number of Visits	Duration	Nativity
<i>Lupinus sp.</i>	–	0.3	2	–	Native
<i>Pedicularis sp.</i>	–	0.3	1	Perennial	Native
<i>Polygonum douglasii</i>	Douglas' knotweed	0.3	3	Annual	Native
<i>Ribes inerme</i>	whitestem gooseberry	0.3	1	Perennial	Native
<i>Senecio eremophilus</i>	desert ragwort	0.3	1	Perennial	Native
<i>Senecio pudicus</i>	bashful groundsel	0.3	1	Perennial	Native
<i>Tragopogon dubius</i>	yellow salsify	0.3	2	Biennial	Non–native
<i>Trifolium repens</i>	white clover	0.3	1	Perennial	Non–native

National Park Service
U.S. Department of the Interior



Science Report NPS/SR—2025/254
<https://doi.org/10.36967/2309325>

Natural Resource Stewardship and Science

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