



Site Characterization and Change Over Time in Semi-Arid Grassland and Shrublands at Three Parks —Chaco Culture National Historic Park, Petrified Forest National Park, and Wupatki National Monument

Upland Vegetation and Soils Monitoring 2007–2021

Natural Resource Report NPS/SCPN/NRR—2024/2616





ON THIS PAGE

Plains zinnia (*Zinnia grandiflora*) growing in the volcanic upland ecosystem at Wupatki National Monument.
NPS Photo (Megan Swan 2010)

ON THE COVER

Pronghorn (*Antilocapra americana*) standing in grassland vegetation at Petrified Forest National Park.
NPS Photo (Maria Gaetani 2012)

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Megan C. Swan

National Park Service
Southern Colorado Plateau Network
930 North Switzer Drive
Flagstaff, Arizona 86001

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Executive Summary

This report presents results of upland vegetation and soil monitoring of semi-arid grasslands at three Parks by the Southern Colorado Plateau Inventory and Monitoring Network (SCPN) from 2007–2021. The purpose is to compare and contrast five grassland ecological sites and examine how they have changed during the first 15 years of monitoring. Crews collected data on composition and abundance of vegetation, both at the species level and by lifeform (e.g., perennial grass, shrub, forb) and soil aggregate stability and soil texture at 150 plots within five target grassland/shrubland communities delineated using NRCS ecological site (ecosite) classification (30 plots per ecosite).

Soils in plots at Petrified Forest NP and Chaco Culture NHP were deeper than those at Wupatki NM. Undifferentiated soil crust comprised the largest component of the soil surface, except at Wupatki where surface gravel dominated. Cover of biological soil crust (cyanobacteria, lichen, and moss) was low. Soil aggregate stability was moderate.

From 2007–2021, SCPN crews identified 283 unique plant species. Overall live foliar cover ranged from 12–24%. Four of five ecological sites were dominated by C4 grass species (>70% of total live foliar cover). Shrubs co-dominated at one site (WUPA L) and forbs were an overall small component of total vegetation cover but contributed most of the diversity in these sites. Less than 4% of species detected were nonnative. Russian thistle (*Salsola tragus*) was the most frequently sampled nonnative, occurring in > 50% of plots at Wupatki in the volcanic upland ecological site. Cheatgrass (*Bromus tectorum*) was the second most common invasive species but occurred in < 10% of the plots at all ecological sites.

Vegetation cover was modeled using Bayesian hierarchical models and included seasonal climatic water deficits, year effects and topographic variables as covariates. Models revealed significant negative time trends (i.e., changes over time that were not explained by changes in seasonal deficit covariates included) in some modeled responses, particularly in the cover of perennial grass at all five ecological sites. Time trends in shrub and forb responses were mixed. Species richness showed variable effects by ecosite, decreasing at CHCU S, and increasing at PEFO S and WUPA V.

Modeled responses were influenced by climate covariates, but direction of these effects varied. The most consistent effects were that greater July water stress and higher accumulated growing degree days (i.e., warmer spring temperatures) increased cover of perennial grasses and shrubs during the same year. However, greater water stress in the spring had a negative effect on many responses as expected.

Decreasing cover of perennial grass and increasing cover of shrubs and weedy forbs has been predicted for southwestern grasslands in response to increasing aridification due to anthropogenic climate change. Perennial grass trends reported here correspond with these predictions with mixed results on shrub and forb community trends. Continued drought conditions will likely exacerbate negative changes in these systems.

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Abbreviations used in this report.

AGDD: Accumulated growing degree days

CHCU: Chaco National Historic Site

D: Climatic water deficit

GRTS: Generalized Random Tessellation Stratified

I&M: Inventory and Monitoring

ITIS: Integrated Taxonomic Information System

Ha: Hectares

JAGS: Just Another Gibbs Sampler

m: Meters

mm: Millimeters

MCMC: Markov Chain Monte Carlo

NPS: National Park Service

NRCS: National Resource Conservation Service

pcp: Precipitation

PEFO: Petrified Forest National Park

PRISM: Parameter-elevation Regressions on Independent Slopes Model

p.z.: Precipitation zone

SCPN: Southern Colorado Plateau Network

SE: Standard error

USDA: United States Department of Agriculture

WUPA: Wupatki National Monument

Introduction

The mission of the National Park Service (NPS) is to conserve unimpaired the natural and cultural resources of the National Park System for the enjoyment of future generations. Semi-arid grassland and shrublands comprise much of the vegetation in parks on the Southern Colorado Plateau (Thomas et al. 2006). These vegetation communities are vitally important to the overall character of Southern Colorado Plateau Network (SCPN) parks, forming an integral component of the natural and cultural landscape. In many SCPN park units, semi-arid grassland communities exist much as they may have prior to European expansion given their long history of protection from domestic grazing (Thomas et al. 2006).

Grasslands and shrublands provide important ecosystem services and are in decline globally (Bengtsson et al. 2019). In SCPN parks, grasslands provide necessary habitat for birds, mammals, reptiles, and insects (Thomas 2006). Species growing and living in grasslands contribute to park diversity. Additionally, intact grassland vegetation stabilizes the soil which, critically, preserves and protects numerous paleontological and prehistoric resources and cultural relics.

The Southern Colorado Plateau Inventory and Monitoring Network began monitoring grassland and shrubland systems in 2007 as part of an initiative to provide long-term, scientifically sound monitoring data to inform park management of natural resources. Specifically, SCPN collects data on the structure and abundance and species composition and richness of upland vegetation, soil surface features, and soil stability (DeCoster et al. 2012).

SCPN staff established sets of long-term monitoring plots in five grassland ecosystem types in three park units: the sandy loam upland ecological site at Chaco Culture National Historical Park (CHCU); sandy loam upland and clayey fan ecosites at Petrified Forest National Park (PEFO); and loamy upland and volcanic upland ecosites at Wupatki National Monument (WUPA). Monitored sites include grassland and mixed grassland shrublands.

Reporting on natural resource status and trend is a primary goal of the Inventory and Monitoring (I&M) program (NPS 2012). This report presents a summary of selected results from upland monitoring in semi-arid grasslands in three parks from 2007–2021. In the first section, data collected over all years are summarized to provide a robust estimate of status for selected indicators. In the second section, Bayesian hierarchical models are employed to look at how selected response variables have changed over time during 15 years of monitoring.

Methods

Study area

The Southern Colorado Plateau Inventory and Monitoring Network encompasses 19 NPS units on 1,857,732 ha of protect lands in the Four Corners region (northern Arizona, northern New Mexico, southern Colorado, southern Utah), including > 750,000 ha of designated or proposed wilderness (Thomas et al. 2006). Within this area, SCPN has been monitoring upland vegetation since 2007.

Semi-arid grassland and mixed grassland/shrubland is a common vegetation type throughout the SCPN (Thomas, 2006). We monitor this ecosystem type in three park units: Chaco Culture National Historical Park (CHCU), Petrified Forest National Park (PEFO) and Wupatki National Monument (WUPA) (Figure 1). Monitoring began in all three parks in 2007.

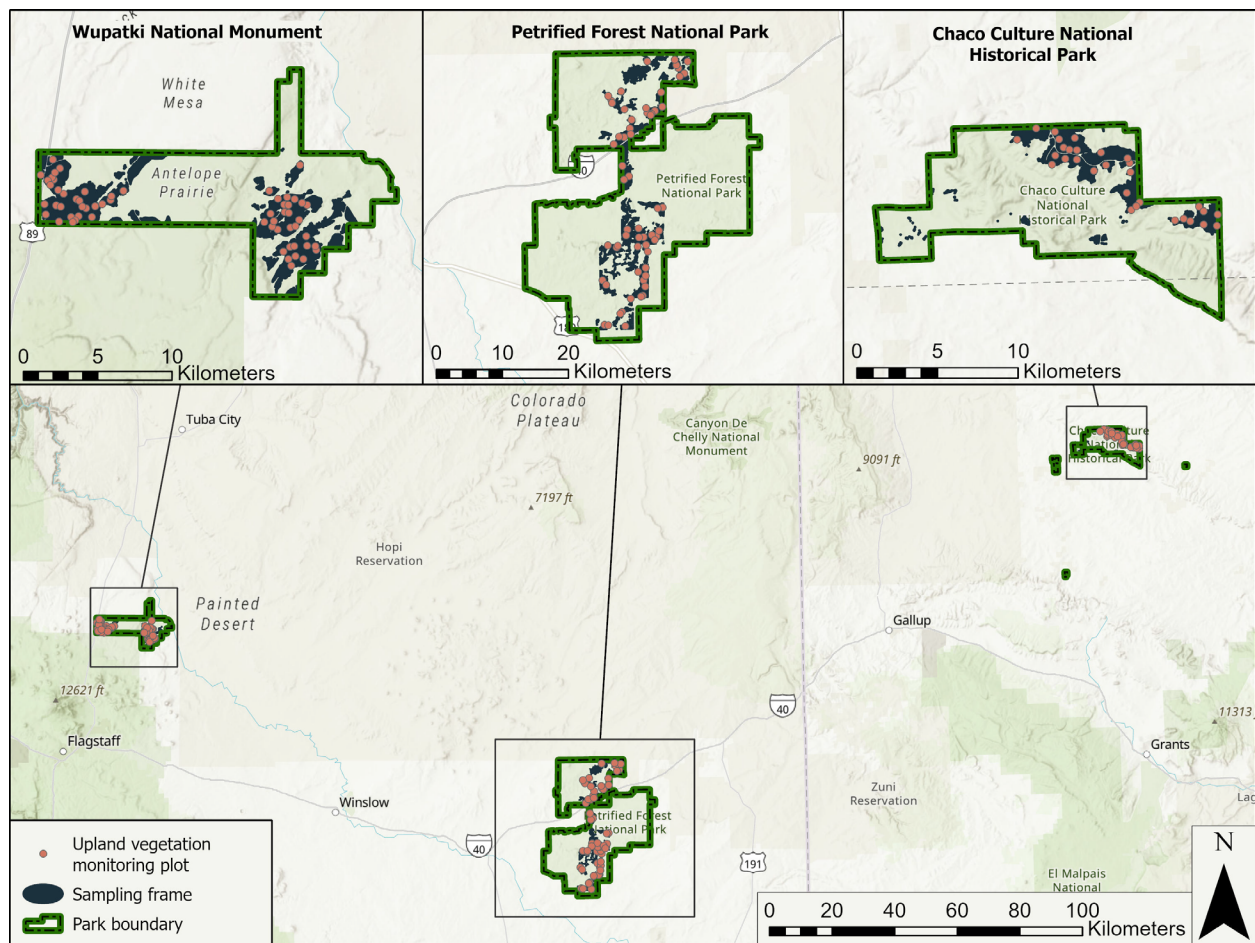


Figure 1. Overview map of the sampling frames and plot locations for the three NPS units included in this report.

Sampling frames

Ecological sites were used to select and define areas for monitoring (DeCoster et al. 2012; Figure 2). An ecological site (ecosite) represents a unique combination of soils and potential vegetation (Caudle et al. 2013). Ecosites with a large spatial extent and valued by park staff and regional experts were selected for monitoring (Thomas et al. 2006).

When developing the sampling frame, soil map units containing high percentages of the target ecosite. were modified by removing areas not appropriate for monitoring, including areas surrounding infrastructure (roads and buildings), heavily disturbed areas, and areas with slopes $>20\%$ (Soil Survey Staff, NRCS SSURGO dataset, 2012). Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) was used to generate a set of spatially distributed potential sampling points within the final sampling frame and points were then field screened to remove any plots that did not align with soil or ecosite characteristics.



Figure 2. An example of the sandy loam upland ecological site at Chaco Culture National Historical Park (NPS/MEGAN SWAN).

Monitoring methods

This report presents data from 150 permanent monitoring plots: 30 plots at CHCU, 60 plots at PEFO, and 60 plots at WUPA (Figure 1). A subset of 10-20 plots in each park was established during 2007 and these plots were resampled every year through 2011 to better understand interannual variability at the sites. Subsequently, additional plots were established, and a structured panel revisit (monitoring) design was implemented at the sites in 2012 (DeCoster et al. 2012). Plots were randomly assigned to one of three monitoring panels (n=10 plots/panel). Two of these panels (20 plots) were sampled every other year in a rotating design. A complete panel revisit cycle, in which all plots are sampled twice, takes five years (Appendix A).

During the monitoring period (2007–2021), the maximum number of revisits to a single plot was seven and the minimum was two. Our panel revisit design was significantly impacted by the onset of the Covid-19 pandemic in 2020. Due to crew health and safety limitations, we were only able to sample a subset of plots at WUPA and no plots at the other park units during that field season. A complete sampling history for all the plots is provided in Appendix A (Figure A-1). At WUPA, an update of the monument’s soil map in 2013 changed our understanding of our target ecosites and altered our sampling frames (USDA 2015). We chose to adjust our sampling frame accordingly, which resulted in seven of our original plots being decommissioned and seven new plots added. At CHCU, one plot was removed after being sampled in 2014 because it didn’t meet the ecosite characteristics and it was replaced with an additional plot. Data from removed and decommissioned plots are not included in this report.

Ecological sites

The grassland monitoring plots comprise five ecological sites in three park units: sandy loam upland and clayey fan at PEFO, volcanic upland and loamy upland at WUPA and sandy loam upland at CHCU (Table 1). CHCU, PEFO (clayey fan) and the lower elevation site at WUPA (loamy upland) are in the 6-10” precipitation zone (p.z.), the others are in the 10-14” p.z. The spatial extent of the ecological sites at PEFO are much larger than the others (Table 2).

Table 1. Names and characteristics of the five ecological sites included in this report.

Unit Name	Ecosite Name	Ecosite Code	Ecosite ID	Elevation (m)	Area (ha)
CHCU	Sandy loam upland 6-10” p.z.	CHCU S	R035XB030NM	1961	1725
PEFO	Clayey fan 6-10” p.z.	PEFO C	R035XA105AZ	1661	5400
PEFO	Sandy loam upland 10-14” p.z.	PEFO S	R035XA117AZ	1782	4191
WUPA	Loamy upland 6-10 “p.z.	WUPA L	R035XB239AZ	1426	1425
WUPA	Volcanic upland 10-14” p.z.	WUPA V	R035XA108AZ	1701	1508

Monitoring plots

Monitoring plots are 50 m x 52 m and consist of three parallel 50 m transects spaced 25 m apart (Figure 3). Within this area, field crews collect data on shrub and herbaceous vegetation and soil attributes using quadrat and transect-based sampling. See the integrated upland monitoring protocol for detailed explanation (DeCoster et al. 2012). Plots were sampled at as close as possible to the same time each year and as close to maximal plant growth as possible given schedule constraints (Appendix A, Figure A-2).

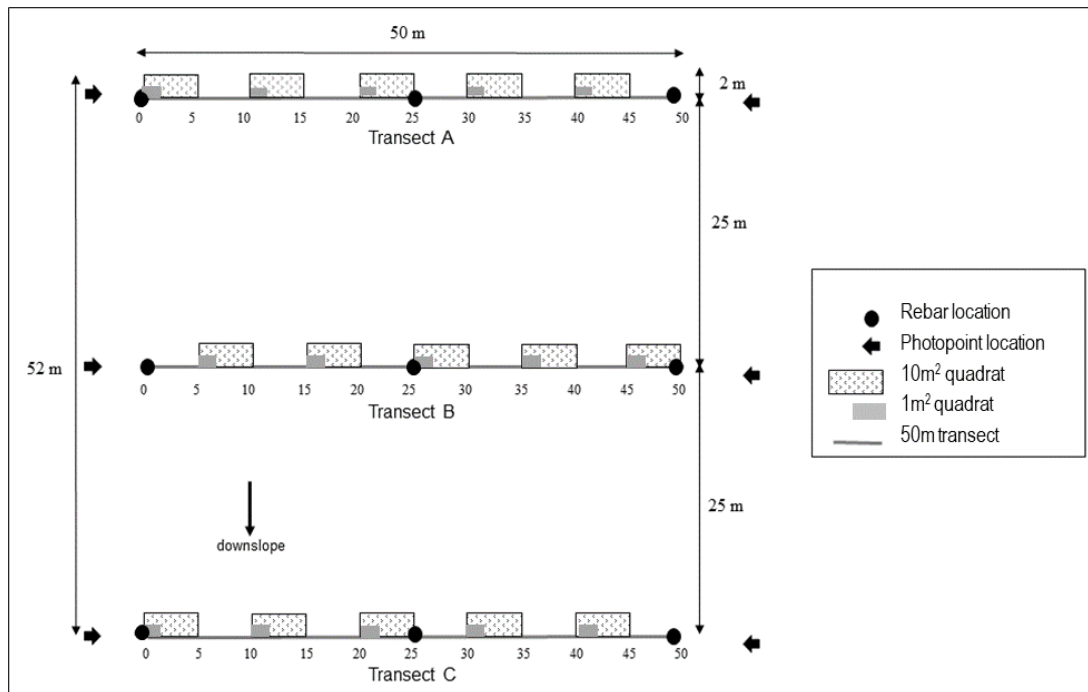


Figure 3. Diagram of a Southern Colorado Plateau Network upland monitoring plot. Shrub and herbaceous cover are measured in 10 m² quadrats, soil surface features in 1 m² quadrats. Basal gaps are sampled along each 50 m transect and photopoints are taken at each transect end facing towards the center of the transect. Soil stability samples are taken from six random locations along each transect.

Soil profile and surface features

When establishing a plot, a soil profile sample is collected using a 1½ inch diameter soil auger. Soil is extracted to the maximum depth possible (or 100 cm), then divided into 10 cm increments. Soil effervescence, color and texture is assessed in the field using standard methods for each depth increment.

When sampling, soil surface features and biological soil crust attributes were assessed in 1 m² quadrats nested within the 10 m² quadrats and located at 10 m intervals along each transect (Figure 3). Crews make ocular estimates of absolute cover for each of the fourteen categories of soil surface features including surface gravel and rocks (characterized by size class), live and dead plant bases, duff and litter, woody debris, cyanobacteria, lichen, and moss using one of 12 possible cover classes (Table 2).

Soil stability

Soil aggregate stability is sampled by collecting soil surface fragments from six random locations along each transect (18 per plot) and immersing the collected soil fragments repeatedly in distilled water, then rating the degree to which the soil particles hold together (Herrick et al. 2009). We rate soil samples on a scale of 1–6. Values close to one indicate lowest particle aggregation. A rating of six is reserved for extremely stable samples that withstand being soaked and dipped in water with no change in volume. Soil stability sampling is not conducted at WUPA, due to the large amount of surface gravel. From 2007 to 2015, when observers encountered deep litter, surface stones, or exposed bedrock during sampling, they did not take the sample. As a result, in years prior to 2016, fewer than 18 soil samples were sometimes collected within a plot. In 2016, the protocol was altered to permit observers to select new random locations to sample when the soil surface is obstructed at the original random sampling point.

Herbaceous and shrub vegetation

Within each plot, field crews estimate percent cover of live herbaceous and shrub vegetation in fifteen 10 m² (2 m × 5 m) quadrats (Figure 3). They place five quadrats at 10 m intervals along each transect and identify all live vascular plants observed in each quadrat to species (or the lowest taxonomic level possible). Ocular estimates of absolute cover for each species are made using one of 12 cover class intervals ranging from >0.1% to 75–100% (Table 2). Plants were considered live if there was evidence that they were living at any point during the current growing season, even if they are dead or senescent during sampling. Plants that have foliar cover within the quadrat but are rooted outside the quadrat are assigned a cover class, but not a frequency.

All live species are then aggregated into lifeform categories (perennial grass, annual grass, forb, shrub, and cacti/succulent) to estimate cover class (Table 2) for each lifeform detected in the quadrat while accounting for layering and overlap. A cover class for the aggregated total of all live cover (total foliar) is also assigned and represent the estimated aggregated total of all live grass, forb and shrub cover in a plot. Lastly, all standing dead herbaceous and standing dead woody vegetation are assigned cover classes within the 10 m² quadrat.

Table 2. Cover classes used by the Southern Colorado Plateau Network for estimating ocular cover during upland monitoring.

Cover Class	Range	Midpoint
0	0	0
1	<0.1%	0.05%
2	0.1–0.5%	0.30%
3	>0.5–1%	0.75%
4	>1–2%	1.50%
5	>2–5%	3.50%
6	>5–10%	7.50%
7	>10–15%	12.50%
8	>15–25%	20.00%
9	>25–35%	30.00%
10	>35–50%	42.50%
11	>50–75%	62.50%
12	>75–100%	87.50%

Data management and analysis methods

Status estimates

Sampling data were entered into Access databases, converted to SQL Server, and analyzed using the R statistical software package (R Core Team 2017, version 3.6.0). All data went through a rigorous Quality Assurance /Quality Control process with valid value constraints and complex logical tests before being loaded into a production database (DeCoster et al. 2012). Scientific names, common names, lifeform (shrub, forb, graminoid), and duration information (annual or perennial) for plant species were obtained from USDA PLANTS database (USDA NRCS 2021). Taxonomy was standardized using the Integrated Taxonomic Information System (ITIS, www.itis.gov). A complete list of plant species encountered at the five grassland ecological sites is provided in Appendix B.

Status estimates describe the characteristics of the site over the monitoring period (2007–2021). For status estimates, I summarized data across all years to minimize the effect of inter-annual variability in plots and responses, which provides a more robust characterization of the ecosite than a single year value. Status estimates are presented as plot averages except for species richness, which is presented at three scales (10 m² quadrat, 50 x 52 m plot, entire ecosite). Since plots were sampled unequal numbers of times, I first averaged all observations for each plot and year to get single-year, plot-level means, then averaged the plot means across years to get a single plot mean for the monitoring period. Plot means were averaged across years to provide ecosite averages.

For plant cover, I used the midpoints of each cover class as a metric value to represent the category and calculated arithmetic means of midpoints (Table 2). An exception is exotic plant frequency, for which absolute frequency (total number of quadrats containing species divided by total number of quadrats sampled) is presented. The approach of using cover class midpoints for status estimates treats categorical data (ordinal cover classes) as numeric data (percent cover) by using arbitrarily based midpoint values which is not statistically supported (Herpigny and Gosselin 2015). However, this approach is still commonly used in ecology (e.g., Johnson et al. 2006, Munson 2011). See Table 3 for a list of responses included in the status section of this report.

Trend estimates

A Bayesian hierarchical modeling approach was used to investigate change over time in plant cover in response to climate and topographic variables. This approach allows us to properly model data despite several challenges: data were intentionally missing because of sampling design; sample sizes were not stable across years; cover class estimates represent percent cover as ordinal classes; and responses were generally not normally distributed (Hobbs and Hooten 2015). Model details are provided in Appendix D and summarized below. See Irvine et al. (2016) and Zachmann et al. (2021) for detailed descriptions of this modeling approach.

The basic form is a general linear model with additive covariates, interpreted as the change in the prediction of the response variable (e.g., foliar cover of perennial grass) per unit time. I fit three types of models for plants depending on the response. Cover class data for dominant perennial grass and shrub species (those that occurred in >30% of plots in at least one ecological site) were modeled using a hurdle at 0 inverse logit deterministic model, and an ordinal latent beta model described by Irvine et al. (2016). This mixed model uses a beta distribution to model a continuous latent cover percentage and includes a hurdle term to separate the presence/absence response from cover when present (Irvine et al. 2016). For responses like perennial grass cover which are present in every plot, inference on the presence/absence component of the model was dropped to improve model fit.

To model the prevalence of annual and perennial forbs and infrequent species with very low overall percent cover, a zero-inflated binomial model was applied to presence/absence data using the five quadrats on each transect as trials and presence in the quadrat as a hit. Finally, for species richness, the number of unique species sampled within each quadrat, was modeled for each ecological site using a generalized Poisson likelihood. Multi-ecosite models failed to converge adequately, so we modeled species richness separately for each ecological site, using the same model and covariates. All responses modeled for trend are listed in Table 3.

Table 3. Summary of response variables assessed in this report. “A” indicates response was assessed (also in green) while “–” indicates response was not assessed in status and trend sections of this report. Status analyses includes all ecological sites, but not all responses were assessed for trend in every ecological site so ecological sites in which the response were modeled for trend is listed in the “Ecological Site” column.

Response	Status	Trend	Ecological site
Climate	A	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Soil depth	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Soil texture	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Soil surface features	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Soil stability	A	–	CHCU S, PEFO C, PEFO S
Cover by lifeform	A	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Species composition	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Quadrat richness	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Plot richness	A	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Exotic species	A	–	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Cover by species	A	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Indian ricegrass	–	A	CHCU S, PEFO C, PEFO S
Black grama	–	A	WUPA V
Blue grama	–	A	CHCU S, PEFO C, PEFO S
New Mexico feathergrass	–	A	WUPA V
Galleta grass	–	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Dropseed	–	A	CHCU S, PEFO C, PEFO S
Four-wing saltbush	–	A	CHCU S, PEFO C, PEFO S
Mound saltbush	–	A	PEFO C
Snakeweed	–	A	CHCU S, PEFO C, PEFO S
Winterfat	–	A	CHCU S
Frequency by lifeform	A	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Annual forbs	–	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Perennial forbs	–	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V
Exotic forbs	–	A	CHCU S, PEFO C, PEFO S, WUPA L, WUPA V

Results represent model-predicted probabilities of the average percent cover, average probability of occurrence or average count of species per quadrat. Probabilities are based on distributions of

predictions accumulated over many iterations of model predictions. Models predict parameters for each site and year, whether or not the plot was sampled, which minimizes the effect of missing data in our panel sampling design (Zachmann et al. 2021). Plots sampled relatively more often have greater influence on model-predicted parameters. All Bayesian analyses were run in R 4.1.2 (R Core Team 2021) using Just Another Gibbs Sampler (JAGS) (Plummer 2019) as the Markov Chain Monte Carlo (MCMC) sampler.

Results are presented as means of the posterior distribution (i.e., modeled predictions of the mean of the response) for each year and the corresponding 95% credible intervals. To determine the effect of covariates, the distribution of the coefficient of each covariate is provided. If the 95th percentile did not include zero, the covariate is significantly correlated with the response variable. The magnitude of these values is comparable *within* a model, but not between models.

For each of the models, model fit was assessed using posterior predictive simulation to generate Bayesian p-values. Bayesian p-values <0.1 and >0.9 indicate significant lack of fit. All models were checked for convergence using the Gelman-Rubin diagnostic (Gelman-Rubin diagnostic ≤ 1.1 , Gelman and Rubin 1992). In cases where the model didn't converge with the full suite of covariates, less influential covariates were dropped until models achieved convergence. Covariates were considered less influential if they had a comparably smaller effect on the modeled response.

Site specific precipitation data used in status analyses were obtained from PRISM (PRISM Climate Group 2022). All summaries and figures were created using R and ggplot2 (R core team 2017; Wickham 2016). Models were run using R and the rjags package (rjags version 4.9, Plummer 2019).

Covariates

Water availability is the primary limiting factor to plant growth on the Colorado Plateau (Comstock and Ehleringer 1992). In previous reports (Swan et al. 2019 & 2022) United States Stage IV Quantitative Precipitation Archive plot-level accumulated seasonal precipitation was used to model plant responses (Lin and Mitchell 2005). However, the influence of precipitation on plant growth is often mediated by temperature, soil properties such as water holding capacity, and timing and intensity of rainfall. In some cases, derived water balance covariates such as soil water or climatic water deficit may better predict plant response than precipitation alone (Thoma et al. 2020). Water balance covariates incorporate temperature and precipitation into a single covariate, such as climatic water deficit (deficit). Deficit is defined as the difference between potential evapotranspiration (PET) and actual transpiration (AET). It is a measurement of water stress; higher deficit indicates plants need more water than is available.

Climatic water deficit (deficit) at the plot level were similarly calculated from Daymet data using a modified Thornthwaite water balance model (Thorton et al. 2016, Tercek et al. 2021) and summed over winter (Nov-Mar), and spring (Apr-Jun) for the current water year. Due to the disparity in sampling dates between WUPA, which is sampled in August, and the other parks, which are sampled in October, a single summer month deficit, July, was used in models including WUPA, while summer deficit (Jul-Sep) was used in models that did not include WUPA. Water balance covariates

were checked for correlation 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.

To partially account for the effects of variation in winter and spring temperatures on plant growth, accumulative growing degree-days (AGDD, January-June) was evaluated as a covariate in the models. AGDD were calculated following McMaster and Wilhelm (1997),

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

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). AGDD was calculated from daily plot temperatures sourced from Daymet (Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4

R1 <https://doi.org/10.3334/ORNLDAAAC/2129>, accessed 2022).

Two plot-scale topographic covariates important to patterns of plant growth: elevation and terrain, were also included as covariates. The terrain covariate incorporates slope and aspect into a single value (calculated as $\sin(\text{slope}) \cdot \cos(\text{aspect})$) to account for differences between plots in topography which could influence vegetation responses. Terrain ranges from -1 to 1. Steep south-facing slopes trend toward -1 and steep north-facing slopes trend toward 1. This and similar calculations have been widely used to approximate insolation (Stage 1976, McCune and Keon 2002) which can indicate topographically mediated variation in effective soil moisture.

Slope and aspect surface parameters were calculated from the 2022 National Elevation Datasets in the native datum (GCS NAD83, NAVD88 - meters) in ArcPro using the quadratic surface type with the adaptive neighborhood distance (which varies the neighborhood size-based changes in the landscape). The data was then extracted to the upland plot points (projected into GCS NAD83) without using bilinear interpolation. Mean elevation was similarly derived. Details on covariates used can be found in Table 4.

Table 4. Details on covariates used in models.

Covariate Name	Description	Data source	Units
AGDD	Accumulated growing degree days	Calculated from plot-level Daymet daily values	hours
Winter deficit	Nov-Mar sum of monthly climatic water deficit	Calculated from plot-level Daymet daily values	mm
Spring deficit	April-June sum of monthly climatic water deficit	Calculated from plot-level Daymet daily values	mm
July deficit	July sum of monthly climatic water deficit	Calculated from plot-level Daymet daily values	mm
Summer deficit	July-Sept sum of monthly climatic water deficit	Calculated from plot-level Daymet daily values	mm
Terrain	Topography variable	2022 National Elevation Datasets	NA
Elev	Mean elevation	2022 National Elevation Datasets	meters

Results and Discussion

Sampling overview

A total of 150 plots were established in the five ecosites and 661 plot sampling visits were made (Appendix A, Figure A-1). During all years, the start of sampling at each ecosite fell within a 20-day window, although sampling windows were occasionally extended to the end of the field season to complete sampling of all required plots (Appendix A, Figure A-2). In some years, not all targeted plots were able to be sampled.

Climate overview

All five ecological sites show a typical bimodal pattern of seasonal precipitation common to the Colorado Plateau. Most precipitation is received during the summer as part of the North American monsoon (Figure 4), although monsoon precipitation also tends to be variable both spatially and temporally (Figures 4 and 5). Winter and spring seasons contribute less precipitation and also tend to exhibit less spatial and temporal variability (Figure 4).

Median annual precipitation varied among ecosites, ranging from 184.5 mm at WUPA L to 253 mm at PEFO S, based on 30-year normal (the average value for each site during the most recent 30-year interval, 1991-2021, Figure 5). WUPA V receives the most summer (Jul-Sep) precipitation of the five sites (Figure 4), but there is notable variation in annual precipitation totals between plots (Figure 5). Median maximum temperature (Tmax) is coldest at CHCU (18.6 C) and warmest at WUPA L (22.5 C) based on the 30-year average (Figure 5).

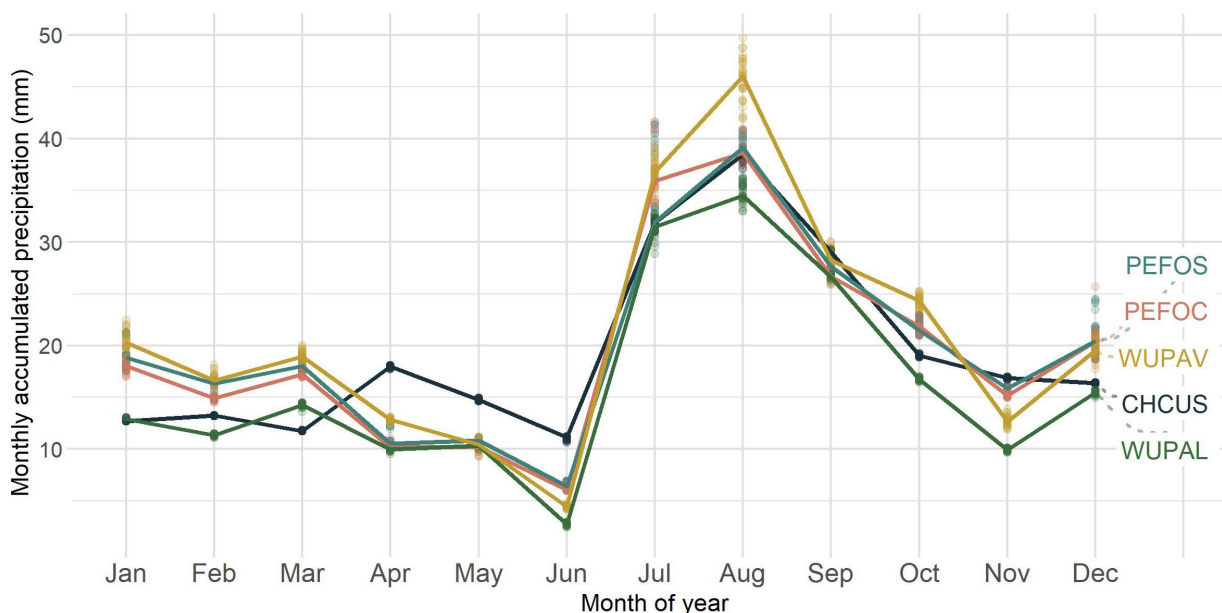


Figure 4. Seasonal precipitation patterns (1991-2021) based on 30-year normal at five ecosites in three National Parks (CHCU, PEFO, WUPA). Lines indicate median average accumulated monthly precipitation for each ecological site, dots represent plot-level values (data from PRISM Climate Group, accessed 17 May 2022).

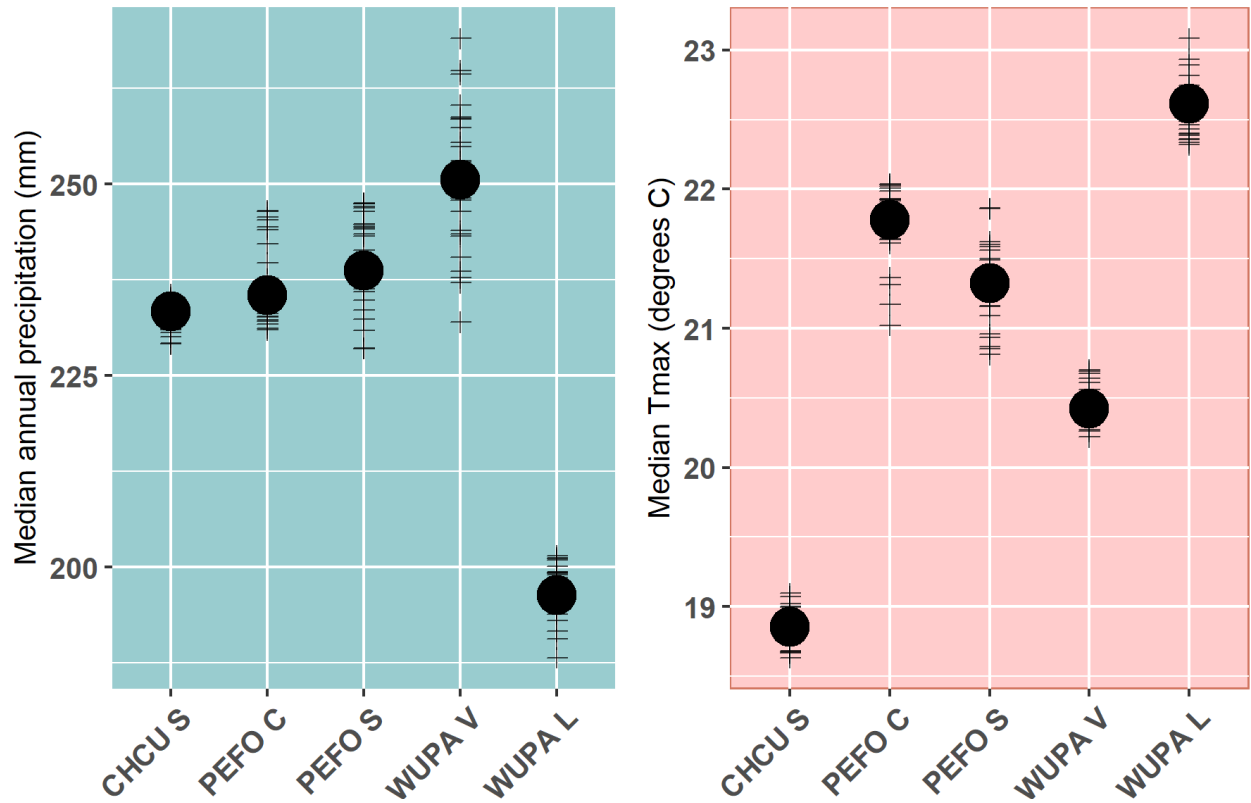


Figure 5. Median annual precipitation (left) and maximum temperature (right) based on 30-year normals (1991-2020) for five ecological sites in three National Parks (CHCU, PEFO, WUPA). The dots indicate medians for the ecological sites, and the crosses show plot-level medians to illustrate spatial variability (data from PRISM Climate Group, accessed 17 May 2022).

Soil overview

Soils in grassland ecological sites are primarily deep to moderately deep. Two-thirds of the plots sampled at PEFO S, PEFO C and CHCU S were at least 100 cm in depth (Figure 6). Soils in both ecosites monitored at WUPA were shallower; only five plots were 100 cm or deeper, and most plots at WUPA were ≤ 40 cm in depth (Figure 6). Since crews used a hand auger to extract soils, they were not able to determine whether the auger depth represented depth to bedrock, or depth to root restricting layers such as large cobbles.

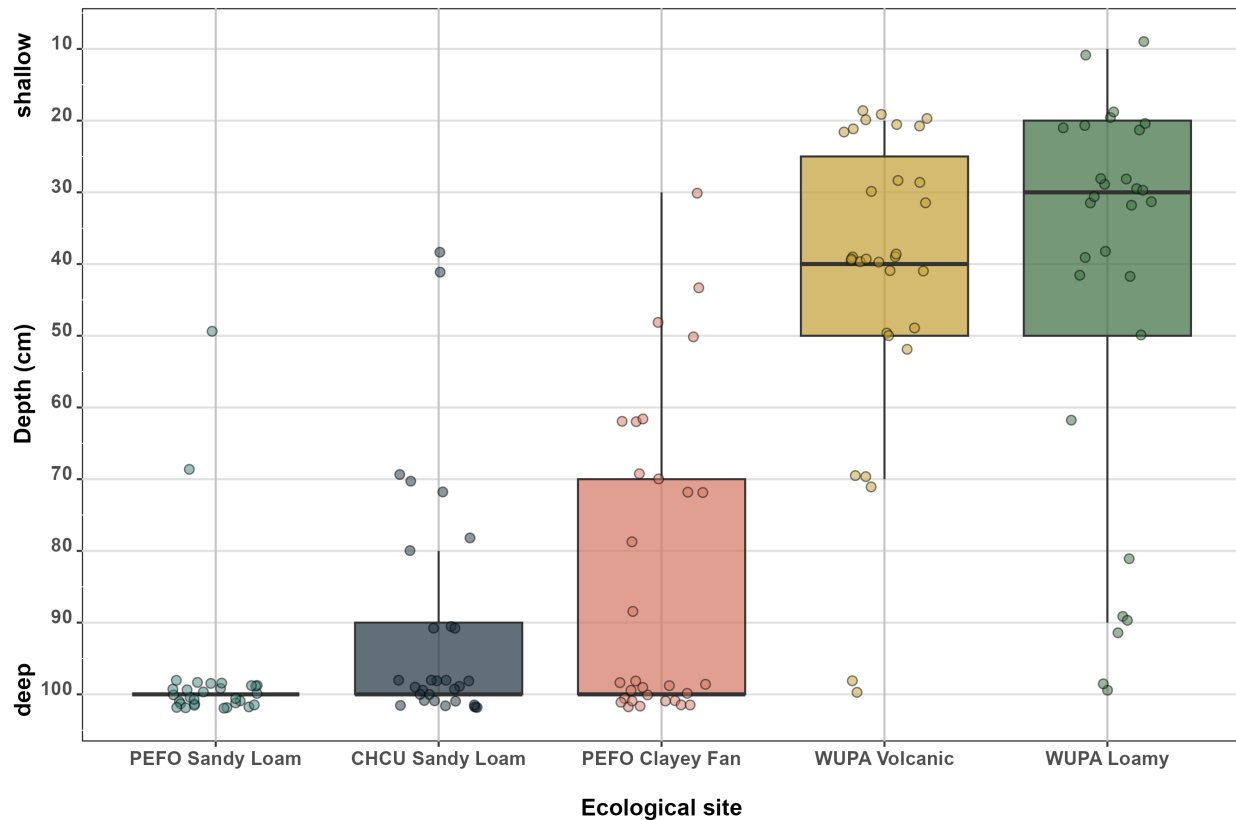


Figure 6. Maximum auger depth of soil profile samples collected during plot establishment at five ecosites in three National Parks (CHCU, PEFO, WUPA). Colored boxes indicate the 25% and 75% percentiles of soil depth, and the vertical lines indicate the range of depth (excluding outliers). Horizontal lines indicate the median depth. Colored dots indicate the soil depth for each plot sampled. 100 cm was the maximum depth collected.

Soil textures were variable between ecosites. Sandy loams and sandy clay loams were the most common soil textures at all depths (Figure 7). PEFO S and CHCU S soils were similar in that clay textures were more common at deeper depths. Soils were most clayey in the PEFO C ecosite, but not strongly so. At WUPA, most plots have a layer of coarse sand/ fine gravel (collectively referred to as cinders) on the soil surface. This surface layer varies in depth from sparse to centimeters deep both between and within plots at WUPA.

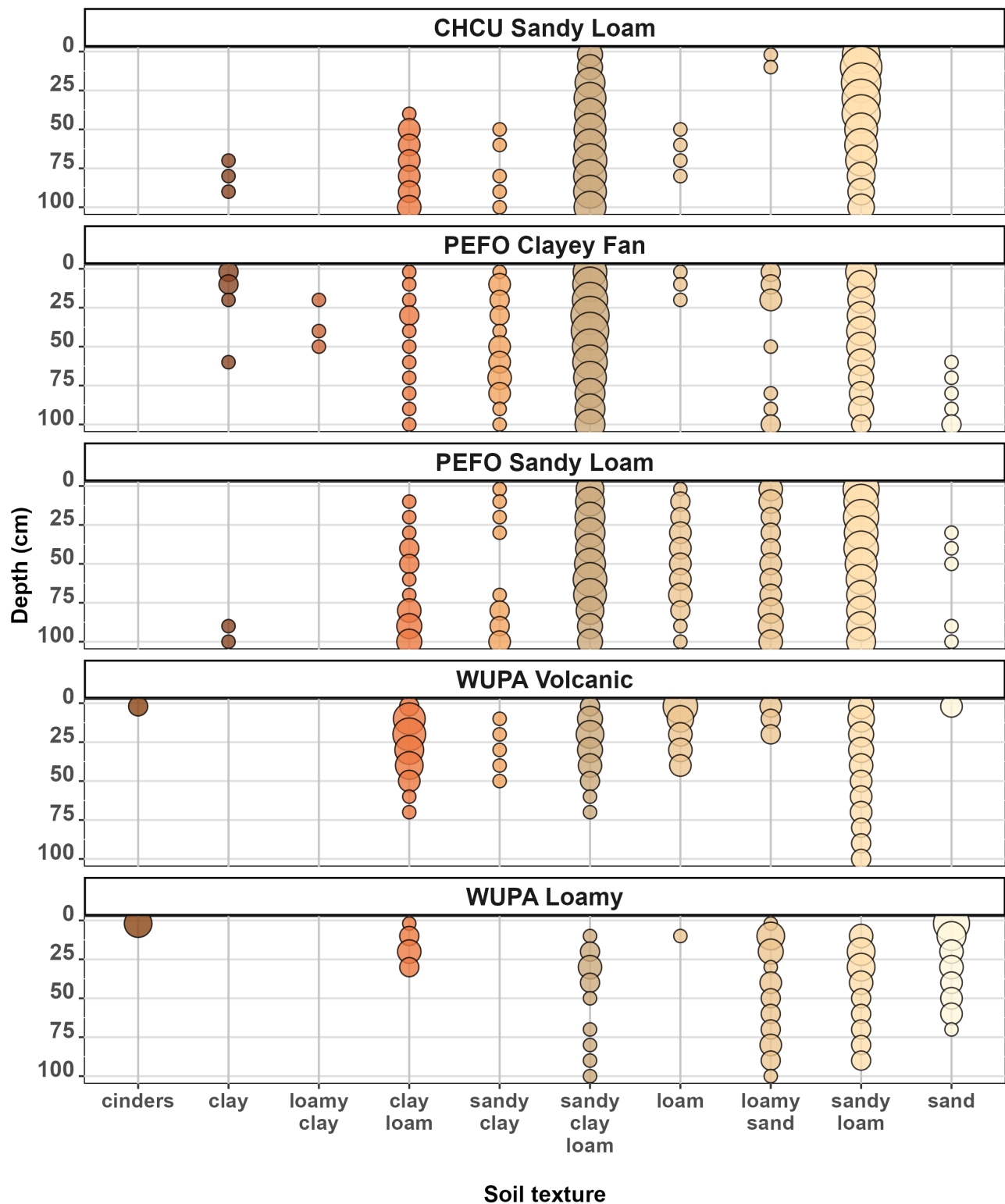


Figure 7. Texture of soil profile samples collected during plot establishment at five ecosites in three National Parks (CHCU, PEFO, WUPA). Textures for each depth increment were summarized across all plots in the ecological site. The size of each dot is determined by the prevalence of the texture for each depth layer.

On the soil surface, undifferentiated crust was the largest component of ground cover in all the plots sampled, except at WUPA where fine gravel dominated as described above (Figure 8).

Undifferentiated crust includes *both* physical crusts formed from raindrop impact on exposed soil (non-biologic), and cyanobacteria-dominated biologic soil crusts that have not yet developed surface roughness or distinct coloration, since these can't be distinguished effectively in the field (Belnap et al. 2008). Bare ground (unconsolidated surface soil) and undifferentiated crust cover were highly variable across plots (Figure 8). Some of this variation may be attributed to weather conditions during sampling, since distinguishing light cyanobacteria on wet soils can be difficult in the field, and physical crusts are most evident following rainfall events and break down quickly during dry periods, especially in sandy soils.

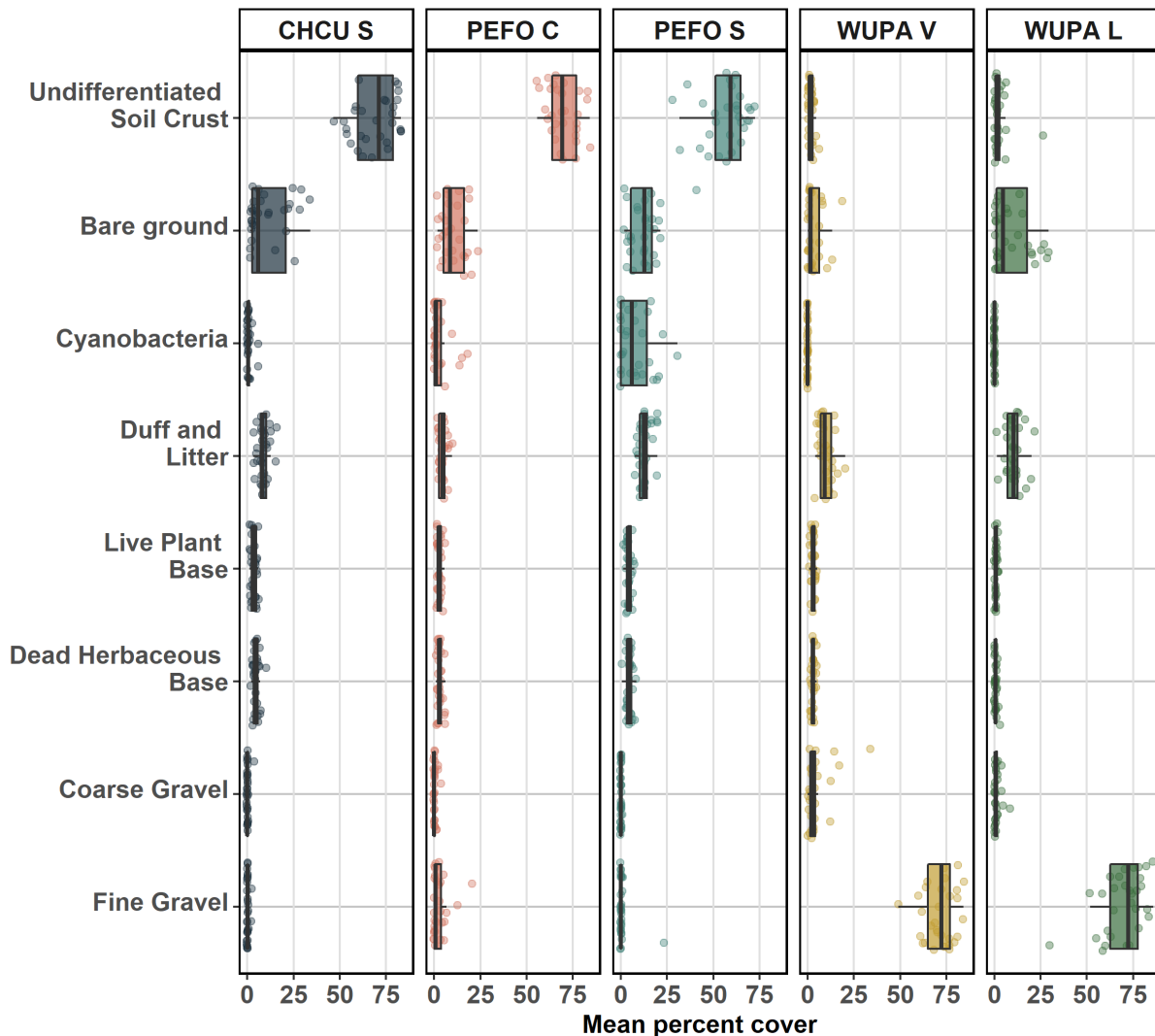


Figure 8. Mean percent cover of soil surface features at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007–2021. Colored boxes indicate the 25 and 75% percentiles, and the horizontal lines indicate the range of percent cover for each surface feature. The vertical line indicates the median percent cover. Colored dots indicate plot-level means. Surface features with less than 1% cover in all ecosites are not shown.

Soil stability sampling was conducted at three ecosites in CHCU and PEFO (Table 5). Soil stability is not monitored at WUPA due to the extremely gravelly surface soils. Overall soil stability was moderate across the three ecosites and generally higher in samples obtained under perennial vegetative cover compared to samples taken from locations with no cover (Table 5).

Table 5. Mean soil stability rating class for three ecosites in two National Parks (CHCU, PEFO) during 2007-2021. Soil stability rating class ranges from one (low soil aggregate stability) to six (high soil aggregate stability). In the Canopy Type column, “Vegetated” indicates samples were taken from under perennial vegetation canopy and “Bare” indicates samples had no perennial canopy cover.

Ecosite	Canopy Type	Mean Rating Class	SE
CHCU S	Overall	3.34	0.02
	Vegetated	4.01	0.02
	Bare	2.68	0.02
PEFO S	Overall	3.04	0.02
	Vegetated	3.55	0.03
	Bare	2.53	0.02
PEFO C	Overall	3.60	0.02
	Vegetated	3.98	0.03
	Bare	3.10	0.02

Vegetation overview

Lifeform groups

Overall mean percent cover of live vegetation ranged from 12% to 24% but was variable across ecological sites and between plots and years (Table 6). Overall cover of live vegetation was greatest at WUPA V, and PEFO S. Perennial grass cover was greatest at WUPA V and comprised $\geq 70\%$ of live foliar cover for all ecosites except WUPA L, where grass cover contributed just 40% of total live cover (Table 6). Cover of shrubs was the greatest contributor to overall cover in plots at WUPA L (~50%) and lowest in plots at WUPA V (1%). Forb cover was greatest in plots at WUPA V and lowest at CHCU S. Annual grass and cactus are very minor components of all ecosites sampled, averaging less than 1% at all sites except for annual grass cover at PEFO C (8%). Native annual grasses (primarily *Sporobolus coromendelianus* and *Bouteloua barbata*) are common in this ecosite and often proliferate during wet periods in areas of clayey surface soils where water pools.

Table 6. Average percent cover (and range) by lifeform in five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007-2021. Range indicates the lowest and highest plot-level mean for each response.

Lifeform	CHCU S	PEFO C	PEFO S	WUPA L	WUPA V
Total live foliar	14.5 (0.91, 43.2)	12.9 (2.78, 43.5)	19.3 (5.0, 32.7)	12.0 (3.9, 36.8)	24.85 (0.47, 62.5)
Perennial grass	10.1 (0.68, 35.8)	8.8 (0.17, 27.8)	13.7 (0.68, 30.7)	5.1 (0, 36.8)	21.08 (0.28, 62.5)
Shrub	3.30 (0.07, 12.3)	1.8 (0.12, 8.8)	4.5 (0.32, 12.1)	5.4 (0.17, 13.7)	0.27 (0, 3.02)
Forb	0.74 (0.02, 5.2)	1.2 (0, 15.4)	1.4 (0, 6.2)	1.7 (0.01, 22.1)	3.4 (0, 33.2)
Annual grass	0.046 (0, 1)	1.1 (1, 23.2)	0.21 (0, 6.5)	0.0081 (0, 0.08)	0.00018 (0, 0.03)
Cactus and succulents	0.097 (0, 0.89)	0.064 (0, 0.7)	0.12 (0, 0.52)	0.0023 (0, 0.08)	0.0095 (0, 0.23)

Species occurrence

Crews detected 283 unique plant species (Appendix B) between 2007 and 2021 across five ecosites (including 42 unknown records and 36 that were grouped at the genus level due to inability to distinguish species reliably in the field). Just 23 of these (excluding unknowns) occurred in all five ecosites. Eighteen more were common to four of five sites. Almost half the species (139) were specific to a single ecosite and did not occur elsewhere.

Galleta grass (*Hilaria jamesii*), dropseeds (*Sporobolus* spp. reported at the genus level; species primarily represent *Sporobolus airoides* and *S. cryptandrus*) and purple 3-awn (*Aristida purpurea*) are warm season (C₄) grasses that occurred in all ecosites sampled. (Figure 10). Two cool season (C₃) grasses, Indian ricegrass (*Achnatherum hymenoides*) and squirreltail (*Elymus elymoides*), also occurred in all ecosites but percent cover did not exceed 1% at any ecosite (Appendix C). A total of 29 grass species were detected during the monitoring period (Appendix C).

Twenty-eight shrub species were detected during the monitoring period (Appendix C). Two species of shrubs, four-wing saltbush (*Atriplex canescens*) and rubber rabbitbrush (*Ericameria nauseosa*), were found in all five ecosites. Six cacti were also detected, two of which (*Cylindropuntia whipplei* and *Opuntia* spp.) occurred in all five ecosites.

Forbs contributed a disproportionate amount of diversity to these ecosites, accounting for >71% of species (N=69 excluding unknowns). Forbs represented a mix of annual, biennial, and perennial species with varied growth forms (Figure 9). Globemallows (*Sphaeralcea* spp.), roseheath (*Chaetopappa ericoides*) and dwarf morning glory (*Evolvulus nuttallianus*) were found in every ecosite, as were Western tansymustard (*Descurainia pinnata*), pigweed (*Amaranthus* spp.), and white-stem blazing star (*Mentzelia albicaulis*). Identification was not confirmed for 35 forbs, these

unknown plants usually occurred in a single plot and single year and most often in a very early stage of growth.



Figure 9. Forbs represent a large component of species richness in grassland ecosites. Thread-stem carpetweed (*Mollugo cerviana*), trailing windmills (*Allionia incarnata*) and Coulter's wrinklefruit (*Clerodendrum coulteri*) are examples of forbs that occurred in a single ecosite (WUPA L).

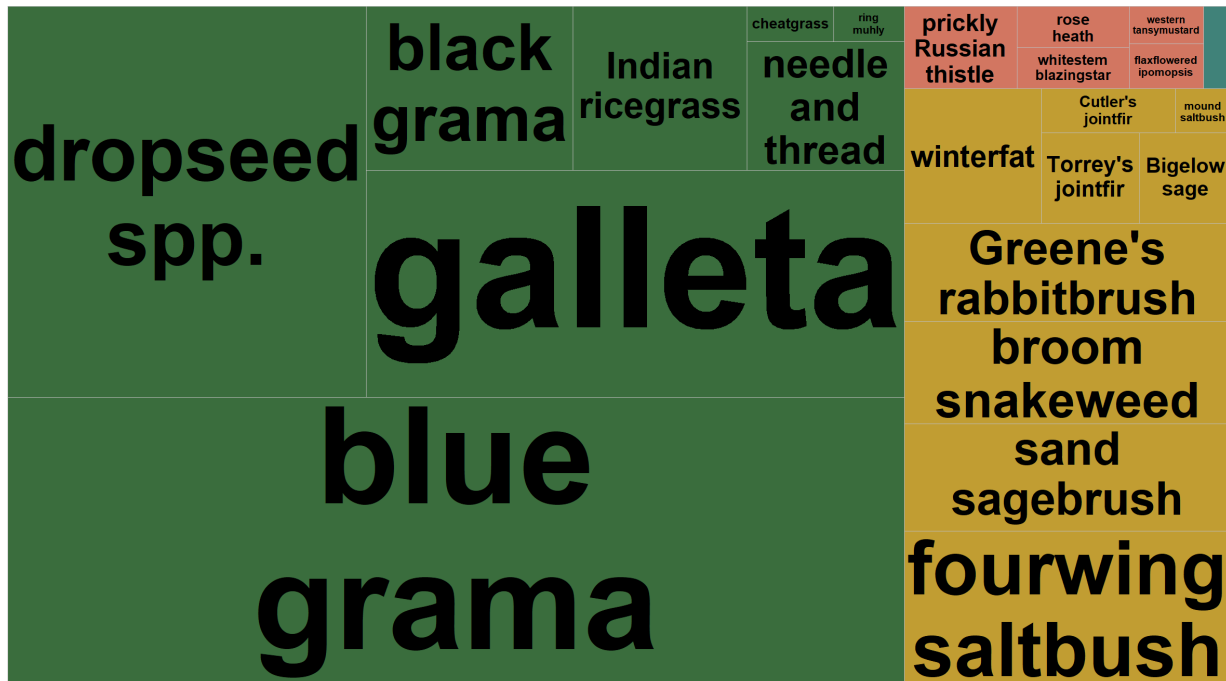
Composition

The following tree maps provide a visual representation of relative proportions of percent cover of dominant species and lifeforms within each ecosite (Figures 10a, b, c). Species composition was generally similar in four of five sites. Foliar cover of grass (indicated in green in Figure 10) comprised >75% of total foliar cover for all ecosites except WUPA L, which was the most shrub dominated of the ecological sites (shown in yellow Figure 10d). Composition of grass species varied among ecosites, with all but one of the most dominant grass species in each ecosite using the C₄ photosynthetic pathway [exception is New Mexico feathergrass (*Hesperostipa neomexicana*) at WUPA V]. Galleta grass (*Hilaria jamesii*) was a dominant grass species in all five ecosites. Most ecosites exhibited co-dominance in grass species with the exception of WUPA V which was strongly dominated by galleta grass. Galleta grass accounted for > 80% of graminoid cover at WUPA V (Figure 10e).



Lifeform forb graminoid shrub cactus succulent

Figure 10a. Tree map of dominant species in the CHCU S (top) and PEFO C (bottom) ecological sites. Box color indicates lifeform group and box size indicates relative dominance of species by percent cover. Species with less than 0.05% cover are not shown. [Data for this figure are available in Appendix C.](#)



Lifeform ■ forb ■ graminoid ■ shrub ■ cactus succulent

Figure 10b. Tree maps of dominant species in the PEFO S (top) and WUPA L (bottom) ecological sites. Box color indicates lifeform group and box size indicates relative dominance of species by percent cover. Species with less than 0.05% cover are not shown. [Data for this figure are available in Appendix C.](#)



Figure 10c. Tree maps of dominant species in the WUPA V ecological site. Box color indicates lifeform group and box size indicates relative dominance of species by percent cover. Species with less than 0.05% cover are not shown. [Data for this figure are available in Appendix C.](#)

Richness

Species richness was highly variable across sites at the quadrat and plot scales (Table 7). At the smallest scale (quadrat: 10 m²), richness ranged from 0–26 species. Highest richness was found at PEFO S with an average of >9 species per quadrat, and lowest quadrat richness was found at WUPA where both ecosites averaged <5 species per quadrat (Table 7).

At the plot scale (2,600 m²), the lowest richness encountered during sampling was four and the highest was 47 species. Average number of species ranged from 12.5–26.5 (Table 7). PEFO S had the greatest plot-scale richness, and WUPA L had the lowest. The wide range of richness at these scales reflects the patchy distribution of species in these grasslands.

Table 7. Average quadrat (10 m²) and plot-scale (2,600 m²) richness estimates and range (lowest and highest values) for five grassland ecological sites in three National Parks during 2007–2021 (CHCU, PEFO, WUPA).

Ecosite	Mean quadrat richness (range)	Mean plot richness (range)
CHCU S	8.38 (2, 20)	20.8 (11, 35)
PEFO C	7.62 (1, 24)	22.6 (5, 47)
PEFO S	9.18 (1, 26)	26.5 (4, 45)
WUPA L	4.24 (0, 12)	13.9 (4, 27)
WUPA V	4.82 (0, 12)	12.5 (4, 23)

Richness is not comparable at the ecosite-scale since we sampled different numbers of plots each year (Appendix A) and the area of each ecosite varies (Table 1).

Non-native species

A total of 18 non-native species were detected across the five ecosites. Russian thistle (*Salsola tragus*) was the only non-native that occurred in all five ecosites and was the most abundant non-native in all ecosites (Table 8). Cheatgrass (*Bromus tectorum*) was encountered in all but one of the five ecosite (WUPA L) but occurred in relatively fewer plots compared to Russian thistle and had less cover. Ten non-native species were unique to a single ecosite.

The highest number of non-native species were found in the two Petrified Forest ecological sites which each had a total of 12 non-native species detected over the monitoring period (2007-2012); Wupatki ecosites both had four non-natives and Chaco Canyon NHP had just three. Most non-native species were annual forbs (77%).

Table 8. Overall percent quadrat frequency of the 18 non-native species encountered during sampling in five ecosites at three National Parks during 2007 to 2021 (CHCU, PEFO, WUPA). Scientific and common names, and duration from IITIS, 2022. NP indicates species did not occur in ecological site.

Scientific Name	Common name	Duration	PEFO C	PEFO S	WUPA L	WUPA V	CHCU S
<i>Bromus rubens</i>	red brome	annual	0.43	0.19	NP	NP	NP
<i>Bromus tectorum</i>*	Cheatgrass*	annual	6.92	5.90	NP	0.15	1.43
<i>Erodium cicutarium</i>	redstem' stork's bill	annual	0.51	0.05	NP	NP	NP
<i>Halogeton glomeratus</i>*	Saltlover*	annual	0.94	NP	NP	NP	NP
<i>Hordeum murinum</i>	mouse barley	annual	NP	0.14	NP	NP	NP
<i>Kochia scoparia</i>*	Burningbush*	annual	NP	1.24	NP	1.64	NP
<i>Mollugo cerviana</i>	threadstem carpetweed	annual	0.68	0.67	1.55	1.14	NP
<i>Polygonum aviculare</i>	prostrate knotweed	annual	NP	0.05	NP	NP	NP
<i>Portulaca oleracea</i>	little hogweed	annual	NP	NP	NP	NP	0.22
<i>Ranunculus testiculatus</i>	curveseed butterwort	annual	0.04	NP	NP	NP	NP
<i>Rumex acetosella</i>	common sheep sorrel	perennial	0.09	NP	NP	NP	NP
<i>Salsola collina</i>	slender Russian thistle	annual	0.13	0.14	NP	NP	NP
<i>Salsola tragus</i>	prickly Russian thistle	annual	37.65	19.43	4.98	55.47	8.50

* Species included on the noxious weed list in Arizona (WUPA, PEFO) or New Mexico (CHCU). Species are also shown in bold.

Table 8 (continued). Overall percent quadrat frequency of the 18 non-native species encountered during sampling in five ecosites at three National Parks during 2007 to 2021 (CHCU, PEFO, WUPA). Scientific and common names, and duration from IITIS, 2022. NP indicates species did not occur in ecological site.

Scientific Name	Common name	Duration	PEFO C	PEFO S	WUPA L	WUPA V	CHCU S
<i>Sisymbrium altissimum</i>	tumblemustard	annual	NP	0.52	NP	NP	NP
<i>Solanum elaeagnifolium</i>	silverleaf nightshade	perennial	NP	NP	2.82	NP	NP
<i>Taraxacum officinale</i>	dandelion	perennial	0.13	NP	NP	NP	NP
<i>Thinopyrum ponticum</i>	tall wheatgrass	perennial	0.26	NP	NP	NP	NP
<i>Tragopogon dubius</i>	yellow salsify	biennial	0.04	0.33	0.05	NP	NP

* Species included on the noxious weed list in Arizona (WUPA, PEFO) or New Mexico (CHCU). Species are also shown in bold.

Trend

Assessing trend

I&M networks are tasked with reporting on status and trend of selected natural resources. While significant change in vegetation communities commonly occurs over decades or centuries, some metrics (e.g., richness, plant cover and frequency) typically exhibit high variability from year to year in response to mechanistic driver variables, such as rainfall and temperature (e.g., de Dios Miranda et al. 2009, Schwinning and Ehleringer 2001). Therefore, assessing trend over relatively short durations, such as the 15-year monitoring period, offers many challenges.

Non-directional, year-to-year weather variation can have a large effect on perceived linear trends, especially if years with extreme highs or lows occur at the start or end of the monitoring period. Annual variation in weather was partially accounted for by adding predictor variables (covariates) to our models. However, climate change is now influencing precipitation patterns and driving temperatures consistently higher every year on a global scale (IPCC 2022). The results presented here indicate our best assessment based on the current toolset. A critical next step will be to explicitly link changes in response variables to system drivers (e.g., weather) to refine estimates.

Climate

During the monitoring period (2007-2021) the Southwest United States has been in a period of historic drought. 2000-2021 was the driest period of this duration since at least 800 CE, and possibly longer (Williams et al. 2022). Despite this, annual precipitation totals have varied, both spatially (between plots) and temporally (between years) (Figure 11). The driest conditions relative to normal were experienced at WUPA L in 2016, when many plots received just 25% of average precipitation for the year (Figure 11). The wettest conditions were at PEFO C in 2010 and during 2013 and at WUPA V; many plots received nearly 200% of normal precipitation during those years (Figure 11). Some years were particularly wet or dry for all the sites. 2015 was wetter than average for all sites, and 2020 was an exceptionally dry year in all sites except PEFO S.

The seasonal timing of annual precipitation was also variable. Winter (November-March) and spring seasons (April-June) have been consistently drier than the long term (1991-2021) average with very few exceptions, and summer (July-September) rainfall has been more variable (Figure 12). On the Southern Colorado Plateau, summer precipitation is largely the result of the North American monsoon, which tends to have greater variability than the other seasons, both spatially and temporally (Adams and Comrie 1997). There is also less certainty about the response of monsoon precipitation to climate change (Bhattacharya 2022), whereas the predicted reduction in future spring precipitation is more certain (Bradford et al. 2021).

Air temperature also varied from long term averages during this period, trending warmer (Figure 13). The median highest monthly temperature (Tmax) exceeded the long-term average for 11 of the 14 years at PEFO S and CHCU S, ten out of 14 years at PEFO C and WUPA V (Figure 13). WUPA L had the highest Tmax of the five ecosites (Figure 5). Interestingly, it was also the site in which Tmax exceeded average the fewest number of times (eight of the 15 years). The minimum temperature (Tmin) exceeded long-term average for fewer years at all sites. A broader analysis of temperature

across the Southwest indicates a 0.91°C increase in temperature from long term averages (Williams et al. 2022).

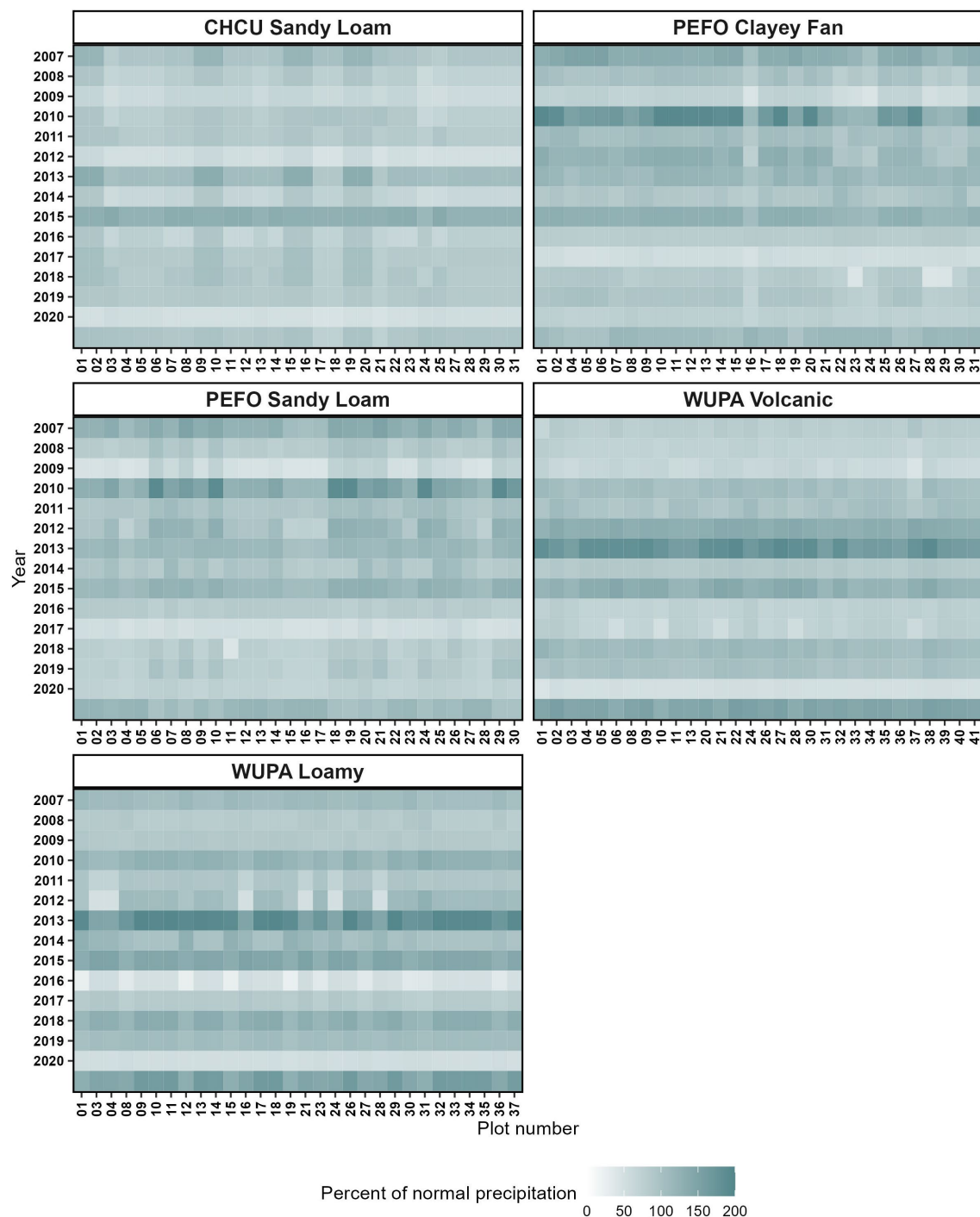


Figure 11. Percent of normal precipitation received at each monitored plot in five ecosystems in three National Parks (CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed 05/17/22). [Data for this figure are available in Table E-1 in Appendix E.](#)

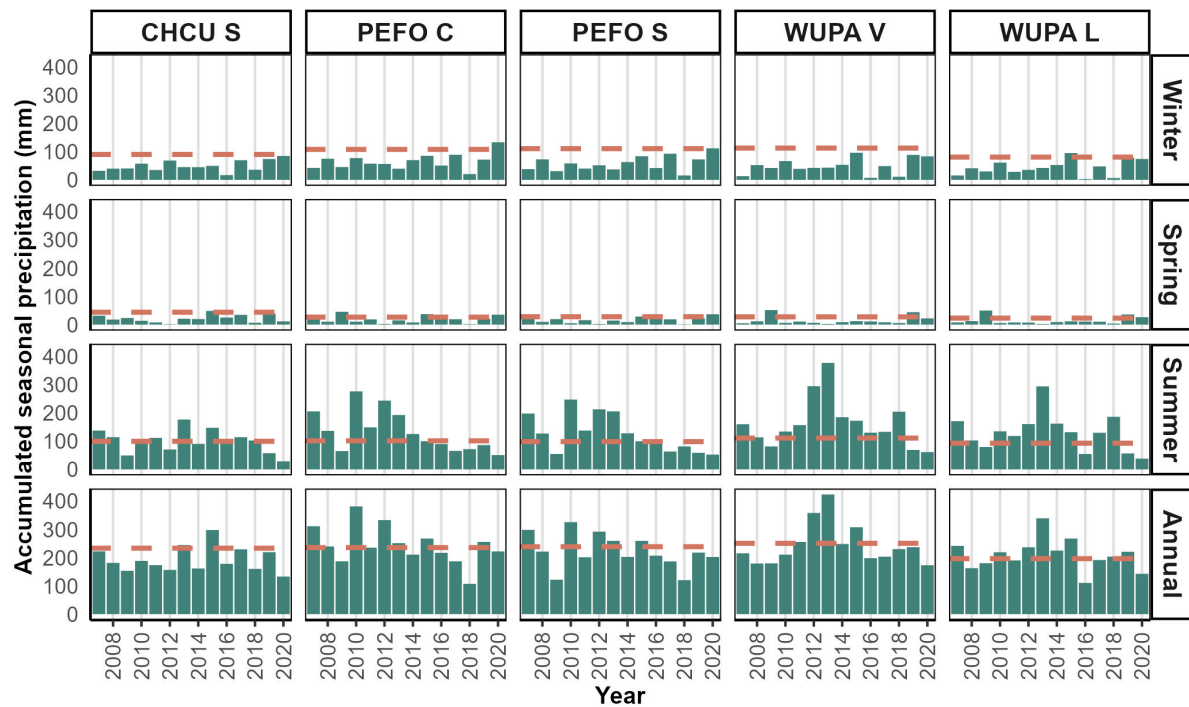


Figure 12. Median accumulated seasonal and annual precipitation totals at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2020. Horizontal red line indicates the 30-year normal (1991-2021) (normal from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

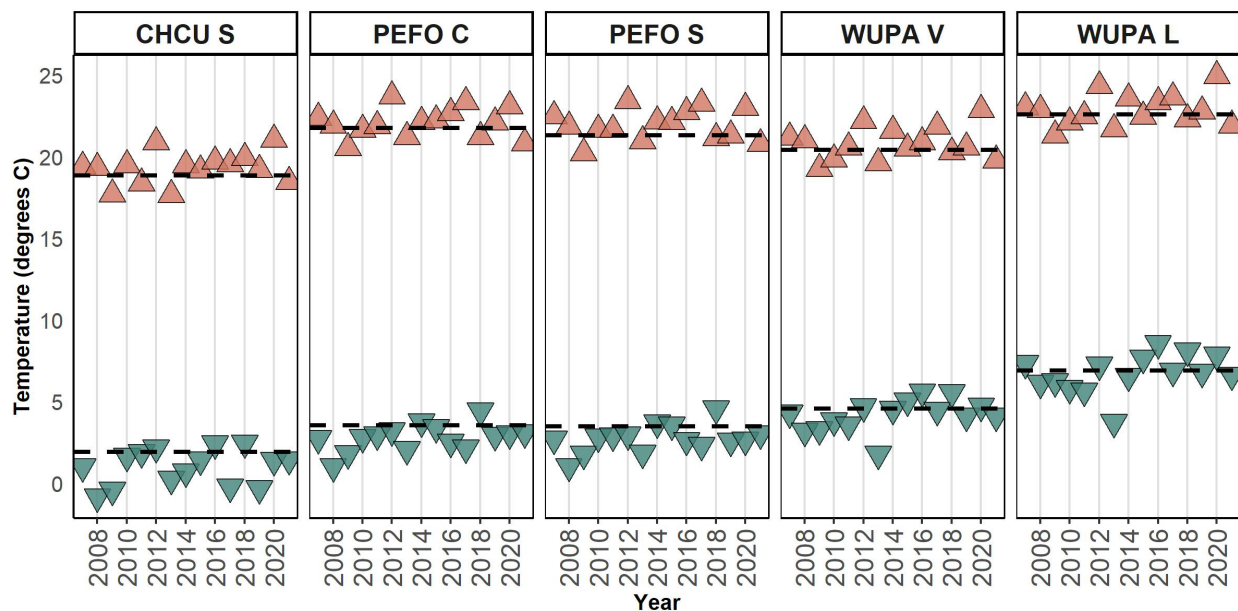


Figure 13. Annual median maximum temperature (Tmax, red triangles) and minimum temperature (Tmin, inverted green triangles) across plots at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Dotted lines represent 30-year normal (PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, Accessed May 17, 2022).

Multi-park models of plant cover

Perennial grass cover--all ecological sites

Live perennial grass cover was modeled across all five ecological sites. The model included winter climatic water deficit, spring deficit, July deficit, and accumulated growing degree days (AGDD; Appendix D). Plot elevation and terrain covariates were dropped from the model to achieve convergence. Inference on trend for the presence/absence component of grass cover was also dropped from this model, since perennial grass cover was present in nearly every quadrat sampled (i.e., the model didn't have enough zeros to estimate trend).

Model predictions of mean perennial grass cover ranged from 4.5% at WUPA L to 22.9% at WUPA V (Figure 14). Mean model-predicted values are similar to mean perennial grass cover calculated from cover class midpoints (Table 6). The 95% credible intervals were large for every ecological site, indicating considerable spatial variability in grass cover between quadrats and considerable uncertainty despite 15 years of data (Figure 14).

Based on the model, perennial grass cover decreased over the monitoring period at all ecological sites except WUPA V, where grass cover increased (Figure 15). The effect of increasing spring deficit on grass cover was negative, but winter and July deficit had a *positive* effect on perennial grass cover (Figure 15). An increase in the number of growing degree days also had a positive effect on grass cover.

Indian ricegrass cover--CHCU, PEFO

Although Indian ricegrass (*Achnatherum hymenoides*) occurred in all five ecological sites, it occurred in >30% of quadrats in the CHCU and PEFO ecological sites, and less than 0.1% of quadrats sampled in the two WUPA ecosites. Models including all 5 sites failed to pass posterior predictive checks, but models including the three ecosites at CHCU and PEFO were fit successfully with the following covariates: AGDD, winter, spring, and summer deficit (Appendix D).

Mean model-predicted cover of ricegrass cover was low (<1%) in all sites modeled, but lowest at PEFO C (where mean cover ranged from <0.01-0.02). The two sandy loam ecosites (CHCU S and PEFO S) showed similar patterns across years (Figure 16). Cover of ricegrass decreased over time in all three ecological sites (Figure 17). Covariate effects were mixed; AGDD and winter deficit had a positive effect on the cover of Indian ricegrass, while spring and summer deficits had a negative effect (Fig 17).

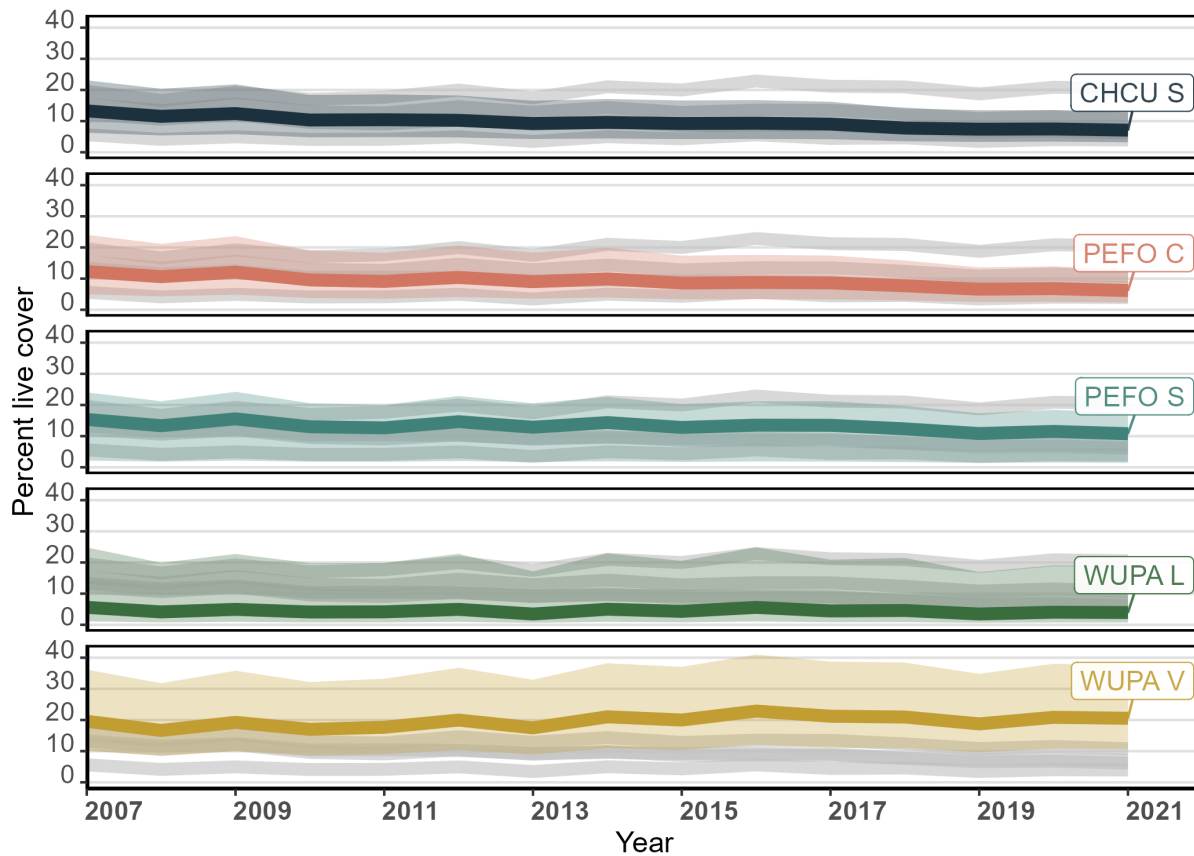


Figure 14. Model-based prediction of the change over time in total live perennial grass cover at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

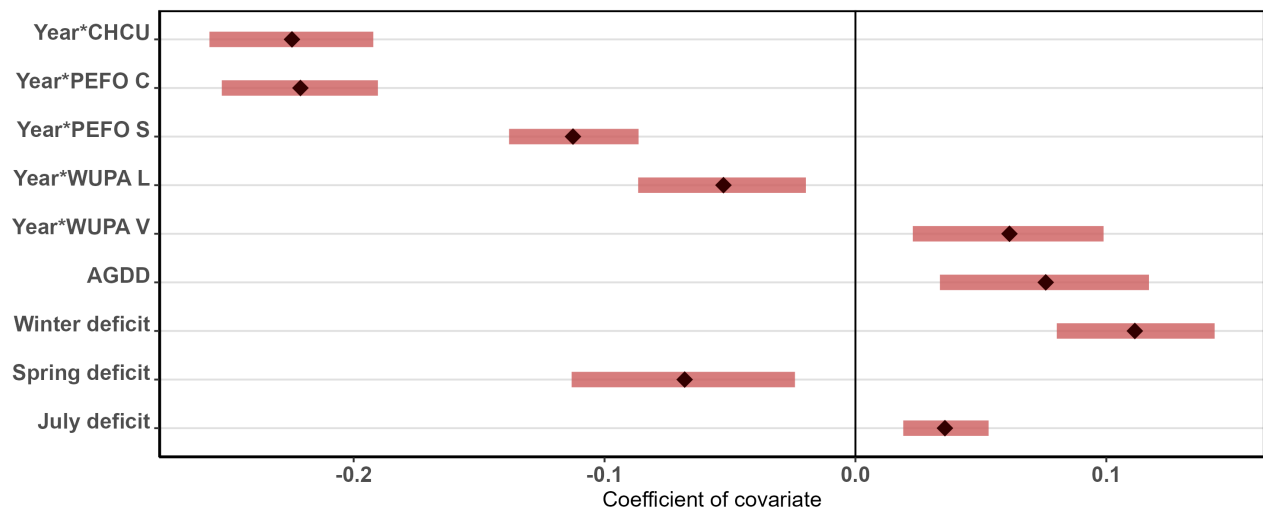


Figure 15. Site-level model predictions of year effect and covariate coefficient estimates for perennial grass cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

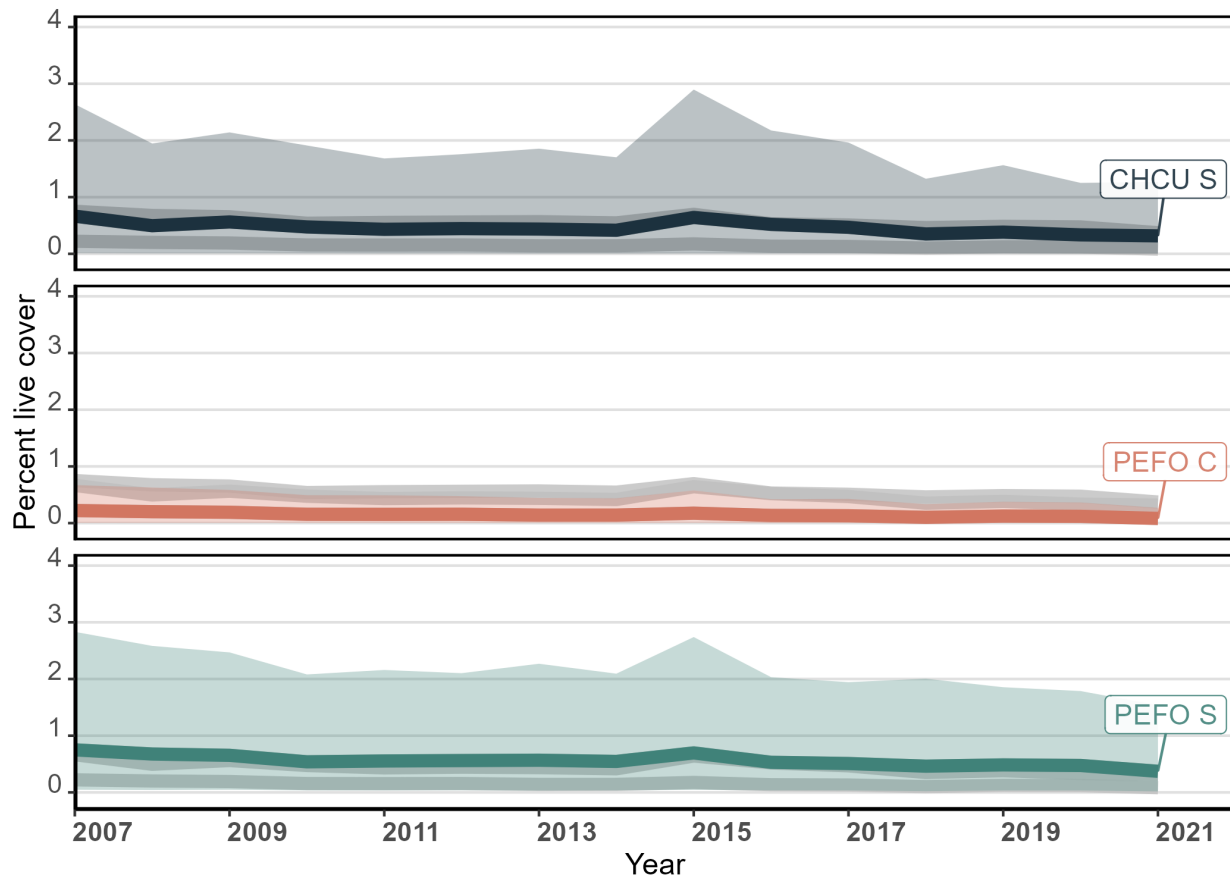


Figure 16. Model-based prediction of the change over time in total live Indian ricegrass (*Achnatherum hymenoides*) cover at three ecosites in two National Parks (CHCU, PEFO) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

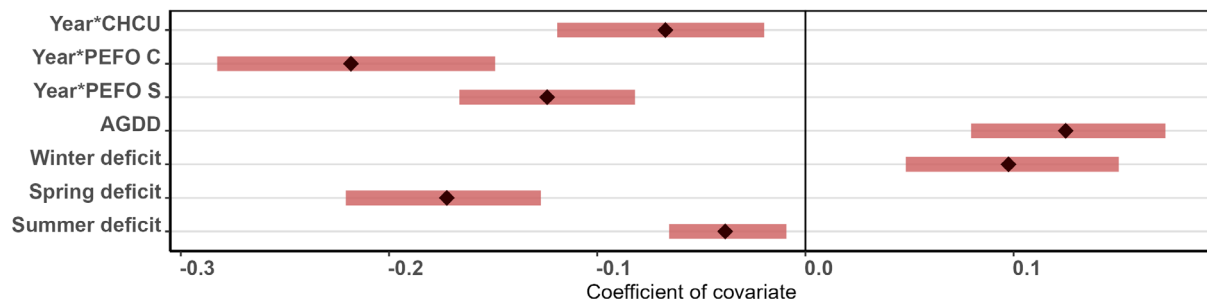


Figure 17. Site-level model predictions of year effect and covariate coefficient estimates for Indian ricegrass (*Achnatherum hymenoides*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Black grama cover--WUPA V

Black grama (*Bouteloua eriopoda*) occurred primarily in the WUPA V ecological site (in 77% of quadrats sampled). It was less frequent but still occurred in >10% of quadrats at WUPA S and PEFO

S (it also occurred in less than 0.5% of plots at PEFO C) but at very low percent cover. Models including PEFO S and WUPA L failed to converge. At WUPA V, model-predicted cover of black grama ranged from 2.9% to 5.6% (Figure 18). The model for WUPA V included July deficit and lag year deficit.

Lag year deficit had a strong negative effect on black grama cover (Figure 19). July deficit's effect was also negative. There was a significant negative time effect, indicating cover of black grama has decreased during the monitoring period in a way not explained by lag year and July deficit (Figure 19).

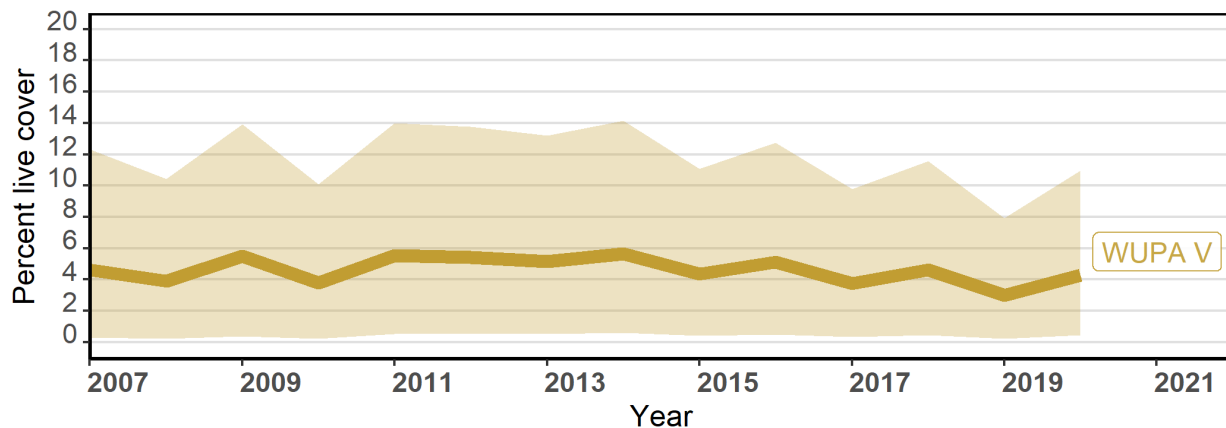


Figure 18. Model-based prediction of the change over time in total live black grama (*Bouteloua eriopoda*) cover in WUPA (2007–2021). Colored line indicates the predicted mean for sampled plots and shaded area indicates the 95% credible interval.

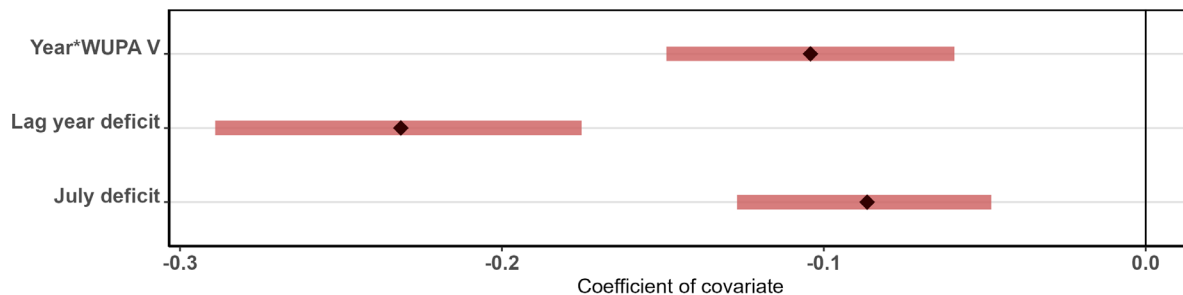


Figure 19. Site-level model predictions of year effect and covariate coefficient estimates for black grama (*Bouteloua eriopoda*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Blue grama cover--CHCU and PEFO

Blue grama (*Bouteloua gracilis*) was found in >40% of quadrats sampled at PEFO C, PEFO S and CHCU S. It also occurred at WUPA V but was present in <1% of quadrats sampled there. Blue grama was modeled for PEFO and CHCU and covariates were limited to spring deficit and AGDD in order to achieve convergence (Appendix D).

Model-predicted mean cover ranged from 1.1% to 6.1% and was lowest at PEFO C (Figure 20). Blue grama cover decreased over time in all three ecological sites. AGDD had a positive effect on cover of blue grama, while spring deficit had a negative effect (Figure 21).

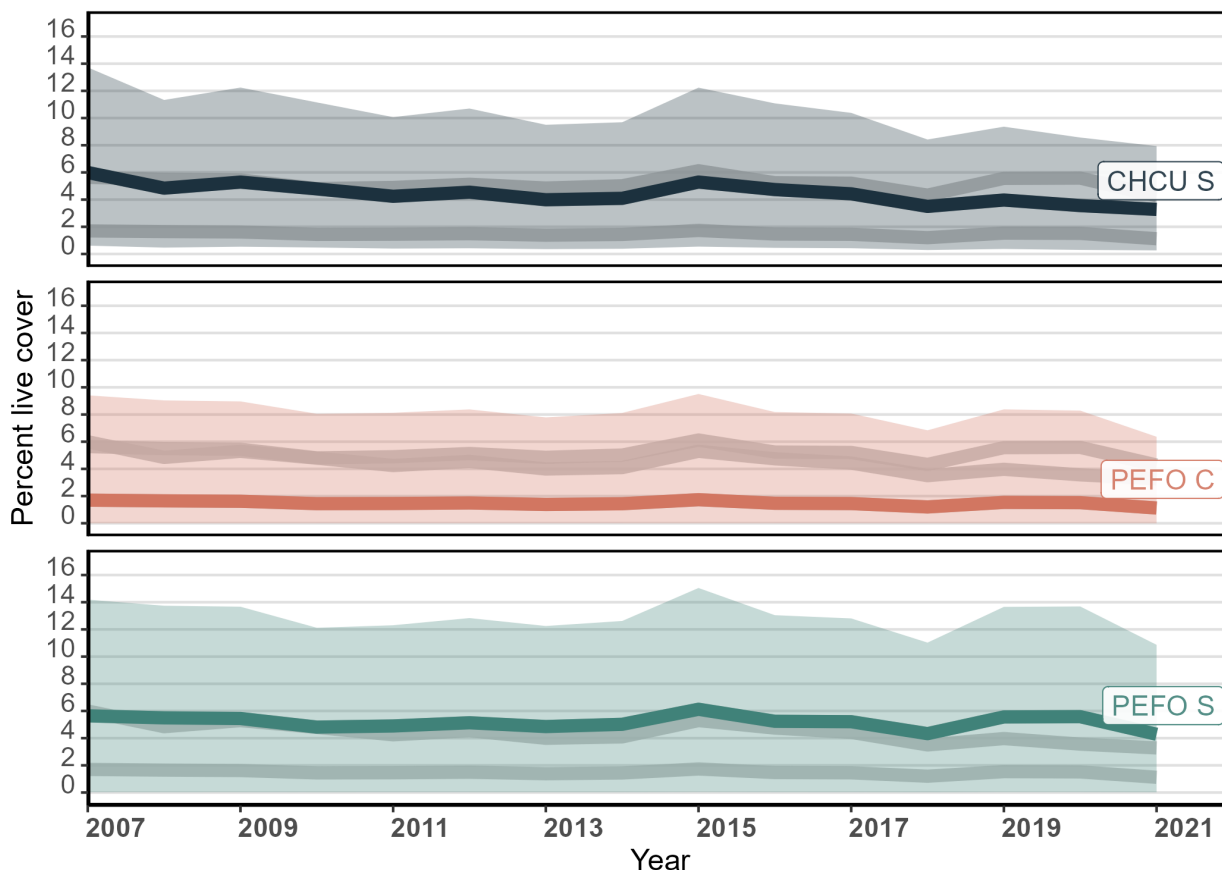


Figure 20. Model-based prediction of the change over time in total live blue grama (*Bouteloua gracilis*) cover at three ecosites in two National Parks (CHUC, PEFO) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

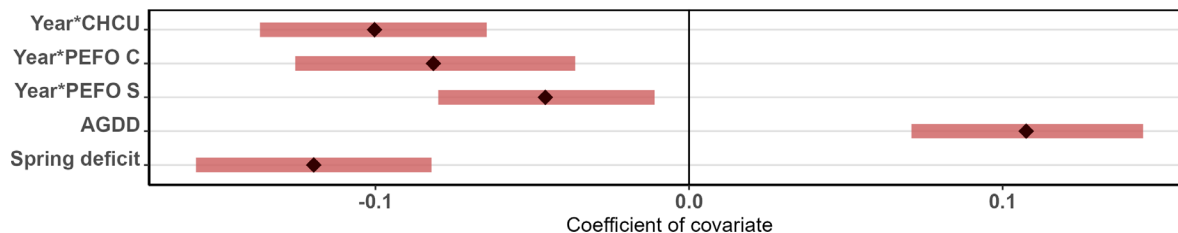


Figure 21. Site-level model predictions of year effect and covariate coefficient estimates for blue grama (*Bouteloua gracilis*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

New Mexico feathergrass cover--WUPA V

New Mexico feathergrass (*Hesperostipa neomexicana*) was present only in the WUPA V ecological site, where it occurred in over 50% of plots. The model for New Mexico feathergrass cover at WUPA V included lag year deficit, winter deficit, spring deficit, and July deficit, elevation, and AGDD (Appendix D).

Credible intervals were very wide for this response, indicating considerable spatial variability (Figure 22). Model-predicted mean annual cover ranged from 0.8-2.6% and decreased over the monitoring period (Figure 23). AGDD, and both spring and July deficit had a positive effect on feathergrass cover, while winter deficit and lag year deficit had negative effects (Figure 23).

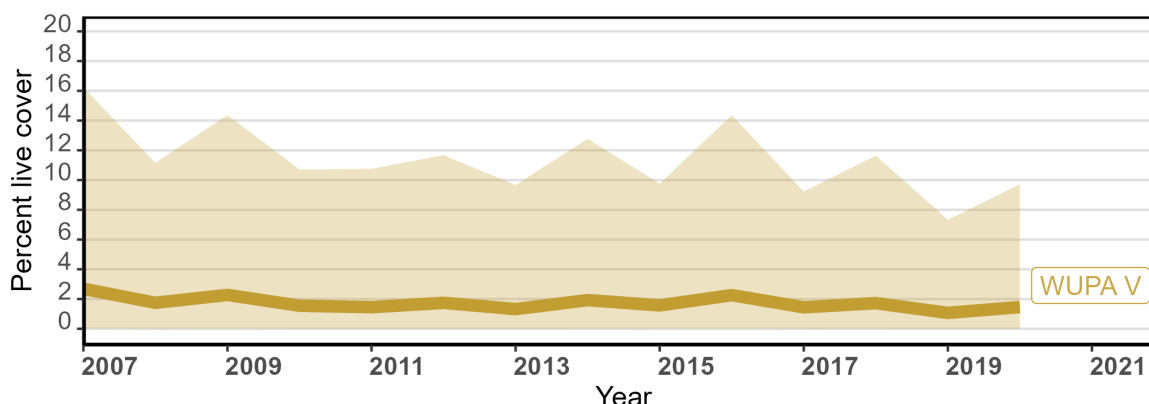


Figure 22. Model-based prediction of the change over time in total live New Mexico feathergrass (*Hesperostipa neomexicana*) cover at WUPA (2007–2021). The line indicates the predicted mean for sampled plots and shaded area indicates the 95% credible interval.

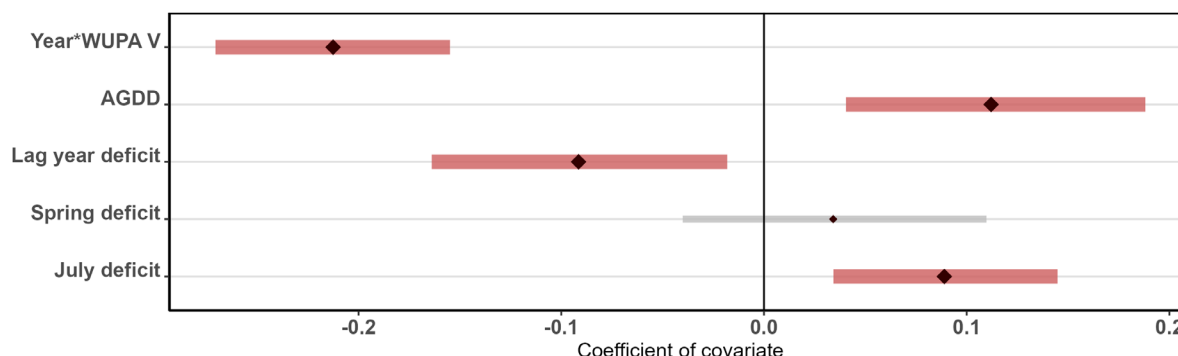


Figure 23. Site-level model predictions of year effect and covariate coefficient estimates for New Mexico feathergrass (*Hesperostipa neomexicana*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Galleta grass cover--all ecological sites

Galleta grass (*Hilaria jamesii*) was the only grass species that occurred in >10% of quadrats within all five ecological sites. Despite trying many different models, there was some evidence of lack of fit

for the estimates of mean cover for this response (Appendix D). Galleta grass cover ($p > 0.9$) was consistently overestimated across all models tested. However, since the departure wasn't too large and this species is an important component of all five grassland ecosites results are included. The final all-sites model for galleta grass cover included AGDD and spring, July, and winter deficit (Appendix D).

Mean predicted galleta grass cover ranged from $<0.1\%$ to 14% (Figure 24). Cover was highest and credible intervals were widest at WUPA V (Figure 24). All five ecological sites exhibited negative trends in galleta grass cover, although the slight negative trend wasn't significant at WUPA V (Figure 25). AGDD and both winter and July deficits had positive effects on cover of galleta grass, while spring deficit effects were not significant (Figure 25).

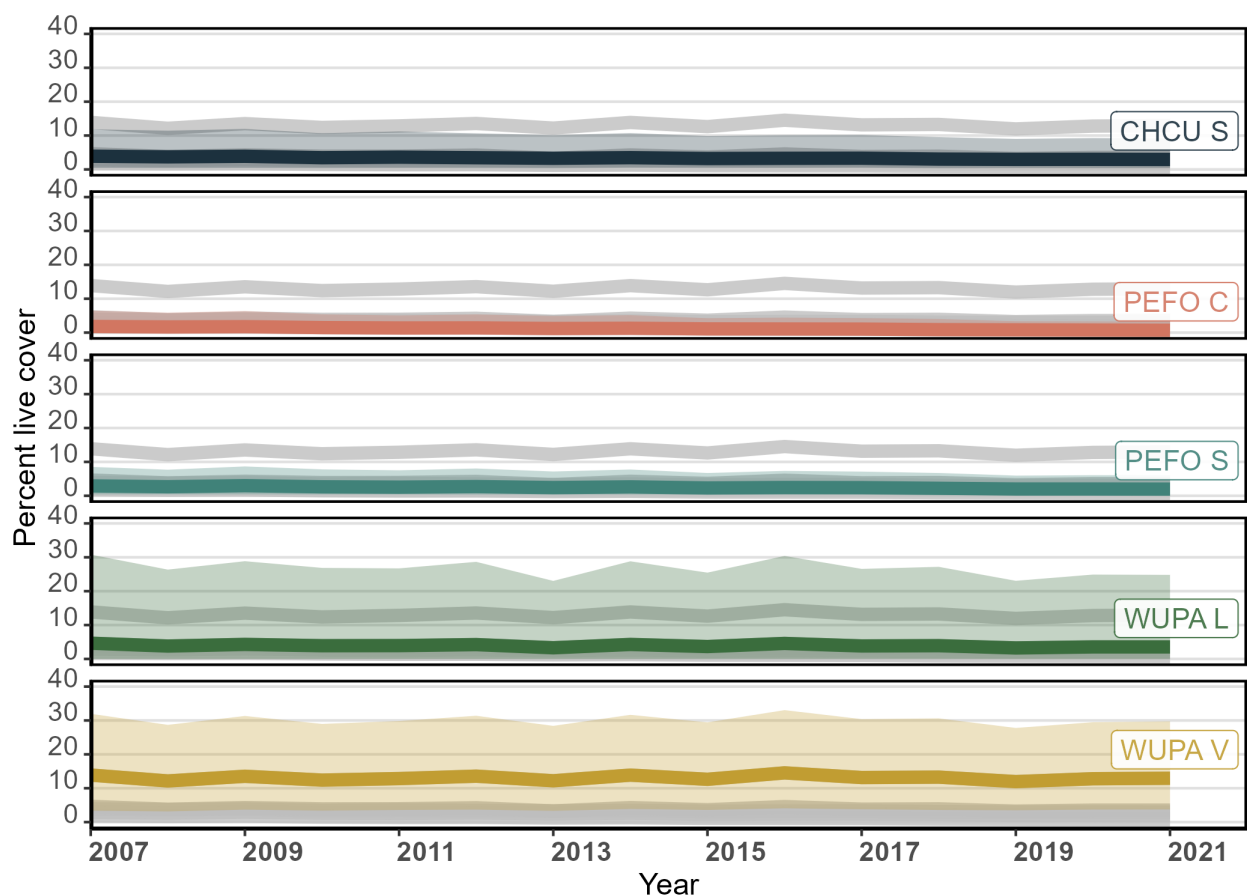


Figure 24. Model-based prediction of the change over time in total live galleta grass (*Hilaria jamesii*) cover at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

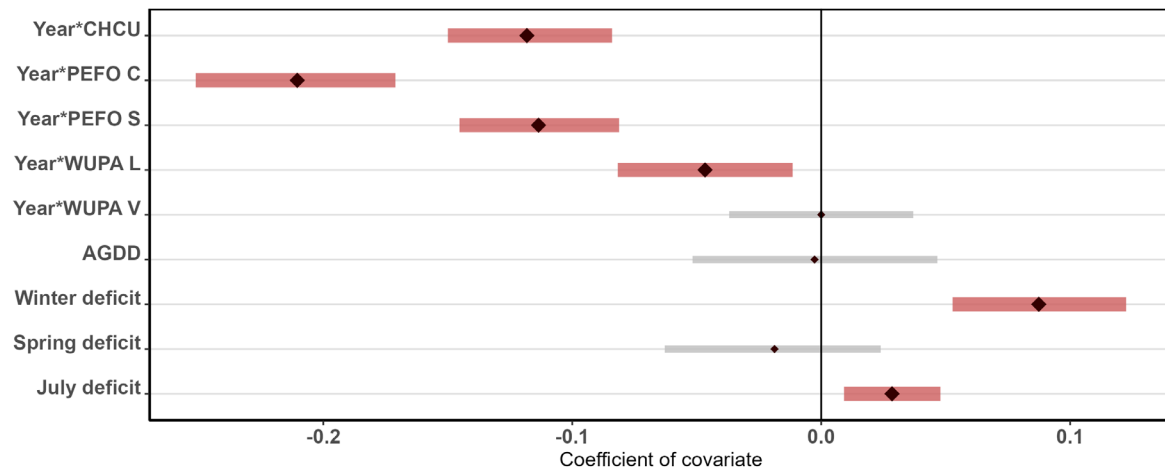


Figure 25. Site-level model predictions of year effect and covariate coefficient estimates for galleta grass (*Hilaria jamesii*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Dropseed cover--CHCU S, PEFO C, PEFO S

The model for dropseed (*Sporobolus* spp.) cover at the three ecosites in CHCU and PEFO included lag year deficit AGDD and July deficit (Appendix D). Model predicted mean cover of dropseed species varied from <1% to 6.5% and was highest at PEFO C (Figure 26).

Cover of dropseed species decreased at all ecological sites (Figure 27). The effect was strongest at CHCU, where drought conditions have been extreme the last three years. Year effect was weakest at PEFO S, and July deficit had a significant positive effect on dropseed cover (Figure 27).

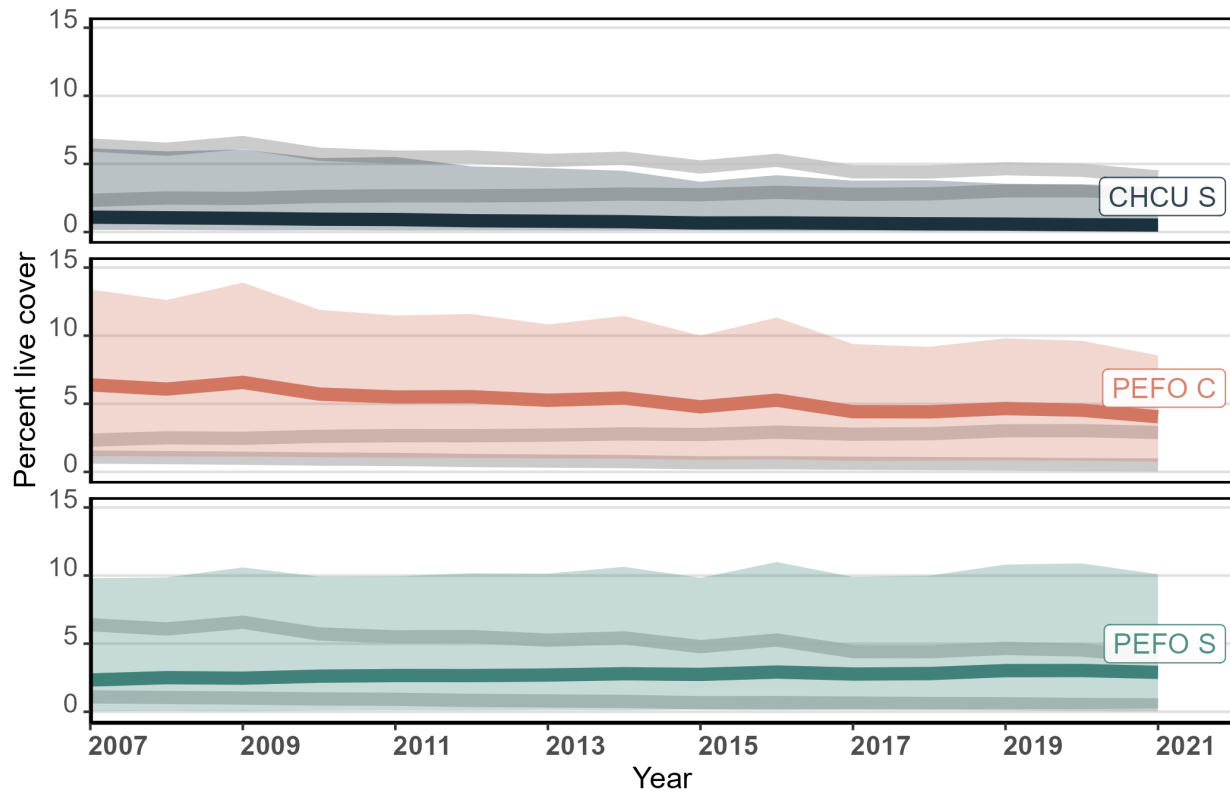


Figure 26. Model-based prediction of the change over time in total live dropseed (*Sporobolus* spp.) cover (2007–2021). Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

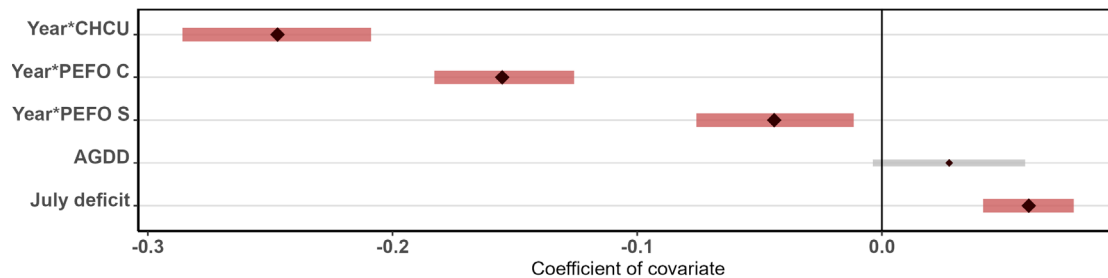


Figure 27. Site-level model predictions of year effect and covariate coefficient estimates for dropseed (*Sporobolus* spp.) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Shrub cover--all ecological sites

Shrub cover was modeled across all five ecological sites. The model included lag year deficit, winter deficit, spring deficit, July deficit and AGDD (Appendix D). Mean model-predicted shrub cover ranged from <1% at WUPA V to a maximum of 6% at WUPA L (Figure 28).

Temporal responses were mixed. Shrub cover increased over the monitoring period at CHCU S and decreased over time at PEFO S (Figure 29). AGDD had a positive effect on shrub cover, while increasing previous year and spring deficit had negative effects (Figure 29). The effects of winter and July deficits on shrub cover were not significant.

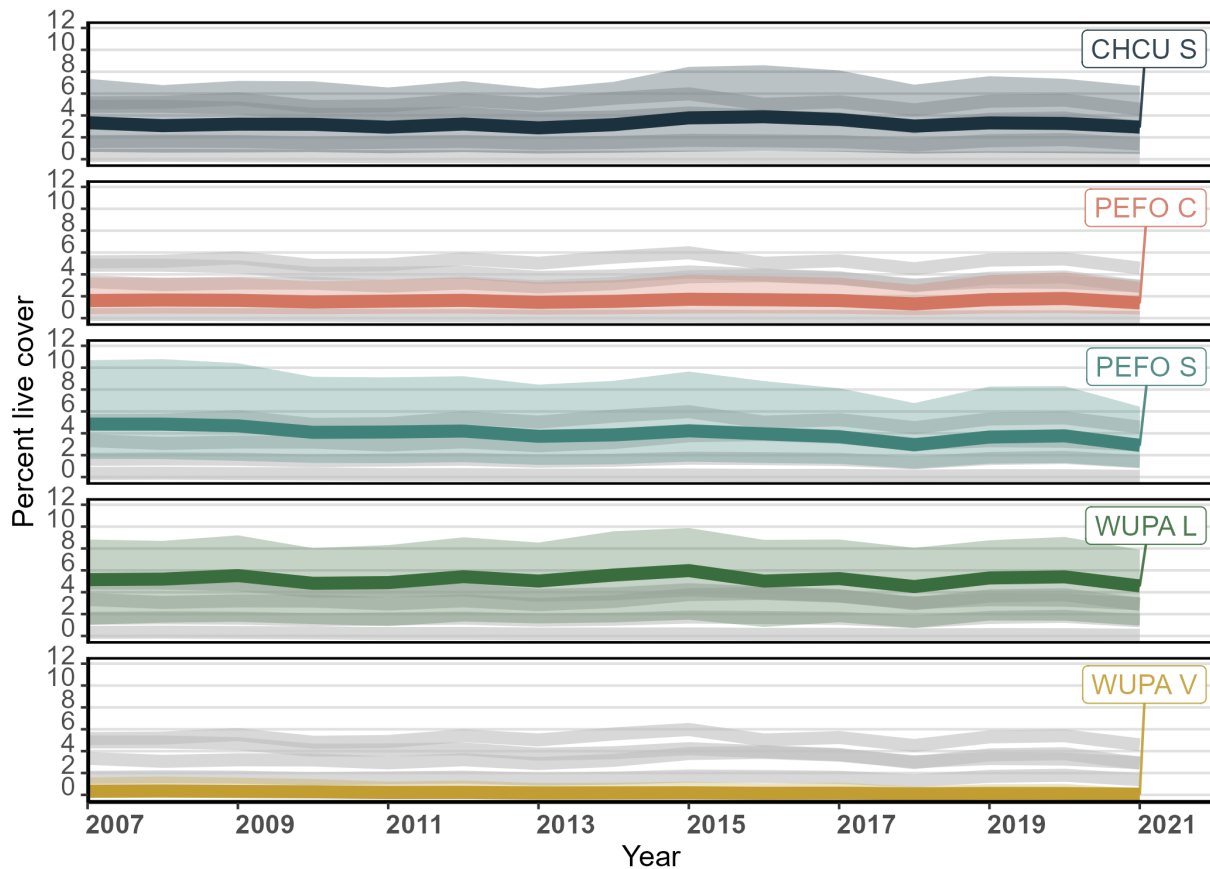


Figure 28. Model-based prediction of the change over time in total live shrub cover at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

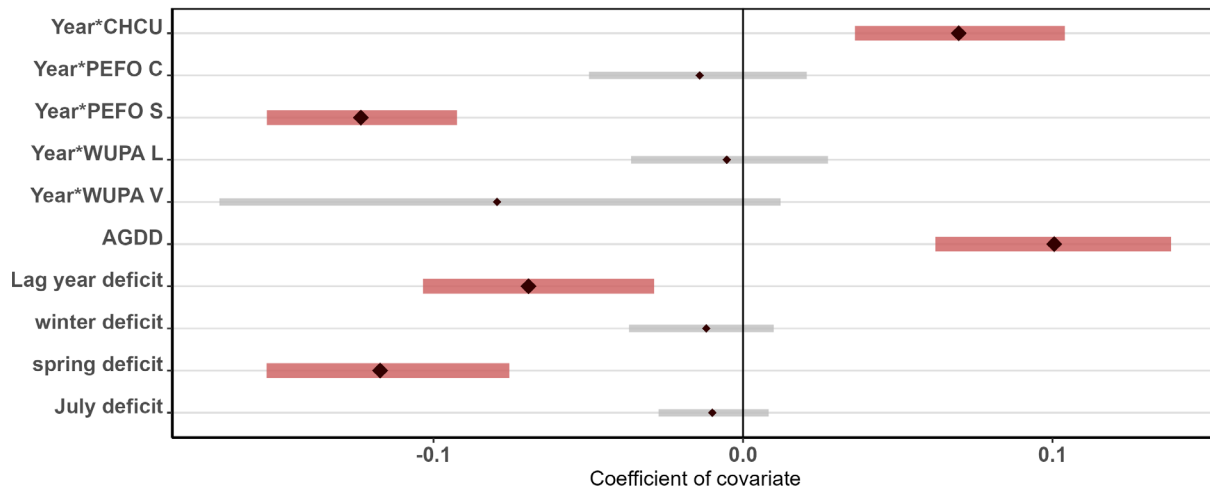


Figure 29. Site-level model predictions of year effect and covariate coefficient estimates for shrub cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Four-wing saltbush cover--CHCU S, PEFO C, PEFO S

Four-wing saltbush (*Atriplex canescens*) occurred in <10% of quadrats at sites other than WUPA V, and models including WUPA L failed to converge. The final model included only the three ecological sites at CHCU and PEFO with all covariates except lag year deficit (Appendix D). Mean model-predicted cover was <1% in all three sites with large credible intervals indicating considerable variation between plots (Figure 30).

Cover of four-wing saltbush increased at CHCU S did not change significantly at PEFO during the monitoring period (Figure 31). Higher spring and summer deficits had negative effects on the cover of four-wing saltbush, but the effects of other covariates were not significant (Figure 31).

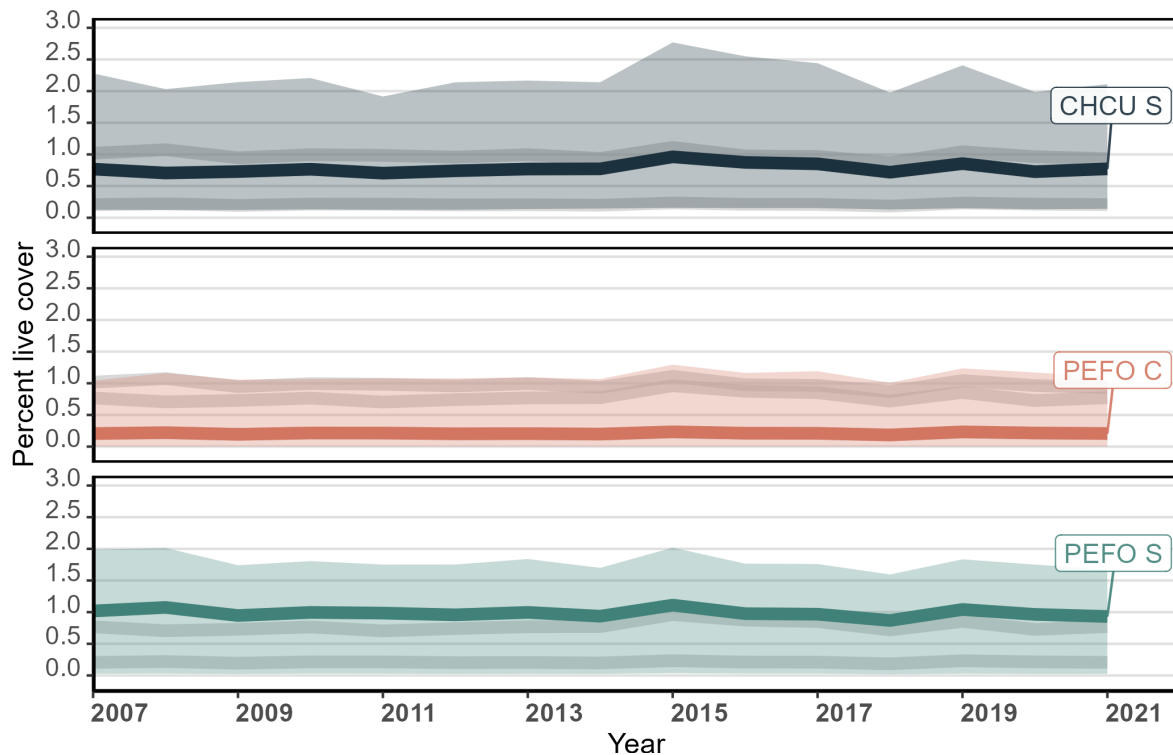


Figure 30. Model-based prediction of the change over time in total live four-wing saltbush (*Atriplex canescens*) cover at three ecosites in two National Parks (CHCU, PEFO) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

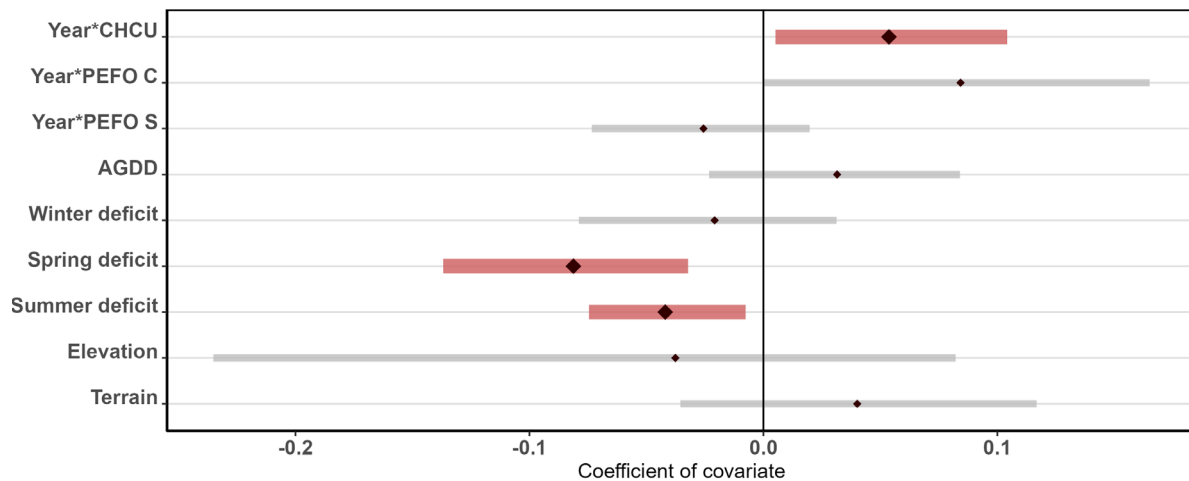


Figure 31. Site-level model predictions of year effect and covariate coefficient estimates for four-wing saltbush (*Atriplex canescens*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

***Atriplex obovata* cover--PEFO C**

Mound saltbush (*Atriplex obovata*) occurred in more than 50% of quadrats sampled at the PEFO C ecological site. Model-predicted mean cover ranged from 0.89% to 1.4% (Figure 32). The final model included AGDD and spring, winter, and summer deficit covariates (Appendix D). There was no significant change in cover during the monitoring period, and none of the included covariates had a significant effect on mound saltbush cover (Figure 33).

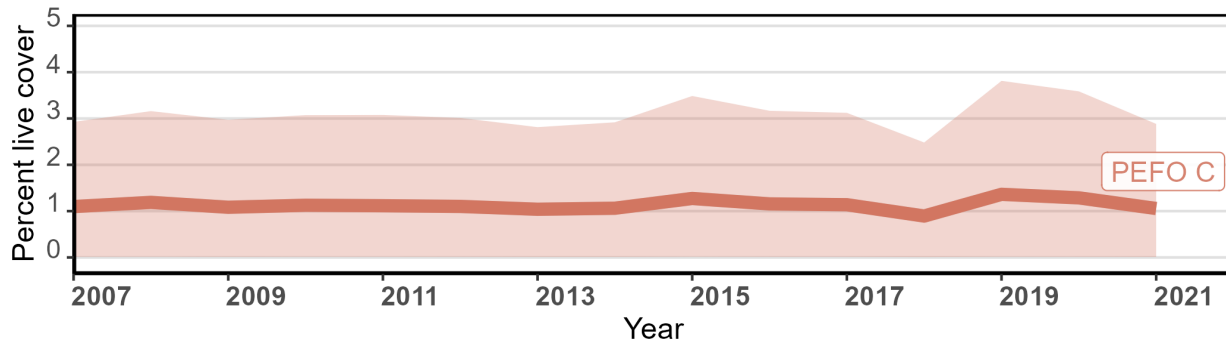


Figure 32. Model-based prediction of the change over time in total live mound saltbush (*Atriplex obovata*) cover in PEFO (2007–2021). The line indicates the predicted mean for sampled plots and shaded area indicates the 95% credible interval.

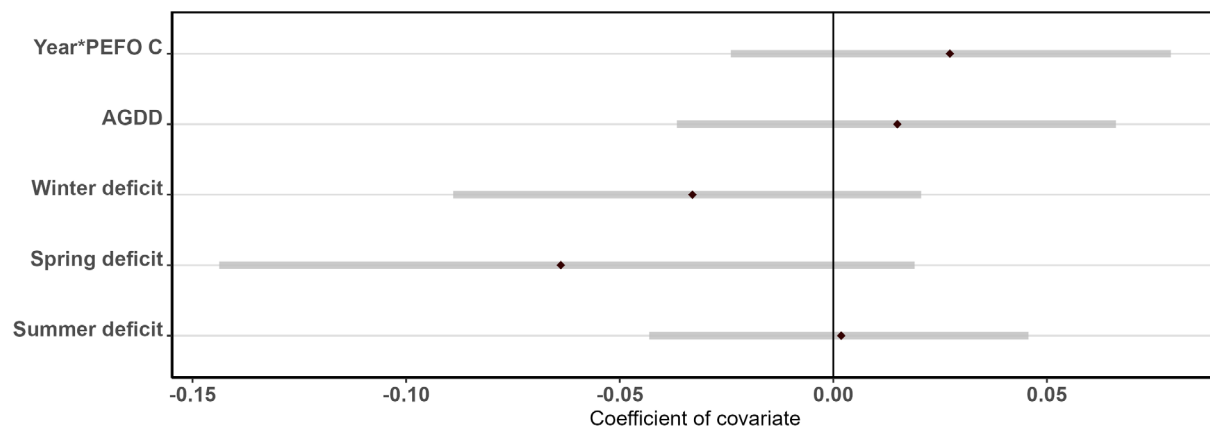


Figure 33. Site-level model predictions of year effect and covariate coefficient estimates for mound saltbush (*Atriplex obovata*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

***Snakeweed* cover--CHCU S, PEFO C, PEFO S**

Snakeweed (*Gutierrezia sarothrae*) occurred in all three ecosites at CHCU and PEFO (a different species, small flowered snakeweed (*Gutierrezia microcephala*), commonly occurs at WUPA). The final model for snakeweed cover included AGDD and winter, spring, and lag year deficit covariates (Appendix D). Model-predicted mean snakeweed cover ranged from <0.1-1.2% and was highest at PEFO S and lowest at PEFO C (Figure 34).

Snakeweed cover decreased over the monitoring period at CHCU S and PEFO S; change in cover over time was not significant at PEFO C (Figure 35). Increasing AGDD had a positive effect on snakeweed cover, while lag year and spring deficit had negative effects (Figure 35).

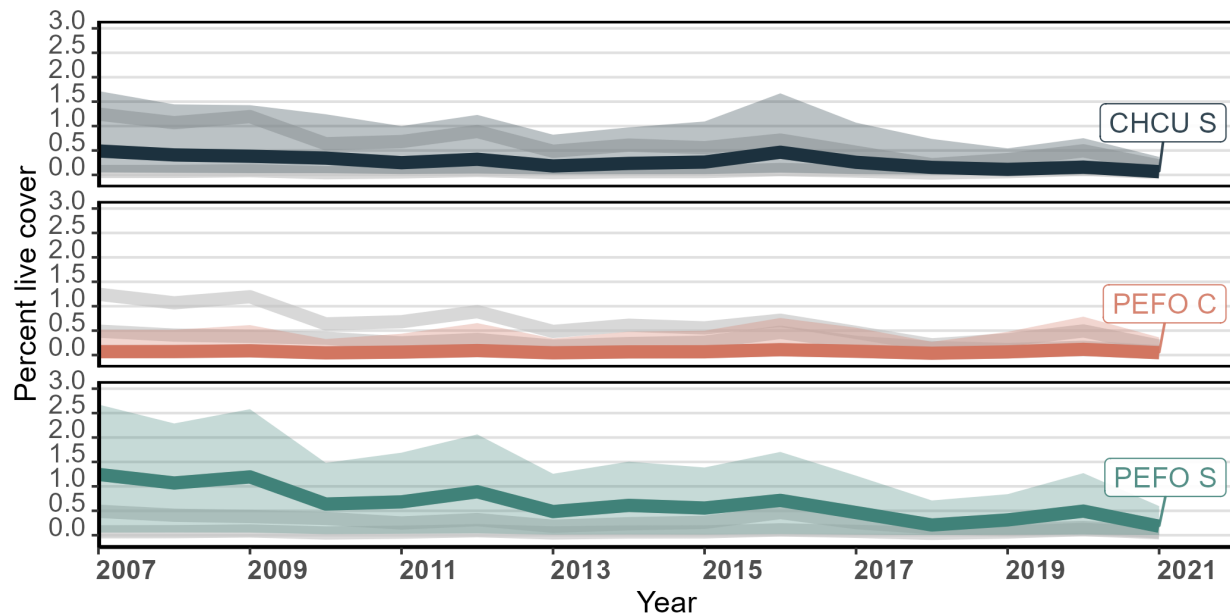


Figure 34. Model-based prediction of the change over time in total live snakeweed (*Gutierrezia sarothrae*) cover at three ecosites in two National Parks (CHCU, PEFO) from 2007 to 2021. Colored lines indicate the predicted mean for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

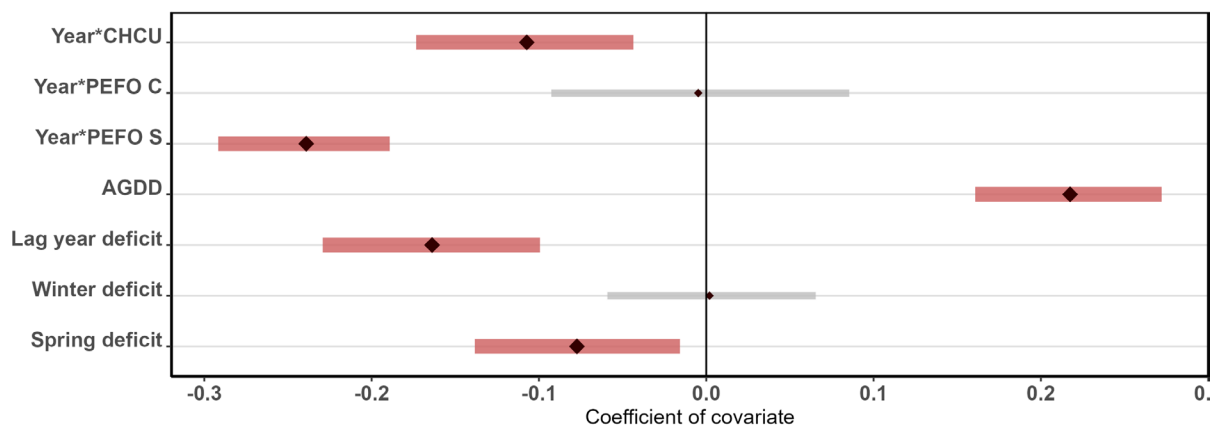


Figure 35. Site-level model predictions of year effect and covariate coefficient estimates for snakeweed (*Gutierrezia sarothrae*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Winterfat cover--CHCU S

Winterfat (*Krascheninnikovia lanata*) occurred primarily at CHCU S where it was present in >30% plots sampled. It was present in lesser amounts at PEFO and WUPA; however, models including all three ecosites failed to pass posterior predictive checks. Covariates included in the final model for CHCU S included lag year deficit, winter deficit, spring deficit, summer deficit, AGDD, elevation, and terrain. Predicted mean winterfat cover ranged from 0.7-1.6% at CHCU (Figure 36).

There was no change in winterfat cover during the monitoring period at CHCU S, and the effects of most of the covariates included in the model were not significant (Figure 37). The exception was lag year deficit which had a small positive effect on winterfat cover.

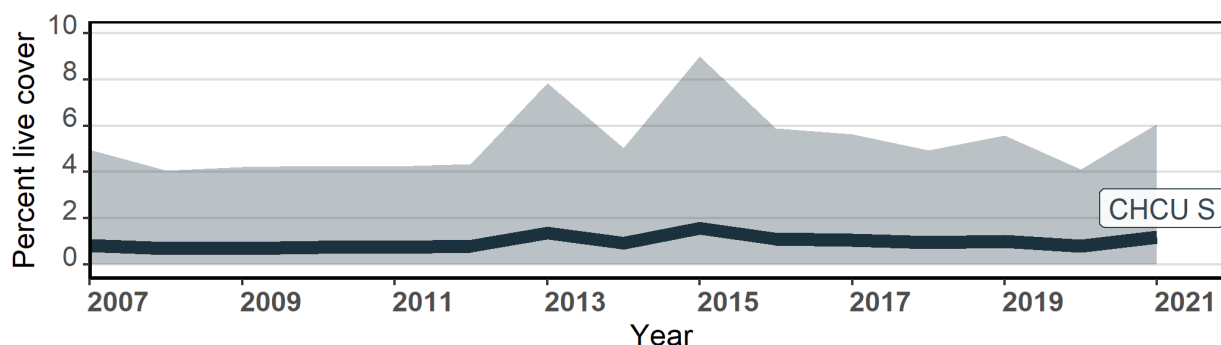


Figure 36. Model-based prediction of the change over time in total live winterfat (*Krascheninnikovia lanata*) cover at CHCU (2007–2021). The line indicates the predicted mean for sampled plots and shaded area indicates the 95% credible interval.

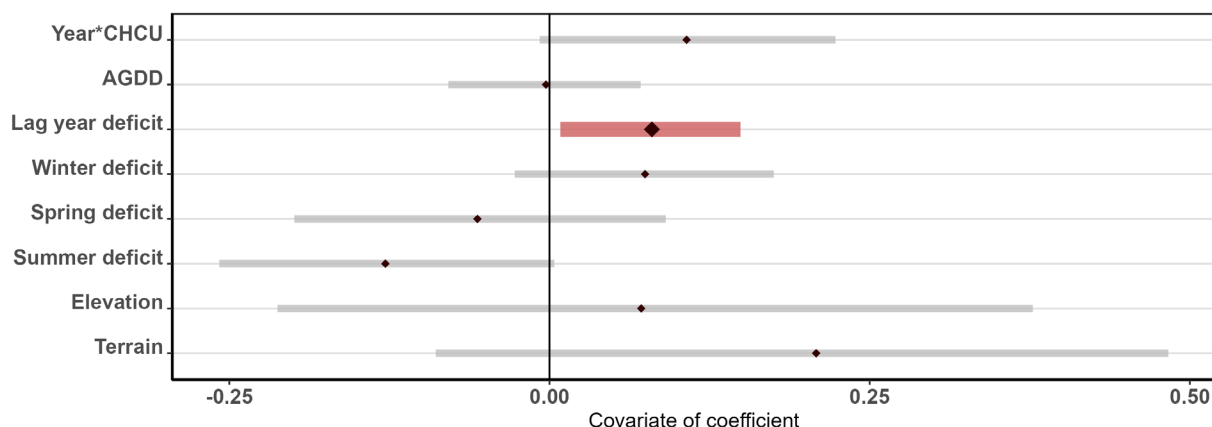


Figure 37. Site-level model predictions of year effect and covariate coefficient estimates for winterfat (*Krascheninnikovia lanata*) cover. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Multi-park models of frequency

Of the 23 plants that occurred in all five ecological sites, most (21 out of 23) occurred in <10% of quadrats sampled. Fitting the above cover model for species that occur so infrequently and at low cover was not possible. Instead, I modeled presence/absence using an inverse logit model for the lifeform groups of annual, exotic annual and perennial forbs. For this model, each of the five quadrats sampled along a transect was considered a “trial” and each quadrat was considered a “hit” if it contained a representative of the lifeform in question (annual, exotic annual, or perennial forb; Figure 3). The nested quadrat size assigned as a trial for each response (lifeform) varied based on overall frequency for each species or group. For example, annual forbs were frequently detected, so “hits” were assigned at the 5m² nested quadrat size. Perennial forbs and exotic annual forbs hits were less frequently detected and assigned a 10 m² quadrat scale for each trial.

Presence/absence of perennial forbs--all ecological sites

Perennial forbs were modeled across all ecological sites. The final model included lag year deficit, winter deficit, springs deficit, July deficit, AGDD, mean elevation and terrain. Perennial forbs occurred in an average of 12-69% of 1m² quadrats sampled and were more than twice as common at PEFO S than the other ecosites (mean occurrence PEFO S = 52%, CHCU S = 23%, PEFO C, WUPA L and WUPA V = 21%, Figure 38). Credible intervals were wide, indicating considerable uncertainty due to high spatial and temporal variation between plots and years.

Perennial forbs increased over time at CHCU and PEFO S but did not show significant trends in other ecological sites (Figure 39). Accumulated growing degree days, lag year deficit, winter deficit, and July deficit all had negative effects on the presence of perennial forbs across ecological sites. The effects of spring deficit, elevation and terrain were not significant.

Presence/absence of annual native forbs--all ecological sites

Frequency of occurrence of annual native forbs was modeled across all 5 ecosites. The model included lag year deficit, winter, spring, and July deficits, AGDD, elevation, and terrain (Appendix D). Best fit was achieved using a stratum-level fixed variance, rather than a site-level hierarchical.

Model-predicted mean frequency of annual forbs varied from 1% to >90% in 1 m² nested quadrats (Figure 40). Native annual forbs occurred less frequently in the WUPA L ecological site (mean frequency 8%) than the other four ecological sites (PEFO S = 39%, CHCU S = 54%, PEFO C = 63%, WUPA L = 52%). Credible intervals were extremely wide, indicating high uncertainty due to spatial and temporal variation between plots and years.

Annual native forbs increased during the monitoring period for CHCU S, PEFO C and PEFO S, and decreased at WUPA L (Figure 41). The time effect at WUPA V was not significant. Spring and winter deficit had negative effects on annual forb presence in our quadrats, while pLag year deficit had a positive effect (Figure 41). The effects of other covariates were not significant.

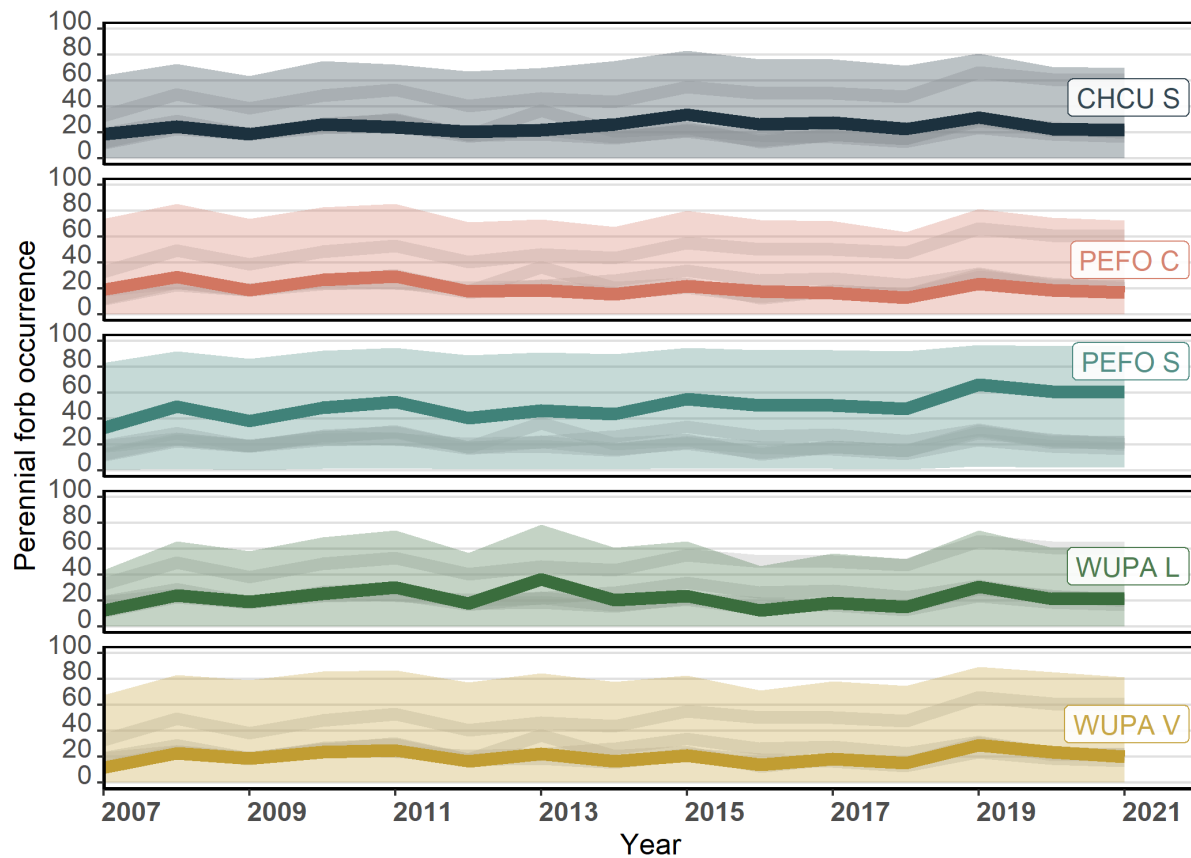


Figure 38. Model-based prediction of the change over time in perennial forb frequency at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted frequency for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

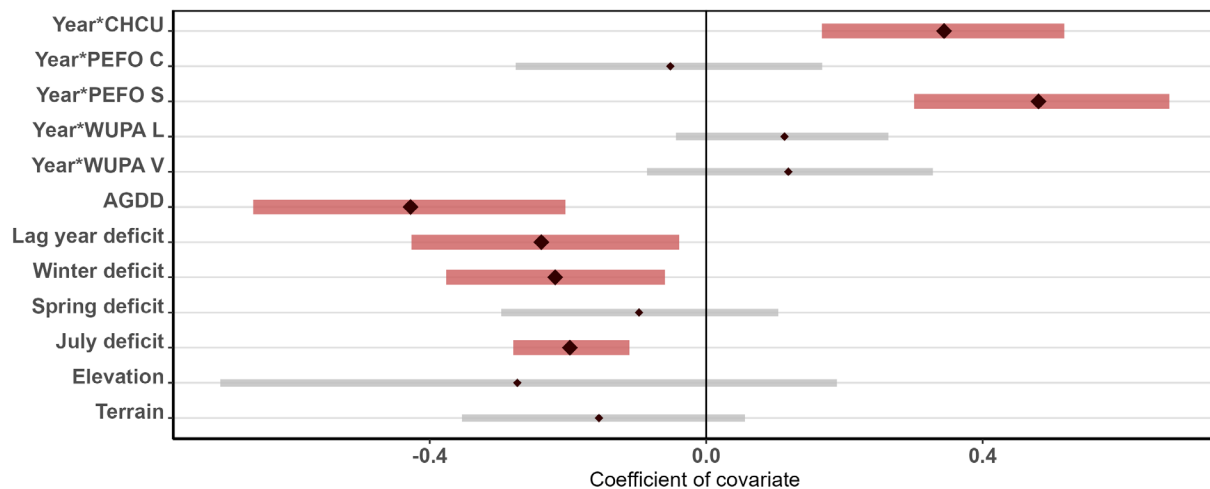


Figure 39. Site-level model predictions of year effect and covariate coefficient estimates for perennial forb frequency. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

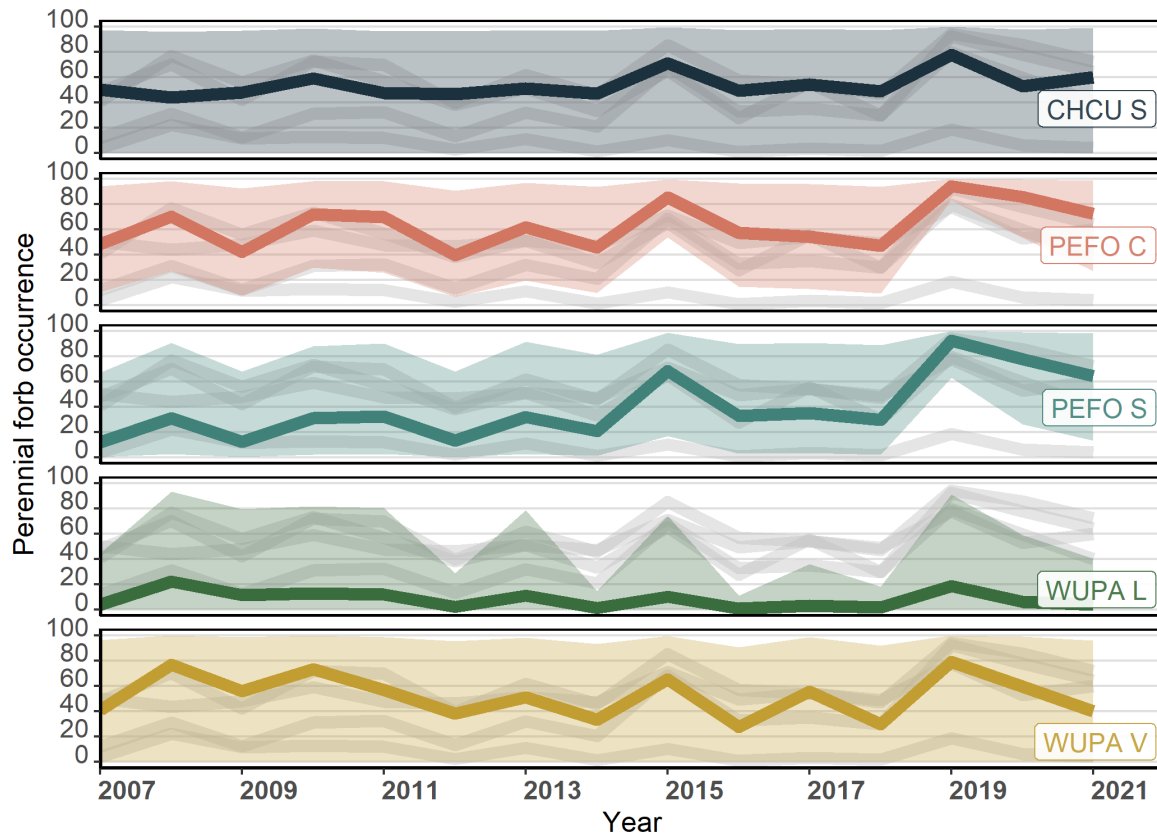


Figure 40. Model-based prediction of the change over time in native annual forb frequency at five ecosites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted frequency for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

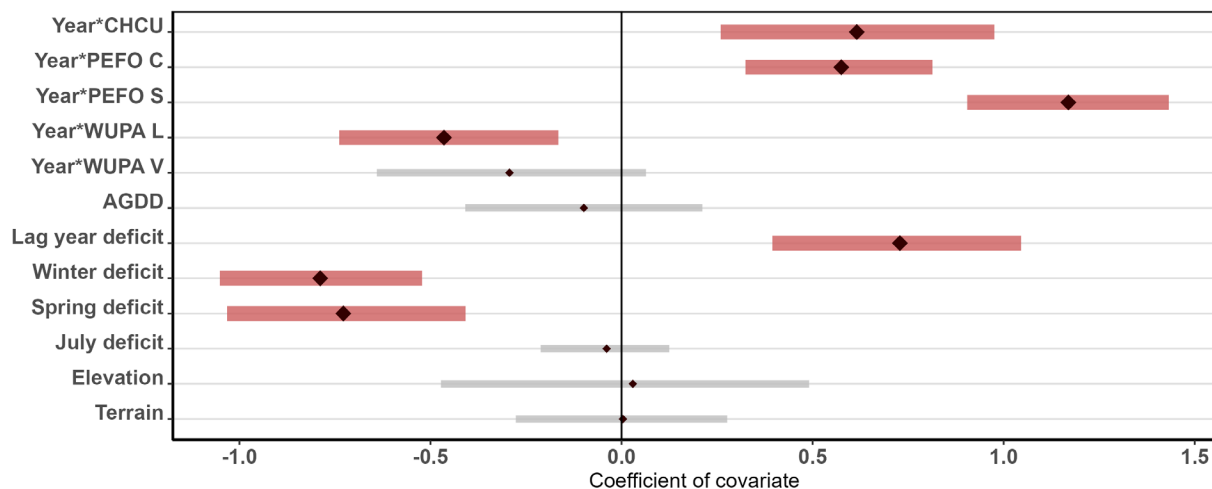


Figure 41. Site-level model predictions of year effect and covariate coefficient estimates for frequency of annual native forbs. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Presence/absence of exotic forbs--all ecological sites

Occurrence of annual exotic forbs was also modeled across all five ecosites. The model included lag year deficit, winter, spring, and July deficits, AGDD, elevation, and terrain (Appendix D). Mean frequency of exotic annual forbs varied from < 3% to 86% in 1 m² nested quadrats and was highest at WUPA V and PEFO C and lowest at WUPA L (Figure 42).

Presence of annual exotic forbs increased over time at CHCU S and decreased at PEFO S, but we detected no significant change over time at PEFO C, WUPA L or WUPA V (Figure 43). AGDD and both July and winter deficits had negative effects on the presence of exotic forbs across the five ecological sites, while previous year deficit had positive effects on exotic forb frequency (Figure 43).

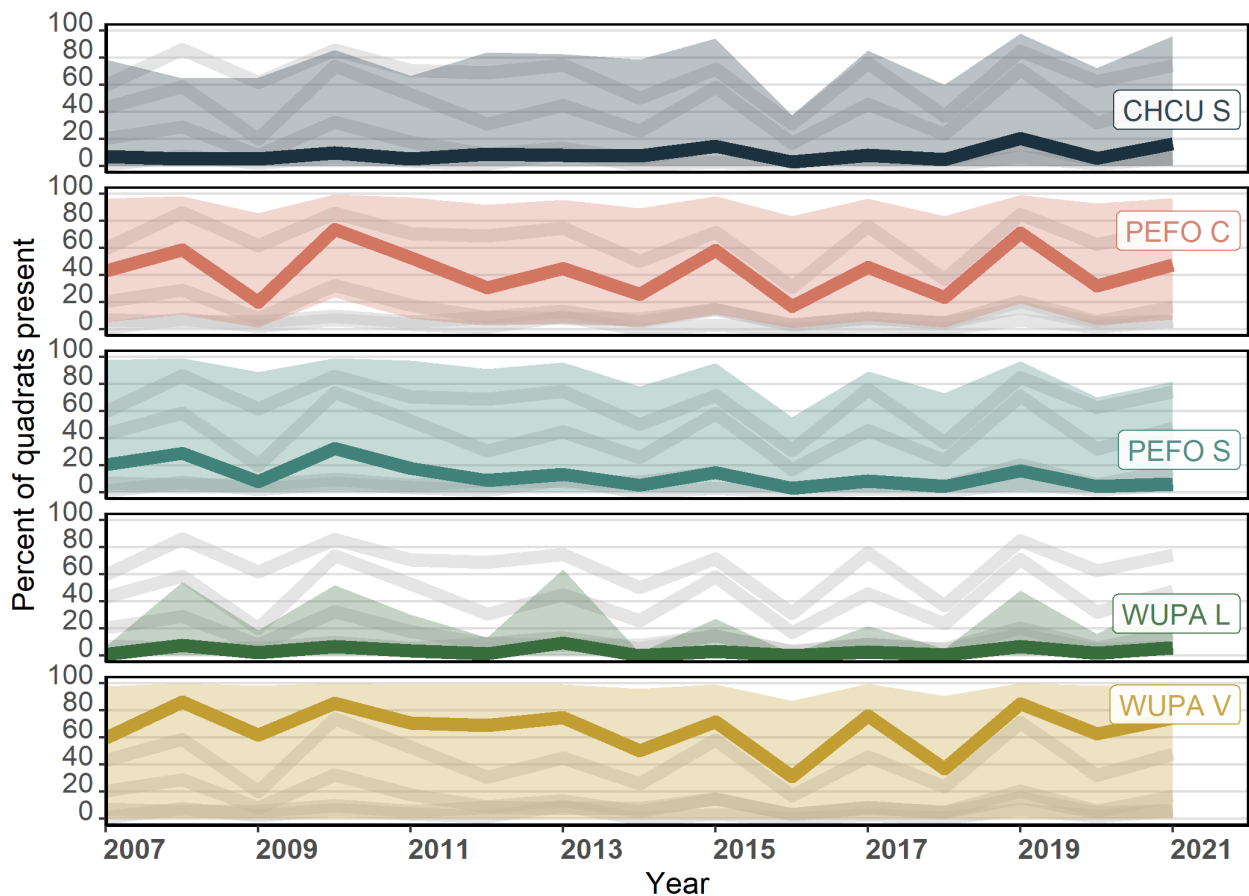


Figure 42. Model-based prediction of the change over time in exotic forb frequency in five ecosites at three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted frequency for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison.

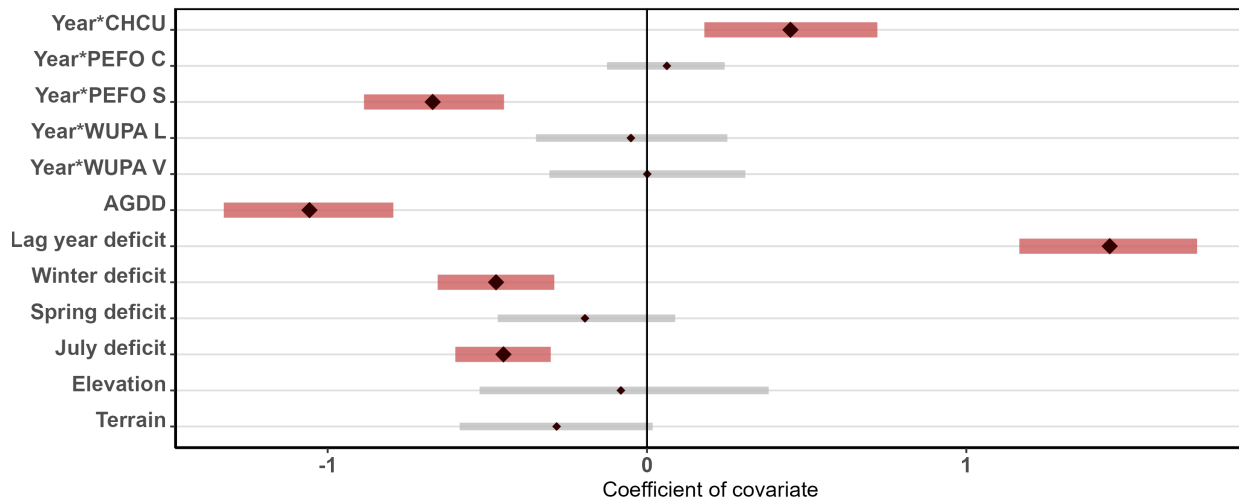


Figure 43. Site-level model predictions of year effect and covariate coefficient estimates for frequency of exotic annual forbs. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Species Richness

Models of species richness were developed for each ecological site and included all covariates (Appendix D). Species richness is commonly underdispersed, and this was the case at our ecological sites, so a generalized Poisson model was used instead of a standard Poisson (Lynch et al. 2014). Although standard Poisson models did adequately estimate mean species richness, models failed to pass posterior predictive checks for variance of the response (Harris et al. 2012).

Mean model-predicted richness ranged from 3.4 to 14 species per 10 m² quadrat (Figure 44), and estimates were similar to richness values summarized in the status section above (Table 6). Overall Richness was lowest at WUPA L (Figure 44).

Species richness increased over the monitoring period at PEFO S and WUPA V and decreased at CHCU S; no change in richness over time was detected at PEFO C and WUPA L (Figure 45). The effects of climate covariates on richness were mixed (Figure 45). Lag year deficit had a negative effect on richness at CHCU S and PEFO C, but a positive effect at PEFO S and WUPA V. AGDD had a negative effect on richness at both PEFO sites and WUPA L, but a positive effect at CHCU. Spring deficit had a positive effect at CHCU and PEFO S, but a negative effect on richness at PEFO C. The effect of winter deficit was negative at all ecosites except WUPA V, and July deficit (WUPA L) and summer deficit (CHCU, PEFO C) also had negative effects on richness (Figure 45). The effects of elevation and terrain on richness were generally not significant, although terrain had positive effects on richness at WUPA V (Figure 45).

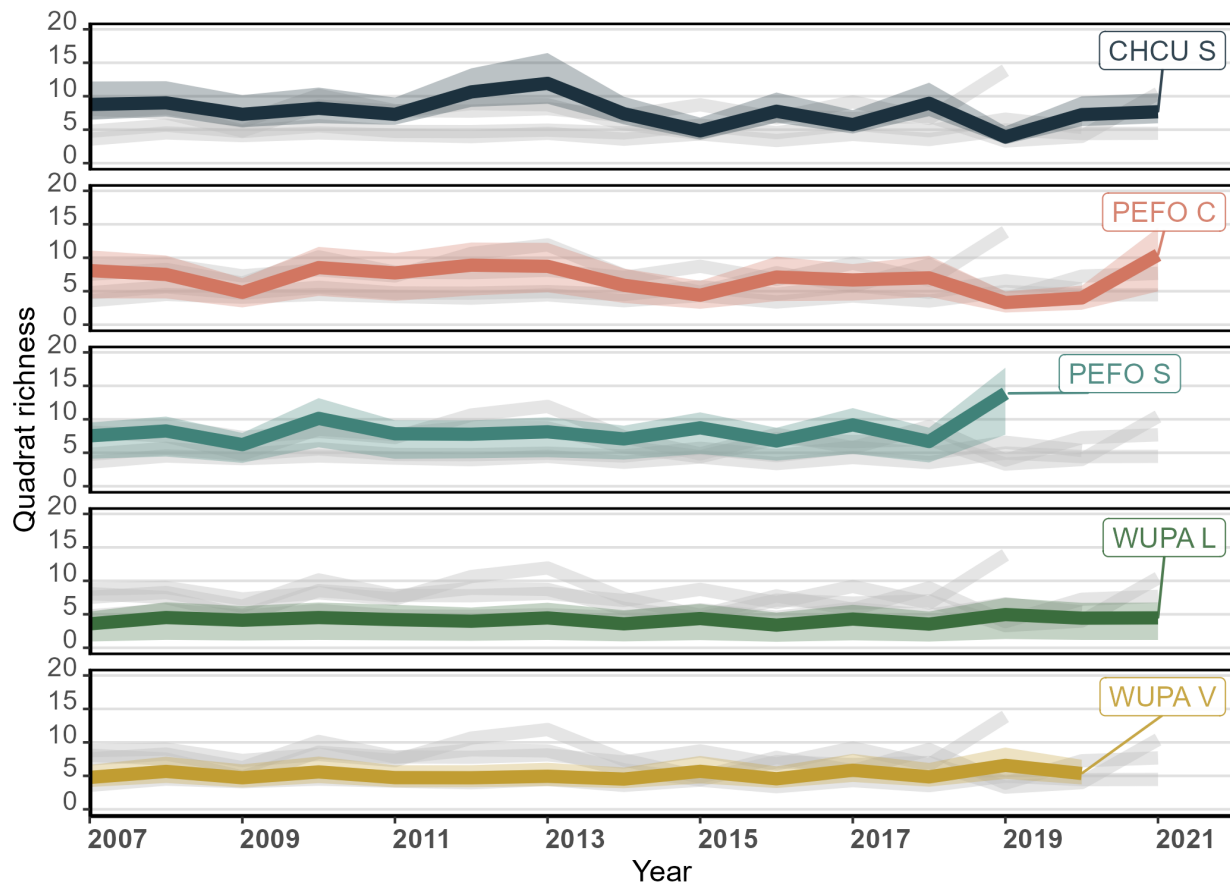


Figure 44. Model-based prediction of the change over time in quadrat-scale species richness for five ecological sites in three National Parks (CHCU, PEFO, WUPA) from 2007 to 2021. Colored lines indicate the predicted richness for sampled plots and colored shaded area indicates the 95% credible interval. The mean prediction for each ecological site is shown in gray to aid comparison. Note: PEFO S model results end in 2019 since that was the most recent year sampled in this monitoring period.

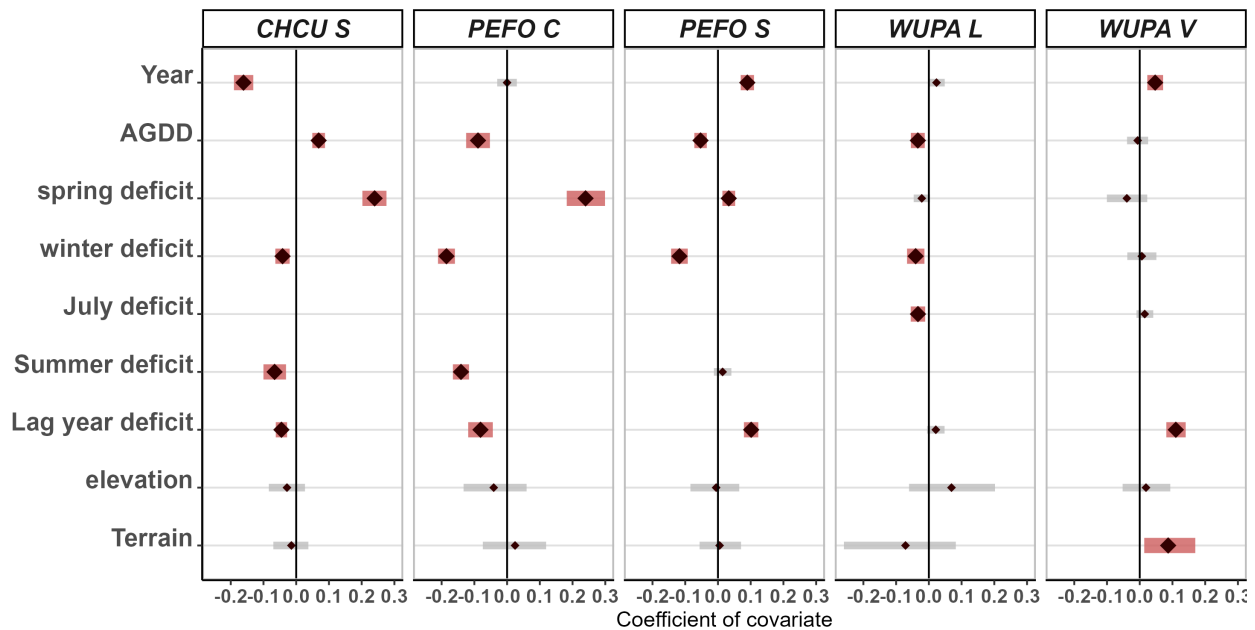


Figure 45. Site-level model predictions of year effect and covariate coefficient estimates for species richness at the 10m² quadrat scale. The horizontal bar represents the 95% credible interval for each coefficient. Means of the distributions are indicated by black diamonds. Significant positive and negative effects are shown in red, nonsignificant effects are shown in gray. Distance and direction from 0 indicate the relative size and direction of effect.

Summary: time trends

Many lifeform groups and species modeled showed significant, directional change over time that was *not* explained by included covariates (Figure 46). Most trends were negative, representing decreases over time in modeled responses. Of particular concern, there was an almost uniform negative trend in perennial grass cover (both the dominant C₄ and less common C₃ species) across all ecological sites except for WUPA V. Although these predicted changes were small (<0.5% per year for perennial grass cover, less for other responses), they raise significant concern that continued drought conditions could lead to mortality, loss of species and/or structural changes in these grasslands (Munson 2013, Cleland 2013). Perennial grasses have been identified as more vulnerable to drought-induced mortality, and a reduction in perennial grass cover corresponds with predictions of ecosystem shifts in favor of shrub dominance due to aridification resulting from climate change (Gremer et al. 2018, Munson et al. 2011, Winkler et al. 2019, Finger-Higgins et al. 2023).

Previous reports on cover of lifeform groups and select grass species at PEFO (Swan et al. 2018) and CHCU (Swan 2022) using data through 2018 did not show significant trends in grass cover or shrub cover in these same ecological sites. However, many of these sites experienced a series of extreme drought conditions in 2018, 2020, and 2021 (Figure 47, Williams et al. 2022). 2018 ranked as one of the three lowest soil water years experienced during the monitoring period for all five ecological sites (Figure 47). And 2021 was a year of exceptional drought across the southwest, with a near complete absence of monsoon precipitation that resulted in a wide-spread juniper mortality event in Northern Arizona (Williams et al. 2022).

Recent drought is expected to impact trend estimates in these systems because extreme years near the end of the monitoring period can strongly influence trend slope and because cumulative drought effects are expected to have greater impact than a single year of drought followed by recovery (e.g., Munson et al. 2022, Müller and Bahn 2022). However, there is also some evidence that intense drought of relatively short duration may result in greater productivity compared to longer but less extreme drought (Carroll et al. 2021). Cumulative (multi-year) drought effects were not included in models.

	CHCU Sandy Loam	PEFO Clayey Fan	PEFO Sandy Loam	WUPA Loamy	WUPA Volcanic
Perennial grasses					
Black grama					
Blue grama					
New Mexico needlegrass					
Galleta grass					
Dropseeds					
Indian ricegrass					
Shrubs					
Four-wing saltbush					
Mound saltbush					
Snakeweed					
Winterfat					
Perennial forbs					
Annual forbs					
Exotic forbs					

Figure 46. Summary of direction of year effects (trend) for modeled responses. Green indicates a positive trend, red a negative trend and a gray box indicates that the trend was non-significant. Non-colored boxes indicate that a given response was not modeled for the ecological site. [Data for this figure are provided in Table E-2 of Appendix E.](#)

The direction of trends over time for shrub and forb responses were mixed (Figure 46). Shrub cover exhibited fewer significant directional trends over time compared to forbs. At CHCU S and PEFO C, shrub cover increased or did not show a significant trend over time, while at PEFO S cover of shrubs decreased (Figure 46). Forbs tended to increase over time. Frequency (how often they were encountered in sampling quadrats) of forbs showed increasing trends at CHCU S, PEFO C and PEFO S. This was especially pronounced at CHCU, where perennial forbs, native annual, and exotic annual forbs *all* showed significant increases over time (Figure 48),

Shrubs are longer-lived with persistent woody structure and deeper root systems which results in less and slower changes in cover in response to relatively short-term fluctuations in conditions compared to herbaceous species (Noy-Meir 1973). Deeper rooting systems allow shrubs to access deep water reserves in the soil profile, making them more resistant to short-term drought and other recent studies have shown them as less vulnerable to drought induced mortality than perennial grasses (Hoover et al., 2015, Finger-Higgins et al. 2023). Few studies have investigated the response of forbs to drought. However, annual species may be less sensitive to drought than perennial grass or shrubs, and typically have seeds that can survive years of dormancy and may increase in the seedbank in response to extreme drought (LaForgia et al. 2018, Finger-Higgins et al. 2023). Perennial forbs were among the least sensitive to drought in one dryland ecosystem study (Munson 2022).

In general, credible intervals for model-predicted means of our response variables were wide. This reflects a high degree of spatial variation between plots and (relatively) small sample size. The effect of a small sample size is further compounded by plots not being sampled every year and highly variable weather conditions at these sites, both seasonally and inter-annually. Although 15 years of data collection is an accomplishment, additional data collection will increase the precision of our estimates and our confidence in the robustness of our time trends.

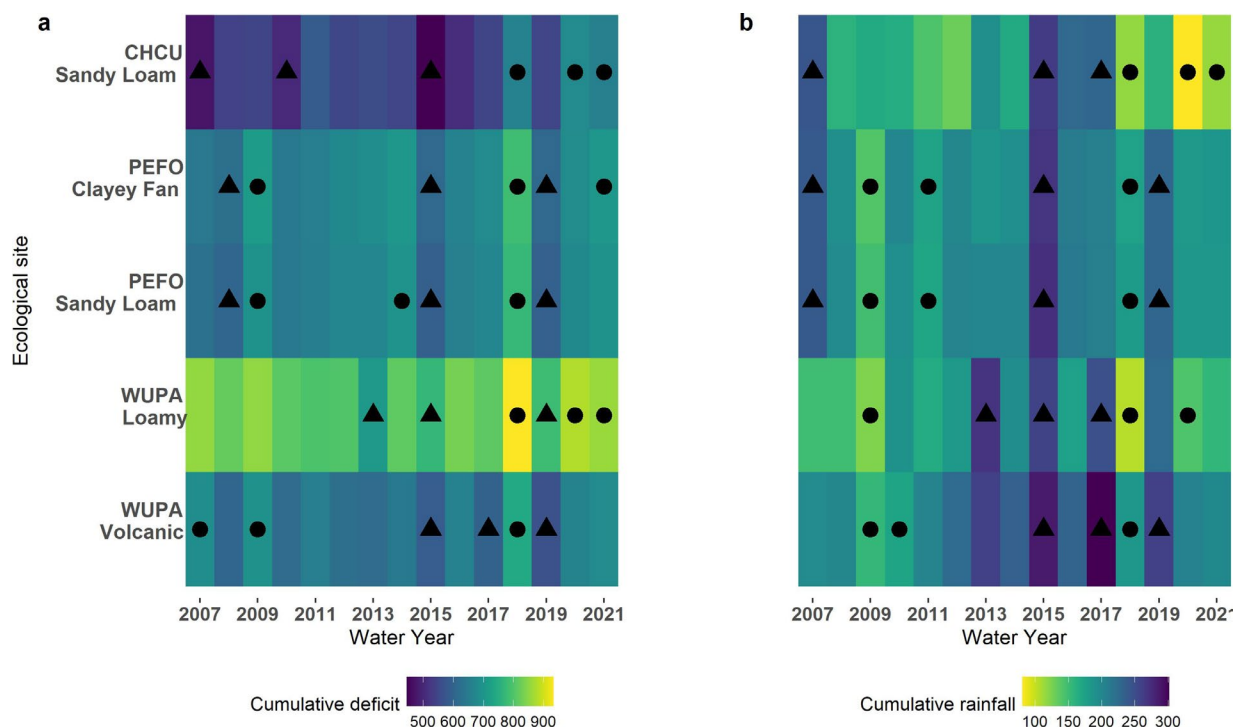


Figure 47. Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA). Circles indicate extreme dry years (i.e., the three highest deficit/lowest rainfall years) and triangles indicate extreme wet years (i.e., the three lowest deficit/highest rainfall years) for each ecological site (2007-2021). For CHCU S and WUPA L, all three highest deficit years occurred in the last 4 years of monitoring (data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>). [Data for this figure are provided in Table E-3 in Appendix E.](#)

Summary: covariate effects

A summary table of the direction of covariate effects on modeled responses is provided in Figure 48. The lifeform groups and species modeled were generally responsive to climatic water deficit and accumulated growing degree day covariates; however, the effect of elevation and terrain covariates effects were mostly neutral (Figure 45). This probably reflects that slopes and elevations are generally consistent between plots and within ecological sites.

Accumulated growing degree days (AGDD) had a positive effect on most responses as expected; however, the response of perennial and exotic forbs to increasing AGDD was negative. While longer periods of springtime temperature favorable to plant growth generally has a positive effect on plant cover (given sufficient available water), studies suggest at least some exotic or annual species in semi-arid grasslands might benefit from cool, wet springs. (Munson 2011, Prevey and Seastedt 2014).

Seasonal climatic water deficits had mixed effects on the modeled responses (Figure 48). Effects of climate variables on plant growth in semi-arid grasslands is notoriously difficult to untangle (Schwinning 2004). For perennial grass other than black grama, July deficit had positive effects on cover (Figure 48). This was unexpected as greater deficits indicate potential evapotranspiration

greatly exceeds actual transpiration, i.e., plants experiencing *more* water stress exhibited greater cover. The reason for this is unclear. Because they can close their stomates to conserve water while continuing to photosynthesize, C₄ grasses are adapted to hot summer conditions. Another study in upland systems on the Colorado Plateau that used water balance variables to explain variation in grass cover reported C₄ species had a positive response to higher June deficits (Witwicki et al. 2016), but several other recent studies on the Plateau have shown perennial grass species are highly sensitive to drought conditions (Munson 2022, Winkler 2019). Plants may use rapid growth and/or earlier growth to escape negative effects of drought stress (Álvarez et al. 2018). Increased carbon dioxide in the atmosphere has also been shown to offset the effect of limited soil moisture in C₄ grasses (Morgan et al. 2011). Additionally, plant responses to water stress have been shown to be strongly dependent on previous conditions as well as interactions with other stressors, which may not have been adequately modeled by our choice of covariates (Seleiman et al. 2021). Winter deficit also had mostly positive effects on C₄ grass cover (Figure 48) in models in which it was included. These positive responses to seasonal deficit, especially summer deficit, warrants additional study.

Spring deficit had mostly negative effects on cover in our models (Figure 48). Overall grass and shrub cover, as well as cover of many of the species modeled, showed reductions in cover in response to higher spring water deficit. Similarly, increased spring precipitation had a positive effect on C₄ grasses elsewhere on the Colorado Plateau (Witwicki et al. 2016). This is particularly concerning since spring deficits are expected to increase in the coming decades due to anthropogenic climate change (Bradford et al. 2020). Earlier spring onset and earlier spring snowmelt are robust predictions that will increase stress in these grasslands (Bradford et al. 2021).

Cool season (C₃) grass species were at low cover (<1%) across all our ecological sites, and as a result, we only modeled one species (Indian ricegrass) across three ecological sites in two parks (PEFO and CHCU). Spring and summer deficit had negative effects on the cover of Indian ricegrass at both PEFO and CHCU ecological sites (for this model, the broader summer deficit covariate, rather than July deficit, was used, since the plots sampled in August at Wupatki were not included). Winter deficit and AGDD had a positive effect. Winter deficit had a negative effect on frequency of modeled forbs. Both C₃ grasses and annual forbs are known to be positively affected by cool season precipitation (Munson 2011).

The effect of covariates on species richness was mixed across ecosites (Figure 45). Species richness has been positively correlated with increased precipitation in dryland ecosystems (Harrison et al. 2015). Higher winter deficit had a negative effect on richness in all ecosites, except for WUPA V. Cooler and wetter winter conditions may be favorable to richness in these ecosites, since much of the richness of these sites is derived from the presence of annual forbs that respond to cooler wetter springs (Munson et al. 2011). But there are often other direct contributors to the number of species. Increased richness may result from environmental germination cues or combinations of wet and dry years and lagged effects; more so than responses such as cover (Adler and Levine 2007).

Mixed results of covariate effects may indicate differences between ecosites in critical timing of deficits. Although more complicated interaction models generally failed to pass model checks and are therefore not presented here, preliminary results did indicate that covariate effects varied in size

and direction between ecological sites, especially for grass species. Earlier studies showed differences between ecosites in critical timing of soil moisture (Andrews et al. 2019 a-e). Additional data will allow us to examine interaction effects in the future.

	Lag year deficit	Winter deficit	Spring deficit	Summer deficit	July deficit	AGDD
Perennial grasses		Green	Red		Green	Green
Black grama	Red				Red	
Blue grama			Red			Green
New Mexico needlegrass	Red		Gray		Green	Green
Galleta grass		Green	Gray		Green	Gray
Dropseeds					Green	Gray
Indian ricegrass		Green	Red	Red		Green
Shrubs	Red	Gray	Red		Gray	Green
Four-wing saltbush		Gray	Red	Red		Gray
Mound saltbush		Gray	Gray	Gray		Gray
Snakeweed	Red	Gray	Red			Green
Winterfat	Green	Gray	Gray	Gray		Gray
Perennial forbs	Red	Red	Gray		Red	Red
Annual forbs	Green	Red	Red		Gray	Gray
Exotic forbs	Green	Red	Gray		Red	Red

Figure 48. Summary of direction of water deficit and aggregated growing degree days (AGDD) covariate effects on modeled responses. Green indicates a positive trend, red a negative trend and a gray box indicates that the trend was non-significant. Non-colored boxes indicate that a given response was not modeled for the ecological site. that a given model did not include that covariate. [Data for this figure are provided in Table E-4 in Appendix E.](#)

Conclusions

Ecological sites varied in soil type and composition. Soil surfaces were dominated by undifferentiated soil crust, except at WUPA, where soil surfaces were dominated by cinders. Soil stability at PEFO and CHCU was moderate. Of the 273 plant species encountered, only 23 species were common to all five ecosites. And of these, only two occurred in >10% of quadrats within each ecosite. Grasses composed >70% of overall cover at all sites. Shrub cover was highest at WUPA L, and composition varied by ecosite. Forbs had low cover but comprised a large portion of the species richness present in these sites. Exotic species were infrequent, except for Russian thistle, which occurred in over 1/3 of plots sampled at PEFO C and WUPA V. Models revealed significant negative time trends in many responses (i.e., changes over time that were not explained by covariates), particularly in the cover of perennial grass at all five ecological sites. Time trends in shrub and forb responses were mixed, although frequency of forbs increased at CHCU S despite extreme drought conditions over the last three years (2019-2021). Richness showed variable effects by ecosite, decreasing at CHCU S and increasing at PEFO S and WUPA V.

Modeled responses were influenced by covariates, but direction of these effects varied. The most consistent effects were that increased July water stress tended to increase perennial grass cover and that warmer springs (>AGDD) increased cover of perennial grasses and shrubs. The consistent negative effects of spring increasing water stress in the spring tended to have negative effects on most responses, which is concerning since predicted earlier snowmelt and higher spring temperatures will almost certainly result in drier springs in the coming decades. Decreasing cover of perennial grass and increasing cover of shrubs and weedy forbs has been predicted for southwestern grasslands in response to increasing aridification due to anthropogenic climate change and results appear to support these predictions. Continued drought conditions will likely exacerbate changes in these systems.

The sites included in this report, as part of the National Park Service, are uniquely protected from localized anthropogenic disturbances, domestic grazing and many other non-climate related drivers of change that commonly lead to reduced cover or mortality of vegetation. Therefore, despite the anomalous positive effect of increasing July and winter deficit on cover of perennial grasses, the overall decrease in cover across the ecological sites is most likely being driven by changing climate. Further refining models and predictor variables, as well as additional years of data will help clarify these relationships.

Management Implications

The negative trend in grass cover across all five ecosites, coupled with the currently low occurrence of exotic forbs, highlights the importance of limiting disturbance in these grassland ecological sites. Evidence of trespass livestock use has been observed by field crews in the past. Trespass livestock not only consume native grass, but they also reduce species richness, generate ground disturbance, and spread seeds which can lead to establishment of non-native species (Fleischner 1994, Floyd et al. 2003).

Road maintenance and trail building is another source of disturbance that can lead to increased presence of exotic species that compete with native grasses. For example, Halogeton (*Halogeton glomeratus*) was first seen immediately following a maintenance project that used fill along the waterline road in the PEFO C ecological site, and that species is now established. At CHCU, cheatgrass (*Bromus tectorum*) has become more prevalent in the campground and other developed areas, and, as a result, is increasingly likely to be transported into other areas by hikers and vehicles. High cover of nonnative plants can lead to changes in fire regimes, increase erosion, decrease species richness, and otherwise degrade the ecosites.

Thoughtful restoration is also important. Consideration of which species will do best under future climate conditions, and timing restoration projects during periods when they are more likely to be successful are two strategies that may increase positive outcomes. Although terrain (slope and aspect) was not a significant predictor of vegetation in this analysis, recent experiments across numerous dryland restoration sites in the southwestern USA, have demonstrated the timing of precipitation and use of fine-scale soil surface treatments (i.e., small pits designed to enhance soil moisture at planting sites) are more important in determining seeded species emergence, survival, and growth than site-specific characteristics (Farrell et al. 2023). The creation of slight variation in the soil surface (small pits) in tandem with seeding resulted in up to 3× greater seedling emergence densities compared with seeding alone (Farrell et al. 2023). This result is extremely valuable to land managers, as minor (multifaceted) changes in revegetation methods can significantly impact the likelihood of success (Farrell et al. 2023).

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Appendix A: Plot Sampling History (2007–2021)

Figures A-1 and A-2 provide plot sampling history and intervals at five ecosites and three National Parks.

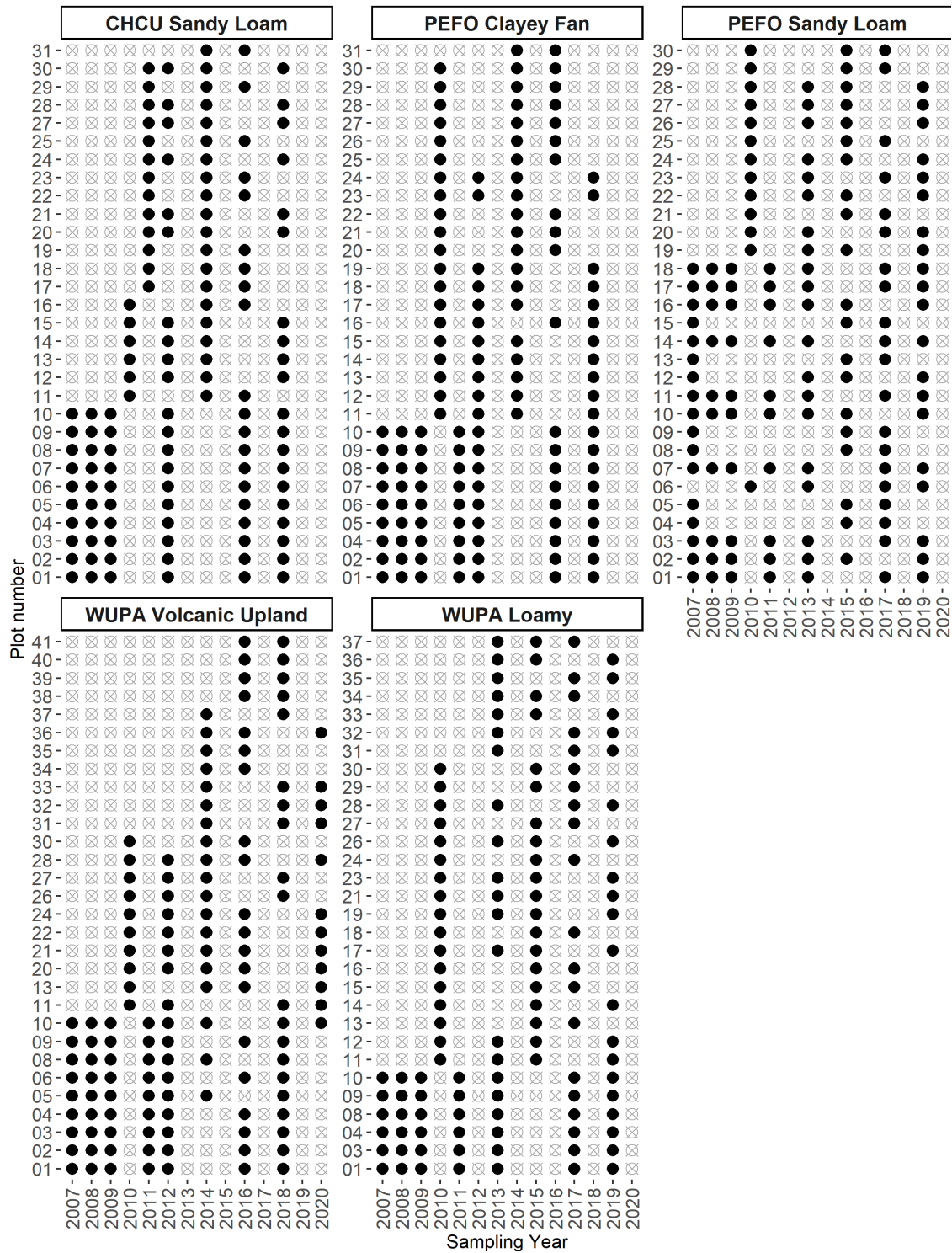


Figure A-1. Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year. [These data are provided in tabular form in Table E-5 in Appendix E.](#)

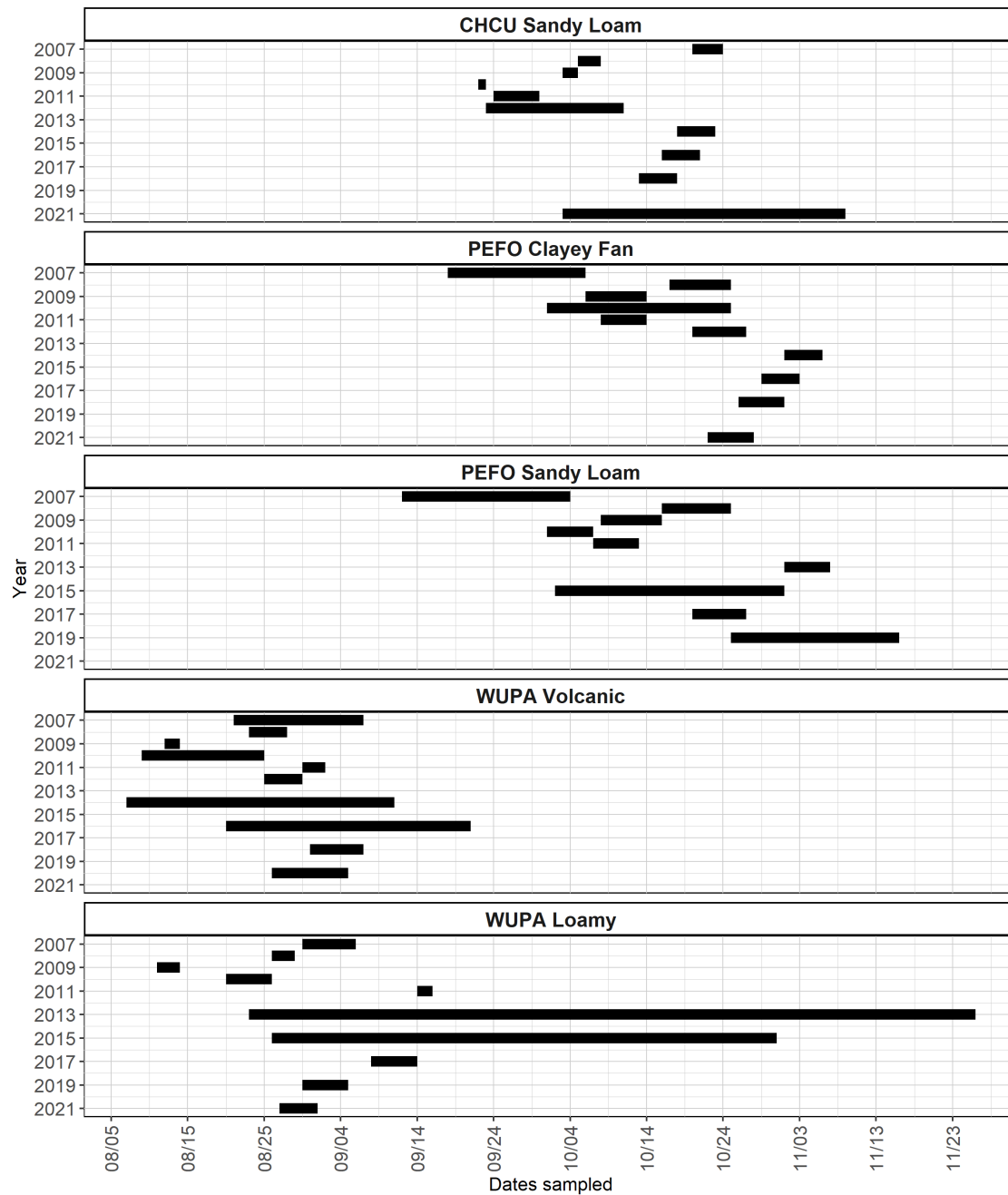


Figure A-2. Plot sampling intervals at five ecosites in three National Parks (CHCU, PEFO, WUPA). Segment indicates sampling start date and end date. Extended sampling periods indicate revisits to complete plots that weren't completed during the initial visit. [These data are provided in tabular form in Table E-6 in Appendix E.](#)

Appendix B: Vascular Plant Species Detected at Grassland Ecological Sites (2007–2021)

Table B-1. List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database (<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Alliaceae	<i>Allium macropetalum</i>	F	N	P	0.07	1.44	NP	NP	NP
Amaranthaceae	<i>Amaranthus acanthochiton</i>	F	N	A	NP	NP	0.22	NP	NP
Amaranthaceae	<i>Amaranthus spp.</i>	F	NA	NA	0.04	0.29	1.90	5.29	0.28
Amaranthaceae	<i>Atriplex canescens</i>	S	N	P	37.41	10.55	42.28	0.22	11.51
Amaranthaceae	<i>Atriplex confertifolia</i>	S	N	P	NP	6.20	2.01	NP	1.99
Amaranthaceae	<i>Atriplex obovata</i>	S	N	P	0.00	56.40	2.67	NP	NP
Amaranthaceae	<i>Atriplex powellii</i>	F	N	A	NP	NP	0.13	NP	NP
Amaranthaceae	<i>Atriplex saccaria</i>	F	N	A	NP	0.38	0.44	NP	NP
Amaranthaceae	<i>Chenopodium spp.</i>	F	NA	NA	23.04	0.23	6.48	NP	NP
Amaranthaceae	<i>Corispermum americanum</i>	F	N	A	NP	0.54	NP	NP	NP
Amaranthaceae	<i>Halogeton glomeratus</i>	F	NN	A	NP	1.20	NP	NP	NP
Amaranthaceae	<i>Kochia scoparia</i>	F	NN	A	NP	NP	1.23	1.39	NP
Amaranthaceae	<i>Krascheninnikovia lanata</i>	S	N	P	31.45	2.10	11.09	0.22	NP
Amaranthaceae	<i>Salsola collina</i>	F	NN	A	NP	0.10	0.17	NP	NP
Amaranthaceae	<i>Salsola tragus</i>	F	NN	A	8.76	36.31	16.93	49.30	5.34
Amaranthaceae	<i>Suaeda nigra</i>	F	N	A	NP	0.89	NP	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

(<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Amaranthaceae	<i>Zuckia brandegeei</i>	S	N	P	NP	0.06	NP	NP	NP
Apiaceae	<i>Cymopterus spp.</i>	F	NA	NA	NP	NP	0.34	NP	NP
Apocynaceae	<i>Amsonia peeblesii</i>	F	N	P	NP	NP	NP	NP	0.17
Apocynaceae	<i>Amsonia spp.</i>	F	NA	NA	NP	NP	NP	NP	0.06
Apocynaceae	<i>Asclepias involucrata</i>	F	N	P	NP	NP	0.07	NP	NP
Apocynaceae	<i>Asclepias macrotis</i>	F	N	P	0.04	NP	NP	NP	NP
Apocynaceae	<i>Asclepias subverticillata</i>	F	N	P	NP	NP	0.06	NP	NP
Asparagaceae	<i>Yucca angustissima</i>	C	N	P	NP	2.15	5.44	NP	0.18
Asparagaceae	<i>Yucca baccata</i>	C	N	P	NP	0.04	0.72	NP	NP
Asteraceae	<i>Ambrosia acanthicarpa</i>	F	N	A	NP	NP	NP	NP	0.61
Asteraceae	<i>Ambrosia spp.</i>	F	NA	NA	NP	0.04	NP	NP	NP
Asteraceae	<i>Artemisia bigelovii</i>	S	N	P	2.72	1.57	6.54	NP	NP
Asteraceae	<i>Artemisia filifolia</i>	S	N	P	3.66	0.90	19.43	0.00	23.46
Asteraceae	<i>Artemisia frigida</i>	F	N	P	10.81	NP	NP	NP	NP
Asteraceae	<i>Artemisia ludoviciana</i>	F	N	P	NP	0.22	NP	NP	NP
Asteraceae	<i>Artemisia tridentata</i>	S	N	P	0.39	NP	NP	NP	NP
Asteraceae	<i>Brickellia oblongifolia</i>	F	N	P	NP	NP	NP	NP	0.10
Asteraceae	<i>Chaenactis spp.</i>	F	NA	NA	NP	1.07	NP	NP	NP
Asteraceae	<i>Chaenactis stevioides</i>	F	N	A	NP	NP	8.62	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

(<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Asteraceae	<i>Chaetopappa ericoides</i>	F	N	P	22.19	3.25	35.13	7.20	2.85
Asteraceae	<i>Chloracantha spinosa</i>	F	N	P	NP	NP	NP	0.06	NP
Asteraceae	<i>Chrysothamnus depressus</i>	S	N	P	NP	NP	NP	0.06	NP
Asteraceae	<i>Chrysothamnus Greenei</i>	S	N	P	29.43	1.18	18.35	NP	NP
Asteraceae	<i>Conyza canadensis</i>	F	N	A	NP	0.03	NP	NP	NP
Asteraceae	<i>Dieteria spp.</i>	F	NA	NA	NP	2.05	NP	NP	NP
Asteraceae	<i>Ericameria nauseosa</i>	S	N	P	1.37	2.11	0.41	14.74	13.91
Asteraceae	<i>Erigeron concinnus</i>	F	N	P	NP	1.44	0.07	NP	NP
Asteraceae	<i>Erigeron divergens</i>	F	N	B	NP	1.83	3.57	NP	NP
Asteraceae	<i>Erigeron eatonii</i>	F	N	P	NP	0.04	NP	NP	NP
Asteraceae	<i>Erigeron spp.</i>	F	NA	NA	0.11	0.39	0.06	NP	NP
Asteraceae	<i>Eriogonum spp.</i>	F	NA	NA	NP	0.04	0.13	NP	NP
Asteraceae	<i>Gaillardia pinnatifida</i>	F	N	P	NP	0.18	0.15	NP	NP
Asteraceae	<i>Gutierrezia microcephala</i>	S	N	P	NP	NP	NP	0.68	5.92
Asteraceae	<i>Gutierrezia sarothrae</i>	S	N	P	33.72	14.46	45.08	NP	0.06
Asteraceae	<i>Helianthus annuus</i>	F	N	A	0.24	0.04	NP	NP	NP
Asteraceae	<i>Heliomeris multiflora</i>	F	N	P	NP	0.18	NP	NP	NP
Asteraceae	<i>Heterotheca villosa</i>	F	N	P	0.04	NP	NP	NP	NP
Asteraceae	<i>Hymenopappus filifolius</i>	F	N	P	0.07	1.13	4.13	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

(<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Asteraceae	<i>Hymenopappus flavescens</i>	F	N	B	NP	0.39	1.53	NP	NP
Asteraceae	<i>Hymenopappus spp.</i>	F	NA	NA	NP	0.11	NP	NP	NP
Asteraceae	<i>Hymenoxys richardsonii</i>	F	N	P	NP	0.31	NP	NP	NP
Asteraceae	<i>Isocoma rusbyi</i>	S	N	P	NP	1.45	0.03	NP	NP
Asteraceae	<i>Laennecia coulteri</i>	F	N	A	NP	0.04	0.59	NP	NP
Asteraceae	<i>Lorandersonia pulchella</i>	S	N	P	0.27	NP	NP	NP	NP
Asteraceae	<i>Lygodesmia grandiflora</i>	F	N	P	NP	0.06	NP	NP	NP
Asteraceae	<i>Malacothrix spp.</i>	F	NA	NA	NP	NP	0.28	NP	NP
Asteraceae	<i>Pectis angustifolia</i>	F	N	A	NP	5.21	1.89	NP	NP
Asteraceae	<i>Pectis spp.</i>	F	NA	NA	NP	NP	NP	NP	0.06
Asteraceae	<i>Psilostrophe sparsiflora</i>	F	N	P	NP	0.03	NP	0.16	0.33
Asteraceae	<i>Psilostrophe tagetina</i>	F	N	B	NP	0.22	NP	NP	NP
Asteraceae	<i>Sanvitalia abertii</i>	F	N	A	0.22	1.86	3.16	0.03	0.13
Asteraceae	<i>Schkuhria multiflora</i>	F	N	A	1.00	1.72	0.20	0.20	NP
Asteraceae	<i>Senecio flaccidus</i>	F	N	P	NP	0.49	0.74	0.37	NP
Asteraceae	<i>Senecio spartioides</i>	F	N	P	0.06	0.26	NP	NP	NP
Asteraceae	<i>Stephanomeria spp.</i>	F	NA	P	1.07	0.11	4.34	5.62	12.96
Asteraceae	<i>Taraxacum officinale</i>	F	NN	P	NP	0.16	NP	NP	NP
Asteraceae	<i>Tetradymia canescens</i>	S	N	P	0.28	NP	NP	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

(<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Asteraceae	<i>Tetranneuris spp.</i>	F	NA	NA	NP	NP	0.03	NP	NP
Asteraceae	<i>Thelesperma megapotamicum</i>	F	N	P	NP	1.39	0.14	NP	NP
Asteraceae	<i>Thymophylla pentachaeta</i>	F	N	P	NP	NP	NP	NP	0.03
Asteraceae	<i>Thymophylla spp.</i>	NA	NA	P	NP	NP	NP	NP	0.03
Asteraceae	<i>Townsendia annua</i>	F	N	A	10.54	19.56	8.93	NP	NP
Asteraceae	<i>Tragopogon dubius</i>	F	NN	B	NP	0.03	0.37	NP	0.03
Asteraceae	<i>Verbesina encelioides</i>	F	N	A	0.11	0.13	NP	NP	NP
Asteraceae	<i>Xanthisma gracile</i>	F	N	A	NP	NP	0.75	NP	NP
Asteraceae	<i>Xanthisma spinulosum</i>	F	N	P	NP	NP	0.91	NP	NP
Asteraceae	<i>Xanthium strumarium</i>	F	N	A	NP	1.92	NP	NP	NP
Asteraceae	<i>Zinnia grandiflora</i>	F	N	P	NP	NP	1.90	6.09	2.28
Boraginaceae	<i>Cryptantha cinerea</i>	F	N	P	NP	NP	NP	1.07	NP
Boraginaceae	<i>Cryptantha flava</i>	F	N	P	NP	0.09	NP	NP	NP
Boraginaceae	<i>Cryptantha spp.</i>	F	NA	NA	25.34	2.65	10.49	0.18	0.17
Boraginaceae	<i>Heliotropium curassavicum</i>	F	N	A	NP	0.04	NP	NP	NP
Boraginaceae	<i>Lappula occidentalis</i>	F	N	A	19.82	13.89	1.92	0.03	NP
Boraginaceae	<i>Lappula spp.</i>	F	NA	NA	0.12	NP	NP	NP	NP
Boraginaceae	<i>Lithospermum incisum</i>	F	N	P	NP	NP	NP	0.22	NP
Boraginaceae	<i>Lithospermum multiflorum</i>	F	N	P	0.04	NP	NP	0.11	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

(<https://plants.sc.egov.usda.gov/java>).

Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Boraginaceae	<i>Nama dichotoma</i>	F	N	A	0.04	NP	0.55	0.37	NP
Boraginaceae	<i>Nama hispida</i>	F	N	A	NP	0.57	2.93	NP	NP
Boraginaceae	<i>Phacelia integrifolia</i>	F	N	A	NP	NP	1.24	NP	NP
Boraginaceae	<i>Phacelia ivesiana</i>	F	N	A	NP	NP	0.20	0.66	NP
Boraginaceae	<i>Phacelia spp.</i>	F	NA	NA	3.90	1.52	1.61	0.67	8.87
Boraginaceae	<i>Physaria intermedia</i>	F	N	P	NP	NP	0.18	NP	NP
Boraginaceae	<i>Tiquilia hispidissima</i>	F	N	P	NP	NP	NP	NP	0.82
Boraginaceae	<i>Tiquilia nuttallii</i>	F	N	A	NP	NP	NP	0.00	2.54
Brassicaceae	<i>Boechera spp.</i>	F	NA	NA	0.04	NP	NP	NP	NP
Brassicaceae	<i>Descurainia pinnata</i>	F	N	A	32.43	7.07	24.95	5.20	0.65
Brassicaceae	<i>Dimorphocarpa wislizeni</i>	F	N	A	NP	2.20	1.53	NP	NP
Brassicaceae	<i>Draba cuneifolia</i>	F	N	A	NP	1.19	NP	NP	NP
Brassicaceae	<i>Elymus elymoides</i>	G	N	P	21.93	1.14	9.20	1.69	0.88
Brassicaceae	<i>Erysimum capitatum</i>	F	N	B	1.16	0.13	2.11	NP	NP
Brassicaceae	<i>Parryella filifolia</i>	S	N	P	NP	1.93	0.44	NP	NP
Brassicaceae	<i>Sisymbrium altissimum</i>	F	NN	A	NP	NP	0.35	NP	NP
Brassicaceae	<i>Stanleya pinnata</i>	F	N	P	NP	NP	NP	NP	2.87
Brassicaceae	<i>Streptanthella longirostris</i>	F	N	A	NP	NP	NP	NP	0.04
Brassicaceae	<i>Thelypodium wrightii</i>	F	N	B	0.17	NP	NP	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Brassicaceae	<i>unk brassicaceae</i>	NA	NA	NA	0.04	NP	NP	NP	NP
Cactaceae	<i>Cylindropuntia whipplei</i>	C	N	P	0.04	4.41	5.92	1.16	0.06
Cactaceae	<i>Echinocereus spp.</i>	C	NA	P	NP	NP	0.54	NP	NP
Cactaceae	<i>Echinocereus triglochidiatus</i>	C	N	P	0.37	0.12	0.06	NP	NP
Cactaceae	<i>Escobaria vivipara</i>	C	N	P	0.87	1.14	1.13	0.13	NP
Cactaceae	<i>Opuntia spp.</i>	C	NA	P	18.65	4.35	7.97	0.80	0.44
Cactaceae	<i>Sclerocactus whipplei</i>	C	N	P	NP	0.27	0.09	NP	NP
Chenopodiaceae	<i>Chenopodium fremontii</i>	F	N	A	NP	NP	NP	0.52	NP
Chenopodiaceae	<i>Chenopodium leptophyllum</i>	F	N	A	NP	0.79	3.05	30.07	0.00
Cleomaceae	<i>Polanisia dodecandra</i>	F	N	A	NP	NP	NP	1.00	NP
Convolvulaceae	<i>Cuscuta spp.</i>	V	NA	NA	NP	NP	NP	0.03	NP
Convolvulaceae	<i>Evolvulus nuttallianus</i>	F	N	P	0.04	1.11	6.35	6.62	NP
Convolvulaceae	<i>Ipomoea costellata</i>	F	N	A	NP	NP	NP	0.60	NP
Ephedraceae	<i>Ephedra cutleri</i>	S	N	P	0.49	0.41	2.81	NP	NP
Ephedraceae	<i>Ephedra torreyana</i>	S	N	P	3.09	1.05	7.15	0.00	29.27
Ephedraceae	<i>Ephedra viridis</i>	S	N	P	1.07	0.16	0.59	NP	3.48
Euphorbiaceae	<i>Euphorbia albomarginata</i>	F	N	P	NP	0.09	NP	0.03	NP
Euphorbiaceae	<i>Euphorbia exstipulata</i>	F	N	A	NP	NP	NP	2.99	2.67
Euphorbiaceae	<i>Euphorbia fendleri</i>	F	N	P	0.14	1.51	0.44	1.66	9.55

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Euphorbiaceae	<i>Euphorbia spp.</i>	F	NA	NA	10.06	48.97	23.25	43.40	56.81
Euphorbiaceae	<i>Tragia ramosa</i>	F	N	P	NP	NP	NP	0.89	NP
Fabaceae	<i>Astragalus amphioxys</i>	F	N	P	NP	11.93	6.22	0.43	NP
Fabaceae	<i>Astragalus ceramicus</i>	F	N	P	NP	0.52	0.87	NP	NP
Fabaceae	<i>Astragalus lentiginosus</i>	F	N	A	NP	NP	0.10	1.22	NP
Fabaceae	<i>Astragalus mollissimus</i>	F	N	P	NP	0.49	8.25	NP	NP
Fabaceae	<i>Astragalus spp.</i>	F	NA	NA	3.97	1.41	0.87	6.00	6.48
Fabaceae	<i>Dalea candida</i>	F	N	P	NP	0.70	0.85	NP	NP
Fabaceae	<i>Dalea lanata</i>	F	N	P	NP	0.04	0.17	NP	NP
Fabaceae	<i>Hoffmannseggia drepanocarpa</i>	F	N	P	NP	NP	NP	1.08	NP
Fabaceae	<i>Lupinus spp.</i>	F	NA	NA	NP	NP	0.15	NP	NP
Fabaceae	<i>Phaseolus spp.</i>	V	NA	NA	NP	NP	NP	0.07	NP
Fabaceae	<i>Pomaria jamesii</i>	F	N	P	NP	0.06	0.88	3.69	NP
Fabaceae	<i>Senna bauhinioides</i>	F	N	P	NP	NP	NP	NP	0.12
Geraniaceae	<i>Erodium cicutarium</i>	F	NN	A	NP	0.78	0.03	NP	NP
Krameriaceae	<i>Krameria erecta</i>	S	N	P	NP	NP	0.06	NP	NP
Lamiaceae	<i>Tetradlea coulteri</i>	F	N	P	NP	NP	NP	0.09	7.76
Lamiaceae	<i>Tetradlea spp.</i>	F	NA	NA	NP	NP	NP	NP	0.28
Liliaceae	<i>Calochortus aureus</i>	F	N	P	NP	3.30	1.89	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Linaceae	<i>Linum aristatum</i>	F	N	A	NP	0.89	2.85	NP	NP
Linaceae	<i>Linum lewisii</i>	F	N	P	NP	0.69	0.11	NP	NP
Linaceae	<i>Linum puberulum</i>	F	N	A	0.27	NP	NP	NP	NP
Linaceae	<i>Linum spp.</i>	F	NA	NA	NP	0.17	NP	NP	NP
Loasaceae	<i>Mentzelia albicaulis</i>	F	N	A	0.59	1.83	12.89	7.50	13.90
Loasaceae	<i>Mentzelia multiflora</i>	F	N	P	NP	0.58	1.63	NP	NP
Loasaceae	<i>Mentzelia spp.</i>	F	NA	NA	NP	0.28	0.44	1.24	4.97
Malvaceae	<i>Sphaeralcea coccinea</i>	F	N	B	NP	NP	NP	0.00	NP
Malvaceae	<i>Sphaeralcea spp.</i>	F	NA	NA	43.13	34.11	28.52	12.83	20.53
Molluginaceae	<i>Mollugo cerviana</i>	F	NN	A	NP	0.83	0.87	1.17	1.77
Montiaceae	<i>Phemeranthus parviflorus</i>	F	N	P	NP	0.22	NP	0.07	NP
Nyctaginaceae	<i>Boerhavia spp.</i>	F	NA	NA	NP	NP	0.39	NP	NP
Oleaceae	<i>Lycium andersonii</i>	S	N	P	NP	NP	NP	0.10	0.26
Oleaceae	<i>Lycium pallidum</i>	S	N	P	0.87	NP	0.07	NP	NP
Oleaceae	<i>Menodora scabra</i>	F	N	P	NP	0.11	0.03	NP	NP
Onagraceae	<i>Camissonia gouldii</i>	F	N	A	NP	NP	NP	0.07	NP
Onagraceae	<i>Oenothera hexandra</i>	F	N	A	NP	NP	NP	0.13	NP
Onagraceae	<i>Oenothera spp.</i>	F	NA	NA	7.34	24.51	36.92	NP	NP
Onagraceae	<i>Oenothera suffrutescens</i>	F	N	P	NP	NP	NP	0.74	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Orobanchaceae	<i>Cordylanthus wrightii</i>	F	N	A	NP	0.13	0.06	NP	NP
Orobanchaceae	<i>Orobanche ludoviciana</i>	F	N	A	0.22	NP	0.07	NP	NP
Plantaginaceae	<i>Penstemon spp.</i>	F	NA	NA	0.30	NP	NP	NP	NP
Plantaginaceae	<i>Plantago patagonica</i>	F	N	A	38.06	26.19	20.66	NP	NP
Poaceae	<i>Achnatherum hymenoides</i>	G	N	P	59.15	29.48	52.27	0.56	9.50
Poaceae	<i>Aristida adscensionis</i>	G	N	A	NP	1.27	0.06	0.09	NP
Poaceae	<i>Aristida havardii</i>	G	N	P	NP	NP	NP	3.80	0.42
Poaceae	<i>Aristida purpurea</i>	G	N	P	10.13	1.86	5.94	4.60	2.99
Poaceae	<i>Bouteloua barbata</i>	G	N	A	0.26	42.02	4.92	NP	1.31
Poaceae	<i>Bouteloua curtipendula</i>	G	N	P	NP	NP	NP	0.22	NP
Poaceae	<i>Bouteloua eriopoda</i>	G	N	P	NP	0.22	14.79	77.81	18.10
Poaceae	<i>Bouteloua gracilis</i>	G	N	P	81.87	40.82	74.83	0.71	0.00
Poaceae	<i>Bromus rubens</i>	G	NN	A	NP	0.50	0.17	NP	NP
Poaceae	<i>Bromus tectorum</i>	G	NN	A	1.24	8.03	5.48	0.16	NP
Poaceae	<i>Dasyochloa pulchella</i>	G	N	P	NP	NP	0.67	NP	10.65
Poaceae	<i>Dieteria canescens</i>	F	N	A	1.86	NP	9.88	0.59	NP
Poaceae	<i>Enneapogon desvauxii</i>	G	N	P	NP	0.16	0.03	NP	NP
Poaceae	<i>Eragrostis pectinacea</i>	G	N	A	NP	6.81	1.97	NP	NP
Poaceae	<i>Hesperostipa comata</i>	G	N	P	6.74	2.83	29.29	NP	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Poaceae	<i>Hesperostipa neomexicana</i>	G	N	P	NP	0.08	NP	56.18	4.82
Poaceae	<i>Hesperostipa spp.</i>	G	NA	NA	0.06	NP	NP	NP	NP
Poaceae	<i>Hilaria jamesii</i>	G	N	P	89.53	50.03	79.60	95.20	61.67
Poaceae	<i>Hopia obtusa</i>	G	N	P	NP	NP	NP	NP	0.22
Poaceae	<i>Hordeum murinum</i>	G	NN	A	NP	NP	0.12	NP	NP
Poaceae	<i>Muhlenbergia porteri</i>	G	N	P	NP	NP	NP	0.00	29.39
Poaceae	<i>Muhlenbergia pungens</i>	G	N	P	0.44	1.37	1.32	NP	NP
Poaceae	<i>Muhlenbergia torreyi</i>	G	N	P	9.82	NP	8.52	NP	NP
Poaceae	<i>Munroa squarrosa</i>	G	N	A	12.44	18.36	8.03	NP	0.17
Poaceae	<i>Oryzopsis asperifolia</i>	G	N	P	NP	NP	0.51	NP	NP
Poaceae	<i>Panicum hirticaule</i>	G	N	A	NP	0.16	NP	NP	NP
Poaceae	<i>Pascopyrum smithii</i>	G	N	P	NP	0.44	NP	NP	NP
Poaceae	<i>Sporobolus coromandelianus</i>	G	N	A	0.04	29.35	3.18	NP	NP
Poaceae	<i>Sporobolus spp.</i>	G	NA	NA	76.73	95.01	71.51	4.68	4.17
Poaceae	<i>Thinopyrum ponticum</i>	G	NN	P	NP	0.27	NP	NP	NP
Poaceae	<i>Vulpia octoflora</i>	G	N	A	10.87	0.91	12.25	NP	NP
Polemoniaceae	<i>Eriastrum diffusum</i>	F	N	A	NP	0.03	NP	NP	NP
Polemoniaceae	<i>Eriastrum spp.</i>	F	NA	NA	NP	NP	0.06	NP	NP
Polemoniaceae	<i>Gilia spp.</i>	F	NA	NA	0.28	NP	0.87	0.03	3.57

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Polemoniaceae	<i>Ipomopsis pumila</i>	F	N	A	0.31	NP	0.17	NP	NP
Polemoniaceae	<i>Ipomopsis gunnisonii</i>	F	N	A	NP	0.30	NP	NP	NP
Polemoniaceae	<i>Ipomopsis longiflora</i>	F	N	A	NP	0.80	21.48	NP	NP
Polemoniaceae	<i>Ipomopsis multiflora</i>	F	N	P	NP	0.57	0.21	NP	NP
Polemoniaceae	<i>Ipomopsis spp.</i>	F	NA	NA	NP	0.09	NP	NP	NP
Polygonaceae	<i>Eriogonum cernuum</i>	F	N	A	8.55	NP	NP	NP	1.51
Polygonaceae	<i>Eriogonum corymbosum</i>	S	N	P	0.37	NP	0.16	NP	0.94
Polygonaceae	<i>Eriogonum deflexum</i>	F	N	A	NP	6.17	1.43	NP	0.94
Polygonaceae	<i>Eriogonum divaricatum</i>	F	N	A	NP	6.93	0.92	NP	NP
Polygonaceae	<i>Eriogonum jamesii</i>	F	N	P	NP	NP	0.13	NP	NP
Polygonaceae	<i>Eriogonum leptocladon</i>	S	N	P	0.31	1.70	0.69	NP	0.85
Polygonaceae	<i>Eriogonum pulchrum</i>	F	N	P	NP	NP	0.48	NP	NP
Polygonaceae	<i>Polygonum aviculare</i>	F	NN	A	NP	NP	0.03	NP	NP
Polygonaceae	<i>Polygonum sawatchense</i>	F	N	A	NP	NP	0.03	NP	NP
Polygonaceae	<i>Rumex acetosella</i>	F	NN	P	NP	0.11	NP	NP	NP
Polygonaceae	<i>Rumex hymenosepalus</i>	F	N	P	1.98	NP	NP	NP	NP
Portulacaceae	<i>Portulaca halimoides</i>	F	N	A	NP	NP	NP	NP	0.06
Portulacaceae	<i>Portulaca oleracea</i>	F	NN	A	0.19	NP	NP	NP	NP
Portulacaceae	<i>Portulaca pilosa</i>	F	N	A	NP	NP	NP	0.06	NP

Table B-1 (continued). List of species detected and their percent quadrat frequency during grassland monitoring at five ecosites in three National Parks (CHCU, PEFO, WUPA) during 2007 to 2021. Lifeform abbreviations include (F = forb, G= graminoid, S = shrub, C = cactus or succulent, V = vine). Nativity (N = native, NN = nonnative), lifeform and duration were derived from USDA Plants database

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Family	Species	Lifeform	Nativity	Duration	CHCU S	PEFO C	PEFO S	WUPA V	WUPA L
Portulacaceae	<i>Portulaca spp.</i>	F	NA	NA	NP	16.69	4.35	0.80	NP
Ranunculaceae	<i>Delphinium spp.</i>	F	NA	NA	NP	NP	0.37	NP	NP
Ranunculaceae	<i>Ranunculus testiculatus</i>	F	NN	A	NP	0.04	NP	NP	NP
Rosaceae	<i>Fallugia paradoxa</i>	S	N	P	NP	NP	NP	0.00	16.46
Santalaceae	<i>Comandra umbellata</i>	F	N	P	0.39	0.33	5.91	NP	NP
Sarcobataceae	<i>Sarcobatus vermiculatus</i>	S	N	P	0.04	0.22	NP	NP	0.06
Solanaceae	<i>Chamaesaracha coronopus</i>	F	N	P	1.67	6.33	4.26	0.92	1.79
Solanaceae	<i>Physalis hederifolia</i>	F	N	P	NP	NP	NP	0.09	0.09
Solanaceae	<i>Quincula lobata</i>	F	N	P	NP	0.53	NP	NP	NP
Solanaceae	<i>Solanum elaeagnifolium</i>	F	NN	P	NP	NP	NP	NP	3.13
Solanaceae	<i>Solanum jamesii</i>	F	N	P	0.23	NP	0.06	NP	NP
Verbenaceae	<i>Glandularia gooddingii</i>	F	N	P	NP	NP	NP	2.32	0.04
Verbenaceae	<i>Verbena bracteata</i>	F	N	A	NP	0.93	0.06	NP	NP
Zygophyllaceae	<i>Kallstroemia californica</i>	F	N	A	NP	NP	NP	0.31	NP
Zygophyllaceae	<i>Kallstroemia parviflora</i>	F	N	A	NP	0.56	0.11	NP	NP

Appendix C: Cover Class Midpoint Medians of Dominant Species

Table C-1. Median percent cover of dominant plants at five ecosites in three National Parks (CHCU, PEFO, WUPA). Cover estimates were calculated using cover class midpoints (see Table 2).

Scientific name	Lifeform	CHCU S	PEFO C	PEFO S	WUPA L	WUPA S
<i>Achnatherum hymenoides</i>	graminoid	0.483	0.16	0.636	NA	NA
<i>Aristida purpurea</i>	graminoid	0.057	NA	NA	NA	NA
<i>Artemisia bigelovii</i>	shrub	0.06	NA	0.184	NA	NA
<i>Artemisia filifolia</i>	shrub	0.124	NA	0.779	NA	1.118
<i>Artemisia frigida</i>	forb	0.07	NA	NA	NA	NA
<i>Atriplex canescens</i>	shrub	0.834	0.21	1.128	NA	0.359
<i>Bouteloua gracilis</i>	graminoid	4.332	1.627	5.768	NA	NA
<i>Chenopodium spp.</i>	forb	0.256	NA	NA	NA	NA
<i>Chrysothamnus Greenei</i>	shrub	0.488	NA	0.714	NA	NA
<i>Cryptantha spp.</i>	forb	0.06	NA	NA	NA	NA
<i>Descurainia pinnata</i>	forb	0.062	NA	0.062	NA	NA
<i>Elymus elymoides</i>	graminoid	0.089	NA	NA	NA	NA
<i>Ephedra torreyana</i>	shrub	0.167	NA	0.198	NA	1.839
<i>Gutierrezia sarothrae</i>	shrub	0.344	0.095	0.752	NA	NA
<i>Hilaria jamesii</i>	graminoid	3.435	1.29	2.732	13.869	3.616
<i>Krascheninnikovia lanata</i>	shrub	1.084	NA	0.411	NA	NA
<i>Muhlenbergia torreyi</i>	graminoid	0.096	NA	0.055	NA	NA
<i>Opuntia spp.</i>	cactus/succulent	0.096	NA	NA	NA	NA
<i>Plantago patagonica</i>	forb	0.072	NA	NA	NA	NA
<i>Sphaeralcea spp.</i>	forb	0.105	0.059	0.074	NA	0.134
<i>Sporobolus spp.</i>	graminoid	0.961	5.373	3.129	0.109	0.132
<i>Atriplex obovata</i>	shrub	NA	1.154	0.055	NA	NA
<i>Bouteloua barbata</i>	graminoid	NA	0.455	NA	NA	NA
<i>Eragrostis pectinacea</i>	graminoid	NA	0.12	NA	NA	NA

Table C-1 (continued). Median percent cover of dominant plants at five ecosites in three National Parks (CHCU, PEFO, WUPA). Cover estimates were calculated using cover class midpoints (see Table 2).

Scientific name	Lifeform	CHCU S	PEFO C	PEFO S	WUPA L	WUPA S
<i>Ericameria nauseosa</i>	shrub	NA	0.061	NA	0.242	0.392
<i>Euphorbia</i> spp.	forb	NA	0.278	0.152	0.276	1.355
<i>Portulaca</i> spp.	forb	NA	0.129	NA	NA	NA
<i>Salsola tragus</i>	forb	NA	0.388	0.207	2.711	NA
<i>Sporobolus coromandelianus</i>	graminoid	NA	0.614	NA	NA	NA
<i>Xanthium strumarium</i>	forb	NA	0.085	NA	NA	NA
<i>Bouteloua eriopoda</i>	graminoid	NA	NA	0.757	4.518	0.551
<i>Bromus tectorum</i>	graminoid	NA	NA	0.068	NA	NA
<i>Chaetopappa ericoides</i>	forb	NA	NA	0.103	NA	NA
<i>Ephedra cutleri</i>	shrub	NA	NA	0.133	NA	NA
<i>Hesperostipa comata</i>	graminoid	NA	NA	0.452	NA	NA
<i>Ipomopsis longiflora</i>	forb	NA	NA	0.074	NA	NA
<i>Mentzelia albicaulis</i>	forb	NA	NA	0.103	NA	NA
<i>Oenothera</i> spp.	forb	NA	NA	0.137	NA	NA
<i>Amaranthus</i> spp.	forb	NA	NA	NA	0.069	NA
<i>Chenopodium leptophyllum</i>	forb	NA	NA	NA	0.182	NA
<i>Hesperostipa neomexicana</i>	graminoid	NA	NA	NA	1.816	NA
<i>Atriplex confertifolia</i>	shrub	NA	NA	NA	NA	0.077
<i>Ephedra viridis</i>	shrub	NA	NA	NA	NA	0.157
<i>Fallugia paradoxa</i>	shrub	NA	NA	NA	NA	1.324
<i>Gutierrezia microcephala</i>	shrub	NA	NA	NA	NA	0.099
<i>Muhlenbergia porteri</i>	graminoid	NA	NA	NA	NA	0.637

Appendix D: Bayesian Models

Table D-1. Model specifications for all responses presented in this report. Models were run using three chains and 8,000-12,000 iterations. Model indicates the type of deterministic model used. Model type indicates whether slope only (b0) or slope and intercepts (b1) varied by site. For the hurdle ordinal model, slopes and intercepts could vary by percent cover response (b0-b1) as well as by present/not present response (g0-g1). Variance type indicates how variance was treated in the model. Fixed site indicates that each site has its own independent variance. Hierarchical site indicates the variance for a site was drawn from an underlying distribution of variances. Likelihood indicates what distribution was used for the likelihood in the model. Covariates used in the model are listed. For model checking, in addition to visually assessing convergence, P_{mean} and P_{sd} are Bayesian p-value for the mean and variance and are used to indicate lack of fit. Models used for cover are mixed models and have two sets of model-checking values, the first represents the percent cover response, and the second set of P values represents the presence/absence response. PPL is posterior predictive loss, models with lowest posterior predictive loss were selected. The Gelman-Rubin diagnostic is an indicator of convergence and should be close to one.

Response	EcoSite ^A	Model	Model type	Variance level and type	Likelihood	Covariates ^B	Percent Cover		Presence/Absence		PPL	Gel
							P_{mean}	P_{sd}	P_{mean}	P_{sd}		
Perennial grass cover	ALL	Inverse logit	b0	stratum, hierarchical	hurdle-ordinal-latent-beta	AGDD, winter D, spring D, July D	0.75	0.33	NA	NA	50410	1.02
Indian ricegrass	CHCU S, PEFO C, PEFO S	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, winter D, spring D, summer D	0.85	0.74	0.53	0.47	7576	1.05
Black grama	WUPA V	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	Lag year D, July D	0.79	0.24	0.53	0.52	9354	1.01
Blue grama	CHCU S, PEFO C, PEFO S	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, spring D	0.89	0.44	0.52	0.51	21946	1.02
New Mexico Feathergrass	WUPA V	Inverse logit	b0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, lag D, spring D, July D	0.89	0.55	0.51	0.51	5662	1.01

^A Ecological sites include Chaco NHP sandy loam upland, Petrified Forest NP sandy loam upland, Petrified Forest NP clayey fan, Wupatki NM loamy upland, Wupatki NM volcanic upland.

^B Covariates include: AGDD=accumulated growing degree days, Terrain=terrain, winter D= cumulative climatic water deficit for Nov-March, spring D= cumulative climatic water deficit for Apr-Jun, summer D=cumulative climatic water deficit for July- September, Jul D= cumulative climatic water deficit for July.

Table D-1 (continued). Model specifications for all responses presented in this report. Models were run using three chains and 8,000-12,000 iterations. Model indicates the type of deterministic model used. Model type indicates whether slope only (b0) or slope and intercepts (b1) varied by site. For the hurdle ordinal model, slopes and intercepts could vary by percent cover response (b0-b1) as well as by present/not present response (g0-g1). Variance type indicates how variance was treated in the model. Fixed site indicates that each site has its own independent variance. Hierarchical site indicates the variance for a site was drawn from an underlying distribution of variances. Likelihood indicates what distribution was used for the likelihood in the model. Covariates used in the model are listed. For model checking, in addition to visually assessing convergence, P_{mean} , and P_{sd} are Bayesian p-value for the mean and variance and are used to indicate lack of fit. Models used for cover are mixed models and have two sets of model-checking values, the first represents the percent cover response, and the second set of P values represents the presence/absence response. PPL is posterior predictive loss, models with lowest posterior predictive loss were selected. The Gelman-Rubin diagnostic is an indicator of convergence and should be close to one.

Response	EcoSite ^A	Model	Model type	Variance level and type	Likelihood	Covariates ^B	Percent Cover		Presence/Absence		PPL	Gel
							P_{mean}	P_{sd}	P_{mean}	P_{sd}		
Galleta grass	ALL	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, winter D, spring D, July D	0.94	0.31	0.53	0.53	45561	1.03
Dropseed	CHCU S, PEFO C, PEFO S	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, July D	0.91	0.26	0.52	0.52	25263	1.01
Shrub cover	ALL	Inverse logit	b0	Site, hierarchical	hurdle-ordinal-latent-beta	AGDD, lag D, winter D, spring D, July D	0.55	0.78	0.53	0.52	35243	1.05
Four-wing saltbush	CHCU S, PEFO C, PEFO S	Inverse logit	b0	Site, hierarchical	hurdle-ordinal-latent-beta	AGDD, winter D, spring D, summer D, elevation, terrain	0.67	0.46	0.46	0.55	10992	1.2
Mound saltbush	PEFO C	Inverse logit	b0	Site, hierarchical	hurdle-ordinal-latent-beta	AGDD, winter D, spring D, monsoon D	0.63	0.49	0.52	0.52	3778	1.01
Snakeweed	CHCU S, PEFO C, PEFO S	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, lag year deficit, winter D, spring D	0.87	0.84	0.48	0.52	7185	1.01

^A Ecological sites include Chaco NHP sandy loam upland, Petrified Forest NP sandy loam upland, Petrified Forest NP clayey fan, Wupatki NM loamy upland, Wupatki NM volcanic upland.

^B Covariates include: AGDD=accumulated growing degree days, Terrain=terrain, winter D= cumulative climatic water deficit for Nov-March, spring D= cumulative climatic water deficit for Apr-Jun, summer D=cumulative climatic water deficit for July- September, Jul D= cumulative climatic water deficit for July.

Table D-1 (continued). Model specifications for all responses presented in this report. Models were run using three chains and 8,000-12,000 iterations. Model indicates the type of deterministic model used. Model type indicates whether slope only (b0) or slope and intercepts (b1) varied by site. For the hurdle ordinal model, slopes and intercepts could vary by percent cover response (b0-b1) as well as by present/not present response (g0-g1). Variance type indicates how variance was treated in the model. Fixed site indicates that each site has its own independent variance. Hierarchical site indicates the variance for a site was drawn from an underlying distribution of variances. Likelihood indicates what distribution was used for the likelihood in the model. Covariates used in the model are listed. For model checking, in addition to visually assessing convergence, P_{mean} , and P_{sd} are Bayesian p-value for the mean and variance and are used to indicate lack of fit. Models used for cover are mixed models and have two sets of model-checking values, the first represents the percent cover response, and the second set of P values represents the presence/absence response. PPL is posterior predictive loss, models with lowest posterior predictive loss were selected. The Gelman-Rubin diagnostic is an indicator of convergence and should be close to one.

Response	EcoSite ^A	Model	Model type	Variance level and type	Likelihood	Covariates ^B	Percent Cover		Presence/Absence		PPL	Gel
							P_{mean}	P_{sd}	P_{mean}	P_{sd}		
Winterfat	CHCU S	Inverse logit	b0 g0	Site, hierarchical	Hurdle-ordinal-latent-beta	AGDD, lag year D, winter D, spring D, summer D, elevation, terrain	0.63	0.59	0.50	0.51	3080	1.03
Quadrat Richness	CHCU S	Exponential	b0	Site, hierarchical	Generalized Poisson	AGDD, lag D, winter D, spring D, summer D, elevation, terrain	0.52	0.69	–	–	2811446	1.02
Quadrat Richness	PEFO C	Exponential	b0	Site, hierarchical	Generalized Poisson	AGDD, lag year D, winter D, spring D, summer D, elevation, terrain	0.49	0.69	–	–	3926497	1.04
Quadrat Richness	PEFO S	Exponential	b0	Site, hierarchical	Generalized Poisson	AGDD, previous year D, winter D, spring D, summer D, elevation, terrain	0.48	0.73	–	–	3379636	1.1
Quadrat Richness	WUPA L	Exponential	b0	Site, hierarchical	Generalized Poisson	AGDD, lag year D, winter D, spring D, July D, elevation, terrain	0.52	0.67	–	–	1309156	1.06

^A Ecological sites include Chaco NHP sandy loam upland, Petrified Forest NP sandy loam upland, Petrified Forest NP clayey fan, Wupatki NM loamy upland, Wupatki NM volcanic upland.

^B Covariates include: AGDD=accumulated growing degree days, Terrain=terrain, winter D= cumulative climatic water deficit for Nov-March, spring D= cumulative climatic water deficit for Apr-Jun, summer D=cumulative climatic water deficit for July- September, Jul D= cumulative climatic water deficit for July.

Table D-1 (continued). Model specifications for all responses presented in this report. Models were run using three chains and 8,000-12,000 iterations. Model indicates the type of deterministic model used. Model type indicates whether slope only (b0) or slope and intercepts (b1) varied by site. For the hurdle ordinal model, slopes and intercepts could vary by percent cover response (b0-b1) as well as by present/not present response (g0-g1). Variance type indicates how variance was treated in the model. Fixed site indicates that each site has its own independent variance. Hierarchical site indicates the variance for a site was drawn from an underlying distribution of variances. Likelihood indicates what distribution was used for the likelihood in the model. Covariates used in the model are listed. For model checking, in addition to visually assessing convergence, P_{mean} , and P_{sd} are Bayesian p-value for the mean and variance and are used to indicate lack of fit. Models used for cover are mixed models and have two sets of model-checking values, the first represents the percent cover response, and the second set of P values represents the presence/absence response. PPL is posterior predictive loss, models with lowest posterior predictive loss were selected. The Gelman-Rubin diagnostic is an indicator of convergence and should be close to one.

Response	EcoSite ^A	Model	Model type	Variance level and type	Likelihood	Covariates ^B	Percent Cover		Presence/Absence		PPL	Gel
							P_{mean}	P_{sd}	P_{mean}	P_{sd}		
Quadrat Richness	WUPA V	Exponential	b0	Site, hierarchical	Generalized Poisson	AGDD, lag year D, winter D, spring D, July D, elevation, terrain	0.53	0.89	–	–	1240097	1.05
Perennial forbs	ALL	Inverse-logit	B0	Stratum, fixed	Beta binomial	AGDD, lag year D, winter D, spring D, July D, elevation, terrain	0.52	0.48	–	–	5259	1.05
Annual forbs	ALL	Inverse-logit	B0	Stratum, fixed	Zero inflated beta binomial	AGDD, lag year D, winter D, spring D, July D, elevation, terrain,	0.52	0.25	–	–	1996	1.1
Exotic forbs	ALL	Inverse-logit	B0	Stratum, fixed	Zero inflated beta binomial	AGDD, lag year D, winter D, spring D, July D, elevation, terrain	0.54	0.22	–	–	1763	1.1

^A Ecological sites include Chaco NHP sandy loam upland, Petrified Forest NP sandy loam upland, Petrified Forest NP clayey fan, Wupatki NM loamy upland, Wupatki NM volcanic upland.

^B Covariates include: AGDD=accumulated growing degree days, Terrain=terrain, winter D= cumulative climatic water deficit for Nov-March, spring D= cumulative climatic water deficit for Apr-Jun, summer D=cumulative climatic water deficit for July- September, Jul D= cumulative climatic water deficit for July.

Appendix E: Tabular Data Versions (Accessible) of Figures

Table E-1 is the tabular data version of Figure 11. Table E-2 is the tabular data version of Figure 46. Table E-3 is the tabular data version of Figure 47. Table E-4 is the tabular data version of Figure 48. Table E-5 is the tabular data version of Figure A-1. Table E-6 is the tabular data version of Figure A-2.

Table E-1. Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks (CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CHCU	S	01	121.4	93.6	67.3	93.6	93.4	62.1	133.9	89.8	129.7	92.1	103.5	103.9	88.7	51.3	97.7
CHCU	S	02	121.4	93.6	67.4	93.6	93.4	62.1	134.0	89.8	129.8	92.1	103.6	104.0	88.7	51.3	97.7
CHCU	S	03	81.3	67.6	52.4	68.2	92.9	51.6	101.8	57.3	138.6	65.7	82.4	95.5	91.2	57.0	97.1
CHCU	S	04	92.8	72.5	58.9	78.2	82.7	51.2	106.2	63.7	125.7	77.9	86.8	84.0	85.7	54.5	95.3
CHCU	S	05	92.6	72.3	58.8	78.0	82.5	51.1	105.9	63.5	125.4	77.7	86.6	83.8	85.7	54.4	95.0
CHCU	S	06	92.2	72.0	58.5	77.7	82.1	50.9	105.4	63.2	124.8	77.3	86.2	83.3	85.4	54.1	94.7
CHCU	S	07	96.3	81.0	68.0	86.5	86.0	53.5	107.9	67.1	133.4	64.7	84.6	91.9	87.3	51.1	90.0
CHCU	S	08	96.1	80.9	67.9	86.3	85.9	53.4	107.7	66.9	133.1	65.1	84.4	91.8	87.3	51.0	89.2
CHCU	S	09	121.2	93.4	67.2	93.5	93.2	62.1	133.7	89.7	129.5	91.9	103.4	104.0	88.5	51.2	96.9
CHCU	S	10	121.5	93.6	67.4	93.7	93.4	62.2	134.0	89.9	129.8	92.1	103.6	104.1	88.7	51.3	97.5
CHCU	S	11	96.0	80.7	67.7	86.1	85.7	53.2	107.5	66.8	132.9	64.6	84.3	91.7	86.8	50.9	89.1
CHCU	S	12	96.0	80.7	67.8	86.2	85.7	53.2	107.5	66.9	132.9	64.6	84.3	91.8	86.9	50.9	89.1
CHCU	S	13	92.4	72.2	58.7	77.9	82.4	51.0	105.7	63.4	125.2	77.6	86.4	83.6	85.5	54.3	94.8
CHCU	S	14	96.3	81.0	68.0	86.5	86.0	53.4	107.9	67.1	133.3	64.8	84.6	92.0	87.4	51.1	89.7

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks (CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CHCU	S	15	121.3	93.5	67.3	93.5	93.3	62.0	133.8	89.7	129.6	92.0	103.4	103.8	88.6	51.2	97.7
CHCU	S	16	120.9	93.2	67.1	93.2	93.0	62.0	133.4	89.5	129.2	91.7	103.1	103.7	88.7	51.1	96.8
CHCU	S	17	101.5	75.9	61.2	97.0	81.8	45.9	88.7	71.8	128.0	70.6	78.3	79.1	79.5	45.2	74.6
CHCU	S	18	101.4	75.8	61.1	96.9	81.7	45.9	88.6	71.7	127.9	70.5	78.2	79.0	79.4	45.1	74.5
CHCU	S	19	121.1	93.3	67.2	93.4	93.1	62.0	133.6	89.6	129.4	91.8	103.3	103.7	88.7	51.1	97.2
CHCU	S	20	121.4	93.6	67.3	93.6	93.4	62.1	133.9	89.8	129.7	92.1	103.5	104.0	88.7	51.3	97.4
CHCU	S	21	101.4	75.8	61.1	96.8	81.7	45.8	88.6	71.7	127.8	70.2	78.1	79.0	79.3	45.1	74.0
CHCU	S	22	96.1	80.8	67.8	86.2	85.8	53.3	107.6	66.9	133.0	65.0	84.4	91.9	87.2	50.9	89.2
CHCU	S	23	96.2	80.9	67.9	86.3	85.9	53.3	107.7	67.0	133.1	64.6	84.4	91.8	87.0	51.0	89.6
CHCU	S	24	87.9	59.9	54.7	63.2	77.9	47.8	104.4	55.6	117.2	85.3	84.6	77.5	93.2	55.7	100.7
CHCU	S	25	81.0	67.3	52.2	68.0	92.6	51.4	101.4	57.1	138.1	65.4	82.1	95.2	90.9	56.8	96.6
CHCU	S	27	92.4	72.2	58.7	77.9	82.4	51.1	105.7	63.4	125.2	77.6	86.4	83.6	85.7	54.3	95.0
CHCU	S	28	92.6	72.4	58.8	78.1	82.6	51.2	105.9	63.5	125.4	77.7	86.6	83.7	85.7	54.4	95.3
CHCU	S	29	92.6	72.4	58.8	78.1	82.6	51.2	106.0	63.5	125.5	77.8	86.6	83.7	85.7	54.4	95.3
CHCU	S	30	92.2	72.1	58.6	77.7	82.2	50.9	105.5	63.2	124.9	77.4	86.2	83.5	85.4	54.2	94.6
CHCU	S	31	92.6	72.4	58.8	78.0	82.5	51.1	105.9	63.5	125.4	77.7	86.6	83.7	85.5	54.4	95.1
PEFO	C	01	132.1	105.7	74.1	193.0	106.2	132.9	122.1	87.9	130.2	81.3	54.7	86.3	93.1	77.5	111.2
PEFO	C	02	140.6	100.9	71.7	186.1	114.6	120.2	116.8	94.2	131.7	81.9	56.5	90.4	97.1	76.5	105.2

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
PEFO	C	04	149.6	93.1	75.4	152.6	114.1	121.5	102.6	87.5	127.9	80.3	50.4	90.8	100.4	71.8	97.1
PEFO	C	05	150.7	95.7	77.2	162.6	100.2	123.9	111.9	92.1	128.0	79.0	49.5	92.2	102.1	73.3	99.2
PEFO	C	06	151.3	96.0	77.5	163.2	100.6	124.4	112.3	92.5	128.5	79.3	49.7	92.6	99.8	73.6	99.7
PEFO	C	07	133.8	102.9	70.2	168.9	101.0	118.5	114.5	84.8	127.1	81.6	53.3	90.4	90.3	76.7	117.6
PEFO	C	08	132.7	97.8	68.6	149.1	105.1	126.2	107.6	95.0	124.8	82.2	54.7	78.7	93.0	81.0	116.6
PEFO	C	09	136.1	99.9	72.2	167.0	109.3	131.8	109.4	99.5	131.2	83.3	59.6	83.8	94.3	77.0	112.2
PEFO	C	10	133.0	106.5	74.6	194.3	106.9	133.8	122.9	88.5	131.1	81.8	55.1	86.8	93.7	78.1	112.0
PEFO	C	11	132.7	106.3	74.5	193.9	106.7	133.5	122.7	88.3	130.8	81.7	55.0	86.7	94.1	77.9	111.7
PEFO	C	12	129.7	104.9	73.6	191.5	105.4	131.9	121.1	87.2	129.2	80.6	54.3	85.6	93.2	76.9	110.4
PEFO	C	13	131.8	105.5	74.0	192.5	106.0	132.6	121.8	87.7	129.9	81.1	54.6	86.1	93.5	77.4	111.0
PEFO	C	14	140.7	100.9	71.8	186.2	114.6	120.2	116.8	94.2	131.8	82.0	56.5	90.5	97.0	76.6	105.2
PEFO	C	15	141.5	96.7	73.0	190.4	106.2	131.7	118.3	83.3	129.3	81.0	54.0	87.3	95.5	77.5	102.1
PEFO	C	16	103.4	80.9	42.9	115.1	86.4	74.8	98.7	79.2	106.6	83.3	48.1	71.4	69.2	67.4	121.1
PEFO	C	17	135.5	99.5	71.9	166.3	108.9	131.2	109.0	99.1	130.6	82.9	59.3	83.5	94.3	76.7	111.7
PEFO	C	18	133.8	107.2	75.1	195.5	107.6	134.7	123.7	89.1	131.9	82.4	55.5	87.4	94.1	78.6	112.7
PEFO	C	19	144.9	92.6	73.1	145.4	101.6	118.6	114.7	90.0	132.5	79.9	56.2	89.0	96.7	75.2	96.1
PEFO	C	20	132.3	105.9	74.3	193.3	106.4	133.1	122.3	88.0	130.4	81.4	54.8	86.4	93.8	77.7	111.4
PEFO	C	21	132.8	97.9	68.6	149.2	105.2	126.3	107.7	95.1	124.9	82.3	54.8	78.8	93.1	81.1	116.7

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
PEFO	C	22	129.8	78.1	55.7	125.5	87.8	91.6	120.8	111.6	119.4	87.4	57.5	73.2	83.3	73.1	117.0
PEFO	C	23	121.2	90.2	51.3	118.3	106.3	96.3	116.0	99.3	115.9	86.7	55.5	41.0	77.8	72.9	116.2
PEFO	C	24	102.2	81.5	42.4	121.2	101.3	83.9	104.7	90.1	110.8	84.7	52.4	76.4	73.1	70.5	115.4
PEFO	C	25	133.6	102.8	70.1	168.7	100.8	118.3	114.3	84.7	126.9	81.4	53.2	90.3	90.3	76.6	117.4
PEFO	C	26	136.8	96.3	69.1	161.7	108.4	121.1	115.0	87.5	129.6	80.0	54.6	90.4	98.8	73.1	97.7
PEFO	C	27	140.9	101.1	71.9	186.6	114.8	120.5	117.0	94.4	132.0	82.1	56.6	90.6	97.3	76.7	105.4
PEFO	C	28	124.9	79.5	50.7	126.8	91.5	100.8	117.6	97.4	117.2	86.8	55.8	41.5	77.9	71.5	118.2
PEFO	C	29	113.6	86.4	55.6	118.2	94.2	89.3	111.2	100.4	117.9	86.8	57.3	43.2	80.0	73.0	113.9
PEFO	C	30	129.7	78.0	55.6	125.4	87.7	91.5	120.7	111.5	119.2	87.3	57.5	73.2	83.2	73.1	116.9
PEFO	C	31	134.3	103.2	70.4	169.4	101.3	118.9	114.9	85.1	127.5	81.8	53.4	90.7	90.6	76.9	117.9
PEFO	S	01	124.3	83.5	47.0	130.0	89.6	93.1	114.1	92.6	113.7	85.7	53.5	79.4	75.6	73.0	122.2
PEFO	S	02	124.2	83.4	47.0	129.9	89.5	92.9	113.9	92.5	113.6	85.6	53.4	79.3	75.5	72.9	122.1
PEFO	S	03	134.1	77.2	51.6	147.5	93.0	109.8	120.9	103.4	118.5	85.3	55.6	72.9	79.3	70.0	115.4
PEFO	S	04	110.0	82.9	43.5	114.6	92.7	73.0	102.2	85.5	107.8	83.5	48.2	74.4	70.5	68.0	120.1
PEFO	S	05	124.3	83.4	47.0	130.0	89.5	93.0	114.0	92.6	113.7	85.7	53.4	79.3	75.5	73.0	122.2
PEFO	S	06	137.5	102.1	78.3	190.7	102.1	127.5	117.6	84.1	127.6	75.7	49.3	87.9	99.2	76.4	98.5
PEFO	S	07	123.1	87.5	59.7	145.9	109.2	123.5	112.2	112.3	122.9	86.8	56.5	75.6	84.3	77.8	110.6
PEFO	S	08	149.6	95.0	76.7	161.4	99.5	123.1	111.1	91.4	127.1	78.4	49.2	92.0	101.2	72.8	98.5

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
PEFO	S	09	132.6	76.3	51.0	145.8	91.9	108.5	119.4	102.2	117.1	84.3	54.9	72.3	78.9	69.2	114.0
PEFO	S	10	140.8	96.2	72.7	189.4	105.6	131.0	117.7	82.8	128.6	80.6	53.8	86.8	95.1	77.1	101.5
PEFO	S	11	123.6	78.7	50.2	125.4	90.5	99.7	116.4	96.4	116.0	85.9	55.2	41.5	78.0	70.7	117.0
PEFO	S	12	125.3	83.1	46.8	129.5	89.2	92.6	113.6	92.2	113.2	85.4	53.2	79.0	75.5	72.7	121.7
PEFO	S	13	124.2	83.4	47.0	129.9	89.5	93.0	114.0	92.5	113.6	85.7	53.4	79.4	75.5	72.9	122.1
PEFO	S	14	132.4	76.2	50.9	145.6	91.7	108.3	119.3	102.1	116.9	84.2	54.8	72.2	78.8	69.1	113.8
PEFO	S	15	108.3	82.8	43.4	114.5	92.6	73.0	102.1	85.4	107.7	83.4	48.1	74.3	70.7	67.9	120.0
PEFO	S	16	102.3	81.3	43.1	115.7	86.8	75.2	99.2	79.6	107.1	83.8	48.4	71.7	70.1	67.7	121.7
PEFO	S	17	108.9	83.2	43.7	115.1	93.1	73.3	102.5	85.8	108.2	83.8	48.4	74.6	71.0	68.2	120.6
PEFO	S	18	140.1	95.7	72.3	188.5	105.1	130.4	117.1	82.4	128.0	80.2	53.5	86.3	94.6	76.7	101.0
PEFO	S	19	137.4	102.1	78.3	190.7	102.1	127.5	117.6	84.1	127.5	75.6	49.3	87.9	98.9	76.4	98.5
PEFO	S	20	132.9	99.2	72.7	152.0	109.4	123.9	112.8	109.4	129.5	83.1	60.6	82.8	88.1	82.5	104.5
PEFO	S	21	149.7	95.1	76.7	161.6	99.6	123.2	111.2	91.5	127.2	78.5	49.2	92.1	101.3	72.9	98.6
PEFO	S	22	133.4	76.7	51.3	146.7	92.5	109.2	120.2	102.9	117.8	84.8	55.3	72.7	79.2	69.6	114.7
PEFO	S	23	123.8	87.3	48.0	125.1	105.4	87.8	111.9	84.2	111.7	85.2	52.2	79.0	74.9	71.6	117.3
PEFO	S	24	142.0	97.1	73.3	191.1	106.6	132.2	118.7	83.5	129.8	81.3	54.2	87.5	96.0	77.8	102.4
PEFO	S	25	124.3	88.4	60.3	147.4	110.3	124.7	113.3	113.4	124.1	87.7	57.0	76.4	85.0	78.6	111.8
PEFO	S	26	135.9	78.6	58.7	140.1	97.5	104.1	119.6	108.0	122.5	80.9	65.4	91.6	85.3	75.0	108.4

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
PEFO	S	27	124.0	83.3	46.9	129.7	89.4	92.8	113.8	92.4	113.5	85.5	53.3	79.2	75.6	72.8	121.9
PEFO	S	28	102.2	81.2	43.0	115.5	86.7	75.1	99.1	79.5	106.9	83.6	48.3	71.6	69.9	67.6	121.5
PEFO	S	29	138.1	102.5	78.7	191.6	102.6	128.0	118.1	84.5	128.1	76.0	49.5	88.2	100.2	76.7	98.9
PEFO	S	30	139.7	92.6	72.2	165.9	101.0	123.8	123.4	88.6	129.2	77.8	52.2	91.2	101.3	72.3	98.7
WUPA	V	01	66.3	80.7	73.6	113.2	95.0	125.5	182.5	84.3	121.4	73.6	81.1	123.5	94.4	42.9	145.2
WUPA	V	02	85.8	77.5	62.8	107.1	110.7	138.5	169.6	89.2	127.8	81.5	83.2	113.9	102.5	53.7	154.6
WUPA	V	03	79.8	72.1	58.4	99.6	103.0	128.9	157.7	83.0	118.7	75.7	77.4	105.3	95.1	49.9	142.8
WUPA	V	04	76.1	71.0	65.2	107.7	94.0	131.2	182.6	88.2	133.5	69.4	68.4	112.2	99.9	50.1	146.7
WUPA	V	05	76.3	71.1	65.3	107.8	94.2	131.4	182.9	88.3	133.7	69.5	68.5	112.4	100.1	50.1	147.0
WUPA	V	06	84.4	70.5	70.7	102.3	88.8	138.7	182.3	87.8	142.5	69.8	53.6	107.9	104.6	52.3	134.4
WUPA	V	08	75.6	70.5	64.8	106.9	93.4	130.3	181.1	87.6	132.4	69.4	67.9	111.6	98.7	49.7	146.2
WUPA	V	09	77.9	72.7	66.8	110.2	96.2	134.2	186.7	90.3	136.5	71.9	70.0	115.2	101.6	51.2	151.2
WUPA	V	10	81.4	67.9	68.2	98.7	85.6	133.7	175.6	84.7	137.3	67.8	51.7	104.2	100.4	50.5	129.9
WUPA	V	11	80.8	73.0	59.1	100.8	104.2	130.4	159.5	84.0	120.1	76.7	78.3	106.8	96.0	50.5	144.8
WUPA	V	13	79.8	72.1	58.4	99.6	102.9	128.9	157.8	83.0	118.8	75.2	77.4	105.0	95.5	49.9	142.2
WUPA	V	20	76.4	71.3	65.5	108.1	94.4	131.7	183.0	88.6	133.8	70.6	68.7	113.2	99.4	50.3	148.5
WUPA	V	21	85.1	71.0	71.2	103.1	89.5	139.8	183.7	88.5	143.6	70.3	54.0	108.7	105.4	52.7	135.4
WUPA	V	22	79.9	74.6	68.5	113.1	98.7	137.6	191.3	92.6	140.0	74.1	71.8	119.0	104.1	52.6	156.1

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
WUPA	V	24	84.7	76.5	62.1	105.8	109.3	136.8	167.5	88.1	126.1	80.4	82.2	112.1	100.9	53.0	152.2
WUPA	V	26	75.5	70.5	64.7	106.8	93.2	130.1	180.9	87.5	132.2	69.3	67.8	111.4	98.5	49.6	146.0
WUPA	V	27	79.4	74.3	68.1	112.4	98.1	136.9	190.6	92.0	139.4	72.4	71.3	117.0	104.2	52.2	153.3
WUPA	V	28	85.1	71.0	71.3	103.2	89.5	139.8	183.8	88.6	143.7	70.3	54.1	108.7	105.5	52.8	135.5
WUPA	V	30	77.7	72.5	66.6	109.9	96.0	133.9	186.4	90.0	136.2	70.8	69.8	114.5	102.0	51.1	149.8
WUPA	V	31	79.8	72.0	58.4	99.5	102.9	128.8	157.5	82.9	118.6	75.7	77.3	105.2	95.0	49.9	142.7
WUPA	V	32	76.4	71.3	65.4	108.0	94.3	131.5	182.8	88.5	133.7	70.5	68.6	113.1	99.3	50.2	148.3
WUPA	V	33	79.3	71.6	58.0	98.9	102.2	128.0	156.6	82.4	117.8	75.2	76.9	104.6	94.4	49.6	141.8
WUPA	V	34	82.4	74.5	60.4	102.9	106.3	133.1	162.9	85.7	122.7	78.0	79.9	108.8	98.3	51.6	147.7
WUPA	V	35	82.4	74.4	60.3	102.8	106.3	133.0	162.9	85.7	122.6	78.0	79.9	108.8	98.3	51.6	147.6
WUPA	V	36	78.0	70.4	57.1	97.2	100.5	125.9	154.0	81.0	115.9	73.6	75.6	102.7	93.1	48.8	139.1
WUPA	V	37	94.3	63.4	43.7	79.0	88.1	142.7	177.1	88.9	129.9	77.0	58.6	103.1	95.2	50.9	141.3
WUPA	V	38	79.7	74.5	68.3	112.7	98.4	137.4	191.3	92.3	139.9	72.4	71.6	117.4	104.8	52.4	153.5
WUPA	V	39	83.7	75.6	61.3	104.5	108.0	135.2	165.5	87.1	124.6	79.4	81.2	110.7	99.7	52.4	150.4
WUPA	V	40	81.9	74.0	60.0	102.2	105.6	132.2	161.8	85.2	121.7	77.8	79.4	108.3	97.4	51.3	146.9
WUPA	V	41	80.2	72.4	58.7	100.1	103.4	129.5	158.5	83.4	119.3	75.8	77.8	105.6	95.7	50.2	143.3
WUPA	L	01	115.1	83.4	90.4	122.0	95.6	95.4	190.7	128.3	134.3	25.7	83.3	116.9	102.0	52.8	131.9
WUPA	L	03	110.0	85.7	86.5	111.5	70.8	49.2	146.8	116.9	149.8	53.5	89.1	130.8	106.1	52.6	146.9

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
WUPA	L	04	109.1	85.1	85.8	110.6	70.2	48.9	145.7	116.0	148.7	53.7	88.4	130.2	105.5	52.2	145.4
WUPA	L	08	112.5	88.7	82.7	120.1	94.0	111.3	170.5	104.7	128.1	34.4	77.8	118.0	107.2	55.6	140.5
WUPA	L	09	106.4	81.1	88.3	128.7	92.7	110.3	196.4	98.9	145.3	49.3	85.4	136.3	109.4	53.4	165.5
WUPA	L	10	105.0	80.0	87.1	127.0	91.4	108.8	193.9	97.5	143.4	49.1	84.2	135.0	108.2	52.6	162.8
WUPA	L	11	106.6	81.2	88.5	129.0	92.9	110.5	196.7	99.0	145.6	49.4	85.5	136.6	109.6	53.5	165.8
WUPA	L	12	115.4	83.6	90.6	122.2	95.8	95.6	191.1	128.5	134.5	25.8	83.5	117.2	102.2	52.9	132.2
WUPA	L	13	106.2	80.9	88.1	128.5	92.5	110.0	195.9	98.6	145.0	49.2	85.2	136.0	109.2	53.2	165.1
WUPA	L	14	104.5	79.6	86.7	126.4	91.0	108.3	192.8	97.1	142.7	48.8	83.8	134.2	108.4	52.4	162.3
WUPA	L	15	114.7	83.1	90.1	121.6	95.3	95.1	190.2	127.8	133.8	25.6	83.0	116.9	102.0	52.6	131.2
WUPA	L	16	110.1	85.8	86.6	111.7	70.9	49.3	147.1	117.0	150.1	53.7	89.3	131.0	106.1	52.6	146.9
WUPA	L	17	106.0	80.8	88.0	128.2	92.3	109.8	195.5	98.5	144.7	49.0	85.0	135.7	109.4	53.1	164.9
WUPA	L	18	106.7	81.2	88.5	129.0	92.9	110.5	196.7	99.1	145.6	49.3	85.5	136.5	110.1	53.5	165.9
WUPA	L	19	113.2	82.0	88.9	120.0	94.0	93.9	187.6	126.2	132.0	25.3	81.9	115.2	100.4	51.3	129.3
WUPA	L	21	110.6	86.2	87.0	112.2	71.2	49.5	147.8	117.6	150.8	54.0	89.7	131.6	106.6	52.9	147.6
WUPA	L	23	113.8	89.7	83.7	121.6	95.1	112.6	172.7	105.9	129.6	34.8	78.7	119.4	108.3	56.2	142.0
WUPA	L	24	109.0	85.0	85.7	110.5	70.1	48.8	145.5	115.8	148.5	53.1	88.4	129.7	105.2	52.1	145.6
WUPA	L	26	107.1	81.6	88.8	129.5	93.2	110.9	197.6	99.4	146.2	49.6	85.9	137.3	110.1	53.7	165.5
WUPA	L	27	113.0	89.1	83.1	120.7	94.4	111.8	171.5	105.1	128.8	34.5	78.1	118.7	105.6	55.8	140.9

Table E-1 (continued). Table of data for [Figure 11](#). Percent of normal precipitation received at each monitored plot in five ecosites in three National Parks CHCU, PEFO, WUPA) demonstrating the large amount of variation, both between years and among plots (30-year normal (1991-2021) from PRISM Climate Group, Oregon State University, <https://prism.oregonstate.edu>, annual precipitation totals from United States Stage IV Quantitative Precipitation Archive. Accessed May 17, 2022).

Park	Eco	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
WUPA	L	28	108.8	84.8	85.5	110.3	70.0	48.7	145.1	115.6	148.2	52.9	88.2	129.3	104.7	52.0	145.0
WUPA	L	29	106.9	81.4	88.7	129.3	93.1	110.8	197.2	99.3	145.9	49.5	85.7	136.9	109.9	53.6	166.2
WUPA	L	30	114.4	90.2	84.2	122.2	95.6	113.2	173.6	106.5	130.3	35.0	79.1	120.0	108.9	56.5	142.8
WUPA	L	31	103.8	94.2	89.6	136.5	89.2	129.0	177.4	98.7	138.9	38.0	76.5	115.5	105.3	56.2	131.7
WUPA	L	32	105.9	80.7	87.9	128.1	92.2	109.7	195.5	98.3	144.7	49.0	84.9	135.8	108.9	53.1	163.7
WUPA	L	33	104.6	79.7	86.8	126.5	91.0	108.4	193.0	97.1	142.8	48.9	83.9	134.4	108.4	52.4	161.5
WUPA	L	34	104.6	79.7	86.8	126.5	91.1	108.4	193.0	97.1	142.8	48.8	83.9	134.3	108.5	52.4	162.5
WUPA	L	35	104.1	79.3	86.4	126.0	90.7	107.9	192.1	96.7	142.2	48.6	83.5	133.8	108.0	52.2	161.8
WUPA	L	36	112.0	88.3	82.4	119.7	93.6	110.9	169.7	104.3	127.5	34.2	77.4	117.4	106.7	55.4	139.9
WUPA	L	37	103.6	78.9	85.9	125.2	90.2	107.3	191.1	96.2	141.3	48.8	83.0	133.3	107.4	51.9	160.4

Table E-2. Table of data for [Figure 46](#). Summary of direction of year effects (trend) for modeled responses.

Response variable	CHCU sandy loam	PEFO clayey fan	PEFO sandy loam	WUPA loamy	WUPA volcanic
Perennial grass	Negative	Negative	Negative	Negative	Positive
Black grama	Not modeled	Not modeled	Not modeled	Not modeled	Negative
Blue grama	Negative	Negative	Negative	Not modeled	Not modeled
New Mexico needlegrass	Not modeled	Not modeled	Not modeled	Not modeled	Negative
Galleta grass	Negative	Negative	Negative	Negative	Not significant
Dropseeds	Negative	Negative	Negative	Not modeled	Not modeled
Indian ricegrass	Negative	Negative	Negative	Not modeled	Not modeled
Shrubs	Positive	Not significant	Negative	Not significant	Not significant
Four-wing saltbush	Positive	Not significant	Not significant	Not modeled	Not modeled
Mound saltbush	Not modeled	Not significant	Not modeled	Not modeled	Not modeled
Snakeweed	Negative	Not significant	Negative	Not modeled	Not modeled
Winterfat	Not significant	Not modeled	Not modeled	Not modeled	Not modeled
Perennial forbs	Positive	Not significant	Positive	Not significant	Not significant
Annual forbs	Positive	Positive	Positive	Negative	Not significant
Exotic forbs	Positive	Not significant	Negative	Not significant	Not significant

Table E-3. Table of data for [Figure 47](#). Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA; data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>).

EcoSite	Year	Accumulated rainfall (cm)	Accumulated water deficit (cm)
CHCU S	2007	242.7 ^B	471.6 ^B
CHCU S	2008	159.8	541.5
CHCU S	2009	167.3	544.4
CHCU S	2010	165.0	501.8 ^B
CHCU S	2011	142.0	585.3
CHCU S	2012	130.0	548.7
CHCU S	2013	191.7	559.0
CHCU S	2014	167.5	547.4
CHCU S	2015	262.6 ^B	445.7 ^B
CHCU S	2016	227.6	507.2
CHCU S	2017	228.9 [†]	544.9
CHCU S	2018	116.3 ^A	659.2 ^A
CHCU S	2019	160.5	546.9
CHCU S	2020	80.8 ^A	676.8 ^A
CHCU S	2021	114.8 ^A	655.9 ^A
PEFO C	2007	239.5 ^B	640.3
PEFO C	2008	191.3	622.8 ^B

^A Indicates value is one of the most extreme dry values during the monitoring period

^B indicates value is one of the most extreme wet values during the monitoring period.

Table E-3 (continued). Table of data for [Figure 47](#). Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA; data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>).

EcoSite	Year	Accumulated rainfall (cm)	Accumulated water deficit (cm)
PEFO C	2009	140.4 ^A	713.6*
PEFO C	2010	200.0	642.5
PEFO C	2011	173.1 ^A	651.1
PEFO C	2012	198.9	673.3
PEFO C	2013	186.2	684.9
PEFO C	2014	192.2	704.1
PEFO C	2015	267.9 ^B	607.5 ^B
PEFO C	2016	209.7	660.9
PEFO C	2017	206.2	676.9
PEFO C	2018	174.5 ^A	783.7 ^A
PEFO C	2019	229.6 ^B	608.2 ^B
PEFO C	2020	182.0	681.7
PEFO C	2021	185.5	705.4 ^A
PEFO S	2007	240.0 ^B	627.5
PEFO S	2008	196.2	603.9 ^B
PEFO S	2009	147.0 ^A	695.2 ^A
PEFO S	2010	192.1	643.2

^A Indicates value is one of the most extreme dry values during the monitoring period.

^B indicates value is one of the most extreme wet values during the monitoring period.

Table E-3 (continued). Table of data for [Figure 47](#). Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA; data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>).

EcoSite	Year	Accumulated rainfall (cm)	Accumulated water deficit (cm)
PEFO S	2011	170.4 ^A	652.4
PEFO S	2012	201.7	669.8
PEFO S	2013	199.9	669.6
PEFO S	2014	200.5	695.6 ^A
PEFO S	2015	271.0 ^B	590.7 ^B
PEFO S	2016	212.5	656.5
PEFO S	2017	207.2	670.1
PEFO S	2018	179.8 ^A	772.6 ^A
PEFO S	2019	230.0 ^B	594.0 ^B
PEFO S	2020	184.5	672.6
PEFO S	2021	184.6	694.8
WUPA V	2007	197.0	684.1 ^A
WUPA V	2008	198.9	606.1
WUPA V	2009	154.7 ^A	689.9 ^A
WUPA V	2010	172.3 ^A	616.5
WUPA V	2011	201.6	651.1
WUPA V	2012	225.6	622.1

^A Indicates value is one of the most extreme dry values during the monitoring period.

^B indicates value is one of the most extreme wet values during the monitoring period.

Table E-3 (continued). Table of data for [Figure 47](#). Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA; data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>).

EcoSite	Year	Accumulated rainfall (cm)	Accumulated water deficit (cm)
WUPA V	2013	259.9	616.5
WUPA V	2014	234.3	643.4
WUPA V	2015	285.9 ^B	586.8 ^B
WUPA V	2016	231.5	662.0
WUPA V	2017	301.3 ^B	597.0 [†]
WUPA V	2018	183.4 ^A	739.8 ^A
WUPA V	2019	260.2 ^B	567.2 ^B
WUPA V	2020	203.5	663.3
WUPA V	2021	198.7	677.7
WUPA L	2007	148.4	854.7
WUPA L	2008	148.6	818.7
WUPA L	2009	122.7 ^A	852.7
WUPA L	2010	188.8	809.2
WUPA L	2011	165.3	795.0
WUPA L	2012	183.3	800.5
WUPA L	2013	268.6 ^B	707.3 ^B
WUPA L	2014	193.1	814.1

^A Indicates value is one of the most extreme dry values during the monitoring period.

^B indicates value is one of the most extreme wet values during the monitoring period.

Table E-3 (continued). Table of data for [Figure 47](#). Cumulative annual (a) climatic water deficit and (b) rainfall for each water year (Oct-Sept) at five ecosites in three National Parks (CHCU, PEFO, WUPA; data from: Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4 R1 <https://doi.org/10.3334/ORNLDAAAC/2129>).

EcoSite	Year	Accumulated rainfall (cm)	Accumulated water deficit (cm)
WUPA L	2015	257.8 ^B	770.1 ^B
WUPA L	2016	177.0	832.9
WUPA L	2017	247.6 ^B	812.5
WUPA L	2018	104.7 ^A	933.4 ^A
WUPA L	2019	225.1	781.8 ^B
WUPA L	2020	141.6 ^A	878.9*
WUPA L	2021	156.3	860.3 ^A

^A Indicates value is one of the most extreme dry values during the monitoring period.

^B indicates value is one of the most extreme wet values during the monitoring period.

Table E-4. Table of data for [Figure 48](#). Summary of direction of covariate effects on modeled responses.

Response variable	Lag year deficit	Winter deficit	Spring deficit	Summer deficit	July deficit	AGDD
Perennial grass	Not modeled	Positive	Negative	Not modeled	Positive	Positive
Black grama	Negative	Not modeled	Not modeled	Not modeled	Negative	Not modeled
Blue grama	Not modeled	Not modeled	Negative	Not modeled	Not modeled	Positive
New Mexico needlegrass	Negative	Not modeled	Not significant	Not modeled	Positive	Positive
Galleta grass	Not modeled	Positive	Not significant	Not modeled	Positive	Not significant
Dropseeds	Not modeled	Not modeled	Not modeled	Not modeled	Positive	Not significant
Indian ricegrass	Not modeled	Positive	Negative	Negative	Not modeled	positive
Shrubs	Negative	Not significant	Negative	Not modeled	Not significant	Positive
Four-wing saltbush	Not modeled	Not significant	Negative	Negative	Not modeled	Not significant
Mound saltbush	Not modeled	Not significant	Not significant	Not significant	Not modeled	Not significant
Snakeweed	Negative	Not significant	Negative	Not modeled	Not modeled	Positive
Winterfat	Positive	Not significant	Not significant	Not significant	Not modeled	Not significant
Perennial forbs	Negative	Negative	Not significant	Not modeled	Negative	Negative
Annual forbs	Positive	Negative	Negative	Not modeled	Not significant	Not significant
Exotic forbs	Positive	Negative	Not significant	Not modeled	Negative	Negative

Table E-5. Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CHCU	S01	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S02	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S03	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S04	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S05	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S06	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S07	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S08	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S09	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S10	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0
CHCU	S11	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
CHCU	S12	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
CHCU	S13	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
CHCU	S14	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
CHCU	S15	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
CHCU	S16	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
CHCU	S17	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S18	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S19	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S20	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CHCU	S21	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
CHCU	S22	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S23	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S24	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
CHCU	S25	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S27	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
CHCU	S28	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
CHCU	S29	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0
CHCU	S30	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
CHCU	S31	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C01	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C02	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C04	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C05	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C06	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C07	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C08	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C09	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C10	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	0
PEFO	C11	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PEFO	C12	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C13	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C14	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C15	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C16	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0
PEFO	C17	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C18	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C19	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C20	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C21	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C22	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C23	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C24	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0
PEFO	C25	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C26	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C27	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C28	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C29	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C30	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0
PEFO	C31	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PEFO	S01	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S02	1	1	1	0	1	0	1	0	1	0	0	0	1	0	0	1
PEFO	S03	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S04	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
PEFO	S05	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S06	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0
PEFO	S07	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S08	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S09	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S10	1	1	1	0	1	0	1	0	1	0	0	0	1	0	0	1
PEFO	S11	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S12	1	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1
PEFO	S13	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S14	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S15	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S16	1	1	1	0	1	0	1	0	1	0	0	0	1	0	0	1
PEFO	S17	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S18	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
PEFO	S19	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0
PEFO	S20	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PEFO	S21	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S22	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1
PEFO	S23	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0
PEFO	S24	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0
PEFO	S25	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1
PEFO	S26	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1
PEFO	S27	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1
PEFO	S28	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0
PEFO	S29	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
PEFO	S30	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
WUPA	V01	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V02	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V03	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V04	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V05	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	0
WUPA	V06	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V08	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	0
WUPA	V09	1	1	1	0	1	1	0	0	0	1	0	1	0	0	0	1
WUPA	V10	1	1	1	0	1	1	0	1	0	0	0	1	0	1	0	0
WUPA	V11	0	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WUPA	V13	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1
WUPA	V20	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1
WUPA	V21	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1
WUPA	V22	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1
WUPA	V24	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1
WUPA	V26	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0
WUPA	V27	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0
WUPA	V28	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	1
WUPA	V30	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	1
WUPA	V31	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
WUPA	V32	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
WUPA	V33	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
WUPA	V34	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1
WUPA	V35	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1
WUPA	V36	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1
WUPA	V37	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
WUPA	V38	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
WUPA	V39	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
WUPA	V40	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
WUPA	V41	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WUPA	L01	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L03	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L04	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L08	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L09	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L10	1	1	1	0	1	0	1	0	0	0	1	0	1	0	0	0
WUPA	L11	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L12	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L13	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L14	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0
WUPA	L15	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L16	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L17	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L18	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L19	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L21	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L23	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L24	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L26	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L27	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0

Table E-5 (continued). Table of data for [Figure A-1](#). Plot sampling history at five ecosites in three National Parks (CHCU, PEFO, WUPA). Plot numbers are provided on y-axes, sampling year on x-axes, and black dots indicate plot was sampled during a year.

Park	Plot	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WUPA	L28	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0
WUPA	L29	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L30	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0
WUPA	L31	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
WUPA	L32	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
WUPA	L33	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L34	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
WUPA	L35	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
WUPA	L36	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	0
WUPA	L37	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0

Table E-6. Table of data for [Figure A-2](#). Plot sampling intervals at five ecosites in three National Parks (CHCU, PEFO, WUPA). Extended sampling periods indicate revisits to complete plots that weren't completed during the initial visit.

Park	Ecological site	Year	Start DOY	Finish DOY
CHCU	CHCU S	2007	292	296
CHCU	CHCU S	2008	277	280
CHCU	CHCU S	2009	275	277
CHCU	CHCU S	2010	264	265
CHCU	CHCU S	2011	266	272
CHCU	CHCU S	2012	265	283
CHCU	CHCU S	2014	290	295
CHCU	CHCU S	2016	288	293
CHCU	CHCU S	2018	285	290
CHCU	CHCU S	2021	275	312
PEFO	PEFO C	2007	260	278
PEFO	PEFO C	2008	289	297
PEFO	PEFO C	2009	278	286
PEFO	PEFO C	2010	273	297
PEFO	PEFO C	2011	280	286
PEFO	PEFO C	2012	292	299
PEFO	PEFO C	2014	304	309
PEFO	PEFO C	2016	301	306
PEFO	PEFO C	2018	298	304
PEFO	PEFO C	2021	294	300
PEFO	PEFO S	2007	254	276
PEFO	PEFO S	2008	288	297
PEFO	PEFO S	2009	280	288
PEFO	PEFO S	2010	273	279
PEFO	PEFO S	2011	279	285
PEFO	PEFO S	2013	304	310
PEFO	PEFO S	2015	274	304
PEFO	PEFO S	2017	292	299
PEFO	PEFO S	2019	297	319

Table E-6 (continued). Table of data for [Figure A-2](#). Plot sampling intervals at five ecosites in three National Parks (CHCU, PEFO, WUPA). Extended sampling periods indicate revisits to complete plots that weren't completed during the initial visit.

Park	Ecological site	Year	Start DOY	Finish DOY
PEFO	PEFO S	2022	293	300
WUPA	WUPA V	2007	232	249
WUPA	WUPA V	2008	234	239
WUPA	WUPA V	2009	223	225
WUPA	WUPA V	2010	220	236
WUPA	WUPA V	2011	241	244
WUPA	WUPA V	2012	236	241
WUPA	WUPA V	2014	218	253
WUPA	WUPA V	2016	231	263
WUPA	WUPA V	2018	242	249
WUPA	WUPA V	2020	237	247
WUPA	WUPA V	2022	229	241
WUPA	WUPA L	2007	241	248
WUPA	WUPA L	2008	237	240
WUPA	WUPA L	2009	222	225
WUPA	WUPA L	2010	231	237
WUPA	WUPA L	2011	256	258
WUPA	WUPA L	2013	234	329
WUPA	WUPA L	2015	237	303
WUPA	WUPA L	2017	250	256
WUPA	WUPA L	2019	241	247
WUPA	WUPA L	2021	238	243

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525