ASSESSING VULNERABILITY AND RESILIENCE OF MAJOR VEGETATION TYPES OF THE WESTERN INTERIOR U.S.

SHRUBLANDS & GRASSLANDS

FINAL REPORT

Final Report for

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ASSESSING VULNERABILITY AND RESILIENCE OF MAJOR VEGETATION TYPES – *Shrublands and Grasslands*

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Technical Report Contents

This report contains the conceptual models and resilience and vulnerability assessment results for a selection of shrubland and grassland ecological system types evaluated with support from the Bureau of Land Management (BLM). Fifty-two ecological systems (hereafter may be called systems, ecosystems, or types) that are of major importance to BLM were selected for the assessment. Sagebrush, pinyon-juniper woodlands, warm desert scrub, montane woodlands and shrublands, and grasslands types were included (**Table 1**). Twenty-eight shrubland and grassland ecosystem types are included in this report.

The technical report is organized to include a summary of the assessment methods, descriptions of the ecological systems included in the report, and assessment results for each system.

The methods for the assessment and the organization of the report content for each system are provided below.

Table 1. List of ecosystems selected for resilience and vulnerability assessments for BLM. Not all are contained in this report, those included in this report are bolded. The table is organized by groups of types, and within those, from types with the largest mapped potential/historic distribution (square miles) to the least; the distribution in either Canada or Mexico is included in the totals. The percent of the type's distribution in the U.S. that is on BLM lands is also provided.

System Name	Total mi² (mapped potential distribution)	Total mi² (mapped current distribution)	% of U.S. range on BLM lands
Sagebrush Shrublands and Steppe			
Inter-Mountain Basins Big Sagebrush Shrubland	109,050	64,742	59.6%
Inter-Mountain Basins Big Sagebrush Steppe	70,315	72,095	35.7%
Inter-Mountain Basins Montane Sagebrush Steppe	32,319	37,871	28.8%
Great Basin Xeric Mixed Sagebrush Shrubland	23,987	14,324	76.8%
Columbia Plateau Steppe and Grassland	9,233	4,843	25.2%
Columbia Plateau Low Sagebrush Steppe	8,248	5,900	64.1%
Colorado Plateau Mixed Low Sagebrush Shrubland	1,641	948	38.9%
Columbia Plateau Scabland Shrubland	1,458	1,636	16.6%
Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	427	4,164	45.2%
Cool Semi-desert & Temperate Shrublands			
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	7,582	7,350	14.6%
Northwestern Great Plains Shrubland	3,778	1,647	3.8%
Colorado Plateau Blackbrush-Mormon-tea Shrubland	3,230	4,987	42.4%
Rocky Mountain Lower Montane-Foothill Shrubland	3,097	1,290	27.4%
Mixed Salt Desert Scrub & Greasewood			
Inter-Mountain Basins Mixed Salt Desert Scrub	36,943	34,847	64.5%
Inter-Mountain Basins Greasewood Flat	22,498	11,932	45.9%
Inter-Mountain Basins Mat Saltbush Shrubland	4,122	5,029	62.8%
Warm Desert Scrub			

System Name	Total mi^2 (mapped potential distribution)	Total mi^2 (mapped current distribution)	% of U.S. range on BLM lands
Sonoran Paloverde-Mixed Cacti Desert Scrub	50,774	37,033	35.6%
Chihuahuan Creosotebush Desert Scrub	35,704	44,764	20.3%
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	35,407	39,745	41.2%
Mojave Mid-Elevation Mixed Desert Scrub	21,146	20,431	46.9%
Chihuahuan Mixed Desert and Thornscrub	8,136	19,330	23.1%
Grasslands			
Northwestern Great Plains Mixedgrass Prairie	239,715	100,758	4.1%
Western Great Plains Shortgrass Prairie	99,949	57,389	1.4%
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	96,269	67,129	15.3%
Western Great Plains Sand Prairie	41,431	35,467	0.1%
Inter-Mountain Basins Semi-Desert Grassland	8,700	13,106	18.7%
Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	7,462	11,879	4.0%
Southern Rocky Mountain Montane-Subalpine Grassland	1,179	4,231	7.4%
Cool Temperate Subalpine Woodlands			
Northern Rocky Mountain Subalpine Woodland and Parkland	24,960	16,415	1.0%
Rocky Mountain Lodgepole Pine Forest	6,204	17,952	4.0%
Aspen & Mountain Mahogany Forests and Woodlands			
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	10,783	2,175	6.0%
Rocky Mountain Aspen Forest and Woodland	9,306	11,499	7.8%
Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and Shrubland	2,796	2,457	30.4%
Montane Conifer Forests and Woodlands			
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	49,822	44,297	1.8%
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	9,878	6,600	7.5%
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	5,958	3,998	9.5%
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	3,460	11,426	10.7%
Ponderosa Pine Woodlands and Savannas			
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	18,995	11,836	3.4%
Southern Rocky Mountain Ponderosa Pine Woodland	14,947	18,770	3.0%
Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna	7,024	9,027	7.7%

System Name	Total mi^2 (mapped potential distribution)	Total mi^2 (mapped current distribution)	% of U.S. range on BLM lands
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland	5,121	3,964	4.1%
Southern Rocky Mountain Ponderosa Pine Savanna	4,978	677	8.9%
East Cascades Oak-Ponderosa Pine Forest and Woodland	181	581	4.7%
Pinyon-Juniper Woodlands			
Madrean Pinyon-Juniper Woodland	17,323	17,904	5.9%
Colorado Plateau Pinyon-Juniper Woodland	15,405	36,021	30.2%
Great Basin Pinyon-Juniper Woodland	8,612	20,360	61.8%
Southern Rocky Mountain Pinyon-Juniper Woodland	4,041	6,158	13.9%
Southern Rocky Mountain Juniper Woodland and Savanna	4,009	4,482	5.7%
Columbia Plateau Western Juniper Woodland and Savanna	3,005	6,077	33.1%
Inter-Mountain Basins Juniper Savanna	591	2,419	13.7%
Rocky Mountain Foothill Limber Pine-Juniper Woodland	514	2,308	34.7%
Colorado Plateau Pinyon-Juniper Shrubland	80	4,220	71.0%

NatureServe Habitat Climate Change Vulnerability Assessment Methods

Objectives

The objectives of this project are to understand current trends in climate change across the western conterminous United States, assess the potential impact of these changes on major vegetation types of high importance to BLM management, and interpret these changes to assist BLM in determining climate smart management strategies. This project is based in part on methods that have been developed in response to BLM management needs during NatureServe's work across the region, on Rapid Ecoregional Assessments in the Great Basin, the Mojave Basin, and the Madrean ecoregions (e.g., Comer et al. 2013, Crist et al. 2014), and on methods piloted with the U.S. Fish and Wildlife Service and the Desert Landscape Conservation Cooperative (Comer et al. 2012).

NatureServe's framework for measuring climate change vulnerability of habitats and ecosystems (HCCVI) provides a practical approach to organize criteria and indicators for this purpose (Comer et al. 2012, Comer et al. *in review*). The methods developed for the HCCVI are applicable to any given ecosystem or community type that the user might select; wildlife habitat can also be assessed with this framework. For this assessment, NatureServe's terrestrial ecological systems classification (Comer et al. 2003) is used to define types being assessed. The advantage of using this classification system for this approach is that it represents an established nationwide classification of several hundred upland and wetland types mapped for use by federal and state resource managers (Comer and Schulz 2007, Rollins 2009) in the USA and adjacent Canada and Mexico (Comer et al. *in prep*). The expected historical extents, or "potential" distribution of each type are used, mapped at 90m pixel resolution, or upscaled to 800m pixel resolution, depending on the specific analysis.

Conceptual Models

An important part of this study includes the review of scientific literature pertinent to each of the selected ecological systems. A “conceptual model” (Gross 2005) sets the stage for understanding the system’s ecological composition, structure, natural dynamic processes, and interactions with major threats and stressors that may have altered the natural characteristics of the system (e.g. invasive plants changing both floristic composition and fire regimes). These models assist with organizing information and stating key assumptions about environmental controls and dynamics, based on current knowledge for each type.

For each of the ecological systems in this study an extensive conceptual model is provided, including the literature reviewed and used to develop the information in the model. In turn these models provide the ecological underpinnings for the spatial application of the HCCVI.

The selected types for this study are listed in **Table 1**. As can be seen in **Figure 1**, these ecosystems occur across extensive areas of the interior western U.S., south into large portions of Mexico, and north into Canada.

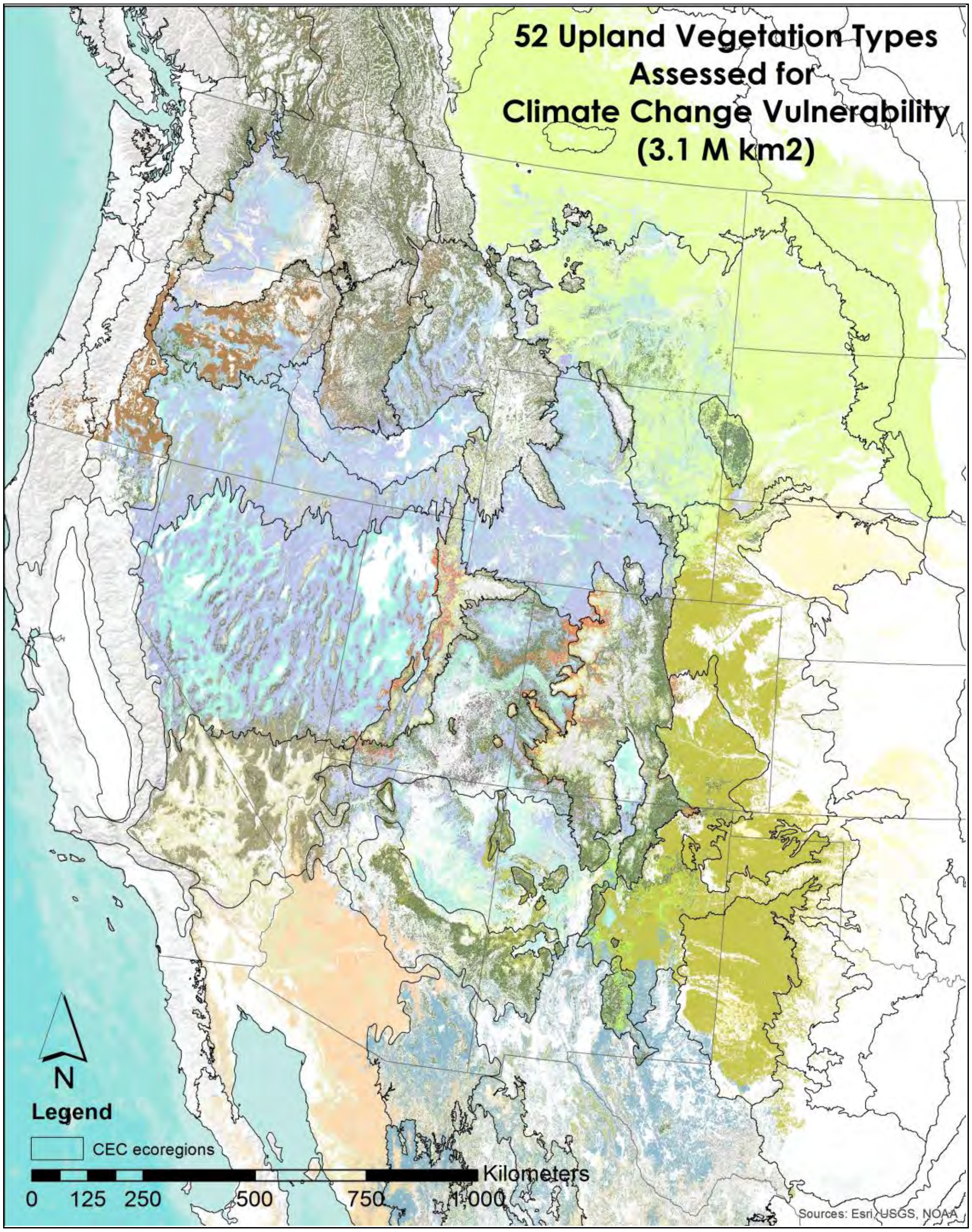

Figure 1. Mapped distributions of 52 ecological systems in western North America, with boundaries of the CEC ecoregions used for reporting on vulnerability (twenty-eight shrubland and grassland ecosystem types are included in this report).

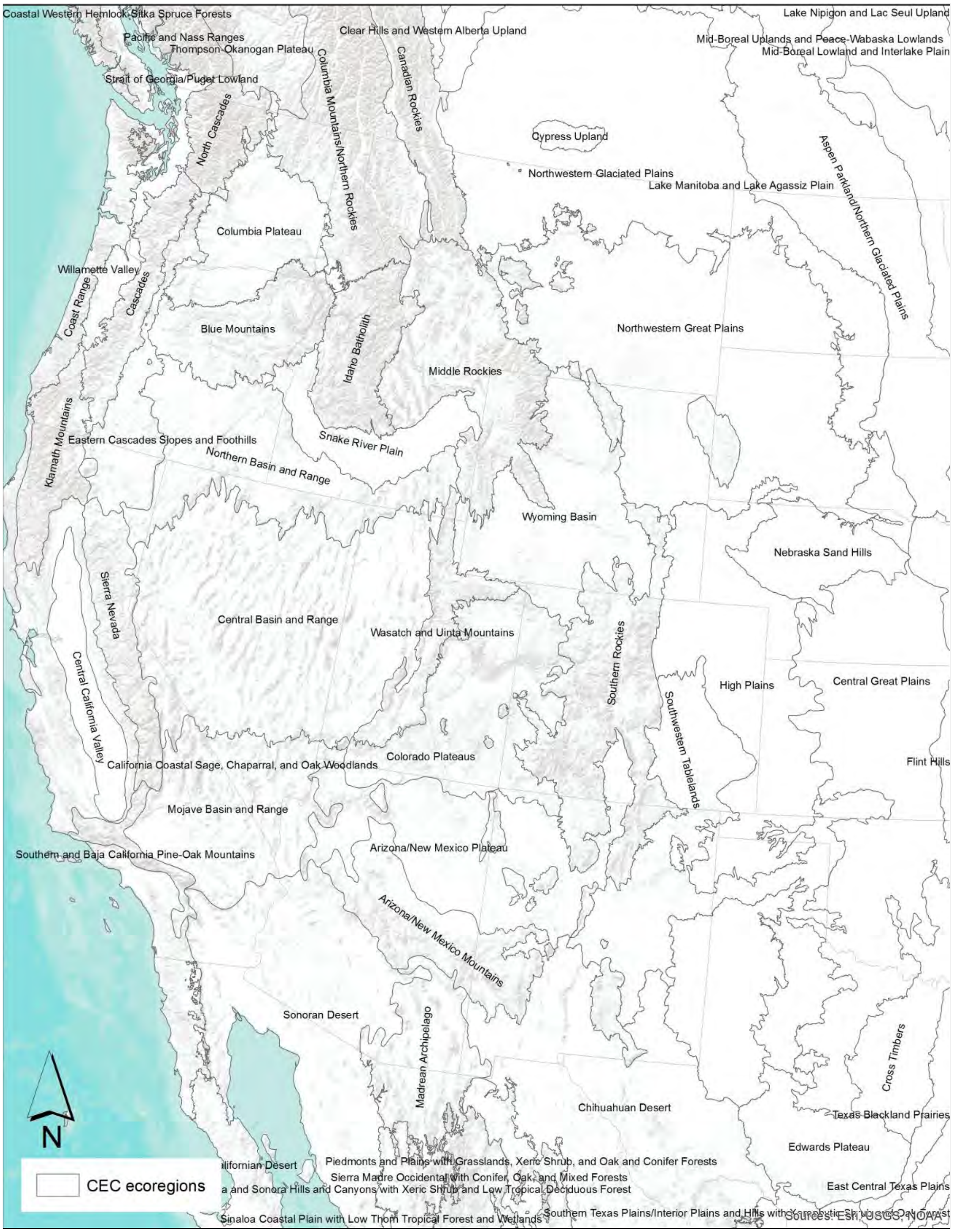

Figure 2. Boundaries and names of the western Commission on Environmental Cooperation (CEC) ecoregions.

The HCCVI Framework

The HCCVI framework used in this study to document climate change vulnerability combines a series of sub-analyses into a coherent structure that sheds light on distinct components of vulnerability, so that each can be evaluated individually, or in combination. This approach follows a number of related indexing approaches to documenting at-risk status of biodiversity (Faber-Langendoen et al. 2009), or climate change vulnerability for species (Young et al. 2010). As the societal response to climate change involves much new science and many recently introduced terms, it is important to clearly define what is meant by vulnerability and how vulnerability and its components are assessed. First, the notion of vulnerability to climate change has been succinctly defined by the Intergovernmental Panel on Climate Change (IPCC 2014) as:

> **"Climate Change Vulnerability** - The degree to which a system is susceptible to - and unable to cope with - adverse effects of climate change; including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity)."

This overall definition points to several contributing components of climate change vulnerability commonly used in current science. These include concepts of 1) **Climate-Change Exposure**, and the 2) **Resilience** of a system, which can be broken down into A) **Sensitivity** and B) **Adaptive capacity**. The HCCVI framework organizes the components of climate change vulnerability into these categories (**Figure 3**), which are defined and explained below.

In this study, VULNERABILITY is defined as the risk of a place to loss of species and ecosystem processes due to climate and non-climate factors. The two components of vulnerability are integrated, EXPOSURE and RESILIENCE, to arrive at a single vulnerability score. Areas most at risk are those that are likely to experience severe changes in temperature and precipitation (i.e., high exposure) but have little capacity to adapt (i.e., low resilience).

Exposure refers to the rate, magnitude, and nature of change a system is experiencing or is forecasted to experience. Exposure encompasses the current and projected changes in climate for an ecosystem (such as changes in temperature and precipitation) and predicted effects on ecosystem-specific processes. Analyses of exposure consider climate change projections themselves, and if possible, their resulting effects that cause increasing ecosystem stress, changing of processes such as wildfire or hydrological regime, and changing species composition.

Resilience encompasses factors that could either impede or support responses to stress induced by climate change in terms of natural ecological processes and species composition. It includes predisposing conditions affecting ecosystem resilience (Holling 1973, Gunderson 2000). Walker et al. (2004) defined resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks."

- **Sensitivity** in the HCCVI framework focuses on human alterations to characteristic patterns and process, such as landscape fragmentation, effects of invasive species, or human alterations to other dynamic processes. These alterations are considered independent of climate change, but once identified, have some potential interactions with forecasted climate change. These analyses also include a temporal dimension, considering both legacies of past land use along with current conditions.
- **Adaptive Capacity** includes natural characteristics that affect the potential for an ecological system to cope with climate change. Analyses of adaptive capacity consider the natural variability in climate that a system experiences across its distribution, as well as geophysical features that

characterize a given ecosystem or community. They also consider aspects of natural species composition, such as the relative vulnerabilities to climate change of individual species that provide "keystone" functions, and relative diversity of species involved in providing important functions and processes.

Climate exposure and resilience are each independently assessed and then combined to arrive at an overall gauge of climate change vulnerability (**Figure 3**). For applications of the HCCVI, climate change exposure may reflect changes in climate that have already occurred (as compared against a 20th century baseline), or reflect projections of future climate change over upcoming decades (e.g., 2010-2040, 2040-2070). ***For climate exposure, this project used 1948-1980 as a baseline and compared the 1981-2014 time frame to the baseline, hence measuring climate change vulnerability over the past 30 years.***

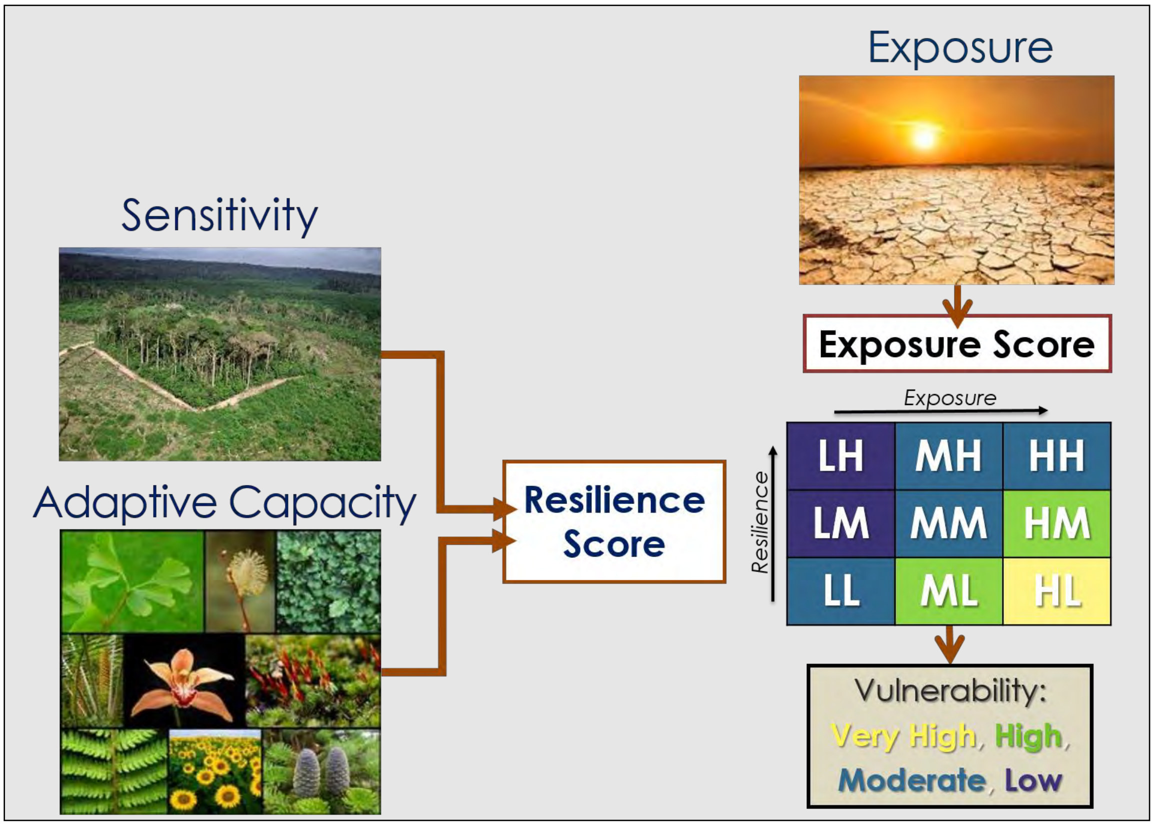

Figure 3. Schematic diagram of the analytical process for the Habitat Climate Change Vulnerability Index. In the matrix for obtaining the final vulnerability index (lower right), low resilience and high exposure result in Very High climate change vulnerability. High or moderate resilience and low exposure result in Low climate change vulnerability.

SCORING RELATIVE VULNERABILITY

Measures for exposure and resilience may be addressed in variety of ways, as appropriate for the given natural community, and using available data. The index aims to use component analyses to consistently arrive at a 4-level series of scores: Very High, High, Moderate, and Low (**Figure 3**).

Very High climate change vulnerability results from combining high exposure with low resilience. These are circumstances where climate change stress and its effects are expected to be most severe, and relative resilience is lowest. Ecosystem transformation is most likely to occur in these circumstances.

High climate change vulnerability results from combining either high or moderate exposure with low or moderate resilience. Under either combination, climate change stress would be anticipated to have considerable impact.

Moderate climate change vulnerability results from a variety of combinations for exposure and resilience; initially with circumstances where both are scored as moderate. However, this also results where resilience is scored high, if combined with either high or moderate exposure. Where both resilience and exposure are low, some degree of climate change vulnerability remains.

Low climate change vulnerability results from combining low exposure with high resilience. These are circumstances where climate change stress and its effects are expected to be least severe or absent, and relative resilience is highest.

Spatial and Temporal Dimensions for Documenting Vulnerability

Climate change vulnerability for ecosystems and habitats needs to be placed within explicit spatial and temporal bounds. For this study, the component measurements are summarized by 100 km^2 hexagons (**Figure 4**) for the distribution of each community type, and results are then further summarized within Level III ecoregions (Commission on Environmental Cooperation (CEC) 1997, Wiken et al. 2011, EPA 2013). These ecoregions (Error! Reference source not found.) provide an appropriate and consistent s patial structure to systematically document climate change vulnerability at national or regional scales. When these ecoregions are discussed or listed in this report, they are called *CEC ecoregions*.

Another scale of spatial reporting used is that of 100 km^2 hexagons (**Figure 4**); see further explanation of this below in **Spatial Analysis and Reporting**. These provide a more spatially nuanced view of the results and are the scale at which the spatial datasets are provided.

Similarly, the temporal dimension of climate change vulnerability must be explicitly considered, as the magnitude of climate exposure varies over time. For this effort, the climate exposure estimates are based on already observed climate data, and therefore, the timeframe for gauging vulnerability is said to be "current" or the date when climate data were last derived (in this study, 2014). Climate projections over the upcoming 50-year timeframe (e.g., between 2020 and 2070) were addressed separately from this study.

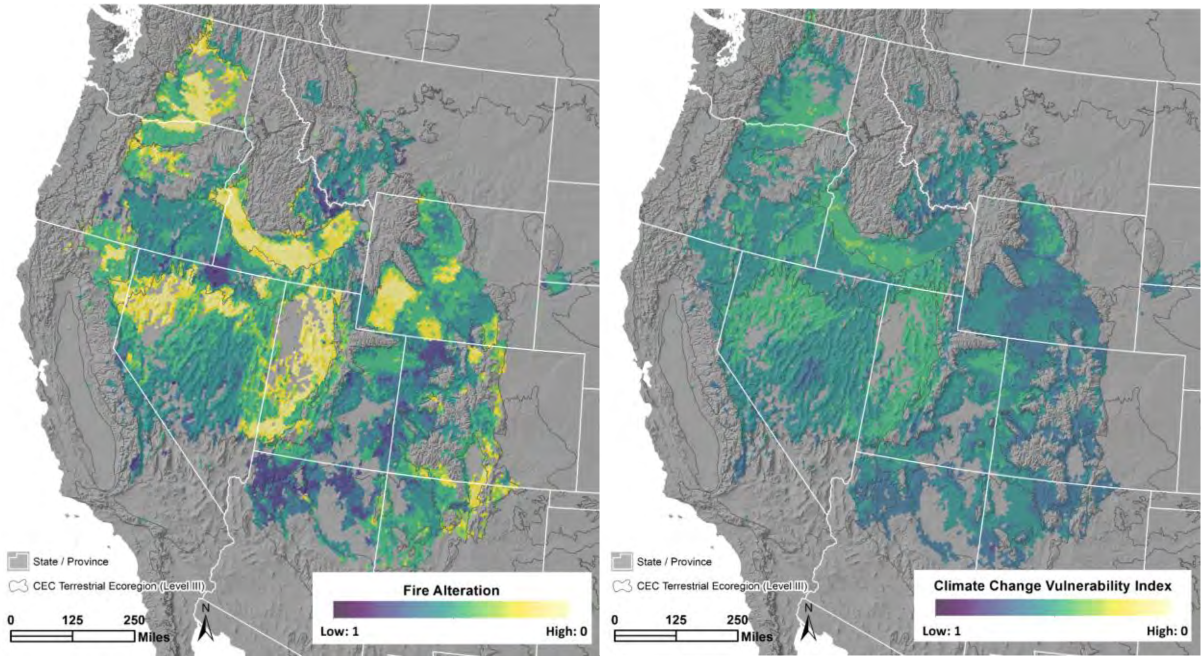

Figure 4. Examples of HCCVI components reported within 100 km^2 hexagons. In all of the maps, the color ramp is the same, with the dark purple representing the least vulnerability or exposure, best ecological condition, or least fragmentation or departure. The greens to yellows represent increasing vulnerability, exposure, or worse ecological condition.

Spatial Analysis and Reporting

A number of quantitative spatial models are used in this assessment, with spatial resolutions of either 90m or 800m. Each model must be comprehensive, i.e. the spatial surface covers all of the study area, which includes the extent of distribution of all ecosystems included in the study - generally the central Great Plains, west to the Pacific coast, south into central Mexico and north into southern Alberta and British Columbia (**Figure 1**). For use in the vulnerability index, each spatial dataset is scaled to have values between 0 and 1, so that averaging can be used to combine scores of 2 or more datasets (see **Table 2**). Provided below (**Table 3**) are brief descriptions and citations for these datasets; see Comer at al. in review for more details on the data and analytical procedures. Because the climate data and analyses are fundamental to this assessment, they are described in more detail; see section **Climate Exposure**.

Each ecological system in this assessment is numerically scored in the spatial analysis for a series of individual metrics and factors (**Table 2**). Numerical scores are normalized to a 0.0 to 1.0 scale, with 0.0 indicating ecologically “least favorable” conditions, and 1.0 indicating “most favorable” conditions. As described below, this allows results to be averaged across different components, producing a single summary vulnerability score ranging from 1.0 (least vulnerable) to 0.0 (most vulnerable). *Overall vulnerability* results from averaging *Exposure* and *Resilience*. In turn *Resilience* scores reflect the summary of sub-scores for ecological sensitivity and adaptive capacity.

The spatial analysis is conducted on individual locations of the ecological system’s mapped potential (i.e. historic) distribution, at a spatial resolution of 90m. In effect, each pixel of the system’s distribution is scored, with a number from 0 to 1, for each of the metrics. The scores for these pixels are then combined, in a weighted averaging method, within 100 km^2 hexagons (see examples in **Figure 4**). With the exception of the diversity within functional species groups, all of the metric scores result from a spatial, quantitative analysis. The score for functional species groups is applied to all of the system’s distribution, in other words, there is no spatial variation. The same is the case for keystone species, if a keystone species is identified for the system.

An additional calculation is done, again using a weighted averaging method, to produce a summary score for each factor and metric for each CEC Level III ecoregion (CEC 1997) where the ecosystem has at least 19 mi^2 (50 km^2) of potential distribution. These results by CEC ecoregion are provided in the **Climate Change Vulnerability** section for each ecological system. The maps reporting on each metric and factor within 100km^2 hexagons are provided on DataBasin. There are 10 maps provided for each ecological system, one each for the components in the HCCVI (**Table 2**).

The results within each CEC for exposure, resilience and overall vulnerability are provided as both a numeric score between 0 and 1, and as a categorical rating (**Figure 3**). The ratings are Low, Moderate, High and Very High. To apply ratings, break-points, or thresholds, for the 0 to 1 numeric scores must be applied; equal quartiles are used:

Score	Rating
≥0.75	Low vulnerability
0.50 to 0.75	Moderate vulnerability
0.25 to 0.50	High vulnerability
≤0.25	Very High vulnerability

Table 2. Example of scoring for an ecological system with notes on how scores for individual metrics are combined into a score for each factor and overall vulnerability. The individual metrics receive a numeric score ranging from 0.0 to 1.0. All of the individual sensitivity metrics are averaged into one sensitivity score; similarly, the adaptive capacity metrics are averaged into one adaptive capacity score. Null values are not included in the averages. Resilience is then calculated as an average of the sensitivity and adaptive capacity scores. Last, resilience and exposure are averaged to obtain the final climate change vulnerability index.

	CEC Ecoregion →	Central Basin and Range	Northern Basin and Range	Notes on scoring
	Miles^2 within ecoregion →	**2,580**	**1,517**	
Factor ↓	Metric ↓			
Exposure	Exposure, 2014	Low	High	exposure expressed as a categorical rating
		0.96	0.42	exposure expressed on a 0.0-1.0 scale
Sensitivity	Landscape Condition	0.68	0.73	
	Fire Regime Departure	0.42	0.52	
	Invasive grasses	0.48	0.36	
	Sensitivity Average	0.53	0.54	average of landscape condition, fire regime departure and invasive grasses
Adaptive Capacity	Topoclimate Variability	0.95	0.97	
	Diversity within Functional Species Groups	0.5	0.5	
	Keystone Species Vulnerability	Null	Null	
	Adaptive Capacity Average	0.73	0.74	average of topoclimate variability, diversity within functional species groups, and keystone species vulnerability (if relevant)
Overall Resilience		Mod	Mod	resilience expressed as a rating
		0.63	0.64	average of sensitivity and adaptive capacity
Climate Change Vulnerability Index		0.80	0.53	average of resilience and exposure
		Low	Mod	Vulnerability expressed as a categorical rating

Datasets Used

CLIMATE EXPOSURE

Nineteen bioclimatic predictor variables, including temperature and precipitation variables, are used to represent climate drivers of each vegetation type. Examples of these variables, all derived from daily and monthly weather station readings, include Mean Temperature of the Warmest Quarter, Precipitation of the Wettest Month, and Annual Precipitation (O'Donnell and Ignizio 2012). Within the conterminous USA, the source climate data is comprised of 800 m pixel resolution gridded surfaces representing monthly means from 1948 through 2014. Minimum and maximum temperature data are from TopoWx (Oyler et al. 2015), which uses a homogenization algorithm to overcome the noise and biases that emerge when gridded climate datasets derived from inconsistent weather station records are used to measure temporal trends. Since precipitation data are not available from TopoWx, they are sourced from the PRISM LT71 dataset (Daly et al. 2008). While PRISM does not remove the artifacts of non-climatic trends in the same manner as TopoWx, LT71 does use a more temporally consistent set of weather stations than other PRISM products, and precipitation is subject to fewer trend quality concerns than temperature.

Climate change exposure is measured as change in climate variables relevant to the individual ecological system across time (year-to-year variability within 30-year timeframes) and across space (variation across geography). In addition to scoring spatial variation of exposure for each ecosystem type within the $100km^2$ hexagons (**Figure 4,** right), variation in time for the ecosystem's distribution is calculated for each of the 19 bioclimate variables, comparing the recent 30-year average (1981-2014) to the 1948-1980 baseline average. The magnitude and direction of change (e.g. degrees of temperature increase or decrease and the significance of that change) are calculated as the number of standard deviations the recent mean (1981-2014) is from the baseline (1948-1980). For all variables with more than 1 standard deviation of change, the percent of the ecosystem type's distribution for that variable is calculated, within each of the CEC ecoregions.

Hence, it's possible to visualize not only the spatial variation in exposure, but also evaluate the *climate trends* of the particular bioclimate variables that are driving the exposure for that ecosystem. While the climate trends tabular data are not provided in this report, they are reported on briefly in the **Climate Change Vulnerability as of 2014** results section for each type.

Results for particular bioclimate variables are described when the recent mean standard deviation for the variable has an absolute value greater than 1 AND the area where that change has occurred is more than 15% of the system's distribution in an ecoregion. For example, *the climate trends data for Great Basin Pinyon-Juniper Woodland show increases of 0.6^o C for Mean Annual Temperature and 0.7^o C for Mean Temperature of the Warmest Quarter throughout the Central Basin and Range ecoregion and into surrounding ecoregions. Similar trends are observed in the adjacent Mojave Basin and Range and Arizona/New Mexico Plateau ecoregions*.

Table 3. Descriptions of the datasets used in this assessment. A brief explanation is provided for each input dataset, as well as the "derived" datasets (sensitivity average, adaptive capacity average, overall resilience and the climate change vulnerability index). The source of the dataset is described and cited as appropriate. The scoring approach is also described; each pixel of ecosystem distribution is scored, then these are averaged into scores for the 100km^2 hexagon or CEC ecoregion. The thresholds for rating exposure, resilience and overall vulnerability are listed; these are the thresholds used for presenting the results by ecoregion for each ecosystem.

Dataset	Justification and Definition	Data Source/Citations
Ecological systems-classification and potential distributions	The Terrestrial Ecological Systems Classification of NatureServe (Comer et al. 2003) provides mid- to local- scale ecological units useful for standardized mapping and conservation assessments of habitat diversity and landscape conditions. Each ecological system type describes complexes of plant communities influenced by similar physical environments and dynamic ecological processes (like fire or flooding). The classification defines some 800 units across the United States and has provided an effective means of mapping ecological concepts at regional/national scales in greater detail than was previously possible (Comer and Schulz 2007, Rollins 2009).	For this study we expanded upon the descriptive material for each system, utilizing available literature and expert knowledge. For distributions, the expected historical extent, or "potential" distribution of each type, mapped at 90 m pixel resolution, or upscaled to 800 m pixel resolution, is used, depending on the specific analysis (NatureServe, unpublished).
Exposure, 2014	Climate exposure is a measure of the degree of climate change a species, landscape, or vegetation type has already experienced or is projected to experience. We analyze current climate change exposure on western vegetation types between a 20th century baseline (1948-1980) and a recent time-period (1981-2014). We measure change in temperature and precipitation variables relative to baseline climatic variability across time (year-to-year variability) and across space (variation across geography).	We created a climate dataset at 800m resolution for use in the project, a combination of TopoWx for temperature and PRISM for precipitation. We obtained minimum and maximum temperature data from TopoWx (Oyler et al. 2015). We sourced precipitation data from the PRISM LT71 dataset (Daly et al. 2008). This climate dataset includes 19 bioclimate variables (O'Donnell and Ignizio 2012); these are then used in a modeling process to assign climate exposure scores to the distribution of each ecosystem type. The scores range from 0.01 to 0.99.

Dataset	Justification and Definition	Data Source/Citations
Landscape Condition	The spatial models of landscape condition used in this project build on a growing body of published methods and software tools for ecological effects assessment and spatial modeling; all aiming to characterize relative ecological condition of landscapes. The intent of these models is to use regionally available spatial data to transparently express user knowledge regarding the relative effects of land uses on natural ecosystems and communities.	This current model was developed and evaluated for the entire conterminous United States (Hak and Comer 2017). It is a continuous surface, which is scaled from 0 (poor condition) to 1 (good condition). This normalized map is overlaid with distributions of each vegetation type to arrive at per pixel scores.
Fire Regime Departure	Fire regimes are characterized quantitatively using state-and-transitions models that describe various successional stages and the transitions between them. Using estimates of fire frequency and successional rates, fire regime models predict the relative proportion of natural successional stages one might expect to encounter for a community type across a given landscape. Comparison of the observed vs. predicted aerial extent of successional stages is then used to gauge relative departure from expected proportions (measured in % departure).	For this study, we made use of the Vegetation Condition Class (VCC) product produced by the US Interagency LANDFIRE effort which provides both quantitative reference models of vegetation states and transitions, as well as spatial models of wildfire regime departure, measured in 10% increments of departure (Rollins 2009). For each vegetation type treated in this project, these percent departure values (in 10% increments) were translated to index scores to reflect "most favorable" to "least favorable" index values as follows: FRCC 1 = 1.0, FRCC 2 = 0.5, and FRCC 3 = 0.15.
Invasive Grasses	The effects of invasive plant species on natural communities are well known and there is considerable concern about their interactions with climate change (Abatzoglou and Kolden 2011). For example, few annual grasses are native to the inter-mountain region and most of the annual grass cover is from invasive non-native grasses; especially *Bromus tectorum, B. madritensis, B. rubens* and *Schismus barbatus*. Spatial models depicting likely presence and abundance of invasive annual grasses provide an important indication of vegetation condition, and therefore, relative sensitivity under the HCCVI framework.	NatureServe has created a model of invasive annual grass risk for the conterminous western U.S. (Comer et al. 2013, Hak and Comer, In Review), expressed in five categories of expected absolute cover (<5%, 5-15%, 16-25%, 26-45%, and >45%). This model is used for this study. These absolute cover values are translated to index scores to reflect "most favorable" to "least favorable" index values as follows: <5% = 1.0, 5-15% = 0.80, 16-25% = 0.6, 26-45% = 0.4, >45% = 0.2.
Sensitivity Average	Includes measures of ecological condition or integrity. With decreasing integrity, ecosystem responses to climate change stress are increasingly compromised.	Average of landscape condition, fire regime departure and invasive grasses; values range from 0.01 to 0.99.

Dataset	Justification and Definition	Data Source/Citations
Topoclimate Variability	The variability in climate expressed by the distribution of a given community can provide a useful indication of adaptive capacity. Natural communities occur across a range of macro and micro-climates. For example, some vegetation types form the upland 'matrix' of an ecoregion, such as grasslands in the Great Plains. Their distribution responds to regional scale patterns of temperature and precipitation. Other vegetation types might occur in relatively limited climates, such as alpine communities that only occur in small high-elevation areas of a 'basin-and-range' ecoregion. As compared to vegetation types occurring in a limited range of climates, those types occurring across a wide range of climates have a higher likelihood of coping with the likely climate change of the upcoming decades. Relative to areas of expansive flat topography, those areas with relatively rugged topography and elevational gradients will support a greater diversity of microclimate conditions.	Maps of terrain ruggedness express the enduring influence of topography on microclimate variability. The terrain ruggedness index (TRI) provided by Riley et al. (1999) was used with 90m digital elevation data of North America. TRI is the sum change in elevation between a given grid cell and its eight neighboring grid cells. For example, a cell located at 200m elevation, surrounded by four cells at 100 m and 4 more cells at 125 meters would yield a TRI of 700 (400+500-200=700). A topoclimatic variability map was derived by normalizing TRI scores to the 0.01-1.0 scale using extreme TRI estimates as projected for North America (TRI = 6,196), where 1.0 equates to the highest topoclimatic variability. This normalized map is overlaid with distributions of each vegetation type to arrive at per pixel scores.
Diversity within Characteristic Functional Species Groups	Natural communities may include a number of functional groups of organisms that pollinate, graze, disperse seeds, fix nitrogen, decompose organic matter, depredate smaller organisms, or perform other functions (Rosenfeld 2002, Folke et al. 2004). Experimental evidence supports the theoretical prediction that communities with functional groups made up of increasingly diverse members tend to be more resilient to perturbations (Folke et al. 2004, Walker et al. 2004, Nyström et al. 2008). Since individual species respond differently to disturbances, where there is high species diversity within a given group, as individual species are lost over time it is more likely that the community will retain key functions and therefore have greater resilience to stressors. The more diverse the group (as measured by taxonomic richness), the greater the likelihood that at least one species will have characteristics that allow it to continue to perform its function in the community even if, say, precipitation patterns or the fire regime change.	Functional roles are determined for each type via review of available literature, and consideration of roles critical to maintenance of the type. For each functional group, lists of species are compiled; and diversity of the group ranked as low, medium or high. The functional group with the lowest diversity is used to score the type across its full range of distribution, under the assumption that the functional group with the lowest diversity could become the most limiting for the adaptive capacity and resilience of the system. Generally functional groups with 1-5 species were scored as low (= 0.16), 6-15 species as medium (0.5), and >15 species as high (0.84).

Dataset	Justification and Definition	Data Source/Citations
Keystone Species Vulnerability	Determining which species can be considered keystone requires an understanding of the natural history of many species in the community being assessed. Although there are quantitative means of identifying keystone species via food web analysis, these methods can be time and data intensive. However, identification of potential keystone species may follow directly from the above process to clarify functional groups of species. That is, if an important ecosystem function is represented by just one species, that species is likely providing some 'keystone' function for purpose of this analysis.	Prairie dogs were identified as keystone species for three of the ecosystems in this assessment. The NatureServe Climate Change Vulnerability Index (CCVI; Young et al. 2015) for species is used to assess prairie dog vulnerability within the range of each ecosystem for which it is identified as a keystone species.
Adaptive Capacity Average	Addresses natural characteristics of the ecosystem type that lend a degree of ability to cope with climate change stress. Biotic measures of adaptive capacity used here include estimates of diversity within functional species groups, and the relative vulnerability of any "keystone" species. An abiotic measure includes topo-climatic variability.	Average of topo-climate variability, diversity within functional species groups, and keystone species vulnerability (if relevant); values range from 0.01 to 0.99.
Overall Resilience	Encompasses factors that could either impede or support responses to stress induced by climate change in terms of natural ecological processes and species composition. It includes predisposing conditions affecting ecosystem resilience.	Average of sensitivity and adaptive capacity; values range from 0.01 to 0.99.
Climate Change Vulnerability Index	Climate exposure and resilience are each independently assessed and then combined to arrive at an overall gauge of climate change vulnerability.	Average of resilience and exposure; values range from 0.01 to 0.99.

Report Content for each Ecological System Type

The content for each system is organized the same way. While ecological systems are not part of the U.S. National Vegetation Classification (USNVC; Franklin et al. 2012, Faber-Langendoen et al. 2014), the classifications are closely related. In the report, the ecological systems are organized by the USNVC hierarchy, first by Division (e.g. 1.B.2.Nc Western North American Pinyon - Juniper Woodland & Scrub), then by Macrogroup (e.g. M026 Intermountain Singleleaf Pinyon - Juniper Woodland) within the Division, followed by the system (e.g., Great Basin Pinyon-Juniper Woodland). This provides some ecological structure to the contents.

The material for each system is presented in three main sections: the Conceptual Model, the Climate Change Vulnerability assessment results, and Considerations for Climate Change Adaption. A comma-delimited list of references for the system is provided; the last section of the overall report has the full citations for all systems included in the study.

Below some explanation of the content for each section is provided.

CONCEPTUAL MODELS

The conceptual models, based on based on extensive literature surveys completed for this study, summarize what is currently known about the ecological composition, structure, dynamic processes, and interactions with major change agents across the distribution of the ecosystem type. The content included for each ecological system is described below.

The descriptions include many names of plant species that are characteristic of the ecological system. In the text, these names are provided as scientific names, as this is the standard way descriptions are stored in NatureServe's ecological databases. Vascular plant species nomenclature follows the nationally standardized list of USDA NRCS (2017), with very few exceptions. Nomenclature for nonvascular plants follows Flora of North America (2007, 2014) for mosses, Esslinger (2018) for lichens, Stotler and Crandall-Stotler (1977) for hornworts, and Stotler and Crandall-Stotler (2017) for liverworts.

CLASSIFICATION AND DISTRIBUTION

This section of the conceptual model provides a brief concept of the ecosystem and provides information about where it is found in the western U.S.

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

This section is generally extensive, and has 4 subsections.

Floristic composition of the type, including dominant and characteristic plant species as well as the general structural characteristics.

Important functional roles that plant and animal species play within the ecosystem. Natural communities may include a number of functional groups of organisms that pollinate, graze, disperse seeds, fix nitrogen, decompose organic matter, depredate smaller organisms, or perform other functions. Functional roles are determined for each type via review of available literature, and consideration of roles critical to maintenance of the type. For each functional species group, a list of the species comprising the group is provided, and the diversity within that group is rated as high, medium or low.

Environmental setting of the type is described. This includes where in the landscape the type is generally found, its climate regime, landforms, and soils or substrate characteristics.

Key processes and interactions are described, focusing primarily on the natural ecosystem dynamics. Natural disturbance regimes, interactions with insects, pathogens, and animals are described, where known. Successional dynamics are explained, often by describing the LANDFIRE-based states-and-transitions which were developed by expert ecologists.

ECOLOGICAL INTEGRITY

In this section the alterations to the natural dynamics of the type are described, both in terms of past alterations (e.g. conversion to agriculture), and what is known to be happening at present, such as invasion by exotics or ongoing fire suppression. These threats and stressors, or "change agents", are impinging upon the ecological integrity of the type, and in the context of assessing vulnerability, make the type more sensitive to the effects of climate change.

CLIMATE CHANGE VULNERABILITY AS OF 2014

This section provides the results for the ecological system of assessing its vulnerability or resilience to climate change. Initially, the results of the *climate exposure* and *climate trends* as of 2014 are summarized, often referring to one or more of the bioclimate variables that exhibit at least one standard deviation of change from the baseline mean for that variable across a large portion of the ecosystem's distribution.

Two maps are provided (out of the 10 in total for each type), one for the overall sensitivity results (see **Table 2** and **Figure 4**) and another for the climate exposure as of 2014.

In addition, a description is provided of the anticipated *climate change effects*, which are impacts to the ecological system from climate change. This incorporates summaries of the known composition, structure and ecological functioning of the ecosystem, and what can be anticipated to happen in response to continuing climate change. For example, in pinyon-juniper woodlands, bark beetle outbreaks have been documented to occur with more frequency and intensity during periods of warm, dry climate conditions. Hence, if the climate warms over the next 30-50 years, it can be anticipated that beetle outbreaks will become more frequent and mortality of pinyons could increase.

The second portion of this section provides a table (see **Table 2** for a simplified example) with the scores for each CEC ecoregion (CEC 1997) for each measured metric and factor. For some widespread ecological system types the number of ecoregions is quite large, so the table is extensive.

In addition, there is a text summary interpreting the results for sensitivity and adaptive capacity. Of note: because in this study the measurement of exposure covers the most recent 30 years (1981-2014) compared to the baseline (1948-1980), for most ecosystems there is limited climate exposure compared to analyses that focus on projected changes in future decades. The overall vulnerability for most types is driven by the sensitivity metrics: landscape condition, invasive annual grasses and fire regime departure. For some of the systems, diversity within one or more functional groups is low; and for many systems the topoclimate variability is also low. Combined, this results in poor adaptive capacity or resilience scores, which also drives the overall vulnerability score toward moderate or high vulnerability.

CONSIDERATIONS FOR CLIMATE CHANGE ADAPTATION

Climate Change Adaptation is the intentional and deliberate consideration of climate change, realized through adopting forward-looking goals and explicitly linking likely **climate change effects** to **management strategies**. It also implies a commitment to monitor changing conditions and adapt actions based on identified trends.

Climate vulnerability assessments can directly inform climate change adaptation strategies. Some have categorized major strategies into three areas, including resistance, resilience, and facilitated transformation (Biringer et al. 2003, Millar et al. 2007, Chambers et al. 2014). In this assessment of major vegetation types found on BLM lands, the geographic areas where each type appears to be more vulnerable were identified. In addition, the components of vulnerability should be used to explore why they are vulnerable in those places. These results can provide insights for resource managers to identify management actions suited to both current conditions and to changing conditions over upcoming decades.

Adaptive Actions - When identifying specific management actions for a given location, consideration should be given to direct effects and interactions among ecosystem-specific drivers of climate change exposure (e.g., increasing probability of drought conditions), sensitivity (e.g., fragmentation, invasive species, altered dynamic regimes), and adaptive capacity (diversity within functional species groups, keystone species vulnerabilities, and topo-climatic variability).

For example, where exposure measures indicate an increasing probability of drought conditions, restorative practices could include selection of native plant materials naturally occurring on relatively drought-prone soils that characterize the vegetation type in the region. Increasing climate exposure elevates the relative urgency of restoring vegetation conditions that may have been impacted by prior fragmentation, invasive species, or fire suppression. In some instances, emerging patterns of temperature and precipitation could suggest either increasing or decreasing patterns of expansion for some invasive plant species. For example, increasing temperatures could promote expansion of invasive annual grasses into higher elevations, but at the same time, increasing drought frequency could also reduce its expansion around and in basins. Relatively low diversity within functional species groups could suggest additional protective actions for fragile soil crusts, further evaluation and enrichment planting of nitrogen fixing species, or plantings to further attract and support pollinators. Certainly, where keystone species have been identified and scored as vulnerable, there is a high urgency to take actions to secure their viability. Landscapes indicated as retaining high topo-climatic variability may well be prioritized over other areas to secure and retain the biodiversity values that they currently support.

Generalized approaches to climate change adaptation can be related directly to the vulnerability score coming from this assessment (**Table 4**). Where scores suggest low overall vulnerability, these conditions suggest high resilience and low climate exposure, so managers can emphasize persistence of high quality current conditions. Taking preventive actions to limit potential vegetation degradation from fragmentation or introduction of invasive species is appropriate. As increasing vulnerability is indicated, proactive measures will be required, first emphasizing restoration to enhance potential for ecosystem resilience. With highest scores for vulnerability, the emergence of novel conditions become increasingly likely, and proactive measures become essential to secure critical ecosystem functions and limit biodiversity loss.

For each system, adaptation strategies are provided in a table similar to **Table 4**, but with the strategies adapted to be relevant to what is known about the composition, structure and natural dynamics of the system.

Table 4. Generalized climate change adaptation strategies relative to vulnerability scores.

VULNERABILITY SCORE	CLIMATE CHANGE EFFECTS	STRATEGIES AND ACTIONS
Low	Both resilient and subject to relatively low climate exposure, these areas are **least at risk.**	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors (e.g., altered dynamics, invasives, and fragmentation).
Moderate	With high-low scores for resilience and moderate-high exposure, these areas likely will continue to support characteristic communities as they slowly transform over upcoming decades.	**Emphasize restoration to enhance resilience.** Actions should focus on (1) decreasing non-climate stressors to restore ecological integrity or connectivity, and (2) retaining diversity in species playing key functional roles.

VULNERABILITY SCORE	CLIMATE CHANGE EFFECTS	STRATEGIES AND ACTIONS
High	Areas with high vulnerability have high exposure but moderate or low resilience. **Species turnover** and **restructuring of communities** can be anticipated.	**Revisit prior desired condition statements.** Monitor and facilitate change to novel community composition. Maintain connected natural landscapes to support turnover in native composition. Maintain ecosystem functions and limit biodiversity loss.
Very High	With high exposure and low resilience, these areas are most likely to face **transformational changes** to native composition and ecosystem functions.	**Plan for transformation to novel conditions.** Maintain ecosystem functions and limit biodiversity loss. Consider needs for "assisted migration" of most vulnerable species.

The Right Action at the Right Time - There is also a critical temporal dimension to climate change adaptation. Conservation decisions are made by people, often within the policy constraints of current law and institutions. While traditional natural resource management has been 'retrospective' – utilizing knowledge of past and current conditions to inform today's management actions – planners are increasingly required to rigorously forecast future conditions. This forecasting must strive to determine the nature and magnitude of change likely to occur, and translate that knowledge to current decision-making. It is no longer sufficient to assess "how are we doing as of today?" and then decide what actions should be prioritized for the upcoming 5-to-15-year management plan. One must now ask "where are we going, and by when?" and then translate that knowledge back into actions to take in the near-term, or medium-term, or those to monitor and anticipate taking over multiple planning horizons.

Since this assessment included only climate changes already observed through 2014, it does not provide forecasts of conditions likely to occur over upcoming planning periods. It is therefore "blind" to climate change effects that have yet to emerge. Analysis using climate projections over upcoming decades can be matched with these current measures of resilience to complete that picture and more completely inform adaptation decisions in upcoming planning cycles.

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CONCEPTUAL MODELS AND ECOSYSTEM VULNERABILITY ASSESSMENTS

2.B.2.Nb. Central North American Grassland & Shrubland

M051. Great Plains Mixedgrass & Fescue Prairie

CES303.674 Northwestern Great Plains Mixedgrass Prairie

Figure 5. Photo of Northwestern Great Plains Mixedgrass Prairie. Photo credit: Jerry and Pat Donaho, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This system extends from northern Nebraska into southern Canada and westward through the Dakotas to the Rocky Mountain Front in Montana and eastern Wyoming, on both glaciated and non-glaciated substrates. Soil texture (which ultimately effects water available to plants) is the defining environmental descriptor; soils are primarily fine and medium-textured and do not include sand, loamy sand, or sandy loam soils. This system occurs on a wide variety of landforms (e.g., rolling uplands stream terraces, ridgetops) and in proximity to a diversity of other systems. Most usually it is found in association with Western Great Plains Sand Prairie (CES303.670) which occupies the coarser-textured substrates. Northwestern Great Plains Shrubland (CES303.662) is intermixed on the landscape in draws and ravines which receive more precipitation runoff and are somewhat protected from fires. In various locales generally north and east of the Missouri River, the topography where this system occurs is broken by many glacial pothole lakes, and this system may be proximate to Great Plains Prairie Pothole (CES303.661). On the eastern Montana and western Dakota plains, mixedgrass prairie is by far the predominant system. Here it occurred continuously for hundreds of square kilometers, interrupted only by riparian areas or sand prairies, which were associated with gentle rises, eroded ridges, or mesas derived from sandstone. The growing season and rainfall are intermediate to drier units to the southwest and mesic tallgrass regions to the east. Graminoids typically comprising the greatest canopy cover include *Pascopyrum smithii, Nassella viridula*, and *Festuca* spp. In Montana these include *Festuca campestris* and *Festuca idahoensis*. Other commonly dominant species in Montana are *Bouteloua gracilis, Hesperostipa comata*, and *Carex filifolia*, while *Festuca campestris* and *Festuca idahoensis* may be more abundant in the north and foothill/montane grassland transition areas. *Bouteloua curtipendula, Elymus lanceolatus, Muhlenbergia cuspidata*, and *Pseudoroegneria spicata* are common, and sometimes abundant, components of this system. Remnants of *Hesperostipa curtiseta*-dominated vegetation are found in northernmost Montana and North Dakota associated with the most productive sites (largely plowed to cereal grains); this species, usually in association with *Pascopyrum smithii*, is much more abundant in Canada. Sites with a strong component of *Nassella viridula* indicate a more favorable moisture balance and perhaps a favorable grazing regime as well because this is one of the most palatable of the mid-grasses. *Hesperostipa comata* is also an important component and becomes increasingly so as improper grazing practices favor it at the expense of (usually) *Pascopyrum smithii*; progressively more destructive grazing can result in the loss of *Pascopyrum smithii* from the system followed by drastic reduction in *Hesperostipa comata* and ultimately the dominance of *Bouteloua gracilis* (or *Poa secunda* and other short graminoids) and/or a lawn of *Selaginella densa*. *Koeleria macrantha*, at least in Montana and southern Canada, is the most pervasive grass; if it has high cover, past intensive grazing is the presumed reason. In the eastern portion of this system's range, tallgrass species, especially *Andropogon gerardii, Panicum virgatum*, and *Sorghastrum nutans*, are often present to common on more mesic sites. Shrub species such as *Symphoricarpos* spp., *Artemisia frigida*, and *Artemisia cana* occur in the western and central portions while *Symphoricarpos* spp. and *Prunus* spp. can be found in the eastern portion. Sites with slightly to moderately saline soils have small to moderate amounts of salt-tolerant species such as *Distichlis spicata* and *Sporobolus airoides*. Fire, grazing and climate constitute the primary dynamics affecting this system. Drought can also impact this system, in general favoring the shortgrass component at the expense of the mid-grasses. With intensive grazing, cool-season exotics such as *Poa pratensis, Bromus inermis*, and *Bromus tectorum* can increase in dominance; both of the rhizomatous grasses have been shown to markedly depress species diversity. Shrub species such as *Juniperus virginiana* can also increase in dominance with fire suppression. This system is one of the most disturbed grassland systems in Nebraska, North and South Dakota, and Canada.

Distribution: This system is found in the western Great Plains north of the shortgrass prairie and west of the northern tallgrass prairie and extends from northern and western Nebraska into southern Canada, and west to central Montana and eastern Wyoming. The U.S. range corresponds to Bailey et al. (1994) sections 331D, 331E, 331F (mostly), 331G, 332A, 332B, 332D, and perhaps minor extensions into 251B, and in Canada to the Moist Mixed Grassland and Fescue Grassland.

Nations: CA, US

States/Provinces: AB, MB, MT, ND, NE, SD, SK, WY

CEC Ecoregions: Middle Rockies, Southern Rockies, Aspen Parkland/Northern Glaciated Plains, Lake Manitoba and Lake Agassiz Plain, Western Corn Belt Plains, Northwestern Glaciated Plains, Northwestern Great Plains, Nebraska Sand Hills, High Plains, Central Great Plains, Wyoming Basin

Primary Concept Source: S. Menard and K. Kindscher

Description Author: S. Menard, K. Kindscher, G. Kittel, S. Cooper, M.S. Reid, K.A. Schulz, J. Drake

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system contains greater than 50% cover of natural, cool-season grasses such as *Festuca* spp., *Pascopyrum smithii, Elymus lanceolatus, Hesperostipa comata, Hesperostipa curtiseta*, and *Nassella viridula*. *Hesperostipa comata* becomes increasingly important where improper grazing regimes have favored it at the expense of (usually) *Pascopyrum smithii*; progressively more destructive grazing can result in the loss of *Pascopyrum smithii* from the system followed by drastic reduction in *Hesperostipa comata* and ultimately the dominance of *Bouteloua gracilis* (or *Poa secunda* and other short graminoids) and/or a lawn of *Selaginella densa*. *Koeleria macrantha*, at least in Montana and southern Canada, is the most pervasive grass; if it has high cover, past intensive grazing is the presumed reason. Shrub species such as *Symphoricarpos* spp. and *Artemisia frigida* also occur. Cover of native, nongrazing-induced shrubs typically does not exceed 25% in conjunction with topographic relief (breaks);

otherwise the stand would be considered part of Northwestern Great Plains Shrubland (CES303.662). Cool-season exotics such as *Poa pratensis, Bromus inermis*, and the annual *Bromus tectorum* can increase in dominance with overgrazing; both of the above-named rhizomatous grasses are sufficiently aggressive to outcompete natives regardless of disturbance regime. Likewise, shrub species such as *Juniperus virginiana* can also increase in dominance with fire suppression.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system are wind-pollinated, most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators. Insects: Bees (Apoidea), wasps and ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera) and beetles (Coleoptera).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Carex filifolia, Carex inops ssp. heliophila, Carex duriuscula, Elymus lanceolatus, Festuca altaica, Festuca campestris, Festuca idahoensis, Hesperostipa comata, Hesperostipa curtiseta, Koeleria macrantha, Nassella viridula, Pascopyrum smithii, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. Black-tailed prairie dog (*Cynomys ludovicianus*) is considered a keystone species of Northwestern Great Plains Mixedgrass Prairie (CES303.674) (Kotliar et al. 2006). Prairie dog colonies create habitat that benefit numerous other species with their burrowing and foraging activities which influence environmental heterogeneity, hydrology, nutrient cycling, biodiversity, landscape architecture, and plant succession in grassland habitats (Kotliar et al. 2006). They are also an important food source for many animals including badgers, coyotes, eagles, hawks, and the critically endangered black-footed ferret (*Mustela nigripes*) (Hoagland 2006). The U.S. Fish and Wildlife Service estimated that about 160 million hectares (395 million acres) of potential habitat historically existed in the U.S., and about 20% was occupied at any one time (Gober 2000). Black-tailed prairie dog overlaps in distribution with much of the range of this ecological system.

Environment: This system extends from northern Nebraska into southern Canada and westward through the Dakotas to the Rocky Mountain Front in Montana and eastern Wyoming, on both glaciated and non-glaciated substrates. It occurs on a wide variety of landforms (e.g., rolling uplands, mesatops, stream terraces) and in proximity to a diversity of other systems. Elevations range typically from 430-1220 m, and up to 1980 m in the northwestern extent (LANDFIRE 2007a).

Climate: The climate is cool, continental, ranging from hot summers (mean daily temperature in July of 15°C in the northwest to 25°C in the southeast) to cold winters (mean daily temperature of -16°C in the northeast to -5°C in the southwest). Precipitation increases from west (25 cm) to east (55 cm) with most falling as rain or snow from April through June (LANDFIRE 2007a). Climate and growing season length for the region this system occurs are intermediate to the shortgrass regions to the west and southwest and the tallgrass regions to the east with a shorter growing season and less humid climate compared to the range of Central Mixedgrass Prairie (CES303.659). Moisture conditions are generally semi-arid.

Physiography/landform: Given the system's rather extensive geographic range, it is not surprising to find it occurring on a wide variety of landforms (e.g., rolling uplands, mesatops, stream terraces) and in proximity to a diversity of other systems.

Soil/substrate/hydrology: Soils are variable as it occurs on both glaciated and non-glaciated substrates generally with Entisols in the west and Mollisols in the east (LANDFIRE 2007a). Soil texture (which ultimately effects water available to plants) is the defining environmental descriptor; soils are primarily fine- and medium-textured, ranging from silt and clay loams, silty clay loams, silt loams to gravelly loam and do not include sands, sandy soils, or coarse sandy loams (Rolfsmeier and Steinauer 2010). In unglaciated areas, soils are derived primarily from fine-textured sedimentary rocks and deposits, primarily Cretaceous Pierre Shales, and to a lesser extent in Tertiary siltstones and chalky shales (Rolfsmeier and Steinauer 2010). Other rock types are included so long as their weathering products are not coarse-textured, namely not sandy soils. In glaciated areas, this system is found over glacial till and sometimes glacial lakeplains. It is found primarily on planar to gently rolling topography but is found on broken topography hillslopes as well. Some examples may include an impermeable or slowly permeable subsoil claypan layer. Other northern soils may be solonetzic and characterized by a subsoil hardpan layer with an excess of sodium (Adams et al. 2013).

Key Processes and Interactions: This grassland system evolved with fire, grazing, and drought, which constitute the primary dynamics affecting this system. The diversity in this mixedgrass system likely reflects both the short- and long-term responses of the vegetation to these often concurrent disturbance regimes (Collins and Barber 1985). Drought, rather than fire, is the primary driver maintaining the dry mixed grassland because it occurs more frequently than fire, inhibits expansion of woody shrubs and reduces the abundance of tallgrasses and mesophytic forbs, and prevents an accumulation of fuel that would maintain a frequent fire regime (Sala et al. 1996). Although variable in area, severe drought years in the Great Plains tend to occur in clusters periodically (1890s, 1930s, mid-1950s, late 1970s, late 1980s to early 1990s, and early 2000s) and have major ecological impacts.

Historic fire-return intervals have been estimated at 8-12 years (LANDFIRE 2007a), but fires burn patchily across the landscape, consuming vegetation in some areas and missing others because of natural firebreaks such as badlands, break in topography/ridge, and rivers. Fire-return intervals were likely longer in the drier, less vegetated central and western portions of this system's range and shorter in the east, near the transition to tallgrass prairie-dominated landscapes. Grazing and prairie dog towns also reduced fuel loads and fire frequency, size and intensity, with the most substantial impacts in valley bottom shrublands and grasslands, and upland grasslands near water (LANDFIRE 2007a). Historically, the majority of human-caused ignitions were concentrated in spring and fall seasons, while the more common lightning-caused fires were concentrated in late summer (Higgins 1984, 1986, LANDFIRE 2007a). This combined with the differential responses of species to burning results in greater diversity across the landscape (Wright and Bailey 1980).

Grazing by native ungulates, primarily bison (*Bos bison*) and small mammals, principally prairie dogs (*Cynomys ludovicianus*) added a further degree of patchy disturbance to the mixedgrass prairie (Whicker and Detling 1988). Available soil moisture drives species composition in this grassland, with a higher percentage of tall grasses on relatively moist, and cooler north-facing slopes, and mid and short grasses on drier steep and warmer southerly exposures (Rolfsmeier and Steinauer 2010). Long-term precipitation variance affects diversity of the central mixedgrass prairie, creating conditions more favorable to shortgrass species during droughts while allowing mixedgrass species to spread during wetter years (Sims et al. 1978, Singh et al. 1983). Extended drought in similar mixedgrass prairie in central Kansas caused loss of most forbs and cool-season grasses, and severe reductions of warm-season grasses (70-80%) (Albertson 1937) and likely has the same effects on mixedgrass prairie further north.

The absence of grazing and replacement fire for many years (e.g., 50 years) would lead to an increased shrub component (often *Symphoricarpos* spp. and *Fraxinus pennsylvanica*, but also possibly *Prunus* spp., *Amelanchier alnifolia, Elaeagnus commutata, Dasiphora fruticosa ssp. floribunda*, and *Juniperus horizontalis*) in precipitation zones greater than 35 cm, and a buildup of dead grass (LANDFIRE 2007a). Within the semi-arid (25-35 cm) precipitation zones, *Artemisia tridentata ssp. wyomingensis* and *Artemisia cana* may also increase. Productivity of the grasses is decreased, resulting in greater mortality from smoldering fire (LANDFIRE 2007a). Mormon crickets (*Anabrus simplex*), grasshoppers

(Orthoptera) and extinct Great Plains locust (*Melanoplus spretus*) probably had more of an impact in this system than currently defined, but the historical impact and frequency are unknown.

LANDFIRE developed a VDDT model for this system which has two classes (LANDFIRE 2007a, BpS 2911410).

A) Early Development 1 All Structures (25% of type in this stage): Herbaceous cover is 0-40%. Class A is the post-fire early-seral stage, combined with the very short-statured vegetation resulting from prairie dog disturbance or repeated high-intensity herbivory or trampling (e.g., watering points or buffalo wallows). This class may also be a short-term response to severe drought, combined with other impacts. This class lasts approximately three years. If in a prairie dog state, then the class would last longer in order to transition out of it; however, this is accounted for by having a prairie dog disturbance in the model, resetting succession and keeping it in this class. The 3-year interval attempts to capture what would happen post-fire or post-drought. Also post-heavy-grazing in current conditions would take longer to transition out of this class. Drought can occur every 30 years, not causing a transition. Replacement fire occurs but not as frequently, due to lack of fuel, every 20 years.

B) Mid Development 1 Closed (75% of type in this stage): Herbaceous cover (41-90%). Class B represents the intact historic plant community functioning under grazing and/or fire, dominated by taller, cool and warm-season rhizomatous perennial grasses, as well as bunchgrasses. This is the all-encompassing mid-to late-development, functioning final stage. Little below-ground mortality occurs after replacement fire, and resprouting of perennial grasses and forbs often occurs within days or weeks, depending on season. Grasses show greater vigor; some forb establishment may occur as a result of exposure of mineral soil. Canopy cover recovers quickly after resprouting. Shrub species could be present at 0-10% cover. Silver sagebrush and winterfat (on deeper soils) are the most common shrub, and would start resprouting. Wyoming big sagebrush can also be a component (on shallower soils) of this BpS, although a small component. Clubmoss might be present in Glaciated Plains at 0-5% cover, but not on shallow clay sites or dense clay sites, sands, saline upland, saline lowland, subirrigated or wet meadow. Replacement fire occurs every 5-15 years. Drought occurs every 30 years and maintains this stage. Native grazing by large ungulates could have occurred, including bison grazing. It is likely heavy locally due to increased succulence of young grasses. It might occur with a probability once every five years or 20% of this class each year. Native grazing by prairie dogs could also occur on a small portion of the landscape, bringing this state to A. Insect/disease occurs very infrequently. Grasshoppers and Mormon crickets might have a larger impact historically; however, there is uncertainty of impact and frequency. With a lack of fire, this class might shift to having more shrubs and tree invasion.

In the LANDFIRE BpS 2011410 model (3 Classes), drought was also thought to occur once every 30 years on average (LANDFIRE 2007a). It was also acknowledged that this system occurs within the very same biotope as Inter-Mountain Basins Big Sagebrush Steppe (CES304.778) or Inter-Mountain Basins Big Sagebrush Shrubland (CES304.777), the only difference being that fire has not been present where the sagebrush systems occur, a purely stochastic outcome (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: Historically, this system covered approximately 61.4 million ha (614,000 square km) in Nebraska, North and South Dakota, and Canada; now it covers approximately 29.9 million ha (299,000 square km) in this region, a 51% reduction in extent. Major threats to this system are loss through direct conversion to crop fields and heavily grazed pastures. Farmland development has fragmented the natural landscape and has eliminated the large-scale processes of fire and grazing by native ungulates and small mammals that were necessary to maintain this system. Lack of fire, grazing, or mowing result in a decrease in productivity as sites accumulate more litter. Lack of fire allows tree cover to increase rapidly, especially on lower, more mesic slopes and in the eastern, more mesic edges of the system's range. Encroachment by *Juniperus virginiana* as a result of fire suppression is problematic in some portions of the system's distribution (Rolfsmeier and Steinauer 2010). This system is well-adapted to moderate grazing over time or heavy grazing for short periods but when used as long-term pasture and with high stocking rates many of the dominant native grasses are reduced or eliminated (Branson and Weaver 1953). Heavy haying or grazing done for extended periods results in a selective reduction in more palatable mid- and tallgrass species. This results in a relative increase in short graminoids, such as *Bouteloua dactyloides, Bouteloua gracilis, Carex* spp., and *Poa secunda* and, where there are nearby seed sources, shrubs such as *Artemisia tridentata, Artemisia cana*, and *Symphoricarpos* spp. or if those are done consistently during the mid-summer months negatively affects the taller warm-season grasses (if present) by removing their biomass before they have flowered. Cool-season grasses and forbs which set seed earlier are favored by these activities as are short and/or less palatable species. Native and non-native forbs, woody species, and C3 grasses increase in the absence of fire, especially when combined with grazing by livestock. Drier sites on hilltops or rocky soils persist longer but mesic sites on lower slopes can be invaded by trees and shrubs after just several years without fire.

Invasion by non-native species degrade the biotic integrity of many stands of this grassland system reducing the abundance of native species (Ogle et al. 2003, Pritekel et al. 2006, Mack et al. 2007, Davies 2011, Fink and Wilson 2011). Exotic grasses (*Agropyron cristatum, Bromus inermis, Poa compressa*, and *Poa pratensis*) have been planted for forage and erosion control on many sites. Invasive upland forb species such as *Acroptilon repens, Centaurea stoebe ssp. micranthos, Linaria* spp., *Melilotus officinalis*, and mesic site species *Cirsium* sp. and *Euphorbia esula* have become naturalized in many areas (LANDFIRE 2007a). Invasion by annual bromes, especially *Bromus arvensis* and *Bromus tectorum*, has impacted many mixedgrass prairie sites, especially those dominated by cool-season grasses *Pascopyrum smithii* and *Nassella viridula* (Ogle et al. 2003).

The natural grazing regime has been replaced with domestic livestock grazing that is targeted toward "moderate" grazing intensity. This is often characterized by grazing each year with removal of herbage over an extended period of the growing season without adequate rest and recovery from grazing. This is contrasted with the expected historic shorter, episodic grazing patterns. One result is more structural homogeneity. Under the current livestock-grazing regime, taller, palatable grasses such as *Nassella viridula* and *Pseudoroegneria spicata* decrease and shorter grasses (*Bouteloua gracilis, Hesperostipa comata, Pascopyrum smithii*, and *Poa secunda*) increase. Only under season-long grazing will warm-season grasses such as *Schizachyrium scoparium* decrease. Season of use and/or twice-over grazing will impact the prevalence of *Schizachyrium scoparium* and other C4 plants. Heavy grazing causes cool-season exotics such as *Poa pratensis* and *Bromus inermis* to increase in dominance.

Shrubs (*Artemisia cana, Artemisia frigida, Artemisia tridentata ssp. wyomingensis, Ericameria* spp., *Symphoricarpos occidentalis*, and *Symphoricarpos oreophilus*) increase greatly over the historic plant community. Compare the ecological site description to avoid using a shrub model for historic plant community when considering a grass site that has changed as a result of uncharacteristic grazing or unnaturally long fire-return intervals. Unnaturally long intervals without fire may contribute to an increased shrub component. Xeric sites will experience an increase in sagebrush (*Artemisia* spp.), whereas western snowberry (*Symphoricarpos* spp.) will increase in mesic areas.

Long-term high-intensity grazing by domestic livestock without periods of rest and recovery can result in a conversion in the vegetation states from a midgrass-dominated community to shortgrass-dominated communities (*Bouteloua gracilis, Bouteloua dactyloides* (in southern portions), *Carex* spp., *Koeleria macrantha*, and *Poa secunda*). This should be distinguished from the class (class B) that's influenced more by presence of prairie dog towns - which have a higher forb component with less of a midgrass component than the other classes. In species composition, communities grazed by prairie dog versus domestic livestock are very different.

In current conditions, there has also been an increase in the amount of woody vegetation on the plains, particularly increases in *Symphoricarpos* spp. on mesic sites and expansion of *Pinus ponderosa* into grasslands and shrublands which were probably maintained in a grassland state under historic fire frequencies. The lack of fire has shifted grassland systems to shrublands or woodlands.

Conversion to agriculture also impacts this system; however, the degree of agricultural alteration of this system is highly variable by geographic region with Montana and Wyoming having experienced much less impact than the estimated 75% percent of the Nebraska-Dakota-south-central Canada region, where this system has been heavily altered. In Montana, this system is the major sustainer of livestock grazing with overall far less than half of it having been lost to agriculture; several Montana counties have more than 90% of this system remaining intact, though impacted by grazing to varying degrees. The shortgrass *Bouteloua gracilis* is frequently abundant and conspicuous on mowed and heavily grazed sites, but on lightly grazed or spring-burned sites the tall grasses are frequently most conspicuous, creating the appearance of tallgrass prairie.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 5** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 6, left**) and sensitivity (**Figure 6, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

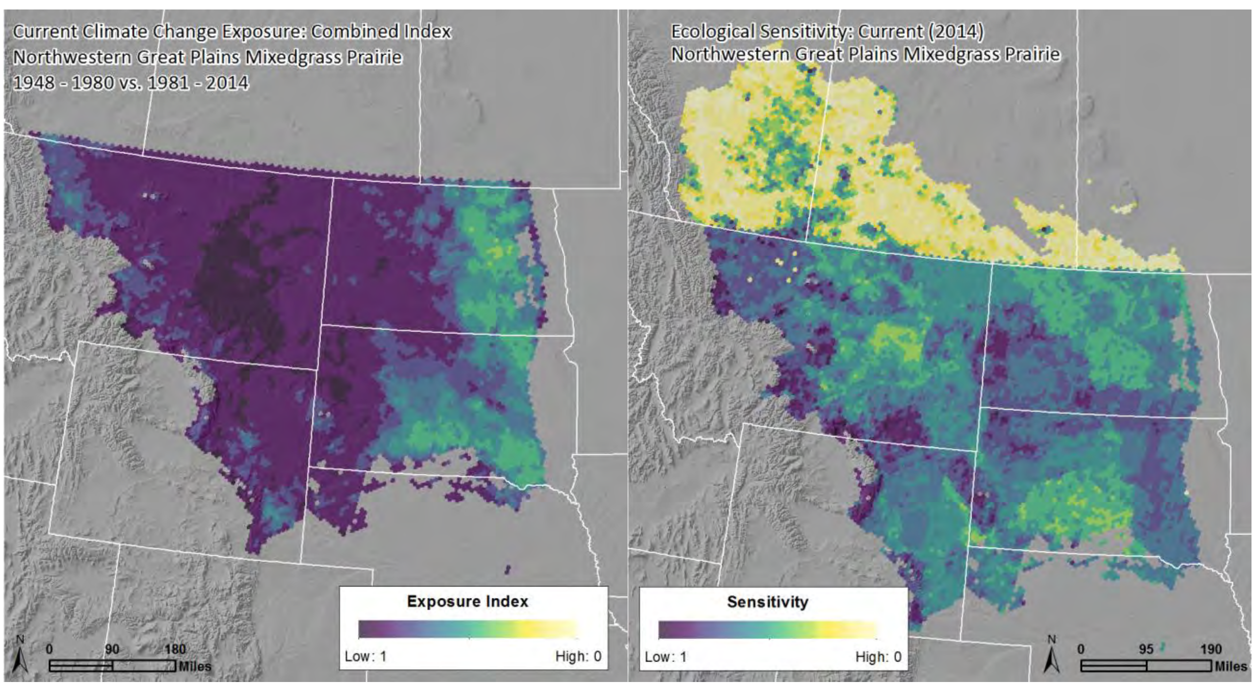

Figure 6. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northwestern Great Plains Mixedgrass Prairie. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 5. Resilience, exposure and vulnerability scores for Northwestern Great Plains Mixedgrass Prairie by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Northwestern Glaciated Plains	Northwestern Great Plains	Aspen Parkland-Northern Glaciated Plains	High Plains	Cypress Upland	Middle Rockies	Southern Rockies	Wyoming Basin	Nebraska Sand Hills	Canadian Rockies
	Sq miles within ecoregion	108,902	78,505	42,091	3,756	2,947	2,013	726	439	167	22
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		Low 0.77	Low 0.83	Mod 0.61	Low 0.78	Low Null	Low 0.84	Low 0.81	Low 0.84	Low 0.85	Low 0.85
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.25	0.49	0.15	0.41	0.43	0.51	0.63	0.76	0.52	0.45
	Fire Regime Departure	0.53	0.71	0.65	0.88	Null	0.80	0.77	0.82	0.83	Null
	Invasive Annual Grasses	0.94	0.69	1.00	0.54	0.99	0.93	0.72	0.66	0.50	1.00
	Sensitivity Average	**0.57**	**0.63**	**0.60**	**0.61**	**0.71**	**0.75**	**0.71**	**0.75**	**0.62**	**0.72**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.09	0.14	0.05	0.16	0.14	0.23	0.26	0.29	0.11	0.19
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
	Adaptive Capacity Average	**0.49**	**0.51**	**0.48**	**0.51**	**0.51**	**0.54**	**0.55**	**0.56**	**0.50**	**0.52**
Vulnerability from Measures of **Overall Resilience**		Mod 0.53	Mod 0.57	Mod 0.54	Mod 0.56	Mod 0.61	Mod 0.64	Mod 0.63	Mod 0.65	Mod 0.56	Mod 0.62
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall for the distribution of this widespread grassland system, exposure in the U.S. as of 2014 ranges from moderate in the Aspen Parkland/Northern Glaciated Plains ecoregion to somewhat limited in the other ecoregions. In the four ecoregions where it is most abundant (Northwestern Great Plains, Northwestern Glaciated Plains, High Plains, and Aspen Parkland/Northern Glaciated Plains), an emerging pattern of changing climate appears as increases of 0.6° to 1.0°C for Annual Mean Temperature across more than 35% of its distribution in these four ecoregions. In the Wyoming Basin and Southern Rockies ecoregions, an increase of 0.6°C for Annual Mean Temperature is seen across more than 90% of its distribution in those ecoregions.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on drier sites in the southern extent, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from changes in temperature and precipitation will affect the composition and diversity of native animals and plants through altering their breeding patterns, water and food supply, and habitat availability. Populations of some pests better adapted to a warmer climate are projected to increase. Grassland bird populations currently effected by habitat loss, fragmentation, and degradation could experience significant shifts and reductions in their range through reduced nest success and effects of greater fire frequency.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change ranges from low (higher scores) to moderate (**Table 5**). However, even in the 5 ecoregions with low sensitivity the scores are approaching moderate, indicating some sensitivity. The drivers of sensitivity vary by ecoregion but are primarily a result of poor landscape condition and fire regime departure, with invasive grass risk being a factor in about half of the ecoregions (although invasives models are incomplete for this type distribution).

Landscape condition is moderate (less development) in general with poor condition (more development) in the Northwestern Glaciated Plains and Aspen Parkland ecoregions, which represent over 60% of the total extent of the system. One ecoregion, Wyoming Basin, scored as good. The poor condition is a reflection of intensive agricultural activity combined with other infrastructure, such as mining or oil and gas operations, which can impact natural vegetation. Large-scale wind power development, transportation corridors and power transmission lines continue to fragment vegetation and provide vectors for invasive species. Throughout its range, there are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive annual grasses is generally low (higher scores) with 7 of 10 ecoregions having low risk and 3 ecoregions having moderate risk. However, 2 ecoregions with low risk are approaching moderate (scores near 0.70). Fire regime departure is generally low (high scores) with 6 ecoregions having low departure and 2 ecoregions having moderate departure. Two ecoregions restricted to Canada do not have fire regime results, as no fire regime departure data are available. The moderate to low departure is likely a reflection of decreased fire frequency due to grazing by livestock, which removes the fine fuels that carry fire. In addition, fire suppression has allowed for increased invasions of shrubs and trees, such as species of *Juniperus*, in some areas. However, in other areas invasive annual grasses will likely continue to spread which may increase fire frequency beyond the natural range of variability.

The interactions of the stressors of fragmentation by development, direct and indirect fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these temperate grasslands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is moderate across the range of this widespread grassland system. Topoclimatic variability is very low everywhere, as these grasslands occur across generally flat to rolling landforms and topography such as rolling uplands, mesa tops, and stream terraces. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups is moderate range-wide. Insect taxa provide a critical function by pollinating the forbs that are important components of this system. The within stand diversity of pollinators is moderate. Perennial cool-season graminoids are members of the other functional group, which also has moderate diversity. The plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

Black-tailed prairie dog (*Cynomys ludovicianus*) was identified as playing a keystone role in this grassland ecological system. This species is widely distributed, and due to its role as a keystone species, it's vulnerability to the recent change in climate was evaluated using the NatureServe Climate Change Vulnerability Index tool. It was found to be Less Vulnerable across the portion of its range that coincides with this system, suggesting it may be able to adapt to recent changes in climate conditions.

Vulnerability Summary for 1981-2014 Timeframe: This grassland type currently scores in the moderate level of vulnerability throughout its range. This is primarily due to its low scores for exposure and moderate adaptive capacity scores. Inherent vulnerabilities are high for these grasslands that naturally occupy extensive flat to rolling plains, stream terraces, and ridgetops (low topoclimate variability). For a given increment of climate change, individual species would need to disperse longer distances per year as compared with those that occur in more rugged landscapes that naturally support higher microclimate diversity. Additionally, these grasslands have moderate to low fire regime departure scores and variable but generally moderate landscape condition scores with lowest scores in agricultural areas. Stands are susceptible to effects of extended drought, overgrazing, and long-term effects of fire regime alterations such as shrub and tree encroachment with fire suppression. In their western extent, stands are moderately susceptible to invasive plants.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 6. Climate change adaptation strategies relative to vulnerability scores for Northwestern Great Plains Mixedgrass Prairie

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (bison wallows, prairie dog towns, cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub invasion.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Adams et al. 2013, Albertson 1937, Anderson 1990b, Bailey et al. 1994, Barbour and Billings 1988, Bragg and Steuter 1995, Branson and Weaver 1953, Collins and Barber 1986, Comer et al. 2003*, Davies 2011, Fink and Wilson 2011, Gober 2000, Higgins 1984, Higgins 1986, Hoagland 2006, Kotliar et al. 2006, LANDFIRE 2007a, MTNHP 2002b, Mack et al. 2007, Ogle et al. 2003, Pritekel et al. 2006, Rice et al. 2012b, Ricketts et al. 1999, Rolfsmeier and Steinauer 2010, Sala et al. 1996, Shiflet 1994, Sims et al. 1978, Singh et al. 1983, Weaver 1954, Weaver and Albertson 1956, Whicker and Detling 1988, Wright and Bailey 1980

CES303.662 Northwestern Great Plains Shrubland

Figure 7. Photo of Northwestern Great Plains Shrubland. Photo credit: Steven V. Cooper, Montana Natural Heritage Program.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system ranges from South Dakota into southern Canada on moderately shallow to deep, fine to sandy loam soils. These sites are typically more mesic than most of the surrounding area. This system may be located along upper terraces of rivers and streams, gently inclined slopes near breaklands, and upland sandy loam areas throughout its range. This system is dominated by shrub species such as *Amelanchier alnifolia, Rhus trilobata, Symphoricarpos* spp., *Shepherdia argentea, Crataegus douglasii, Elaeagnus commutata, Dasiphora fruticosa ssp. floribunda*, and dwarf-shrubs such as *Juniperus horizontalis*. Midgrasses such as *Festuca* spp., *Koeleria macrantha*, and *Pseudoroegneria spicata* and species such as *Carex filifolia* can co-occur. This system differs from Northwestern Great Plains Mixedgrass Prairie (CES303.674) in that it contains greater than 10% cover in conjunction with topographic relief (breaks) of natural shrub species. Fire and grazing constitute the primary dynamics affecting this system; drought can also impact this system. This system may include areas of Northwestern Great Plains Mixedgrass Prairie (CES303.674) where fire suppression has allowed for a greater cover of shrub species. This system is similar to Northern Rocky Mountain Montane-Foothill Deciduous Shrubland (CES306.994) but occurs in the grassland matrix of the Great Plains, whereas the Rocky Mountain system occurs adjacent to the lower treeline of generally forested mountains and highlands. Floristically their shrub composition is similar, but associated grasses and forbs will differ somewhat given their respective adjacent vegetation types.

Distribution: This system extends from South Dakota into southern Canada, west into the foothills of north-central Montana. The U.S. range corresponds to Bailey et al. (1994) sections Northeast Glaciated Plains (332A), Western Glaciated Plains (332B), North Central Glaciated Plains - extreme western part (251B), and in Canada to the Moist Mixed Grassland and Fescue Grassland.

Nations: CA, US

States/Provinces: AB, MB, MT, ND, SD, SK, WY

CEC Ecoregions: Canadian Rockies, Middle Rockies, Aspen Parkland/Northern Glaciated Plains, Northwestern Glaciated Plains, Northwestern Great Plains

Primary Concept Source: S. Menard and K. Kindscher

Description Author: S. Menard, K. Kindscher, G. Kittel, M.S. Reid, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is dominated by shrub and dwarf-shrub species such as *Amelanchier alnifolia, Rhus trilobata, Symphoricarpos* spp., *Dasiphora fruticosa ssp. floribunda*, and *Juniperus horizontalis*. Mid grasses such as *Festuca* spp., *Koeleria macrantha*, and *Pseudoroegneria spicata* can also occur. This system differs from Northwestern Great Plains Mixedgrass Prairie (CES303.674) in that it contains greater than 60% cover of natural shrub species.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although some dominant shrubs in this system, such as *Amelanchier alnifolia, Juniperus horizontalis, Sarcobatus vermiculatus* and the graminoids, are chiefly self- or wind-pollinated, other dominant shrubs (*Dasiphora fruticosa ssp. floribunda, Elaeagnus commutata, Rhus trilobata*) and forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Esser 1994a, Fryer 1997, Anderson 2001d, 2004a, 2004b, Gucker 2006g). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for wildlife such as sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds important for certain species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially for red tubular flowers).

Perennial Cool-Season Graminoids; Species Diversity: High
Achnatherum nelsonii, Agrostis scabra, Bromus carinatus, Carex duriuscula, Carex filifolia, Carex geyeri, Carex inops ssp. heliophila, Carex rossii, Carex obtusata, Danthonia intermedia, Danthonia parryi, Elymus lanceolatus, Festuca campestris, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Pascopyrum smithii, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species provide a vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this shrubland type.

Environment: Climate and growing season length for the region this system occurs are intermediate to the shortgrass regions to the west and the tallgrass regions to the east with a shorter growing season with semi-arid moisture conditions. This system occurs on sites more mesic than most of the surrounding area such as upper river terraces, gently inclined slopes, and upland sandy areas. Soils range from shallow to deep and fine to sandy loams.

Key Processes and Interactions: Fire and grazing constitute the primary dynamics affecting this system. Drought can also impact this system.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has three classes in total (LANDFIRE 2007a, BpS 2010850). These are summarized as:

A) Early Development 1 Open (herbaceous-dominated - 35% of type in this stage): Cover is 0-50%. Grasses such as little bluestem, western wheatgrass, stipa, bluebunch wheatgrass, sideoats grama and upland sedges dominate this class. This class is a combination of grasses and very short-statured vegetation resulting also from prairie dog disturbance (maybe only in draws - snowberry). A variety of forb species such as fetid marigold, scarlet globemallow, scarlet gaura, skeleton weed and dotted gayfeather tend to dominate this class. Some sprouting of snowberry, chokecherry and serviceberry. The fuel in this class would be initially too sparse to carry fire, but then fuel increases. This class lasts for 9 years then succeeds to class B, mid-open state. (Although, if it were a dense stand initially and then re-sprouted, might take fewer than 9 years to get to class B.) Replacement fire occurs every 30 years, and sets this class back to its beginning stage. Grazing (0.07 probability or 7% of this class each year), the combination of drought and grazing (0.02 probability or 2% of this class each year) and drought modeled as wind/weather/stress (0.05 probability or 5% of this class each year) all occur and maintain this class but don't set it back to its beginning state. Prairie dog impact occurs with a probability of 0.0035 (0.35% of class each year) and returns this class to its beginning. The only shrub that prairie dogs might impact in this BpS would be the snowberry sites and draws/drainageways.

B) Mid Development 1 Open (shrub-dominated - 25% of type in this stage): Shrub cover is 0-20%. More open community than late stage. Seedling shrubs. Dominant shrubs coming in include snowberry, chokecherry, skunkbush, creeping juniper and buffaloberry. Western wheatgrass, needlegrasses, little bluestem and upland sedges are common grasses - same as in class A. Bluebunch wheatgrass can be locally common with skunkbush. Common forbs include scurfpea, prairie coneflower, Rocky Mountain beeplant, scarlet globemallow and dotted gayfeather. Herbaceous cover is approximately 30-70% and approx. 0.5 m in height. This class lasts 9 years and then succeeds to the late-development stage. Replacement fires occur every 30 years. Grazing (0.02 probability or 2% of this class each year) and the combination of drought and grazing (0.01 probability) occur and cause a transition back to the early stage, class A. Grazing (0.02 probability), the combination of drought and grazing (0.003 probability) and drought modeled as wind/weather stress (0.1 probability) can also occur while maintaining this class in this stage. Prairie dog impact occurs with a probability of 0.0003, taking the class back to class A.

C) Late Development 1 Closed (shrub-dominated - 40% of type in this stage): Tree cover is 21-80%. Denser, higher canopy cover. Mature canopy. Vegetation community is similar to previous class. Forbs are present still. Litter layer tends to be relatively continuous. Herbaceous cover 50-65% and 0.5 m in height. Snowberry average cover could be 65%. Maximum up to 75%, minimum approx. 45%. Skunkbush cover average approximately 25%. Horizontal juniper average 44%, range of 25-65% cover. Each of the shrub species associated with own habitat type with moisture gradient. Skunkbush is dry end, and snowberry/chokecherry is wet end.

The northern mixed-grass prairie and shrublands are strongly influenced by wet-dry cycles. Fire, grazing by large ungulates and small mammals such as prairie dogs and soil disturbances (i.e., buffalo wallows and prairie dog towns) are the major disturbances in this vegetation type. In MZ30, many of these shrubland types occur on moderate to steep slopes (west- to northwest-facing).

From instrumental weather records, droughts are likely to occur about 3 in every 10 years. Historically, there were likely close interactions between fire and grazing since large ungulates tend to be attracted to post-fire communities. Conversely, fire presumably was less likely in areas recently heavily grazed by herbivory, thus contributing to spatial and temporal variation in fire occurrence.

Average fire intervals are estimated at 8-25 years, although in areas with very broken topography fire intervals may have been greater than 30 years. The model for MZ20 reflects a 30-year FRI. This system's FRI should be very similar to 1141 mixedgrass prairie, since this system is just inclusions within 1141. It might be a little less frequent because of moisture; however, it should be similar.

Fires were most common in July and August, but probably occurred from about April to September. Seasonality of fires influences vegetation composition. Early-season fires (April - May) tend to favor warm-season species, while late-season fires (August - September) tend to favor cool-season species. Replacement fire in our model does remove 75% of the above-ground cover as assumed in the literature. However, loss of the above-ground cover by the replacement fire will not necessarily induce a retrogression back to an earlier seral stage from the late stage because the main component of dominant grasses remains unharmed to insure the continuity of the seral stage. The shrub species, however, are sprouters. Fire would remove them, and they would resprout. The exception would be horizontal juniper and skunkbush which would not resprout. It would take longer for them to become re-established.

Different levels of native ungulate grazing intensities were used in LANDFIRE modelling. Light grazing was assumed to not alter the community enough to change classes but increasing grazing intensity would move the community back to earlier stages. Grazing return interval probably occurred every 7-10 years but grazing would only result in a class change maybe once every 80-100 years. Overall, the grazing frequency was modeled at every 20 years - that includes grazing just occurring with no transition resulting, as well as grazing taking the stage back to an earlier class. And, overall, the drought plus grazing impact frequency was modeled as every 70 years - that includes the no-transition plus transition to early stage (LANDFIRE 2007a, BpS 2010850). In addition to fire, drought, grazing and insect outbreaks (Rocky Mountain locust) would have impacted all classes, historically.

ECOLOGICAL INTEGRITY

Change Agents: Conversion to agriculture can impact this system, and its range has probably been decreased by human activities. Impacts from energy extraction in oil and gas fields in the Dakotas and eastern Montana have recently fragmented large areas with road networks to well pads and pipelines. Livestock grazing and trampling can negatively impact these shrublands, especially during the winter as stands often occur in swales and stream terraces that offer livestock and wildlife some protection from winter storms.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 7** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 8, left**) and sensitivity (**Figure 8, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

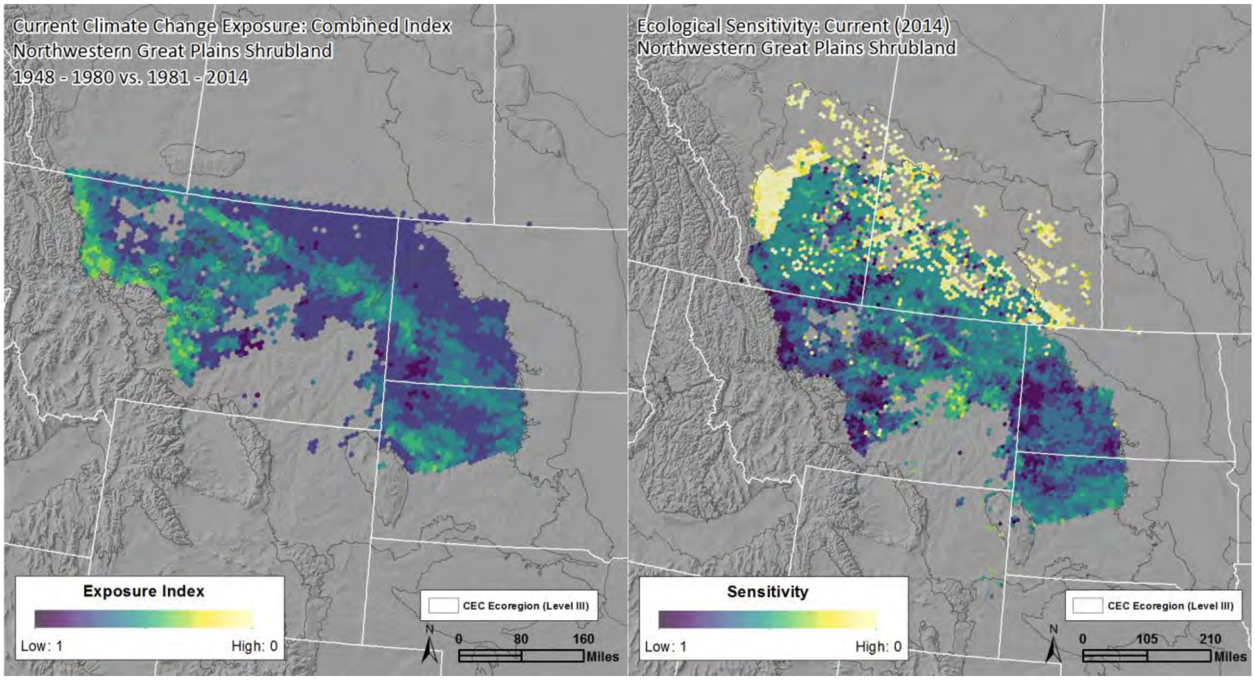

Figure 8. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northwestern Great Plains Shrubland. The results have been summarized and are displayed in 100km2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 7. Resilience, exposure and vulnerability scores for Northwestern Great Plains Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Northwestern Glaciated Plains	Northwestern Great Plains	Middle Rockies	Aspen Parkland-Northern Glaciated Plains	Cypress Upland
	Potential square miles within ecoregion	1,969	1,603	214	135	88
Contributions to Relative Vulnerability by Factor						
Vulnerability from **Exposure (2014)**		Mod 0.62	Mod 0.59	Mod 0.58	Mod 0.65	Low 0.76
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.48	0.54	0.84	0.11	0.61
	Fire Regime Departure	0.60	0.74	0.66	1.00	Null
	Invasive Annual Grasses	0.96	0.82	1.00	1.00	1.00
	Forest Insect & Disease	Null	Null	Null	Null	Null
	Sensitivity Average	**0.68**	**0.70**	**0.83**	**0.70**	**0.81**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.17	0.20	0.35	0.10	0.25
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.33**	**0.35**	**0.42**	**0.30**	**0.37**
Vulnerability from Measures of **Overall Resilience**		Mod 0.51	Mod 0.52	Mod 0.63	Mod 0.50	Mod 0.59
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Contribution to vulnerability from exposure (as of 2014) for this shrubland system is moderate across its potential range. Scores were moderate in all but the smallest ecoregion (Cypress Upland), which scored at the moderate end of low. Annual mean temperature has increased between 0.8° and 1.0°C across approximately 50% of the potential distribution. These changes were widespread in the three largest ecoregions (40-50% effected in each region) and pervasive in the Aspen Parkland-Northern Glaciated ecoregion (100%). Other climate exposure effects were restricted to very small portions of ecoregions, aside from a 1.85°C increase in mean winter temperature across 23% of the Middle Rockies ecoregion.

Climate Change Effects: The Great Plains region experiences multiple climate and weather hazards, including floods, droughts, severe thunderstorms, tornadoes, and winter storms. There is concern that the frequency and severity of these events may be altered by climate change, especially increased drought in the southern Great Plains (Shafer et al. 2014). Average annual temperature is projected to continue to increase in the Great Plains region with winter and spring precipitation projected to increase in the northern states (Shafer et al. 2014). Potential climate change effects on this ecosystem may include a shift to plant species more common on hotter, sites with increased to warm-season (C4) grasses such as *Bouteloua curtipendula, Bouteloua gracilis*, or *Schizachyrium scoparium* (Shafer et al. 2014).

Ecological consequences from changes in temperature and precipitation will affect the composition and diversity of native animals and plants through altering their breeding patterns, water and food supply, and habitat availability. Populations of some pests better adapted to a warmer climate are projected to increase. Shrubland and plains bird populations currently damaged by habitat loss, fragmentation and degradation could experience significant shifts and reductions in their range through reduced nest success and effects of greater fire frequency in some portions of the range.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was moderate to low, with three of the five ecoregions scoring moderate, including the two largest ecoregions. The remaining two ecoregions scored low for sensitivity. Sensitivity scores were driven largely by landscape condition.

Contributions to sensitivity from landscape condition were high to moderate, with the Northwestern Great Plains and Northwestern Glaciated Plains scoring high and moderate, respectively. These comprise 90% of the estimated potential distribution of this system. Landscape condition was variable across the other three ecoregions, ranging from very high to low. Landscape condition reflects fragmentation from agricultural conversion, with high contributions from grazing and from fragmentation associated with oil and gas development in the northern Great Plains. Fragmentation is less severe in montane foothills within the range as these areas are less conducive to intensive agriculture.

Fire regime departure was moderate or low across the ecoregions. This reflects fire suppression practices across much of the region, which likely lead to stand conditions having high relative cover of shrubs to grasses. Risk from invasive grasses was low across the range of the system.

Overall, landscape fragmentation has resulted in changes to the structure of these shrublands, leading to an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across all ecoregions of this shrubland system. This low adaptive capacity is related to very low scores for topo-climate variability in four of the five ecoregions in which the system occurs. These reflect a low level of topographic diversity associated with the flat to rolling plains characteristic of where this system occurs.

In terms of vulnerability related to functional groups, the system scores moderate in terms of pollinator diversity (insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system). Diversity of warm- and cool-season graminoids was also moderate, suggesting a somewhat limited capacity for these to respond to changed climate conditions based on diversity of photosynthetic pathways. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. Warm-season graminoid species use the less common C4 photosynthesis pathway to fix carbon, which functions best at higher temperatures; this is the most efficient pathway under low CO² concentrations, high light intensity and higher temperatures and is well-adapted to relatively warm, dry climates. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this shrubland system scores in the moderate range of current overall climate change vulnerability. This is primarily due to high contributions to sensitivity from landscape condition associated with conversion to agriculture, grazing, and oil and gas development. Low adaptive capacity associated with very low topoclimate diversity also contributes to the vulnerability of this system.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 8. Climate change adaptation strategies relative to vulnerability scores for Northwestern Great Plains Shrubland.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soils and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression. Restore natural disturbances provided by bison wallows or prairie dogs. Monitor for invasive plant expansion and effects of climate stress.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for shrub regeneration, and invasive plant expansion and effects of climate stress, and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
	forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: AOU 1983, Anderson 2001d, Anderson 2004a, Anderson 2004b, Arnold and Higgins 1986, Bailey et al. 1994, Barnett and Crawford 1994, Bent et al. 1968, Blankespoor 1980, Comer et al. 2003*, Crawford et al. 2004, Drut et al. 1994, Ersch 2009, Esser 1994a, Fryer 1997, Gregg and Crawford 2009, Gucker 2006g, Kahl et al. 1985, LANDFIRE 2007a, Shafer et al. 2014, Shiflet 1994, Smith 1963, Vickery 1996, Wiens 1969

M052. Great Plains Sand Grassland & Shrubland

CES303.670 Western Great Plains Sand Prairie

Figure 9. Photo of Western Great Plains Sand Prairie. Photo credit: Ben Christen, used under Creative Commons license CC BY 2.0.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: Sand prairies are often considered part of the tallgrass or mixedgrass regions in the western Great Plains but can contain elements from Western Great Plains Shortgrass Prairie (CES303.672), Central Mixedgrass Prairie (CES303.659), and Northwestern Great Plains Mixedgrass Prairie (CES303.674). The largest expanse of sand prairies (approximately 5 million ha) can be found in the Sandhills of north-central Nebraska and southwestern South Dakota. These areas are relatively intact. The primary use of this system has been grazing (not cultivation), and areas such as the Nebraska Sandhills can experience less degeneration than other prairie systems. Although greater than 90% of the Sandhills region is privately owned, the known fragility of the soils and the cautions used by ranchers to avoid poor grazing practices have allowed for fewer significant changes in the vegetation of the Sandhills compared to other grassland systems. Nonetheless, the sustained annual grazing within pastures by cattle has altered the mix of vegetation. The unifying and controlling features for this system is coarse-textured soils and the dominant grasses are well-adapted to this condition. Soils in the sand prairies can be relatively undeveloped and are highly permeable. Soil texture and drainage along with a species' rooting morphology, photosynthetic physiology, and mechanisms to avoid transpiration loss are highly important in determining the composition of the sand prairies. In the northwestern portion of its range, stand size corresponds to the area of exposed caprock sandstone, and small patches predominate, but large patches are also found embedded in the encompassing Northwestern Great Plains Mixedgrass Prairie (CES303.674). Another important feature is their susceptibility to wind erosion. Blowouts and sand draws are some of the unique wind-driven disturbances in the sand prairies, particularly where there are fine sands, such as in the Nebraska Sandhills (where the rare *Penstemon haydenii* occurs). In most of eastern Montana, substrates supporting this system have weathered in place from sandstone caprock; thus the solum is relatively thin, and the wind-sculpted features present further east, particularly in Nebraska, do not develop. Graminoid species dominate the sand prairies, although relative dominance can change due to impacts of wind disturbance. *Andropogon hallii* and *Calamovilfa longifolia* are the most common species, but other grass and forb species such as *Hesperostipa comata, Schizachyrium scoparium, Carex inops ssp. heliophila*, and *Panicum virgatum* are often present. Apparently only *Calamovilfa longifolia* functions as a dominant throughout the range of the system. In the western extent, *Hesperostipa comata* becomes more dominant, and *Andropogon hallii* is less abundant but still present. Communities of *Artemisia cana ssp. cana* are included here in central and eastern Montana. Patches of *Quercus havardii* can also occur within this system in the southern Great Plains. Fire and grazing constitute the other major dynamic processes that can influence this system. In the Western Great Plains in Texas, prairies on deep sands and sandhills which currently represent far southern outliers of this system, are dominated by species such as *Andropogon gerardii, Andropogon hallii, Calamovilfa gigantea, Cenchrus spinifex, Hesperostipa comata, Paspalum setaceum, Schizachyrium scoparium, Sporobolus cryptandrus*, and *Sporobolus giganteus*. Some woody species may be present, including *Artemisia filifolia* and *Quercus havardii*. Shrub species such as *Artemisia filifolia, Prunus angustifolia, Rhus trilobata*, and *Quercus havardii* may be present but constitute relatively little cover.

Distribution: This system is found throughout the Western Great Plains Division. The largest and most intact example of this system is found within the Sandhills region of Nebraska and South Dakota. However, it is also common (though occurring in predominantly small patches) farther west into central and eastern Montana. Its western extent in Wyoming is still to be determined, but it does occur in mapzone 29 on weathered-in-place sandy soils, where *Calamovilfa longifolia* is found, along with *Artemisia cana*. In addition, outliers have been described from the Western Great Plains in Texas (Monahans Sandhills State Park).

Nations: US

States/Provinces: KS, MT, ND, NE, NM, OK, SD, TX, WY

CEC Ecoregions: Middle Rockies, Western Corn Belt Plains, Northwestern Glaciated Plains, Northwestern Great Plains, Nebraska Sand Hills, High Plains, Central Great Plains, Southwestern Tablelands, Flint Hills, Cross Timbers, Edwards Plateau

Primary Concept Source: S. Menard and K. Kindscher

Description Author: S. Menard, K. Kindscher, M.S. Reid, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is distinguished by the dominance of graminoids such as *Andropogon hallii* and *Calamovilfa longifolia*. Other graminoids such as *Hesperostipa comata, Carex inops ssp. heliophila*, and *Panicum virgatum* may be present. Characteristic forbs differ by region, but species of *Psoralidium, Pediomelum*, and *Eriogonum* are a common feature, along with sand-loving annuals such as *Helianthus petiolaris* and *Oenothera rhombipetala*. *Penstemon haydenii* is endemic to the sand prairie system and of special conservation concern because of its probable decline due to grazing and fire suppression. Very diffuse patches of *Rhus trilobata* are found on shallow sandy soils, often associated with breaklands; other shrubs occasionally occurring include *Artemisia cana ssp. cana, Betula occidentalis, Juniperus horizontalis, Prunus pumila var. besseyi (= Prunus besseyi), Prunus angustifolia*, and *Yucca glauca*. Many of the warm-season graminoids extend at least to the Rocky Mountain Front as dominant components on appropriate sites or as a response to disturbance. All the characteristic species mentioned for Nebraska and South Dakota are also found in Montana stands (and possibly Wyoming and perhaps the rest of the states cited). Some of the communities cited as part of the concept in Nebraska and South Dakota are only marginally present in Montana, but others are found throughout Montana's Great Plains region. In the southern range of this system, patches of *Quercus havardii* can also occur.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system are wind-pollinated, most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators. Insects: Bees (Apoidea), wasps and ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera) and beetles (Coleoptera).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
Diversity: medium = 11-20 spp. This grassland system is adapted to a bimodal precipitation pattern with both warm-season summer and cool-season winter precipitation. Although this system has high graminoid diversity rangewide, locally stands have a moderately diverse mixture of warm- and cool-season graminoids such as:

Cool-season graminoids: *Achnatherum hymenoides, Carex filifolia, Carex inops ssp. heliophila, Hesperostipa comata, Piptatheropsis micrantha, Poa fendleriana*, and *Pseudoroegneria spicata*.

Warm-season graminoids: *Andropogon hallii, Aristida basiramea, Bouteloua gracilis, Calamovilfa gigantea, Calamovilfa longifolia, Eragrostis trichodes, Panicum virgatum, Sporobolus cryptandrus, Sporobolus giganteus*, and *Schizachyrium scoparium*.

Keystone Species: Keystone species provide an important vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this grassland type.

Environment: The distribution, species richness and productivity of plant species within the sand prairie ecological system are controlled primarily by environmental conditions, in particular, the temporal and spatial distribution of soil moisture and topography. Soils in the sand prairies can be relatively undeveloped and are highly permeable. Soil texture and drainage along with a species' rooting morphology, photosynthetic physiology, and mechanisms to avoid transpiration loss are highly important in determining the composition and distribution of communities/associations within the sand prairies. Another important aspect of soils in the sand prairies is their susceptibility to wind erosion. Blowouts and sand draws are some of the unique wind-driven disturbances in the sand prairies, particularly the Nebraska Sandhills, which can profoundly impact vegetation composition and succession within this system. This tallgrass prairie is found primarily on sandy and sandy loam soils that can be relatively undeveloped and highly permeable as compared to Western Great Plains Tallgrass Prairie (CES303.673), which occurs on deeper loams. This system is usually found in areas with a rolling topography and can occur on ridges, midslopes and/or lowland areas within a region. It often occurs on moving sand dunes, especially within the Sandhills region of Nebraska and South Dakota. In Montana, occurrences are intimately associated with Northwestern Great Plains Mixedgrass Prairie (CES303.674), usually occupying higher positions in local landscapes where sandy members of some geologic formations (that are predominantly marine shales) constitute the highest (and most weathering-resistant) points in the landscape. In Texas, this system occurs on rolling to level, eolian or alluvial, deep sand deposits classed as Deep Sand or Sandhill Ecological Sites.

Key Processes and Interactions: The distribution, species richness and productivity of plant species within the sand prairie ecological system are controlled primarily by environmental conditions, and in particular, the temporal and spatial distribution of soil moisture and topography. Another important aspect of this system is its susceptibility to wind erosion. Blowouts and sand draws are some of the unique wind-driven disturbances in the sand prairies, particularly the Nebraska Sandhills, which can profoundly impact vegetation composition and succession within this system.

Fire and grazing constitute the other major disturbances that can influence this system. The most extensive fires are likely to have occurred in years with wet springs followed by hot, dry summers when grazing pressure was low. Wet springs would have resulted in more productive and more continuous plant cover (i.e., fuel) that would have supported and expanded fires ignited under dry conditions occurring later in the season. In addition, litter accumulation over several fire-free years would also have supported widespread fire, in any conditions. The litter component, a determining factor in fire size and frequency, is correlated with seral stage. Several fire-free years produce enough litter to carry another fire (LANDFIRE 2007a).

Drought has additional impact in these very sandy soils and the high water table of the sandhills also affects the vegetation and encourages invasive trees (K. Kindscher pers. comm.). Extended periods of severe drought are likely to have affected both species composition and the stability of the sandhill soil, particularly when compounded by temperature, wind and heavy grazing. These conditions may have led to the development of blowouts making it difficult for vegetation to re-establish quickly. The occurrence of blowout penstemon (*Penstemon haydenii*) suggests long periods when blowouts were common across the landscape although causes resulting in this feature have not been determined (LANDFIRE 2007a).

Overgrazing, fire and trampling that leads to the removal of vegetation within those areas susceptible to blowouts can either trigger a blowout or perpetuate one already occurring. Overgrazing can also lead to significant erosion. The major large grazer, bison (*Bos bison*), occurring in large numbers in this system has largely been replaced by cattle. Both species impact the range by grazing and trampling; however, bison also significantly impacted local areas by wallowing. Unlike elsewhere in the Great Plains mixed and shortgrass prairie dog towns were a minor component of the Sandhills landscape and limited to where soils were finer-textured and in flat uplands and in valleys and the eastern Sandhills where the water table was not high (LANDFIRE 2007a).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has two classes in total (LANDFIRE 2007a, BpS 3111480). These are summarized as:

A) Early Development 1 Open (25% of type in this stage): Herbaceous cover is 0-20%. Class A represents immediate to three-year post-disturbance conditions. Vegetation consists of resprouting and seedling grasses and forbs. Total bare soil is greater than before the disturbance particularly on less productive sites. The vigor of new growth and the specific species effected depend on the season of the disturbance and on pre- and post-disturbance environmental conditions (e.g., available soil moisture). Litter is low initially but increases until, by year three, there is enough to support fire under average burning conditions. Fire was therefore modeled as occurring somewhat less frequently than in class B. In uplands, where soil type is dominated by coarse-grained sands with low water-holding capacity, post-disturbance primary production initially decreases, thus fire may only carry under ideal conditions. Under these conditions, grazing is likely to be light. In lowlands, with finer-textured soils, primary production is determined largely by moisture availability. *Artemisia cana* can resprout immediately after fire, so it could be present in this stage as well. It could, however, be killed following intensive fires. But since there is not much litter in these sites, possibility of intense fire is reduced. Repeated grazing of these areas will prevent succession to class B. Grazing occurs with a probability of 0.05. Prairie dog grazing was modeled as optional 1, with a very unlikely probability of 0.0007. Both will set succession back to the beginning.

B) Mid Development 1 Closed (80% of type in this stage): Herbaceous cover is 21-80%. Class B is sandhill grassland, the dominant historical condition. This class has a moderately dense herbaceous layer (20-80% cover) up to 1 m tall. Fire (every 10 years) would return this class to A, while lack of fire (after 40 years) would move it toward class C. Shrubs may make up to 25% of the cover but is more commonly 0-10%. Native grazing maintains this class. Severe, multiple-year drought (every 100 years) moves this to class C by reducing grass cover and fuel loads and giving a competitive advantage to the usually spare shrub cover.

C) Late Development 1 All Structures (shrub-dominated - 10% of type in this stage): Shrub cover is 21-100%. Class C is the shrub-dominated sandhill grassland and differs from the sandhill shrubland (BpS 1094) which is modeled separately based on edaphic differences. Fire returns this to class A (MFRI = 0.10). Dominate shrubs include sand sagebrush, shinnery oak and sand cherry.

ECOLOGICAL INTEGRITY

Change Agents: Conversion to agriculture can impact this system, and its range has decreased from human activities. Impacts from energy extraction in oil and gas fields in have recently fragmented larges areas with road networks to well pads and pipelines. Overgrazing by livestock grazing and fires can remove vegetation cover and promote blowouts.

The dominant species are adapted to frequent fires, sprouting from rhizomes post-fire. Fire suppression and moderate grazing have caused unevenness in structure and favored invasion of introduced grasses *Poa pratensis* and *Bromus inermis* across the sandhills (Sims 1988, Hauser 2005). A variety of seral stages are desirable to provide habitat for all phases of the lesser or greater prairie-chicken life cycle. The vegetation ideally exhibits a diversity of native short to tall grasses and native forbs interspersed with sparse to somewhat dense low-growing shrubby cover which includes sufficient cover for nesting and brood-rearing, as well as open areas suitable for leks.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 9** for this ecological system. The numeric scores can range from 0.01 to

1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 10, left**) and sensitivity (**Figure 10, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

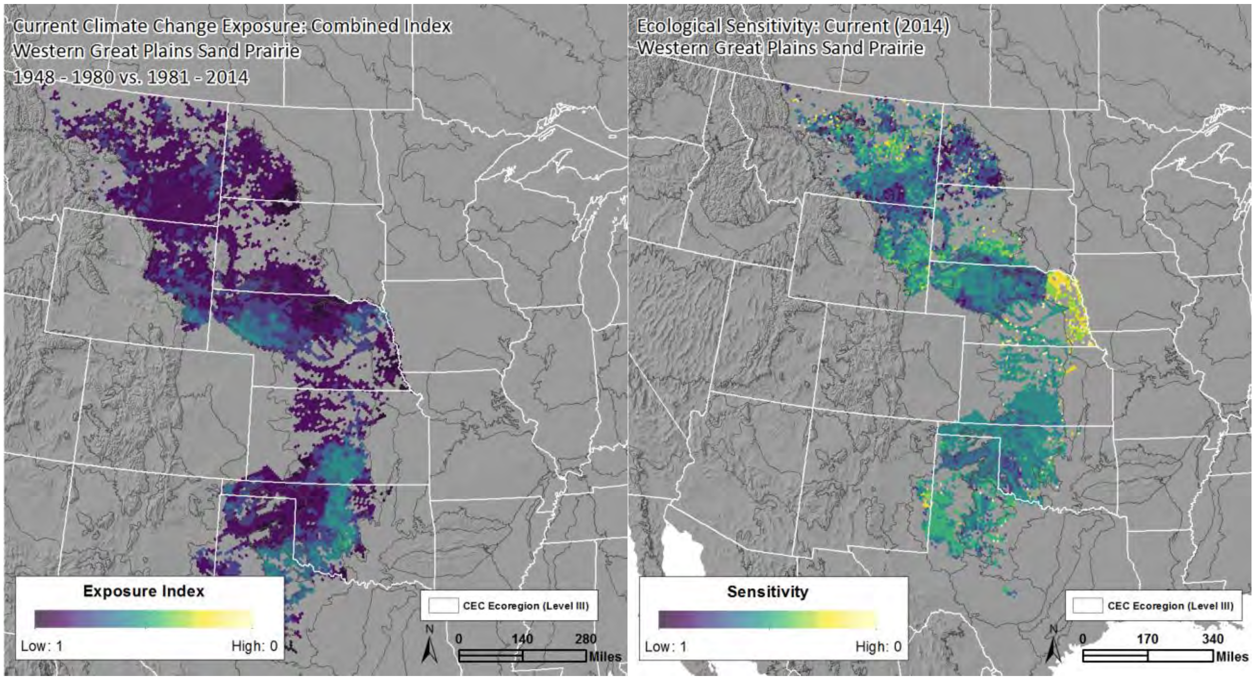

Figure 10. Climate exposure as of 2014 (left) and overall sensitivity (right) for Western Great Plains Sand Prairie. The results have been summarized and are displayed in 100km2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 9. Resilience, exposure and vulnerability scores for Western Great Plains Sand Prairie by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Nebraska Sand Hills	Central Great Plains	High Plains	Southwestern Tablelands	Northwestern Great Plains	Western Corn Belt Plains	Northwestern Glaciated Plains	Cross Timbers
	Potential square miles within ecoregion	15,916	10,005	5,974	4,399	3,336	917	809	53
Contributions to Relative Vulnerability by Factor									
Vulnerability from **Exposure (2014)**		**Low** 0.76	**Mod** 0.71	**Mod** 0.72	**Low** 0.77	**Low** 0.84	**Mod** 0.72	**Low** 0.83	**Mod** 0.60
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.80	0.18	0.23	0.37	0.49	0.14	0.27	0.16
	Fire Regime Departure	0.54	0.51	0.45	0.44	0.75	0.49	0.74	0.33
	Invasive Annual Grasses	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.78**	**0.56**	**0.56**	**0.60**	**0.74**	**0.54**	**0.67**	**0.49**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.14	0.06	0.09	0.11	0.12	0.07	0.08	0.09
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.32**	**0.28**	**0.30**	**0.30**	**0.31**	**0.28**	**0.29**	**0.29**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.55	**High** 0.42	**High** 0.43	**High** 0.45	**Mod** 0.53	**High** 0.41	**High** 0.48	**High** 0.39
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**High**

Exposure Summary for 1981-2014 Timeframe: The exposure as of 2014 for this grassland system is moderate to low across its range. Exposure tended to be in the low range within the northern portion of the distribution (Nebraska Sandhills, Northwestern Great Plains, Glaciated Plains) and moderate in more southern and eastern areas (Central Great Plains, High Plains, Western Corn Belt). Annual mean temperature has increased between 0.8° and 1.0°C across 17-26% of the Northwestern Great Plains and Glaciated Plains ecoregions. Summer temperature increases of 2.5° to 3.0°C characterize 21% of the Southwestern Tablelands and 10% of the Central Great Plains ecoregions. Increased summer temperatures have the potential to exacerbate drought effects, which can lead to degraded conditions through declines in vegetative cover and increases in sand blowouts within this system.

Climate Change Effects: The Great Plains region experiences multiple severe weather hazards, including floods, droughts, severe thunderstorms, tornadoes, and winter storms. There is concern that the frequency and severity of these events may be altered by climate change, especially increased drought in the southern Great Plains (Shafer et al. 2014). Average annual temperature is projected to continue to increase in the Great Plains region with number of hot days per year increasing by one to two dozen annually in the western portions of the region. Winter and spring precipitation is also projected to increase in the northern states (Shafer et al. 2014). Potential climate change effects on this ecosystem may include a shift to plant species more common on hotter, drier sites such with increased to warm-season (C4) grasses such as *Bouteloua curtipendula, Bouteloua gracilis*, or *Schizachyrium scoparium* (Shafer et al. 2014).

Potential climate change effects on this ecosystem would likely include a shift to plant species more common on drier sites. The dominant grasses can withstand long periods of drought and respond quickly to moisture (Tolstead 1942, Weaver 1958b, Hauser 2005). However, extended (multi-year) drought can damage and kill even the most drought-tolerant species such as *Bouteloua gracilis* (Rondeau et al. 2017).

Ecological consequences from changes in temperature and precipitation will affect the composition and diversity of native animals and plants through altering their breeding patterns, water and food supply, and habitat availability. Populations of some pests better adapted to a warmer climate are projected to increase. Shrubland and plains bird populations currently damaged by habitat loss, fragmentation and degradation could experience significant shifts and reductions in their range through reduced nest success and effects of greater fire frequency.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was moderate across most of the range of the system, with six ecoregions scoring moderate and one scoring at the moderate end of high sensitivity. However, the largest ecoregion, the Nebraska Sandhills, scored low for sensitivity. This variation in sensitivity largely reflects differences in landscape condition.

Contributions to sensitivity from landscape condition were low in the Nebraska Sand Hills region which includes areas of protected lands and areas less suited for conversion to row crops. However, landscape condition contributions to sensitivity were high or very high in the remaining ecoregions. Landscape condition largely reflects fragmentation from agricultural conversion, with additional contributions from overgrazing, suburban development, and from fragmentation associated with oil and gas development in the Great Plains.

Fire regime departure was moderate to high across the ecoregions. This reflects fire suppression practices across much of the region, which likely lead to stand conditions having high relative cover of shrubs to grasses. Risk from invasive annual grasses was low across the range of the system, although available data are limited for this indicator.

Overall, landscape fragmentation has resulted in changes to the structure of these grasslands, leading to an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Contribution from adaptive capacity to vulnerability is high across all ecoregions of this grassland system. This limited adaptive capacity is related to very low scores for topoclimatic variability in all ecoregions in which the system occurs. These reflect a very low level of topographic diversity associated with the flat to rolling plains and hills characteristic of where this system occurs. In terms of vulnerability related to functional groups, the system scores as moderate in terms of both pollinator and warm- and cool-season graminoid diversity. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this grassland system scores in the moderate range of overall climate change vulnerability. This is primarily due to high contributions to sensitivity from landscape condition associated with conversion to agriculture, grazing, and oil and gas development outside of the Nebraska Sandhills ecoregion. Low adaptive capacity associated with very low topoclimatic diversity also contributes to the vulnerability of this system.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 10. Climate change adaptation strategies relative to vulnerability scores for Western Great Plains Sand Prairie.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soils and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native grass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (bison wallows, small prairie dog colonies, cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub invasion.
High	**Revisit prior desired condition statements.** Consolidate fragmented areas with anticipation of enlarging drought-induced blowouts over time. Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Very High	**Plan for transformation to novel conditions.** Consolidate fragmented areas with anticipation of enlarging drought-induced blowouts over time. Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barbour and Billings 1988, Bell 2005, Comer et al. 2003*, Elliott 2012, Eyre 1980, Hauser 2005, LANDFIRE 2007a, Maser et al. 1984, Rolfsmeier and Steinauer 2010, Rondeau et al. 2016, Rondeau et al. 2018, Shafer et al. 2014, Shiflet 1994, Sims 1988, Tolstead 1942, Weaver 1958b

M053. Western Great Plains Shortgrass Prairie
CES303.672 Western Great Plains Shortgrass Prairie

Figure 11. Photo of Western Great Plains Shortgrass Prairie. Photo credit: Patrick Comer

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is found primarily in the western half of the Western Great Plains Division in the rainshadow of the Rocky Mountains and ranges from the Nebraska Panhandle south into Texas and New Mexico, although grazing-impacted areas appearing as this type may reach as far north as southern Canada where it is a component of Northwestern Great Plains Mixedgrass Prairie (CES303.674). This system occurs primarily on flat to rolling uplands with loamy, ustic soils ranging from sandy to clayey. In much of its range, this system forms the matrix system with *Bouteloua gracilis* dominating. Associated graminoids may include *Aristida purpurea, Bouteloua curtipendula, Bouteloua hirsuta, Bouteloua dactyloides, Carex filifolia, Carex inops ssp. heliophila, Hesperostipa comata, Hesperostipa neomexicana, Koeleria macrantha, Pascopyrum smithii, Pleuraphis jamesii, Sporobolus airoides*, and *Sporobolus cryptandrus*. Although mid-height grass species may be present, especially on more mesic land positions and soils, they are secondary in importance to the sod-forming short grasses. Sandy soils have higher cover of *Hesperostipa comata*, and *Sporobolus cryptandrus*. Scattered shrub and dwarf-shrub species such as *Artemisia filifolia, Artemisia frigida, Artemisia tridentata, Atriplex canescens, Eriogonum effusum, Gutierrezia sarothrae, Lycium pallidum*, and *Yucca glauca* may also be present. Also, because this system spans a wide range, there can be some differences in the relative dominance of some species from north to south and from east to west. Large-scale processes such as climate, fire and grazing influence this system. High variation in the amount and timing of annual precipitation impacts the relative cover of cool- and warm-season herbaceous species.

In contrast to other prairie systems, fire is less important, especially in the western range of this system, because the often dry and xeric climate conditions can decrease the fuel load and thus the relative fire frequency within the system. However, historically, fires that did occur were often very extensive. Currently, fire suppression and more extensive livestock grazing in the region have likely decreased the fire frequency even more, and it is unlikely that these processes could occur at a natural scale. A large part of the range for this system (especially in the east and near rivers) has been converted to agriculture. Areas of the central and western range have been impacted by the unsuccessful attempts to develop dryland cultivation during the Dust Bowl of the 1930s. The short grasses that dominate this system are extremely drought- and grazing-tolerant. These species evolved with drought and large herbivores and, because of their stature, are relatively resistant to overgrazing. This system in combination with the associated wetland systems represents one of the richest areas for mammals and birds. The endemic bird species of the shortgrass system may constitute one of the fastest declining bird populations in North America.

Distribution: This system is found primarily in the western half of the Western Great Plains Division east of the Rocky Mountains and ranges from the Nebraska Panhandle south into the panhandles of Oklahoma and Texas and New Mexico, although some examples may reach as far north as southern Canada where it grades into Northwestern Great Plains Mixedgrass Prairie (CES303.674).

Nations: US

States/Provinces: CO, KS, NE, NM, OK, TX, WY

CEC Ecoregions: Middle Rockies, Southern Rockies, Northwestern Great Plains, Nebraska Sand Hills, High Plains, Central Great Plains, Southwestern Tablelands, Edwards Plateau, Arizona/New Mexico Plateau, Chihuahuan Desert, Arizona/New Mexico Mountains

Primary Concept Source: S. Menard and K. Kindscher

Description Author: S. Menard, K. Kindscher, M. Pyne, L. Elliott and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system spans a wide range and thus there can be some differences in the relative dominance of some species from north to south and from east to west. This system is primarily dominated by *Bouteloua gracilis* and *Bouteloua dactyloides (= Buchloe dactyloides)* throughout its range with various associated graminoid species depending on precipitation, soils and management. Associated graminoids may include *Achnatherum hymenoides, Aristida purpurea, Bouteloua curtipendula, Bouteloua hirsuta, Bouteloua dactyloides, Carex filifolia, Hesperostipa comata, Koeleria macrantha (= Koeleria cristata), Muhlenbergia torreyana, Pascopyrum smithii (= Agropyron smithii), Pleuraphis jamesii, Sporobolus airoides*, and *Sporobolus cryptandrus*. In southern examples of this system (Texas), *Bouteloua dactyloides* and *Bouteloua hirsuta* may dominate (especially where soils are rocky) in addition to *Bouteloua gracilis*. In addition, *Bothriochloa laguroides ssp. Torreyana, Bouteloua rigidiseta, Erioneuron pilosum, Hilaria belangeri, Hordeum pusillum, Pleuraphis mutica*, and *Scleropogon brevifolius* may occur in Texas examples (Elliott 2011). Although mid-height grass species may be present especially on more mesic land positions and soils, they are secondary in importance to the sod-forming short grasses. Sandy soils have higher cover of *Hesperostipa comata, Sporobolus cryptandrus*, and *Yucca elata*. Scattered shrub and dwarf-shrub species such as *Artemisia filifolia, Artemisia frigida, Artemisia tridentata, Atriplex canescens, Eriogonum effusum, Gutierrezia sarothrae*, and *Lycium pallidum* may also be present. In Texas examples, shrub cover is generally low but may include species such as *Acacia greggii, Rhus microphylla, Rhus trilobata, Dalea formosa, Mahonia trifoliolata, Juniperus* sp., and *Prosopis glandulosa*. Forbs such as *Calylophus* sp., *Melampodium leucanthum, Krameria lanceolata, Ratibida columnifera, Psoralidium tenuiflorum*, and others are often present. *Gutierrezia sarothrae* may be present with significant cover, especially on sites with intense and continuous grazing (Elliott 2011). High annual variation in amount and timing of precipitation impacts relative cover of herbaceous species. Cover of cool-season grasses is dependent on winter and early spring precipitation. The vegetation description is based on several other references, including Shaw et al. (1989), Hazlett (1998), and Schiebout et al. (2008).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological crust diversity is based on Rosentreter and Belnap (2003) descriptions for the Great Plains. Cyanobacteria (1+) (*Nostoc commune* is common with species of *Chlorococcum, Microcoleus, Oscillatoria, Phormidium, Scytonema*, and *Ulothrix*). Vagrant lichens (3) are dominant, especially *Xanthoparmelia chlorochroa, Xanthoparmelia camtschadalis*, and *Xanthoparmelia vagans*. Lichens (6) on stands with more exposed soil may have *Aspicilia hispida, Cladonia cariosa, Collema tenax, Diploschistes scruposus, Endocarpon pusillum*, or *Physconia muscigena* present. Calcareous soils are common on many sites and may include additional lichens (5) such as *Fulgensia bracteata, Heppia lutosa, Psora decipiens, Caloplaca tominii*, and *Squamarina lentigera*. Mosses are common (10) and may include *Astomum muehlenbergianum, Bracythecium albicans, Bryum argenteum, Ceratodon purpureus, Ephemerum spinulosum, Funaria hygrometrica, Homalothecium nevadense, Phascum cuspidatum, Syntrichia ruralis*, and *Weissia controversa*.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system are wind-pollinated, most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators with birds important for other species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially red tubular flowers).

Nitrogen Fixation; Species Diversity: Medium
Western Great Plains shortgrass prairie occurs in semi-arid climate often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. The semi-arid portions of this system typically have low to moderate herbaceous cover and low diversity of N-fixing species. Relatively mesic stands have higher cover and diversity of vascular plants, but lower cover and diversity of nonvascular N-fixing species. Most species of Fabaceae (including species of *Astragalus, Dalea, Lupinus, Psoralidium*, and *Sophora*) and many Poaceae (*Bouteloua gracilis, Bouteloua dactyloides, Hesperostipa comata, Pascopyrum smithii*, and *Sporobolus cryptandrus*), and some Brassicaceae fix nitrogen. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap 2001, Belnap et al. 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Nostoc* and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: High
Cool-season graminoids (8): *Achnatherum hymenoides, Carex inops ssp. heliophila, Elymus elymoides, Hesperostipa comata, Hesperostipa neomexicana, Koeleria macrantha, Lycurus phleoides*, and *Pascopyrum smithii*. Warm-season graminoids (15): *Aristida purpurea, Bothriochloa laguroides, Bouteloua curtipendula, Bouteloua hirsuta, Bouteloua dactyloides, Distichlis spicata, Erioneuron pilosum, Muhlenbergia arenacea, Muhlenbergia torreyi, Pleuraphis jamesii, Schedonnardus paniculatus, Schizachyrium scoparium, Scleropogon brevifolius, Sporobolus airoides*, and *Sporobolus cryptandrus*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. Black-tailed prairie dog (*Cynomys ludovicianus*) is considered a keystone species of Western Great Plains Shortgrass Prairie

(CES303.672) (Kotliar et al. 2006). Prairie dog colonies create habitat that benefit numerous other species with their burrowing and foraging activities which influence environmental heterogeneity, hydrology, nutrient cycling, biodiversity, landscape architecture, and plant succession in grassland habitats (Kotliar et al. 2006). They are also an important food source for many animals, including badgers, coyotes, eagles, hawks, and the critically endangered black-footed ferret (*Mustela nigripes*) (Hoagland 2006). The U.S. Fish and Wildlife Service estimated that about 160 million hectares (395 million acres) of potential prairie dog habitat historically existed in the U.S., and about 20% was occupied at any one time (Gober 2000). Black-tailed prairie dog overlaps in distribution with all the range of this ecological system.

Environment: This system forms the matrix grassland in the southwest of the Great Plains and largely occurs in the rainshadow of the Rocky Mountains. This system occurs on various geologic formations, primarily on flat to rolling uplands. Soils typically are loamy and ustic (bordering on aridic) but can range from sandy to clayey (Scifres 1980, Shiflet 1994).

Climate: Climate is temperate, semi-arid, and continental with mean annual precipitation generally about 300 mm ranging to 500 mm to the east. Annual precipitation has a bimodal distribution occurring mostly before the growing season in winter and early spring and then during summer as monsoon thunderstorms (Sims et al. 1978). In most years, rates of evaporation are greater than precipitation for this system. Most of the annual precipitation occurs during the growing season as thunderstorms. Precipitation events are mostly <10 cm with occasional larger events (Sala and Lauenroth 1982). High variation in amount and timing of annual precipitation impacts the relative cover of cool- and warm-season herbaceous species. This is the driest of the Great Plains grasslands ecosystems. Average daily temperature in July varies from 27°C in the southeast to 21°C in the northwest and along the foothills of the Rocky Mountains. Average daily temperature in January varies from 3°C in the south to -6°C in the northwest.

Physiography/landform: Stands occur on primarily flat to rolling uplands and to a lesser extent mesatops and plateaus.

Soil/substrate/hydrology: Soils are typically well-drained, shallow to moderately deep, loamy and ustic and range from sandy to clayey (Scifres 1980, Shiflet 1994). In the southeasternmost expression of the system in Texas, it occurs on sites with soils providing relatively dry conditions such as Rough Breaks, Shallow Clay, Very Shallow, Very Shallow Clay, Moderately Alkaline Deep Hardland, and Hardland Ecological Sites (Elliott 2013).

Key Processes and Interactions: Large-scale processes such as climate, fire and grazing constitute the primary processes impacting this system. The short grasses that dominate this system are extremely drought- and grazing-tolerant (Lauenroth and Milchunas 1992, Lauenroth et al. 1994a). These species evolved with large herbivores and drought (Milchunas and Lauenroth 2008) and adapted to historical heavy grazing with their low stature making them relatively resistant to overgrazing (Lauenroth et al. 1994a). The return intervals for grazing varied with areas distant from water sources likely grazed less heavily as those near water. However, the shortgrass prairie is probably the system with the highest intensity of grazing than other systems historically (Lauenroth et al. 1994a, Milchunas 2006). This is a drought-tolerant system. Many shortgrass species are drought-tolerant and have root systems that extend up near the soil surface where they can utilize low precipitation events (Salas and Lauenroth 1982). If blue grama is eliminated from an area by extended drought (3-4 years) or disturbance such as plowing, regeneration is slow because of very slow tillering rates (Samuel 1985), low and variable seed production (Coffin and Lauenroth 1992), minimal seed storage in soil (Coffin and Lauenroth 1989) and limited seedling germination and establishment due to particular temperature and extended soil moisture requirements for successful seedling establishment (Hyder et al. 1971, Briske and Wilson 1978, 1980).

In contrast to other prairie systems, fire is less frequent, especially in the western range of this system, because the often dry and xeric climate conditions can decrease the fuel load and reduce lightning events, and thus the relative fire frequency within the system. However, historically, fires that did occur were often very extensive. Wright and Bailey (1982c) suggest that in semiarid areas, big prairie fires usually occurred during drought years that followed one to three years of above average precipitation, because of the abundant and continuous fuel. Consequently, these wildfires could travel far when the winds and air temperatures were high and relative humidity was low. There is debate as to the mean fire-return interval (MFRI) for this shortgrass system. Because of the lack of long-lived trees, and trees that do exist are in relatively productive sites, there is absolutely no way to reconstruct a reliable historic fire-return interval. All estimates of historic fire-return intervals must be based on those for surrounding vegetation types that do have means for reconstruction, and then extrapolating based on differences in primary production and herbivore removal of fuel loads. Therefore, there is no means to directly obtain the estimate, and the range is varied. It depends on many factors: portions will be drier, and portions will vary in frequency over time and there will be decadal variation. Anderson (2003) reports a broad fire-return interval (FRI) of <35 years for shortgrass prairie. There is a wide variability of MFRI across this system, based on precipitation, fuel and ignition sources (LANDFIRE 2007a).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 2711490).

A) Mid Development 1 Open (20% of type in this stage): Instead of calling the classes early, mid and late, which do not actually apply in shortgrass prairie and the different stages that we are describing, we are calling all the stages "mid-development." The stages of the grassland are created and/or maintained by disturbances or lack thereof. Class A is the low biomass (0-1" based on the Robel pole density / visual obstruction method), heavy disturbance-dependent community. It combines 2 types of communities. One consists of the high cover blue grama-buffalo grass sod that looks like a golf course (high cover in patches). The other is the low cover bare soil, *Aristida*, and forb stage, which could have taller grasses than the sod, but they are spaced apart due to bare soil between. See biomass in Milchunas and Lauenroth (1989) and Milchunas et al. (1994) and basal cover for sod class by point frame in Milchunas et al. (1989). Please note that this system should be distinguished by on-the-ground biomass and not cover, since the cover in class A actually varies from a low, mosaic-bare-ground cover to a high sod-cover, which includes litter too. Due to mapping constraints, we are defining dropdown boxes on cover; however, this stage could go up to 70% cover, including litter, with very low biomass. Basal cover for high cover sod is approximately 45% or higher if including litter. Basal cover for low cover prairie dog areas is approximately 20-25% cover. On the ground, this class should be distinguished by biomass. There are relatively few cool-season grasses in this stage. There is always blue grama in this stage, as in the others. Cactus is present (and could even be a dominant in the class A sod depending on soil type). *Aristida* is present, which increases with prairie dog colonies. Annual grasses - sixweeks fescue, red three-awn, ragweed, annual forbs. [Currently, you would see non-native annuals in this class such as cheatgrass and kochia - only in the high biomass type. Annuals and exotics are actually less abundant in the sod type than any other class (Milchunas et al. 1989, Milchunas and Lauenroth 1989, Milchunas et al. 1988); the landscape might also have non-natives of bindweed on prairie dog towns today, but not historically.] On loamier or sandier sites, there is sand dropseed. For the southern, New Mexico version, other indicator species are lemonweed, showy goldeneye, and verbena.

B) Mid Development 2 Closed (60% of type in this stage): Instead of calling the classes early, mid and late, which do not actually apply in shortgrass prairie and the different stages that we are describing, we are calling all stages "mid-development." The stages of the grassland are created and/or maintained by disturbances or lack thereof. Class B is the mid biomass (2-4" based on the Robel pole density / visual obstruction method), mid cover stage. See biomass in Milchunas and Lauenroth (1989) and Milchunas et al. (1994). This stage again consists of blue grama. Cactus is often present and could even be the second dominant depending on soil type. There is less needle-and-thread and western wheatgrass than in class C. This also includes the "historic climax plant community" with blue grama, buffalograss, and western wheatgrass, galleta grass, green needle grass (not in New Mexico), fringed sage, and New Mexico feather grass in the south. Historically, there would have been more midgrasses (Harvey Sprock et al. pers.

comm.). In New Mexico, there would be scatterings of black grama, vine-mesquite on heavier soils. Fire does occur in this stage. If there is 1-2 years of no grazing or 4-10 years of no fire, then 4-10 years post-fire, this class would transition to the high biomass class C stage. This was modeled as "alternate succession" occurring as a probability of 0.05, for modeling purposes. Prairie dogs could occur in this stage. If they do, the long-term prairie dog grazing causes a transition to class A.

C) Mid Development 3 Closed (20% of type in this stage): Instead of calling the classes early, mid and late, which do not actually apply in shortgrass prairie and the different stages that we are describing, we are calling all of the stages "mid-development." The stages of the grassland are created and/or maintained by disturbances or lack thereof. Class C is the high biomass (4+" based on the Robel pole density / visual obstruction method), high cover stage. See biomass in Milchunas and Lauenroth (1989) and Milchunas et al. (1994) and basal cover in Milchunas et al. (1989). The same grasses are present as the previous. However, there are also more C3 perennial cool-season grasses. (However, some have questioned the increase in cool-season grasses with succession as being speculative. There are definite edaphic differences. Gravelly sites in New Mexico often support *Hesperostipa neomexicana* even under intense grazing regimes.) Blue grama is still present and dominant. Needle-and-thread, galleta grass and western wheatgrass are more prominent. Note also that more annuals and exotics occur in the ungrazed than in the heavily grazed sod class (Milchunas et al. 1989, Milchunas et al. 1992). This stage is arrived at through lack of fire and grazing, although while already in this stage, fire would be more likely to occur due to the increased biomass. Fire does occur in this stage. If there is fire and then grazing, this will over time transition to class B, and with long-term heavy grazing to class A. Fire alone may not cause a transition but can especially on coarser textured soils and also when fire occurs with heavy grazing. Regular grazing can just move the class to class B. Prairie dogs are unlikely to occur in this class, but when they do, they will occur as a patch within the matrix and will cause a transition.

During LANDFIRE modeling workshops, some experts suggest that the MFRI was historically approximately 25-35 years with small fires at times so fire-return interval at one spot was longer than expected, i.e., a fire can burn somewhere on the landscape often, but it may not necessarily return to the same spot for 25-50 years or more (LANDFIRE 2007a). However, other experts thought MFRI was shorter, between 5-20 years, dependent on the precipitation gradient east to west with shorter FRI (5 years) occurring in the more mesic eastern extent of the shortgrass prairie (LANDFIRE 2007a). A proposed precipitation gradient between drier versus wetter of approximately 350-375 mm annual precipitation to delineate a change in fuels and fire behavior across the west to east gradient in precipitation / above-ground primary productivity. The western portion would have a MFRI of 15-20 years and in the eastern portion, it would be shorter (5-10 years) (LANDFIRE 2007a). A MFRI of 5 years is similar to mixed and tallgrass prairies (Bragg and Hulbert 1976, Bragg 1986, Umbanhowar 1996, LANDFIRE 2007a).

Black-tailed prairie dogs are an ecologically important component of the grazing regime in shortgrass prairie and would have occurred extensively (Lauenroth and Milchunas 1992, Milchunas and Lauenroth 2008). There were some very large towns, but there were also areas without any towns. Quantitative historical estimates of black-tailed prairie dogs abundance are difficult to obtain, but the U.S. Fish and Wildlife Service estimated that about 160 million ha (395 million acres) of potential habitat historically existed in the U.S., and about 20% was occupied at any one time (Gober 2000). Shortgrass has most of the suitable soil types for prairie dogs; in general, they need loamy or clay soil. In historic times, there was frequent and broad-scale grazing by bison and pronghorn antelope. Through the growing season, bison might have been there for relatively short periods in some years and longer in other years. There were also resident herds of bison in areas of Colorado (LANDFIRE 2007a). Historically, such areas would also have been populated by bison in sufficient numbers to support populations of wolves. Bamforth (1987) suggested that bison herds under relatively undisturbed conditions (prior to 1846) most often ranged in size from several hundred to several thousand. Shaw and Lee (1997) reviewed diaries of European travels in the southern Great Plains from 1806 to 1857. Organized by historical period and biome type, the authors suggest populations of three major large herbivores (bison, elk and pronghorn) changed in the first half of the nineteenth century; bison were most numerous on the shortgrass prairie prior to 1821, pronghorn were most abundant on the shortgrass prairie between 1806 and 1820, again in the 1850s (LANDFIRE 2007a). The dry half of the Great Plains has high interannual rainfall variability, so historically, the population declined faster in dry years (LANDFIRE 2007a). This resulted in a time lag or temporal variability, in which density could be reduced greatly. Bison historically moved nomadically in response to vegetation changes associated with rainfall, fire and prairie dog colonies (LANDFIRE 2007a). The time lag for return movements provided deferment during the regrowth period, which according to both historic and archeological records, may have ranged from 1 to 8 years (Malainey and Sherriff 1996). If there was a series of droughts followed by a wetter year, there would have been little grazing pressure, which would then result in a higher severity or frequency of fire. Drought and grazing were probably most important disturbances historically and greatly influenced fire frequency and extent. Insects such as grasshoppers, range caterpillars, and Mormon crickets were also a natural disturbance agent on the landscape (LANDFIRE 2007a).

Biological soils crusts (BSC) are important for soil fertility, soil moisture, and soil stability in semi-arid ecosystems such as the drier portions of the shortgrass prairie (Belnap and Lange 2003). Cyanobacteria (especially *Nostoc*) fix large amounts of soil nitrogen and carbon (Evans and Belnap 1999, Belnap and Lange 2003). Generally, BSC are more important on sites with more exposed soil surface and less herbaceous and litter cover; however, cover varies locally with site characteristics, especially disturbance (Belnap et al. 2001, Belnap and Lange 2003).

ECOLOGICAL INTEGRITY

Change Agents: Historically, fires were often very expansive, especially after a series of years with above-average precipitation when litter/fine fuels built up. Currently, fire suppression, fragmentation of landscapes, and more extensive grazing in the region have likely decreased the fire frequency even more, and it is unlikely that these processes could occur at a natural scale. Heavy continuous livestock grazing, military training, invasive non-native species, altered fire regime (fire suppression), conversion to agriculture, fragmentation from roads and development such as exurban and urban development, and more recently gas and oil exploration and extraction stress the shortgrass prairie ecosystem. Of these, altered grazing and fire regimes stressors are prevalent throughout the range. Cultivation for row crop agriculture has been widespread and extensive in the higher precipitation parts of the range, where more conducive soil moisture conditions exist, or where irrigation is possible. Habitat fragmentation from roads is common throughout the range, probably less in the drier parts of the range where large ranches are more common, but none the less, still at levels limiting natural fire regimes through the range. Stressors related to urban and suburban development and military training affect a relatively small proportion of the range of this system, but where they occur, impacts are often severe.

Conversion to agriculture and pastureland with subsequent irrigation has degraded and extirpated this system in approximately 40% of its range (Samson and Knopf 1994). Conversion of this type has commonly come from dryland wheat cultivation in the less xeric portion in eastern Colorado and western Kansas and from all types of irrigated agriculture typically near rivers such as the Platte and Arkansas basins. Historically, areas of the central and western range have been impacted by the unsuccessful attempts to develop dryland cultivation during the Dust Bowl of the 1930s (CNHP 2010). Urban and exurban development along the Front Range and water developments/reservoirs are also significant. Locally, mechanical disturbance (roads, mechanized military training, ORVs, sacrifice areas surrounding livestock tanks, etc.) may eliminate cover of blue grama and other grasses that are slow to recover. Conversion to invasive non-native species is generally not a widespread or significant problem on dry upland sites. Invasion and conversion to woodlands by native trees *Juniperus* spp. and *Prosopis glandulosa* (in southern extent) is an issue where alteration of natural fire regime has permitted woodland expansion into former grasslands.

Common stressors and threats include fragmentation, altered fire regime, overgrazing by livestock, and invasive species (in the less xeric regions). Fire suppression and certain grazing patterns such as continuous heavy grazing in the region have likely decreased the fire frequency even more, and it is unlikely that these processes could occur at a natural scale. The short grasses that dominate this system are extremely drought- and grazing-tolerant although continuous heavy grazing and extended drought (3-4 years) will reduce cover of dominant species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 11** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 12, left**) and sensitivity (**Figure 12, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

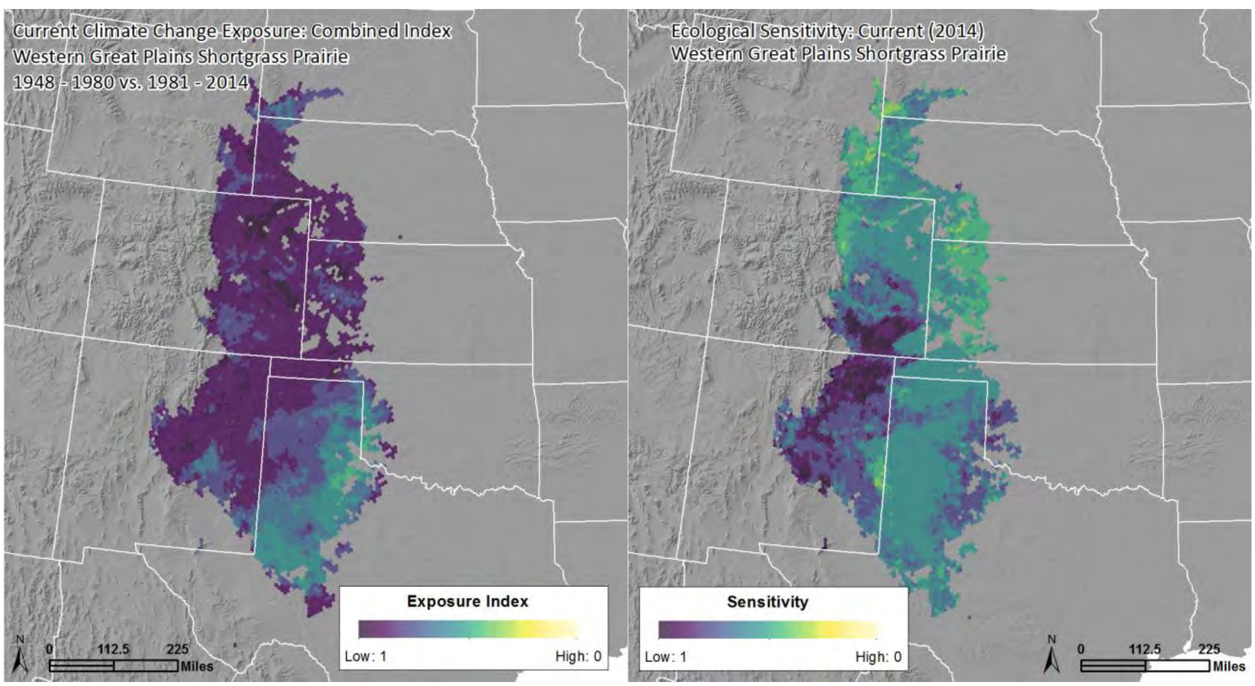

Figure 12. Climate exposure as of 2014 (left) and overall sensitivity (right) for Western Great Plains Shortgrass Prairie. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 11. Resilience, exposure and vulnerability scores for Western Great Plains Shortgrass Prairie by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	High Plains	Southwestern Tablelands	Edwards Plateau	Northwestern Great Plains	Central Great Plains	Southern Rockies	Arizona-New Mexico Mountains	Chihuahuan Desert	Nebraska Sand Hills	Arizona-New Mexico Plateau
	Sq miles within ecoregion	59,897	35,982	1,244	1,191	927	227	173	141	112	101
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Low** 0.79	**Low** 0.80	**Mod** 0.70	**Mod** 0.74	**Low** 0.77	**Low** 0.81	**Low** 0.84	**Low** 0.76	**Low** 0.84	**Low** 0.82
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.24	0.60	0.53	0.58	0.25	0.55	0.64	0.72	0.41	0.64
	Fire Regime Departure	0.51	0.64	0.19	0.75	0.49	0.56	0.84	0.37	0.63	0.45
	Invasive Annual Grasses	0.95	1.00	1.00	0.32	0.95	0.80	1.00	1.00	0.59	1.00
	Sensitivity Average	**0.57**	**0.75**	**0.57**	**0.55**	**0.56**	**0.64**	**0.83**	**0.70**	**0.54**	**0.70**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.08	0.14	0.08	0.14	0.14	0.24	0.22	0.11	0.12	0.20
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
	Adaptive Capacity Average	**0.49**	**0.51**	**0.49**	**0.51**	**0.51**	**0.54**	**0.53**	**0.50**	**0.50**	**0.53**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.53	**Mod** 0.63	**Mod** 0.53	**Mod** 0.53	**Mod** 0.54	**Mod** 0.59	**Mod** 0.68	**Mod** 0.60	**Mod** 0.52	**Mod** 0.61
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall for the distribution of this widespread grassland system, exposure as of 2014 ranges from moderately limited in the Edwards Plateau ecoregion to limited in the Arizona/New Mexico Mountains. In the Southwestern Tablelands, High Plains, Arizona/New Mexico Plateau, Arizona/New Mexico Mountains, and Southern Rockies ecoregions, an emerging pattern of changing climate appears as increases of 0.56°C for Annual Mean Temperature across 12% to 90% of its distribution in these five ecoregions. In three ecoregions (Southwestern Tablelands, High Plains, and Edwards Plateau) Mean Temperature of the Driest Quarter shows increases of 2.5°C for some 10% of the system's distribution in each ecoregion.

Climate Change Effects: Potential climate change effects could include a shift in overall extent. As the driest of Great Plains grasslands, this system is susceptible to climate change and increasing drought. During extended drought there is mortality of the dominant species, blue grama. If eliminated from an area by extended drought (3-4 years) or disturbance, regeneration by seed is slow because of low and variable seed production, minimal seed storage in soil, and limited seedling germination and establishment due to temperature and extended soil moisture requirements for successful seedling establishment. Polley et al. (2013) suggest anticipated warming and drying from climate change will to reduce soil water availability, net primary productivity, and other ecosystem processes in the southern Great Plains. These effects may alter plant community composition and species distributions including range contraction of key native species and expansion of invasive species. Recent trends and model projections indicate continued directional change and increasing variability in climate including extended drought. If climate change has the predicted effect of less effective moisture with increasing mean temperature, then this shortgrass prairie species may migrate east into areas currently supporting mixedgrass prairie (western Kansas).

Other potential climate change effects would likely include a shift to plant species more common on hotter sites in the southern extent, if climate change has the predicted effect of less available moisture with increasing mean temperature. Rondeau et al. (2018) documented a significant decline of *Bouteloua gracilis*, a dominant and important forage grass, during a time that included two severe drought years (2002, 2012). Ecological consequences from such a climate shift would be similar to extended drought and will affect the composition and diversity of native plants and animals through altering amount and timing of precipitation, animal breeding patterns, water and food supply, and habitat availability. Populations of some pests better adapted to a warmer climate are projected to increase. Grassland and plains bird populations currently damaged by habitat loss, fragmentation, and degradation could experience significant shifts and reductions in their range through reduced nest success.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be moderate; 4 ecoregions tend towards lower sensitivity (higher scores). However, 2 ecoregions with low sensitivity have scores of 0.70, suggesting limited sensitivity. This low to moderate sensitivity is a result of interactions between fire regime departure and landscape condition, with invasive grass risk being a factor in one ecoregion where data are available (the Northwestern Great Plains).

Landscape condition is moderate (less development) in general with poor condition (more development) in the High Plains and Central Great Plains ecoregions, which represent over 60% of the total extent of the system. In the Chihuahuan Desert ecoregion landscape condition is good (higher score, less fragmented). The poor-condition ecoregions reflect intensive agricultural activity combined with other infrastructure, such as mining or oil and gas operations, which can impact natural vegetation. In addition, large-scale wind power development, transportation corridors and power transmission lines continue to fragment vegetation and provide vectors for invasive species. Throughout its range, there are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive annual grasses is generally low (higher scores), but the Nebraska Sand Hills and Northwestern Great Plains ecoregions have moderate and high risk, respectively. Both ecoregions occur further north where the climate is cooler and wetter with a higher proportion of winter precipitation that favors cheatgrass. Fire regime departure is generally moderate, 7 of 10 ecoregions have moderate departure. The Northwestern Great Plains and Arizona-New Mexico Mountains have low departure and the Edwards Plateau has high departure. The moderate to high departure areas are likely a reflection of decreased fire frequency due to grazing by livestock, which removes the fine fuels that carry fire. In addition, fire suppression has allowed for increased invasions of cacti, dry shrubs and trees such as species of *Juniperus* and *Prosopis*. However, increases in invasive annual grasses in the Northwestern Great Plains ecoregion will likely increase fire frequency above the natural range of variability.

The interactions of the stressors of fragmentation by development, direct and indirect fire suppression, and some invasive annual grass invasion have resulted in changes to the composition and structure of these semi-arid grasslands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is moderate across the range of this widespread grassland system. Topoclimatic variability is very low everywhere, as these grasslands occur across some of the flattest landscapes of the western Great Plains, on flat to rolling uplands. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups is moderate range-wide. Of the four functional species groups identified, two are moderately diverse (biotic pollination and nitrogen-fixers) and are the more limiting for the system's capacity to adapt to changing climate conditions. Insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system. Nitrogen-fixers are more important in this system than in the Northwest Great Plains Mixedgrass Prairie due to a generally drier climate and differences in soils nutrients, such that nitrogen is a limiting factor.

The other two functional species groups appear to have high within group diversity (soil crust forming taxa and the mix of perennial cool-season/warm-season graminoids). Soil crusts seem to have high diversity and include many species of lichens. A mix of cool-season and warm-season graminoids is a characteristic of this system, and the high variation in the amount and timing of precipitation influences the relative abundance of cool- versus warm-season taxa. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. Warm-season graminoid species use the less common C4 photosynthesis pathway to fix carbon that functions best at higher temperatures; this is most efficient pathway under low CO_2 concentrations, high light intensity and higher temperatures and is well-adapted to relatively warm, dry climates where this system occurs.

Black-tailed prairie dog (*Cynomys ludovicianus*) was identified as playing a keystone role throughout this grassland ecological system. This species is wide-ranging, and due to its role as a keystone species, it's vulnerability to the recent change in climate was evaluated using the NatureServe Climate Change Vulnerability Index tool. It was found to be Less Vulnerable across the portion of its range that coincides with this system, suggesting it has been able to adapt to recent changes in climate conditions.

Vulnerability Summary for 1981-2014 Timeframe: This Great Plains grassland type scores in the moderate level of vulnerability throughout its range. This is primarily due to its low scores for exposure and moderate scores for adaptive capacity. Inherent vulnerabilities are high for these grasslands that naturally occupy extensive flat to rolling plains (low topoclimate variability). For a given increment of climate change, individual species would need to disperse longer distances per year as compared with those that occur in more rugged landscapes that naturally support higher microclimate diversity. Additionally, these grasslands have variable fire regime departure scores and landscape condition scores with lowest scores in intensive agricultural areas. Stands are susceptible to effects of extended drought, overgrazing, and long-term effects of fire regime alterations such as shrub and tree encroachment with fire suppression. Stands are more susceptible to invasive plants in the relatively mesic northerly extent.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 12. Climate change adaptation strategies relative to vulnerability scores for Western Great Plains Shortgrass Prairie

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (soil crusts, prairie dogs, bison wallows, cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from removal of herbivores, wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub invasion.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Anderson 2003a, Bamforth 1987, Barbour and Billings 1988, Bell 2005, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Bragg 1986, Bragg and Hulbert 1976, Briske and Wilson 1978, Briske and Wilson 1980, CNHP 2010, Coffin and Lauenroth 1989, Coffin and Lauenroth 1992, Comer et al. 2003*, Dick-Peddie 1993, Elliott 2011, Elliott 2013, Evans and Belnap 1999, Fuhlendorf et al. 2006, Gober 2000, Hazlett 1998, Hoagland 2006, Hyder et al. 1971, Kotliar et al. 2006, LANDFIRE 2007a, Lauenroth and Milchunas 1992, Lauenroth et al. 1994a, Malainey and Sherriff

1996, Milchunas 2006, Milchunas and Lauenroth 1989, Milchunas and Lauenroth 2008, Milchunas et al. 1988, Milchunas et al. 1989, Milchunas et al. 1992, Milchunas et al. 1994, Polley et al. 2013, Ricketts et al. 1999, Rolfsmeier and Steinauer 2010, Rondeau et al. 2018, Rondeau pers. comm., Rosentreter and Belnap 2003, Sala and Lauenroth 1982, Samson and Knopf 1994, Samuel 1985, Schiebout et al. 2008, Scifres 1980, Shaw and Lee 1997, Shaw et al. 1989, Shiflet 1994, Sims et al. 1978, Umbanowar 1996, Wright and Bailey 1982c

2.B.2.Nf. Western North American Grassland & Shrubland

M048. Central Rocky Mountain Montane-Foothill Grassland & Shrubland

CES306.040 Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland

Figure 13. Photo of Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland. Photo credit: Matt Lavin, , used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system of the northern Rocky Mountains is found at lower montane to foothill elevations in the mountains and large valleys of northeastern Wyoming and western Montana, west through Idaho into the Blue Mountains of Oregon, and north into the Okanagan and Fraser plateaus of British Columbia and the Canadian Rockies. They also occur to the east in the central Montana mountain "islands," foothills, as well as the Rocky Mountain Front and Big and Little Belt ranges. These grasslands are floristically similar to Inter-Mountain Basins Big Sagebrush Steppe (CES304.778), Columbia Basin Foothill and Canyon Dry Grassland (CES304.993), and Columbia Basin Palouse Prairie (CES304.792), but are defined by shorter summers, colder winters, and young soils derived from recent glacial and alluvial material. These grasslands reflect a shift in the precipitation regime from summer monsoons and cold snowy winters found in the southern Rockies to predominantly dry summers and winter precipitation. In the eastern portion of its range in Montana, winter precipitation is replaced by a spring peak in precipitation. They are found at elevations from 300 to 1650 m, ranging from small meadows to large open parks surrounded by conifers in the lower montane, to extensive foothill and valley grasslands below the lower treeline. In the southern extent, some of these valleys may have been primarily sage-steppe with patches of grassland in the past, but because of land-use history post-settlement (herbicide, grazing, fire, pasturing, etc.), they have been converted to grassland-dominated areas. Soils are relatively deep, fine-textured, often with coarse fragments, and non-saline, often with a microphytic crust. The most important species are cool-season perennial bunchgrasses and forbs (>25% cover), sometimes with a sparse (<10% cover) shrub layer. *Pseudoroegneria spicata, Festuca campestris, Festuca idahoensis*, or *Hesperostipa comata* commonly dominate sites on all aspects of level to moderate slopes and on certain steep slopes with a variety of other grasses, such as *Achnatherum hymenoides, Achnatherum richardsonii, Hesperostipa curtiseta, Koeleria macrantha, Leymus cinereus, Elymus trachycaulus, Bromus inermis var. pumpellianus, Achnatherum occidentale, Pascopyrum smithii*, and other graminoids such as *Carex filifolia* and *Danthonia intermedia*. Other grassland species include *Opuntia fragilis, Artemisia frigida, Carex petasata, Antennaria* spp., and *Selaginella densa*. Important exotic grasses include *Phleum pratense, Bromus inermis*, and *Poa pratensis*. Shrub species may be scattered, including *Amelanchier alnifolia, Rosa* spp., *Symphoricarpos* spp., *Juniperus communis, Artemisia tridentata*, and in Wyoming *Artemisia tripartita ssp. rupicola*. Common associated forbs include *Geum triflorum, Galium boreale, Campanula rotundifolia, Antennaria microphylla, Geranium viscosissimum*, and *Potentilla gracilis*. A soil crust of lichen covers almost all open soil between clumps of grasses; *Cladonia* and *Peltigera* are the most common lichens. Unvegetated mineral soil is commonly found between clumps of grass and the lichen cover. The fire regime of this ecological system maintains a grassland due to rapid fire return that retards shrub invasion or landscape isolation and fragmentation that limits seed dispersal of native shrub species. Fire frequency is variable but is presumed to be generally less than 20 years to reduce shrub cover and maintain grassland. These are extensive grasslands, not grass-dominated patches within the sagebrush shrub-steppe ecological system. *Festuca campestris* is easily eliminated by grazing and does not occur in all areas of this system.

Distribution: This lower montane, foothill and valley grassland system occurs throughout the southern interior and southern portion of the Fraser Plateau, as well as the valleys around the Fraser River in the Pavilion Ranges, the Nicola River and the Similkameen River in British Columbia. It also occurs in the mountains and large valleys of northwestern Wyoming and western Montana, east to the central Montana Rocky Mountain Front and mountain "island" ranges, west through Idaho into the Blue Mountains of Oregon.

Nations: CA, US

States/Provinces: BC, ID, MT, OR, WA, WY, AB

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Blue Mountains, Middle Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, Columbia Plateau, Wyoming Basin, Snake River Plain

Primary Concept Source: R. Crawford

Description Author: R. Crawford, M.S. Reid, G. Kittel, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The most important species are cool-season perennial bunchgrasses and forbs (>25% cover), sometimes with a sparse (<10% cover) shrub layer. *Pseudoroegneria spicata, Festuca campestris, Festuca idahoensis*, or *Hesperostipa comata* commonly dominate sites on all aspects of level to moderate slopes and on certain steep slopes with a variety of other grasses, such as *Achnatherum hymenoides, Achnatherum richardsonii, Hesperostipa curtiseta, Koeleria macrantha, Leymus cinereus, Elymus trachycaulus, Bromus inermis var. pumpellianus (= Bromus pumpellianus), Achnatherum occidentale (= Stipa occidentalis), Pascopyrum smithii*, and other graminoids such as *Carex filifolia* and *Danthonia intermedia*. Other grassland species include *Opuntia fragilis, Artemisia frigida, Carex petasata, Antennaria* spp., and *Selaginella densa*. Important exotic grasses include *Phleum pratense, Bromus inermis*, and *Poa pratensis*. Shrub species may be scattered, including *Amelanchier alnifolia, Rosa* spp., *Symphoricarpos* spp., *Juniperus communis, Artemisia tridentata*, and in Wyoming *Artemisia tripartita ssp. rupicola*. Common associated forbs include *Geum triflorum, Galium boreale, Campanula rotundifolia, Antennaria microphylla, Geranium viscosissimum*, and *Potentilla gracilis*. A soil crust of lichen covers almost all open soil between clumps of grasses; *Cladonia* and *Peltigera* are the most common lichens. Unvegetated mineral soil is commonly found between clumps of grass and the lichen cover.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system are wind-pollinated, most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators. Insects: Bees (Apoidea), wasps and ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera) and beetles (Coleoptera).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Diversity: medium = 11-20 spp. This grassland system has a predominantly cool-season winter precipitation pattern, and although some warm-season grasses may be present, it is dominated by cool-season grasses. Although this system has high graminoid diversity rangewide, locally stands have a moderately diverse mixture of warm- and cool-season graminoids such as *Achnatherum hymenoides, Achnatherum nelsonii, Achnatherum occidentale, Achnatherum richardsonii, Bromus inermis ssp. pumpellianus, Calamagrostis rubescens, Carex filifolia, Carex hoodii, Carex inops ssp. heliophila, Carex petasata, Carex obtusata, Danthonia intermedia, Elymus lanceolatus, Elymus trachycaulus, Festuca campestris, Festuca idahoensis, Hesperostipa comata, Hesperostipa curtiseta, Koeleria macrantha, Leucopoa kingii, Leymus cinereus, Leymus salinus ssp. salmonis, Pascopyrum smithii, Poa cusickii, Poa nemoralis, Poa secunda*, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species provide an important vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this grassland type.

Environment: This system is found at lower montane to foothill elevations in the mountains and large valleys of northeastern Wyoming and western Montana, west through Idaho into the Blue Mountains of Oregon, and north into the Okanagan and Fraser plateaus of British Columbia and the Canadian Rockies. They also occur to the east in the central Montana mountain "islands" and foothills, as well as the Rocky Mountain Front Range and Big and Little Belt ranges. These grasslands are floristically similar to Inter-Mountain Basins Big Sagebrush Steppe (CES304.778), Columbia Basin Foothill and Canyon Dry Grassland (CES304.993), and Columbia Basin Palouse Prairie (CES304.792), but are defined by shorter summers, colder winters, and young soils derived from recent glacial and alluvial material. These lower montane and valley grasslands represent a shift in the precipitation regime from summer monsoons and cold snowy winters found in the Southern Rockies to predominantly dry summers and winter precipitation. In the eastern portion of its range in Montana, winter precipitation is replaced by a huge spring peak in precipitation. They are found at elevations from 300 to 1650 m, ranging from small meadows to large open parks surrounded by conifers in the lower montane, to extensive foothill and valley grasslands below the lower treeline. In the southern extent some of these valleys may have been primarily sage-steppe with patches of grassland in the past, but because of land-use history post-settlement (herbicide, grazing, altered fire regime, pasturing, etc.), they have been converted to grassland-dominated areas. Soils are relatively deep, fine-textured, often with coarse fragments, and non-saline, often with a microphytic crust.

Key Processes and Interactions: These are extensive grasslands, not grass-dominated patches within the sagebrush shrub-steppe ecological system. *Festuca campestris* is easily eliminated by grazing and does not occur in all areas of this system. The most droughty sites produce little and discontinuous fuel and likely have much longer fire regimes. Isolation of grassland patches by fragmentation may also limit seed dispersal of native shrubs leading to persistence of the grassland. Soil drought and herbivory retard shrub and tree invasion resulting in a patchy distribution of shrubs and trees when present.

The high-frequency fire regime of this ecological system maintains a grassland due to rapid fire return that retards shrub invasion or landscape isolation and fragmentation that limits seed dispersal of native shrub species. Fire frequency is presumed to be less than 20 years generally. Johnson and Swanson (2005) presumed fire frequency to be less than 35 years in the Blue and Ochoco mountains of Oregon. Wikeem and Wikeem (2004) compiled average fire intervals for interior grasslands in British Columbia which range from 5-20 years. Klenner et al. (2008) research supports a fire regime of predominantly mixed-severity fires that maintain grasslands in the dry forest and grasslands ecotone in the southern interior of British Columbia.

Biological soil crust cover is important in these grasslands. It alters the composition of perennial species and increases the establishment of native disturbance-increasers and annual grasses, particularly *Bromus tectorum* and other exotic annual bromes (WNHP 2011). Crust cover and diversity are greatest where not impacted by trampling, other soil surface disturbance and fragmentation (Belnap et al. 2001, Rosentreter and Eldridge 2002, Tyler 2006).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has three classes in total (LANDFIRE 2007a, BpS 1911390). These are summarized as:

A) Early Development 1 All Structures (5% of type in this stage): Graminoid cover is 0-10%. Post-fire, early-seral community dominated by bunchgrasses and forbs. Herbs and forbs will generally have higher cover than pre-burn and may include milkvetch, balsamroot, lupine, yarrow and prairie junegrass. Cover ranges from 0-10%. In the absence of fire or heavy animal impact, this condition succeeds to a mid-development condition (class B). Age ranges from 0-2 years. Idaho fescue may be present but will recover more slowly than the bluebunch wheatgrass after fire.

B) Mid Development 1 Closed (25% of type in this stage): Graminoid cover is 11-30%. Mid-development with moderate canopy closure dominated by bunchgrasses with forb cover generally higher than pre-burn. Typically lasts 5 years.

C) Late Development 1 Closed (70% of type in this stage): Tree cover is 31-100%. Late-development, closed canopy of grasses and forbs. Bunchgrasses dominate with low densities of shrubs (<10%) in some areas, particularly where this BpS transitions to shrub- or tree-dominated communities. Shrub species may include big sagebrush, buckwheat, ceanothus, bitterbrush and snowberry.

This type has frequent replacement fires (fire regime group II). Most species in this type are fire-adapted and respond favorably to these fire types. Where these systems occur within forested ecosystems, fire frequency will be strongly influenced by the surrounding forest's fire regime (e.g., 10-20 years). Where these systems occur below lower treeline, fire frequencies may be longer (e.g., 20-30 years) (LANDFIRE 2007a, BpS 1911390).

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of the system are associated with livestock practices, exotic species, fire regime alteration, direct soil surface disturbance, and fragmentation (WNHP 2011). Excessive grazing stresses the system through soil disturbance increasing the probability of establishment of native disturbance-increasers and annual grasses, particularly exotic annual bromes (*Bromus racemosus, Bromus arvensis, Bromus hordeaceus, Bromus tectorum*) and *Ventenata dubia* on more xeric sites and exotic perennial grasses *Bromus inermis, Phleum pratense*, and *Poa pratensis* on more mesic sites (WNHP 2011). Other exotic species threatening this ecological system through invasion and potential complete replacement of native species include *Hypericum perforatum, Potentilla recta, Euphorbia esula*, and knapweeds, especially *Centaurea stoebe ssp. micranthos*. Persistent grazing will further diminish native perennial cover, expose bare ground, and increase exotics (Johnson and Swanson 2005). Darambazar et al. (2007) cite Johnston (1962) that when bare ground is approximately 15%, reduced infiltration and increased runoff occurs in *Festuca* grassland ecosystems. Fire further stresses livestock-altered vegetation by increasing exposure of bare ground and consequent increases in exotic annuals and decrease in perennial bunchgrass. Grazing effects are usually concentrated in less steep slopes although grazing does create contour trail networks that can lead to addition slope failures. Fire suppression leads to deciduous shrubs (*Symphoricarpos* spp., *Physocarpus malvaceus, Holodiscus discolor*, and *Ribes* spp.) and in some areas trees (*Pseudotsuga menziesii*) to increase (WNHP 2011).

Festuca campestris is highly palatable throughout the grazing season, and summer overgrazing for 2 to 3 years can result in the loss of *Festuca campestris* in the stand. Although a light stocking rate for 32 years did not affect range condition, a modest increase in stocking rate led to a marked decline in range condition. The major change was a measurable reduction in basal area of *Festuca campestris*. Long-term heavy grazing on moister sites can result in a shift to a *Poa pratensis - Phleum pratense* type. *Pseudoroegneria spicata* shows an inconsistent reaction to grazing, increasing on some grazed sites while decreasing on others. It seems to recover more quickly from overgrazing than *Festuca campestris*. It tolerates dormant-period grazing well but is sensitive to defoliation during the growing season. Light spring use or fall grazing can help retain plant vigor. It is particularly sensitive to defoliation in late spring. Exotic species threatening this ecological system through invasion and potential complete replacement of native species include *Bromus arvensis, Potentilla recta, Euphorbia esula*, and all manner of knapweed, especially *Centaurea stoebe ssp. micranthos*.

Conversion of this type has commonly come from invasive by non-native species such as *Bromus tectorum, Centaurea stoebe ssp. micranthos, Centaurea solstitialis, Hypericum perforatum, Poa pratensis*, and *Prunus cerasifera*. These invasive species increase post disturbance including long-term excessive grazing by livestock, or direct soil disturbance from severe trampling by livestock and roads.

Altered fire regimes, primarily fire suppression, has allowed succession and conversion to deciduous shrublands (*Symphoricarpos* spp., *Physocarpus malvaceus, Holodiscus discolor, Rosa* spp., and *Ribes* spp.) and in some areas trees (*Pinus ponderosa* or *Pseudotsuga menziesii*) to increase (Wikeem and Wikeem 2004, LANDFIRE 2007a, WNHP 2011).

Common stressors and threats include fragmentation from roads, altered fire regime from fire suppression and indirectly from livestock grazing and fragmentation, and introduction of invasive non-native species (WNHP 2011). Potential climate change effects could include a shift to species more common on hotter, drier southern aspects, if climate change has the predicted effect of less effective moisture with increasing mean temperature (TNC 2013).

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 13** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 14, left**) and sensitivity (**Figure 14, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

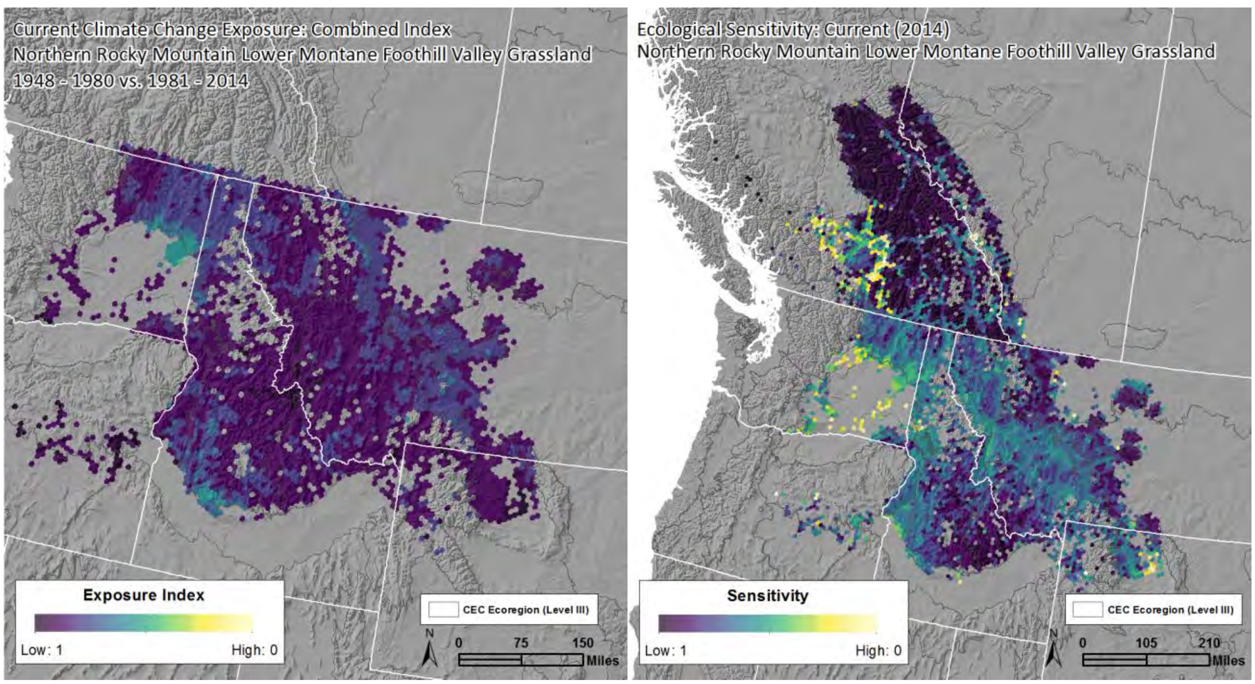

Figure 14. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland. The results have been summarized and are displayed in 100km2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 13. Resilience, exposure and vulnerability scores for Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Middle Rockies	Columbia Mountains-Northern Rockies	Northwestern Glaciated Plains	Northwestern Great Plains	Thompson-Okanogan Plateau	Idaho Batholith	Canadian Rockies	Blue Mountains	Wyoming Basin	Columbia Plateau	Snake River Plain	Northern Basin & Range
	Potential square miles within ecoregion	2,366	1,339	1,214	912	553	420	290	281	216	72	33	20
Contributions to Relative Vulnerability by Factor													
Vulnerability from **Exposure (2014)**		Low 0.82	Low 0.78	Low 0.78	Low 0.79	Mod 0.70	Low 0.80	Low 0.77	Low 0.83	Low 0.84	Mod 0.74	Mod 0.74	Low 0.90
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.36	0.34	0.60	0.49	0.50	0.48	0.41	0.50	0.67	0.33	0.57	0.77
	Fire Regime Departure	0.57	0.66	0.89	0.71		0.56	0.78	0.46	0.53	0.44	0.59	0.75
	Invasive Annual Grasses	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.90	0.92	0.97
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.64**	**0.66**	**0.83**	**0.73**	**0.75**	**0.68**	**0.73**	**0.65**	**0.73**	**0.56**	**0.69**	**0.83**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.28	0.25	0.21	0.28	0.21	0.47	0.19	0.44	0.30	0.24	0.29	0.28
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.39**	**0.37**	**0.36**	**0.39**	**0.36**	**0.49**	**0.34**	**0.47**	**0.40**	**0.37**	**0.39**	**0.39**
Vulnerability from Measures of **Overall Resilience**		Mod 0.51	Mod 0.52	Mod 0.59	Mod 0.56	Mod 0.55	Mod 0.58	Mod 0.54	Mod 0.56	Mod 0.57	High 0.46	Mod 0.54	Mod 0.61
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Low

Exposure Summary for 1981-2014 Timeframe: Overall, the climate exposure as of 2014 for this grassland system is low, with nine of the 12 ecoregions (comprising 91% of the potential range of the system) scoring low and the remaining three ecoregions scoring at the moderate end of low.

The annual mean temperature has increased by 0.5° to 0.9°C across substantial portions (23-79%) of all nine ecoregions. Other climate exposure effects were smaller in area or magnitude, but consistent with greater increases in night-time temperatures. For example, diurnal temperature range decreased by 0.5°C across 10-15% two ecoregions.

Climate Change Effects: Climate change can affect vegetation communities by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks. In the Pacific Northwest and Northern and Central Rocky Mountains regions where this system is common, the average annual temperature is projected to continue to increase with more frequent droughts, along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Mote et al. 2014, Shafer et al. 2014). These temperate grasslands occur on moderately dry to mesic environments on flat to rolling slopes and parks that are surrounded by montane and subalpine forests.

Under these warming conditions this grassland system is likely to increase rangewide at the expense of adjacent forest and woodland stands. Stevens-Rumann et al. (2017) documented a decrease in post-fire forest and woodland resilience during 2000-2015 when compared to 1985-1999 interval. Post-fire conversion of forests to non-forest vegetation such as fire-adapted grasslands because of tree regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate, with nine ecoregions accounting for 75% of the potential distribution of this type scoring moderate, and the remaining three scoring low for sensitivity.

Contributions to sensitivity from landscape condition were high to moderate across ecoregions. This likely reflects an influence of extensive grazing and conversion to pasture across the distribution of the system, as well as fragmentation from roads, suburban and exurban development.

Fire regime departure was variable across the system, ranging from high in lower elevation portions of the Pacific Northwest to low in the Great Plains. This likely reflects fire suppression practices across much of the range of this system that have increased invasion of woody species and succession to shrubland or woodland types in some areas. Risk from invasive annual grasses was low across all ecoregions. However, stands associated with grazing may be characterized by high cover of invasive annual plants and grass species not captured by the invasive grass landscape assessment.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally low across all ecoregions of this grassland system. This low adaptive capacity is related to low or very low scores for topoclimatic variability across all ecoregions. This reflects a low level of topographic diversity associated with the flat to rolling plains and moderate slopes characteristic of where this system occurs. In terms of vulnerability related to functional groups, the system scores moderate in terms of pollinator diversity and cool-season graminoids, suggesting increased vulnerability due to individual species vulnerabilities to factors such as drought and human disturbance. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this grassland system scores in the moderate range of overall climate change vulnerability. This is primarily due to high contributions to sensitivity from landscape condition associated with grazing and fragmentation, as well as from low adaptive capacity associated with low topoclimate variability. Although the system has moderate vulnerability, increases in temperature may favor dominant grasses in this system relative to shrub species.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 14. Climate change adaptation strategies relative to vulnerability scores for Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (bison wallows, cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub invasion.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: BCCDC unpubl. data 2018, Bell et al. 2009, Belnap et al. 2001, Comer et al. 2003*, Darambazar et al. 2007, Ecosystems Working Group 1998, Johnson and Swanson 2005, Klenner et al. 2008, LANDFIRE 2007a, McKenzie et al. 2004, McKenzie et al. 2008, Mote et al. 2014, Rosentreter and Eldridge 2002, Shafer et al. 2014, Shiflet 1994, Steen and Coupé 1997, Stevens-Rumann et al. 2017, TNC 2013, Tyler 2006, WNHP 2011, WNHP unpubl. data 2018, Westerling et al. 2006, Wikeem and Wikeem 2004

M168. Rocky Mountain-Vancouverian Subalpine-High Montane Mesic Meadow

CES306.824 Southern Rocky Mountain Montane-Subalpine Grassland

Figure 15. Photo of Southern Rocky Mountain Montane-Subalpine Grassland. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This Rocky Mountain ecological system typically occurs between 2200 and 3000 m elevation on flat to rolling plains and parks or on lower sideslopes that are dry, but it may extend up to 3350 m on warm aspects. Soils resemble prairie soils in that the A-horizon is dark brown, relatively high in organic matter, slightly acidic, and usually well-drained. An occurrence usually consists of a mosaic of two or three plant associations with one of the following dominant bunchgrasses: *Danthonia intermedia, Danthonia parryi, Festuca idahoensis, Festuca arizonica, Festuca thurberi, Muhlenbergia filiculmis*, or *Pseudoroegneria spicata*. The subdominants include *Muhlenbergia montana, Bouteloua gracilis*, and *Poa secunda*. These large-patch grasslands are intermixed with matrix stands of spruce-fir, lodgepole pine, ponderosa pine, and aspen forests. In limited circumstances (e.g., South Park in Colorado), they form the "matrix" of high-elevation plateaus. Small-patch representations of this system do occur at high elevations of the Trans-Pecos where they present as occurrences of *Festuca arizonica - Blepharoneuron tricholepis* Grassland (CEGL004508). These occurrences often occupy sites adjacent to Madrean Oriental Chaparral (CES302.031).

Distribution: This system occurs between 2200 and 3000 m (7200-10,000 feet) elevation in the Colorado Rockies. Where it transitions in Wyoming to Northern Rocky Mountain Subalpine-Upper Montane Grassland (CES306.806) still needs to be clarified. Southern outliers of this system also occur in small patches in high elevations of the mountains of the Trans-Pecos of Texas.

Nations: US

States/Provinces: AZ, CO, NM, TX, UT, WY, ID

CEC Ecoregions: Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, High Plains, Southwestern Tablelands, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

Description Author: L. Elliott, J. Teague and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Occurrences of this system are often a mosaic of different bunchgrass associations and may be dominated by *Blepharoneuron tricholepis, Bouteloua gracilis, Danthonia intermedia, Danthonia parryi, Festuca idahoensis, Festuca arizonica, Festuca thurberi, Muhlenbergia filiculmis*, or *Pseudoroegneria spicata*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system are wind-pollinated, most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators. Insects: Bees (Apoidea), wasps and ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera) and beetles (Coleoptera).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
Diversity: medium = 11-20 spp. This grassland system is adapted to a bimodal precipitation pattern with both warm-season summer and cool-season winter precipitation. Although this system has high graminoid diversity rangewide, locally stands have a moderately diverse mixture of warm- and cool-season graminoids such as:

Cool-season graminoids: *Achnatherum hymenoides, Achnatherum lettermanii, Achnatherum pinetorum, Bromus anomalus, Carex duriuscula, Carex inops ssp. heliophila, Carex rossii, Carex siccata, Danthonia intermedia, Danthonia parryi, Deschampsia cespitosa, Elymus elymoides, Elymus lanceolatus, Elymus trachycaulus, Festuca arizonica, Festuca brachyphylla, Festuca calligera, Festuca idahoensis, Festuca thurberi, Hesperostipa comata, Koeleria macrantha, Leymus cinereus, Pascopyrum smithii, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*.

Warm-season graminoids: *Agrostis scabra, Agrostis variabilis, Blepharoneuron tricholepis, Bouteloua curtipendula, Bouteloua gracilis, Muhlenbergia filiculmis, Muhlenbergia montana*, and *Schizachyrium scoparium*.

Keystone Species: Keystone species provide an important vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this grassland type.

Environment: This Rocky Mountain ecological system typically occurs between 2200 and 3000 m elevation on flat to rolling plains and parks or on lower sideslopes that are dry, but it may extend up to 3350 m on warm aspects. These are typically grasslands of forest openings and park-like expanses in the montane and subalpine coniferous forests. Although smaller montane grasslands are scattered throughout the southern Rocky Mountains and high plateaus in the Colorado Plateaus, the largest occurrence by far (over a million acres) is on the valley floor of South Park in central Colorado. Soils resemble prairie soils in that the A-horizon is dark brown, relatively high in organic matter, slightly acidic, and usually well-drained.

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

Historically, much of the montane grasslands where this system occurs were heavily grazed by livestock, primarily cattle and sheep (also at subalpine elevation) (Shepherd 1975). Under moderate grazing, the shorter grasses such *Muhlenbergia filiculmis* may have had a competitive advantage over the taller and more palatable *Festuca arizonica* (West 1992). Season of use is also important. In stands with cool-season *Festuca arizonica* or *Hesperostipa comata* and warm-season *Muhlenbergia montana*, fall grazing will favor the cool-season grasses over the later-blooming, warm-season *Muhlenbergia montana* (Clary 1978). The reverse is true if grazing is always limited to late summer. Overgrazing will reduce or eliminate *Festuca arizonica, Hesperostipa comata, Muhlenbergia filiculmis*, *Muhlenbergia montana*, and the other palatable species, leaving the more grazing-tolerant *Bouteloua gracilis* and less palatable plants such as *Hymenoxys, Artemisia*, and *Chrysothamnus* species to dominate the site (West 1992). Clary (1978) reported that complete natural recovery of montane *Festuca arizonica* may require over 100 years, based on areas where recovery had reached only the "half-shrub" stage after 10 years. Because of the long time needed for recovery, much of the range may be in a seral state. If the range is properly managed, *Muhlenbergia* and *Festuca arizonica* grasslands could potentially become more common.

Higher-elevation grasslands are dominated by *Festuca thurberi* and typically have sharp ecotones with adjacent *Picea engelmannii*- and *Abies lasiocarpa*-dominated subalpine forests. There is rarely any invasion by tree seedlings in the adjacent grasslands. These high-elevation meadows are typically dry with southern or western aspects. The soils are deep and well-developed, typical of sites with long histories of being grassland. They may need catastrophic disturbance, such as forest-destroying crown fire, to be created. It is unclear how these grasslands were maintained in the subalpine forest zone; however, it is thought to be by a combination of factors such as herbivory, fire, deep soils, early summer drought and competition from grass species (Moir 1967, Andrews 1983). In addition, south- and west-facing clearcuts are often difficult to reforest because seedlings are damaged by full sun. The ecotones between stands adjacent to *Populus tremuloides*-dominated subalpine forests are not as sharp because the forest understory consists of the same graminoid and forb species (Andrews 1983).

Where the soil is thinner and rockier in these subalpine parks, *Danthonia parryi* becomes the dominant species with *Festuca thurberi* and *Artemisia* spp. subdominant (Andrews 1983). The spread of the exotic species *Poa pratensis* and *Taraxacum officinale* in subalpine parks is likely from heavy grazing by livestock (Moir 1967, Andrews 1983). These species are more common in heavily grazed bottomlands and near trails in the uplands (Moir 1967).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has three classes in total (LANDFIRE 2007a, BpS 2811460). These are summarized as:

A) Early Development 1 All Structures (graminoid-dominated - 10% of type in this stage): Herb cover is 0-30%. Low cover and frequency of Thurber fescue, Arizona fescue, sheep fescue, mountain muhly, timber/Parry's oatgrass, Kentucky bluegrass, nodding brome, tufted hairgrass, and various sedges in moist (concave) sites. Pine dropseed is common.

B) Mid Development 1 Closed (graminoid-dominated - 30% of type in this stage): Herb cover is 31-70%. Thurber fescue, Arizona fescue, sheep fescue, mountain muhly, timber/Parry's oatgrass, Kentucky bluegrass, nodding brome, tufted hairgrass, and various sedges in moist (concave) sites.

C) Late Development 1 Closed (graminoid-dominated - 50% of type in this stage): Tree cover is 71-100%. Thurber fescue, Arizona fescue, sheep fescue, mountain muhly, timber/Parry's oatgrass, Kentucky bluegrass, nodding brome, tufted hairgrass, and various sedges in moist (concave) sites.

Predicted historic stand-replacement fire regime of approximately 30-60 years based upon historic photographic analysis (B. Johnston-R2 pers. comm. 2018) and inference from mean/max and min fire regimes of adjacent forest types (*Pinus ponderosa)* 3-12 years, *Abies concolor/Pseudotsuga menziesii* 14-46 years, *Picea engelmannii / Abies lasiocarpa* 60-180+ years). Anthropogenic (pre-European cf.) fire use ignitions 5-15 years, current regime greater than 60 years in montane and 100 years in subalpine systems (LANDFIRE 2007a, BpS 2811460).

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of these communities are associated with livestock grazing. Excessive grazing stresses the system through soil disturbance, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and invasive exotic species, particularly *Bromus inermis, Cardaria draba, Cirsium vulgare, Leucanthemum vulgare, Linaria dalmatica*, and *Poa pratensis*. Other concerns are fragmentation from roads and ORVs, altered fire or altered hydrological regimes.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 15** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 16, left**) and sensitivity (**Figure 16, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

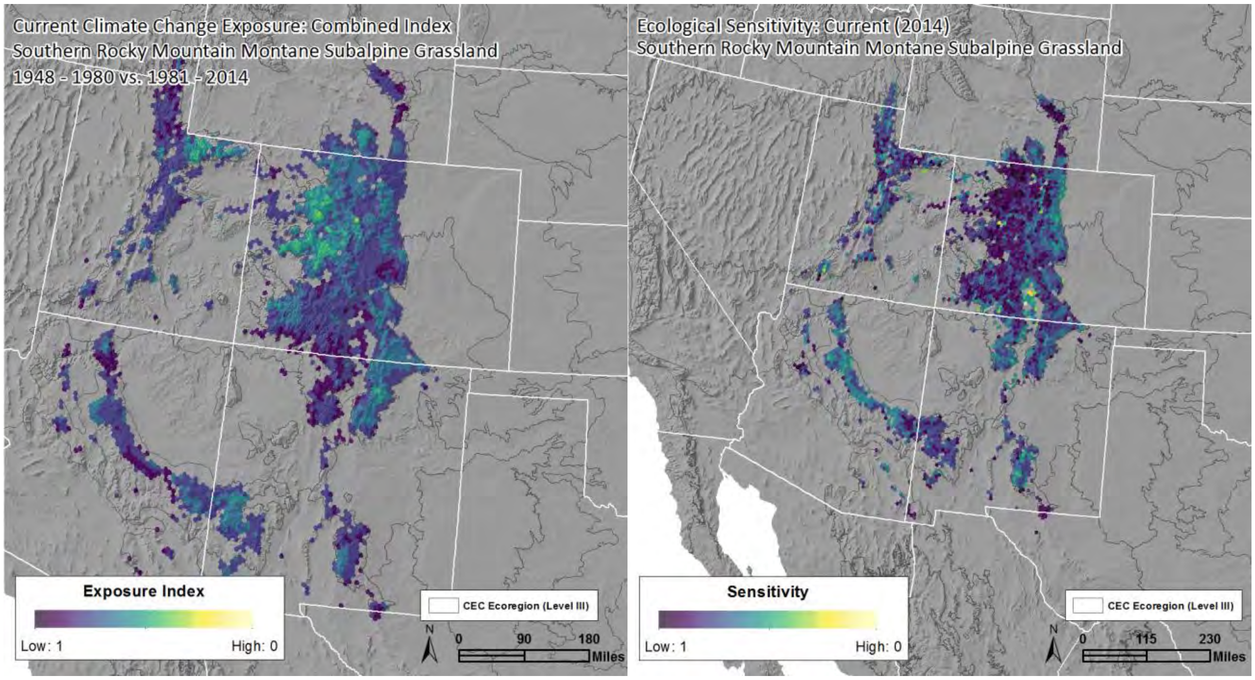

Figure 16. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Montane-Subalpine Grassland. The results have been summarized and are displayed in 100km2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 15. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Montane-Subalpine Grassland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g., no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Southern Rockies	Arizona-New Mexico Mountains	Wasatch & Uinta Mountains
	Potential square miles within ecoregion	781	329	54
Contributions to Relative Vulnerability by Factor				
Vulnerability from **Exposure (2014)**		**Mod** 0.70	**Mod** 0.71	**Low** 0.75
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.73	0.72	0.67
	Fire Regime Departure	0.47	0.53	0.45
	Invasive Annual Grasses	1.00	1.00	1.00
	Forest Insect & Disease	Null	Null	Null
	Sensitivity Average	**0.73**	**0.75**	**0.71**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.42	0.27	0.48
	Diversity within Functional Species Groups	0.50	0.50	0.50
	Adaptive Capacity Average	**0.46**	**0.39**	**0.49**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.60	**Mod** 0.57	**Mod** 0.60
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this grassland system is moderate, with two of the three ecoregions (comprising 95% of the range of the system) scoring moderate and the remaining ecoregion scoring at the moderate end of low. The annual mean temperature has increased by 0.6° to 0.7°C across large portions of all three ecoregions. This increase was widespread in in two areas (>40% of each region) and pervasive in the Arizona-New Mexico Mountains ecoregion. Annual mean temperature increases were reflected by increases in summer temperatures of 0.6° to 0.7°C affecting over 50% of all three ecoregions and increases in winter temperature >1°C affecting >30% of the Wasatch and Uinta Mountains and Arizona-New Mexico Mountains ecoregions.

Climate Change Effects: Climate change can affect vegetation communities by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks. In the southern Rocky Mountains and Colorado Plateau regions where this system is common, the average annual temperature is projected to continue to increase with more frequent droughts, and the annual snowpack and streamflow is predicted to decline (Garfin et al. 2014). These temperate grasslands occur on moderately dry to mesic environments on flat to rolling slopes and parks that are surrounded by montane and subalpine forests.

Under these conditions this grassland system is likely to increase rangewide at the expense of adjacent forests and woodlands stands. With increasing average annual temperature the number and severity of wildfires and insect outbreaks is expected to increase (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). Stevens-Rumann et al. (2017) documented a decrease in post-fire forest and woodland resilience during 2000-2015 when compared to 1985-1999 interval. Post-fire conversion of forests to non-forest vegetation such as fire-adapted grasslands because of tree regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across all three ecoregions of this grassland system.

Contributions to sensitivity from landscape condition were moderate in all ecoregions. This likely reflects an influence of extensive grazing across the potential distribution of the system, which generally occurs in areas of low fragmentation.

Fire regime departure was high or near the high end of moderate across all ecoregions. This likely reflects fire suppression practices across much of the range of this system that may have increased invasion of woody species in some areas. Risk from invasive grasses was low across all ecoregions.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally low across all ecoregions of this grassland system. This low adaptive capacity is related to low scores for topoclimatic variability across all ecoregions. These reflect a low level of topographic diversity associated with the flat to rolling plains and moderate slopes characteristic of where this system occurs. In terms of vulnerability related to functional groups, the system scores moderate in terms of both pollinator diversity and warm- and cool-season graminoids, suggesting increased vulnerability. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this grassland system scores in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure and landscape condition from intensive grazing, as well as from low adaptive capacity associated with low topoclimate variability. Although the system has moderate vulnerability, increases in temperature may favor expansion of the grassland system relative to adjacent woodland systems with more drought-vulnerable trees.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 16. Climate change adaptation strategies relative to vulnerability scores for Southern Rocky Mountain Montane-Subalpine Grassland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soils and viable colonies of burrowing animals (e.g., pocket gophers); maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (burrowing mammals, cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub or tree invasion.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub or tree invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub or tree regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson and Baker 2005, Andrews 1983, Bowns and Bagley 1986, CNHP 2010, Cantor and Whitham 1989, Clary 1978, Comer et al. 2002, Comer et al. 2003*, Coop and Givnish 2007, Ellison 1946, Garfin et al. 2014, Hess 1981, Hess and Wasser 1982, LANDFIRE 2007a, McKenzie et al. 2004, McKenzie et al. 2008, Moir 1967, Neely et al. 2001, Passey et al. 1982, Schauer et al. 1998, Shepherd 1975, Stevens-Rumann et al. 2017, Stewart 1940, Tuhy et al. 2002, Turner 1975, Turner and Dortignac 1954, West 1992, Westerling et al. 2006, Zier and Baker 2006

M049. Southern Rocky Mountain Montane Shrubland

CES306.818 Rocky Mountain Gambel Oak-Mixed Montane Shrubland

Figure 17. Photo of Rocky Mountain Gambel Oak-Mixed Montane Shrubland. Photo credit: Jeff Mitten, used under Creative Commons license CC BY 2.0.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in the mountains, plateaus and foothills of the southern Rocky Mountains and Colorado Plateau, including the Uinta and Wasatch ranges and the Mogollon Rim. These shrublands are most commonly found along dry foothills, lower mountain slopes, and at the edge of the western Great Plains from approximately 2000 to 2900 m in elevation and are often situated above pinyon-juniper woodlands. Substrates are variable and include soil types ranging from calcareous, heavy, fine-grained loams to sandy loams, gravelly loams, clay loams, deep alluvial sand, or coarse gravel. The vegetation is typically dominated by *Quercus gambelii* alone or codominant with *Amelanchier alnifolia, Amelanchier utahensis, Artemisia tridentata, Cercocarpus montanus, Prunus virginiana, Purshia stansburiana, Purshia tridentata, Robinia neomexicana, Symphoricarpos oreophilus*, or *Symphoricarpos rotundifolius*. There may be inclusions of other mesic montane shrublands with *Quercus gambelii* absent or as a relatively minor component. This ecological system intergrades with the lower montane-foothills shrubland system and shares many of the same site characteristics. Density and cover of *Quercus gambelii* and *Amelanchier* spp. often increase after fire. In Texas, this system includes high mountain shrublands dominated by the deciduous oak species *Quercus gambelii*. This species often forms nearly monotypic shrublands, but other species present may include *Cercocarpus montanus, Robinia neomexicana, Symphoricarpos oreophilus*, and *Rhus trilobata*. These shrubland patches represent southern outliers of the extensive and diverse system further north.

Distribution: This system occurs in the mountains, plateaus and foothills of the southern Rocky Mountains and Colorado Plateau, including the Uinta and Wasatch ranges and the Mogollon Rim. It also extends into the high mountains of the Trans-Pecos of Texas.

Nations: US

States/Provinces: AZ, CO, NM, TX, UT, WY

CEC Ecoregions: Wasatch and Uinta Mountains, Southern Rockies, High Plains, Southwestern Tablelands, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Mojave Basin and Range, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Vegetation types in this system may occur as sparse to dense shrublands composed of moderate to tall shrubs. Occurrences may be multi-layered, with some short shrubby species occurring in the understory of the dominant overstory species. In many occurrences of this system, the canopy is dominated by the broad-leaved deciduous shrub *Quercus gambelii*, which occasionally reaches small tree size. Occurrences can range from dense thickets with little understory to relatively mesic mixed-shrublands with a rich understory of shrubs, grasses and forbs. These shrubs often have a patchy distribution with grass growing in between. Scattered trees are occasionally present in stands and typically include species of *Pinus* or *Juniperus*. Characteristic shrubs that may co-occur, or be singularly dominant, include *Amelanchier alnifolia, Amelanchier utahensis, Arctostaphylos patula, Artemisia tridentata, Cercocarpus montanus, Ptelea trifoliata, Prunus virginiana, Purshia stansburiana, Robinia neomexicana, Rosa* spp., *Symphoricarpos oreophilus*, and *Symphoricarpos rotundifolius*. The herbaceous layer is sparse to moderately dense, ranging from 1-40% cover. Perennial graminoids are the most abundant species, particularly *Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Aristida* spp., *Carex inops, Carex geyeri, Elymus arizonicus, Eragrostis* spp., *Festuca* spp., *Koeleria macrantha, Muhlenbergia* spp., and *Stipa* spp. Many forb and fern species can occur, but none have much cover. Commonly present forbs include *Achillea millefolium, Artemisia* spp., *Geranium* spp., *Maianthemum stellatum, Thalictrum fendleri*, and *Vicia americana*. Ferns include species of *Cheilanthes* and *Woodsia*. Annual grasses and forbs are seasonally present, and weedy annuals are often present, at least seasonally.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although the dominant shrubs in this system (*Quercus gambelii, Artemisia tridentata*) are chiefly self- or wind-pollinated, some of the other shrubs and most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Tirmenstein 1999c, Simonin 2000d). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for wildlife such as sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds important for certain species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially for red tubular flowers).

Nutrient-Cycling/Litter Decomposers; Species Diversity:
Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, data on species diversity of litter decomposers for this system are deficient in scientific literature. Therefore, no diversity metric was calculated for this FSG.

Diversity: cannot be assessed.

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: High
Diversity: high >20 spp. This system is adapted to a bimodal precipitation pattern with both warm-season summer and cool-season winter precipitation. Warm-season grasses are more important in the southern range. Local stands have a moderate to highly diverse mixture of warm- and cool-season graminoids such as:

Cool-season graminoids: *Achnatherum hymenoides, Achnatherum nelsonii, Achnatherum pinetorum, Bromus carinatus, Bromus porteri, Calamagrostis rubescens, Carex geophila, Carex geyeri, Carex hoodii, Carex inops ssp. heliophila, Carex occidentalis, Carex rossii, Carex siccata, Elymus elymoides, Festuca campestris, Festuca idahoensis, Festuca thurberi Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus salinus, Pascopyrum smithii, Piptatheropsis micrantha, Poa fendleriana*, and *Pseudoroegneria spicata*.

Warm-season graminoids: *Blepharoneuron tricholepis, Bouteloua gracilis, Pleuraphis jamesii, Muhlenbergia montana, Schizachyrium scoparium*, and *Sporobolus cryptandrus*.

Seed Dispersal; Species Diversity: Medium
Diversity: medium = 6-11 spp. Gambel oak acorns are primarily dispersed by avian and small mammals and birds, especially woodpeckers (Harper et al. 1985, Clary and Tiedeman 1986, Simonin 2000d). Birds: Band-tailed pigeons (*Columba fasciata*), scrub jays (*Aphelocoma coerulescens*), Steller's jays (*Canocitta stelleri*), Lewis woodpeckers (*Asyndexmus lewis*), and acorn woodpeckers (*Melanerpes* formicivorus) are agents of longer distance dispersal (Harper et al. 1985). Mammals: small mammal Utah rock squirrel (*Spermophilus variegatus*), Abert's squirrels (*Sciurus aberti*), and likely other rodents commonly disperse and cache (Rasmussen 1941, Harper et al. 1985, Clary and Tiedeman 1986).

Keystone Species: Keystone species provide an important vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this shrubland type.

Environment: This ecological system typically occupies the lower slope positions of the foothill and lower montane zones. They may occur on level to steep slopes, cliffs, escarpments, rimrock slopes, rocky outcrops, and scree slopes. Climate is semi-arid and characterized by mostly hot-dry summers with mild to cold winters and annual precipitation of 25 to 70 cm. Precipitation mostly occurs as winter snows but may also consist of some late-summer rains. Soils are typically poorly developed, rocky to very rocky, and well-drained. Parent materials include alluvium, colluvium, and residuum derived from igneous, metamorphic, or sedimentary rocks such as granite, gneiss, limestone, quartz, monzonite, rhyolite, sandstone, schist, and shale. Although this is a shrub-dominated system, some trees may be present. In older occurrences, or occurrences on mesic sites, some of the shrubs may acquire tree-like sizes. Adjacent communities often include woodlands or forests of *Abies concolor, Pinus ponderosa, Pseudotsuga menziesii*, or *Populus tremuloides* at higher elevations, and *Pinus edulis* and *Juniperus osteosperma* on the lower and adjacent elevations. Shrublands of *Artemisia tridentata* or grasslands of *Festuca* sp., *Stipa* sp., or *Pseudoroegneria* sp. may also be present at the lower elevations. In Texas, this system primarily occurs on limestone formations on slopes and rolling landforms of the Trans-Pecos mountains, on Limestone Hill and Mountain and High Montane Conifer Ecological Sites.

Key Processes and Interactions: Fire typically plays an important role in this system, causing die-back of the dominant shrub species in some areas, promoting stump sprouting of the dominant shrubs in other areas, and controlling the invasion of trees into the shrubland system. Natural fires typically result in a system with a mosaic of dense shrub clusters and openings dominated by herbaceous species. In some instances, these associations may be seral to the adjacent *Pinus ponderosa, Abies concolor*, and *Pseudotsuga menziesii* woodlands and forests. Ream (1964) noted that on many sites in Utah, Gambel oak may be successional and replaced by bigtooth maple (*Acer grandidentatum*).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has four classes in total (LANDFIRE 2007a, BpS 2311070). These are summarized as:

A) Early Development 1 All Structures (shrub-dominated - 5% of type in this stage): Shrub cover is 0-20%. Post-replacement sprouts to approximately 2 feet high. Dense resprouting with high number of stems/acre. Abundant grass and forb cover.

B) Mid Development 1 Closed (tree-dominated - 50% of type in this stage): Tree cover is 21-70%. Oak 3-6 feet tall to 3 inches dbh. There will be some stem mortality due to competition and self-thinning, with slight decrease in understory species due to shading. Grasses and forbs declining.

C) Mid Development 1 Open (tree-dominated - 15% of type in this stage): Tree cover is 51-70%. This class has >6 feet tall and >3 inches dbh oak. Small stands <30 m across usually scattered throughout a grassland or shrub type (Brown 1958).

D) Late Development 1 Closed (shrub-dominated - 30% of type in this stage): Tree cover is 71-100%. This class has >6 feet tall and 3 inches dbh. Nearly continuous stand two or more hectares in size with only occasional openings (Brown 1958).

Fire regime group IV or III. The primary disturbance mechanism is replacement fire, resulting in >75% top-kill. Gambel oak responds to fire with vigorous sprouting from the root crown. Larger forms may survive low-intensity surface fire. Extended drought also contributes to disturbance (LANDFIRE 2007a, BpS 2311070).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this shrubland system include altered fire regime, fragmentation from roads and development near urban areas, mining, invasive species, livestock grazing disturbance or other human disturbances (CNHP 2010). These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed. Invasive exotic species such as *Bromus tectorum* can become abundant in disturbed areas and alter floristic composition and provide fine fuels that many increase fire frequency and severity beyond the natural range of variation.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 17** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 18, left**) and sensitivity (**Figure 18, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

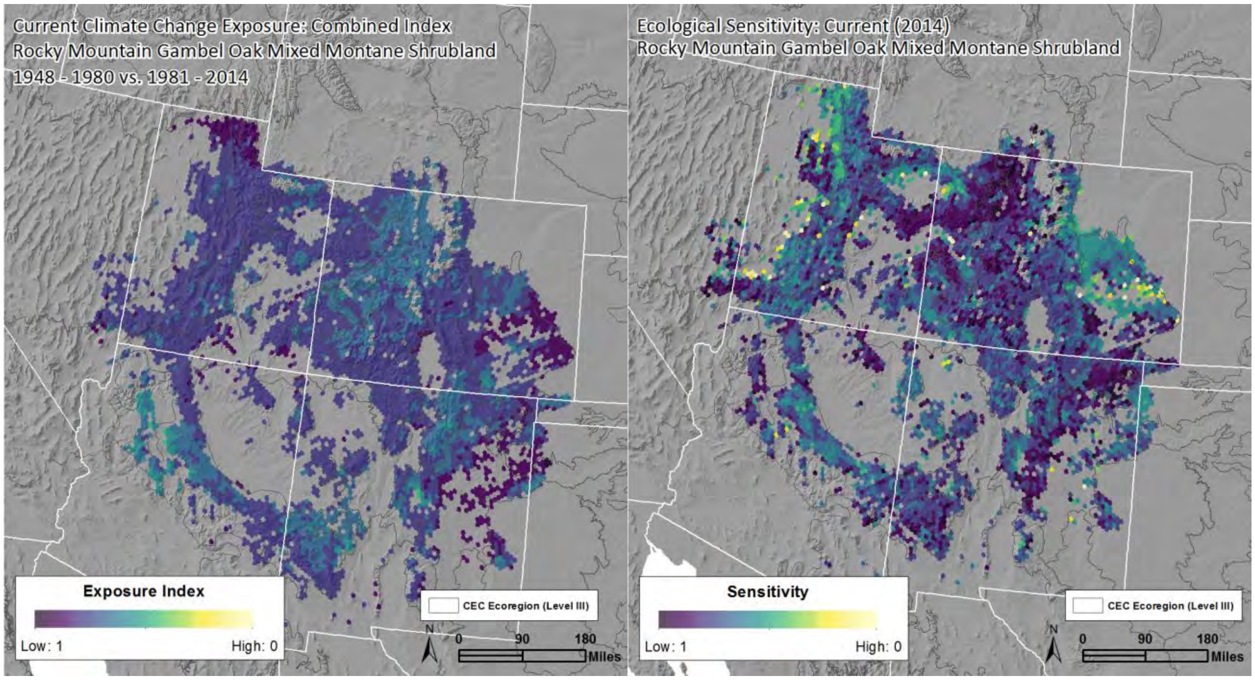

Figure 18. Climate exposure as of 2014 (left) and overall sensitivity (right) for Rocky Mountain Gambel Oak-Mixed Montane Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 17. Resilience, exposure and vulnerability scores for Rocky Mountain Gambel Oak-Mixed Montane Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g., no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Southern Rockies	Colorado Plateaus	Wasatch & Uinta Mountains	Central Basin & Range	Southwestern Tablelands	Arizona-New Mexico Mountains	Wyoming Basin	Arizona-New Mexico Plateau	Mojave Basin & Range	High Plains
Potential square miles within ecoregion		2,415	1,932	1,640	803	364	202	126	102	49	38
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Mod** 0.70	**Mod** 0.72	**Low** 0.75	**Mod** 0.75	**Mod** 0.72	**Mod** 0.68	**Mod** 0.70	**Mod** 0.70	**Mod** 0.56	**Mod** 0.71
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.76	0.66	0.58	0.43	0.35	0.75	0.65	0.85	0.97	0.18
	Fire Regime Departure	0.62	0.66	0.46	0.49	0.55	0.35	0.88	0.36	0.33	0.53
	Invasive Annual Grasses	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.79**	**0.77**	**0.68**	**0.64**	**0.63**	**0.70**	**0.84**	**0.74**	**0.76**	**0.57**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.44	0.44	0.46	0.32	0.24	0.36	0.36	0.36	0.34	0.20
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.47**	**0.47**	**0.48**	**0.41**	**0.37**	**0.43**	**0.43**	**0.43**	**0.42**	**0.35**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.63	**Mod** 0.62	**Mod** 0.58	**Mod** 0.52	**Mod** 0.50	**Mod** 0.57	**Mod** 0.64	**Mod** 0.58	**Mod** 0.59	**High** 0.46
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: The exposure as of 2014 for this shrubland system is moderate across nine of ten ecoregions, and at the moderate end of low in the tenth (Wasatch and Uinta Mountains).

Annual mean temperature has increased between 0.5° and 0.7°C across more than 10% of all ecoregions, and this increase was pervasive (>75%) within five ecoregions. Annual temperature increases are reflected in summer temperature increases of 0.6° to 0.7°C characterizing >50% of eight ecoregions. Changes in mean diurnal temperature range suggest increases in night-time lows are outpacing daytime highs, as temperature range decreased by 0.4° to 0.6°C across approximately 25% of three ecoregions.

Climate Change Effects: Climate change can affect vegetation communities by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks. In the southwestern U.S., including the southern Rocky Mountains and Colorado Plateau where this system is common, the average annual temperature is projected to continue to increase with more frequent droughts, and the annual snowpack and streamflow are predicted to decline (Garfin et al. 2014). *Quercus gambelii* is adapted to moderately dry environments; however, successful seedling establishment is correlated with consistently high presence of soil moisture (Neilson and Wullstein 1986, Simonin 2000d), which may become more intermittent in future requiring above-average annual precipitation years. This may significantly decrease seedling requirement on more xeric lower-elevation sites.

Under these conditions this shrubland system could expand at the expense of adjacent woodlands such as pinyon-juniper and ponderosa pine stands. With increasing average annual temperature the number and severity of wildfires and insect outbreaks is expected to increase (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). Stevens-Rumann et al. (2017) documented a decrease in post-fire forest and woodland resilience during 2000-2015 when compared to 1985-1999 interval. Post-fire conversion of forests to non-forest vegetation such as fire-adapted shrublands because of tree regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017). Many stands of this ecological system occur in foothill zone of taller mountain ranges so it may be possible for the characteristic species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was low to moderate, with four ecoregions accounting for 60% of the potential distribution of this type having moderate sensitivity, and six ecoregions scoring moderate. Sensitivity scores were driven by a combination of fire regime departure and landscape condition.

Contributions to sensitivity from landscape condition were variable, ranging from very high in the High Plains to high in the Southwestern Tablelands and Central Basin and Range ecoregions, and low in four ecoregions. Poorer landscape condition scores reflect areas where this type extends onto plains and lower-elevation slopes with urban and suburban development (e.g., Wasatch Front, Colorado Springs) as well as dryland agriculture. Away from urban areas, moderate condition scores are associated with mining, fragmentation from road networks, and livestock grazing disturbance.

Fire regime departure was high to moderate across this type, aside from the low departure scores in the Wyoming Basin. This reflects alteration of fire regime associated both with increased fire frequency resulting from invasive grasses at lower elevations and fire suppression at higher-elevation stands. Increased fire intervals can lead to succession to woodland conditions from invasion of *Pinus edulis, Juniperus osteosperma, Pinus ponderosa*, and *Pseudotsuga menziesii*, while increased fire frequency from flushes of invasive annual grasses can cause declines of recruitment for *Quercus gambelii*. Overall sensitivity from invasive annual grasses was low in all ecoregions.

Landscape fragmentation and fire regime departure have resulted in changes to the structure of these shrublands, leading to an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is moderate, with nine ecoregions accounting for 99% of the potential distribution of this type having moderate sensitivity, and one ecoregion scoring near the moderate end of high (High Plains ecoregion). This moderate adaptive capacity is related to low to very low scores for topoclimate variability. Although these shrublands can occur on steep slopes, they tend to occur in foothill and plateau regions where local climates vary little within short distances and limited options exist for species to move across these landscapes to adapt to changing climate conditions.

In terms of vulnerability related to functional group diversity, scores vary from moderate to high. This shrubland type scores high for pollinator diversity, but moderate in terms of seed dispersers (a key group for oaks) and moderate in terms of nitrogen fixers and perennial cool- and warm-season grasses. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this shrubland system scores in the moderate range of overall climate change vulnerability. This is primarily due to low adaptive capacity associated with low topoclimate diversity, which can interact with contributions to sensitivity from fire regime departure (both increases and decreases in frequency) and landscape condition.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 18. Climate change adaptation strategies relative to vulnerability scores for Rocky Mountain Gambel Oak-Mixed Montane Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soils, native seed dispersers, and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native grass and forb diversity and evaluate needs for restoring species providing other functional roles (cool season grasses, seed dispersers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, trends in soil moisture regime, and shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, trends in soil moisture regime, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.

Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson 1988, Barnett and Crawford 1994, Brown 1958, CNHP 2010, Christensen 1955, Clary and Tiedeman 1986, Comer et al. 2002, Comer et al. 2003*, Crawford et al. 2004, Drut et al. 1994, Elliott 2012, Ersch 2009, Garfin et al. 2014, Gregg and Crawford 2009, Harper et al. 1985, Johnston and Hendzel 1985, Kunzler and Harper 1980, Kunzler et al. 1981, LANDFIRE 2007a, McKell 1950, McKenzie et al. 2004, McKenzie et al. 2008, Neely et al. 2001, Neilson and Wullstein 1986, Price and Brotherson 1987, Rasmussen 1941, Ream 1960, Ream 1964, Rondeau 2001, Shepperd 1990, Shiflet 1994, Simonin 2000d, Stevens-Rumann et al. 2017, Tirmenstein 1999c, Tuhy et al. 2002, Westerling et al. 2006

CES306.822 Rocky Mountain Lower Montane-Foothill Shrubland

Figure 19. Photo of Rocky Mountain Lower Montane-Foothill Shrubland. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is found in the foothills, canyon slopes and lower mountains of the Rocky Mountains and on outcrops and canyon slopes in the western Great Plains. It ranges from southern New Mexico, extending north into Wyoming, and west into the Intermountain West region. These shrublands occur between 1500 and 2900 m elevation and are usually associated with exposed sites, rocky substrates, and dry conditions, which limit tree growth. It is common where *Quercus gambelii* is absent, such as the northern Colorado Front Range and in drier foothills and prairie hills. This system is generally drier than Rocky Mountain Gambel Oak-Mixed Montane Shrubland (CES306.818) but may include mesic montane shrublands where *Quercus gambelii* does not occur. *Cercocarpus montanus* dominates pure stands in parts of Wyoming and Colorado. Scattered trees or inclusions of grassland patches or steppe may be present, but the vegetation is typically dominated by a variety of shrubs, including *Amelanchier utahensis, Cercocarpus montanus, Purshia tridentata, Rhus trilobata, Ribes cereum, Symphoricarpos oreophilus*, or *Yucca glauca*. Grasses are represented as species of *Muhlenbergia, Bouteloua, Hesperostipa*, and *Pseudoroegneria spicata*. Fires play an important role in this system as the dominant shrubs usually have a severe die-back, although some plants will stump sprout. *Cercocarpus montanus* requires a disturbance such as fire to reproduce, either by seed sprout or root-crown sprouting. Fire suppression may have allowed an invasion of trees into some of these shrublands, but in many cases sites are too xeric for tree growth. In Wyoming, stands where *Cercocarpus montanus* is a component of mixed shrublands are placed in Northern Rocky Mountain Montane-Foothill Deciduous Shrubland (CES306.994).

Distribution: This system is found in the foothills, canyon slopes and lower mountains of the Rocky Mountains and on outcrops and canyon slopes in the western Great Plains. It ranges from southern New Mexico, extending north into Wyoming, and west into the Intermountain West region.

Nations: US

States/Provinces: AZ, CO, MT, NE, NM, SD, WY, ID, NV

CEC Ecoregions: Blue Mountains, Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Great Plains, High Plains, Southwestern Tablelands, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Chihuahuan Desert, Arizona/New Mexico Mountains

Primary Concept Source: NatureServe Western Ecology Team

Description Author: M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Cercocarpus montanus* dominates pure stands in parts of Wyoming and Colorado. Scattered trees or inclusions of grassland patches or steppe may be present, but the vegetation is typically dominated by a variety of shrubs, including *Amelanchier utahensis, Cercocarpus montanus, Purshia tridentata, Rhus trilobata, Ribes cereum, Symphoricarpos oreophilus*, or *Yucca glauca*. Grasses are represented as species of *Muhlenbergia, Bouteloua, Hesperostipa*, and *Pseudoroegneria spicata*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biotic Pollination; Species Diversity: Medium
Although a dominant shrub in this system such as *Cercocarpus montanus* and the graminoids are chiefly self- or wind-pollinated, other dominant shrubs (*Amelanchier utahensis, Fallugia paradoxa, Prunus virginiana, Purshia tridentata, Rhus trilobata, Ribes cereum, Rhus trilobata*, and

Symphoricarpos oreophilus) and most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for wildlife such as sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators, with birds important for certain species. Insects: Bees (*Apoidea*), butterflies and moths (*Lepidoptera*), wasps and ants (*Hymenoptera*), flies (*Diptera*) and beetles (*Coleoptera*). Vertebrates: hummingbirds (especially for red tubular flowers).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: High
Warm-season grasses are important in the southern range and cool-season grasses dominate the northern extent and higher elevation sites.

Cool-season graminoids: *Achnatherum hymenoides, Achnatherum lettermanii, Achnatherum nelsonii, Achnatherum pinetorum, Achnatherum scribneri, Bromus carinatus, Bromus inermis var. pumpellianus, Carex geophila, Carex geyeri, Carex inops ssp. heliophila*, *Carex rossii, Elymus elymoides, Elymus albicans, Elymus lanceolatus, Festuca arizonica, Koeleria macrantha, Leymus ambiguus, Leymus salinus, Piptatheropsis micrantha, Poa fendleriana, Poa secunda, Pseudoroegneria spicata*, and *Tridens muticus*.

Warm-season graminoids: *Andropogon gerardii, Aristida purpurea, Bouteloua curtipendula, Bouteloua gracilis, Pleuraphis jamesii, Muhlenbergia montana*, and *Schizachyrium scoparium*.

Keystone Species: Keystone species provide a vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this shrubland type.

Environment: This ecological system is found in the foothills, canyon slopes and lower mountains of the Rocky Mountains and on outcrops and canyon slopes in the western Great Plains. It ranges from southern New Mexico, extending north into Wyoming, and west into the Intermountain West region. These shrublands occur between 1500 and 2900 m elevation and are usually associated with exposed sites, rocky substrates, and dry conditions, which limit tree growth. It is common where *Quercus gambelii* is absent, such as the northern Colorado Front Range and in drier foothills and prairie hills.

Key Processes and Interactions: Fires play an important role in this system as the dominant shrubs usually have a severe die-back, although some plants will stump sprout. *Cercocarpus montanus* requires a disturbance such as fire to reproduce, either by seed sprout or root-crown sprouting. Fire suppression may have allowed an invasion of trees into some of these shrublands, but in many cases sites are too xeric for tree growth.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2810860). These are summarized as:

A) Early Development 1 All Structures (grass-dominated - 15% of type in this stage): Grass cover is 0-10%. Early succession, usually after moderately frequent stand-replacement fires; grasses and forbs dominant.

B) Mid Development 1 Closed (shrub-dominated - 15% of type in this stage): Shrub cover is 11-80%. Greater than 10% shrub cover (i.e., line intercept method) by weakly sprouting and seed-producing shrubs; grasses/forbs dominant in scattered openings.

C) Mid Development 1 Open (10% of type in this stage): Shrub cover is 0-10%, with grasses/forbs dominant in extensive openings.

D) Late Development 1 Open (10% of type in this stage): Shrub cover is 0-10%, with over-matured shrubs as patchy dominant overstory (e.g., in rock outcrops); grasses/forbs dominant in extensive openings.

E) Late Development 1 Closed (shrub-dominated - 50% of type in this stage): Shrub cover is 11-80%. Greater than 10% shrub cover; all age classes present but dominated by over-matured shrubs (e.g., in rocky draws).

Historically, this type may have been in a Fire Regime IV or II -- primarily moderate-interval (e.g., 20-50 years) stand-replacement fires in the shrub-dominated layer. Nearly all the dominant species in this BpS have the capability to resprout after disturbance (LANDFIRE 2007a, BpS 2810860).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this shrubland system include altered fire regime, fragmentation from roads and development near urban areas, mining, invasive species, livestock grazing disturbance or other human disturbances (CNHP 2010). These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed. Invasive exotic species such as *Bromus tectorum* can become abundant in disturbed areas and alter floristic composition and provide fine fuels that many increase fire frequency and severity beyond the natural range of variation.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 19** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 20, left**) and sensitivity (**Figure 20, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

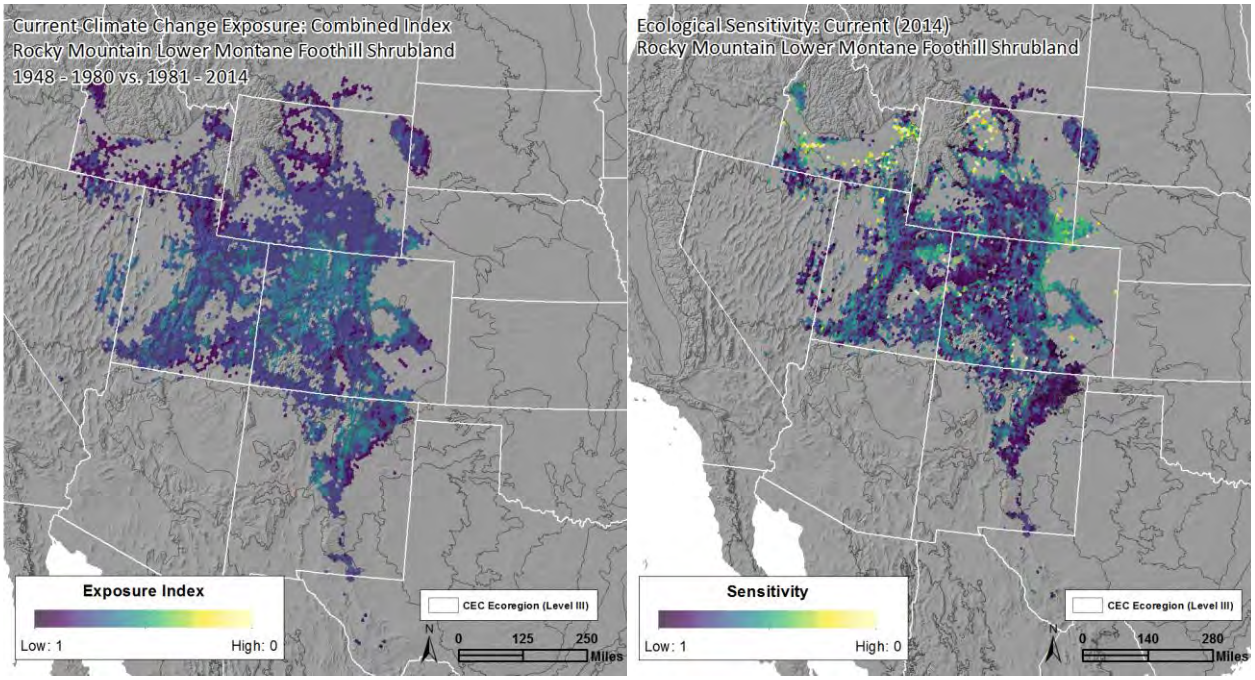

Figure 20. Climate exposure as of 2014 (left) and overall sensitivity (right) for Rocky Mountain Lower Montane-Foothill Shrubland. The results have been summarized and are displayed in 100km2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 19. Resilience, exposure and vulnerability scores for Rocky Mountain Lower Montane-Foothill Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Southern Rockies	Colorado Plateaus	Wyoming Basin	Wasatch & Uinta Mountains	High Plains	Southwestern Tablelands	Middle Rockies	Arizona-New Mexico Mountains	Arizona-New Mexico Plateau	Central Basin & Range	Northwestern Great Plains
	Potential square miles within ecoregion	1,326	500	303	298	237	222	60	55	52	29	20
Contributions to Relative Vulnerability by Factor												
Vulnerability from **Exposure (2014)**		**Mod** 0.71	**Mod** 0.71	**Mod** 0.71	**Mod** 0.71	**Mod** 0.68	**Mod** 0.69	**Low** 0.77	**Mod** 0.72	**Mod** 0.73	**Mod** 0.70	**Low** 0.80
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.66	0.63	0.74	0.65	0.30	0.60	0.70	0.89	0.70	0.69	0.81
	Fire Regime Departure	0.53	0.63	0.60	0.55	0.48	0.74	0.69	0.41	0.45	0.48	0.62
	Invasive Annual Grasses	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.73**	**0.75**	**0.78**	**0.73**	**0.60**	**0.78**	**0.80**	**0.77**	**0.72**	**0.72**	**0.81**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.38	0.38	0.35	0.48	0.21	0.17	0.38	0.39	0.29	0.44	0.35
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.44**	**0.44**	**0.42**	**0.49**	**0.36**	**0.33**	**0.44**	**0.45**	**0.40**	**0.47**	**0.42**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.58	**Mod** 0.60	**Mod** 0.60	**Mod** 0.61	**High** 0.48	**Mod** 0.56	**Mod** 0.62	**Mod** 0.61	**Mod** 0.56	**Mod** 0.59	**Mod** 0.62
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: The exposure as of 2014 for this shrubland system is moderate across nine of 11 ecoregions comprising 97% of the potential distribution of this type. Exposure was low in the Middle Rockies and Northwestern Great Plains ecoregions. Climate exposure tended to be greater at higher elevations.

Annual mean temperature has increased between 0.5° and 0.7°C across more than 20% of all ecoregions, and this increase was widespread (>50%) within seven ecoregions. Annual temperature increases are reflected in summer temperature increases of 0.6° to 0.7°C characterizing >40% of six ecoregions. Changes in mean diurnal temperature range suggest increases in night-time lows are outpacing daytime highs, as temperature range decreased by 0.4° to 0.6°C across approximately 10-25% of three ecoregions.

Climate Change Effects: Climate change can affect vegetation communities by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks. In the southwestern U.S., including the southern Rocky Mountains and Colorado Plateau where this system is common, the average annual temperature is projected to continue to increase with more frequent droughts, and the annual snowpack and streamflow are predicted to decline (Garfin et al. 2014). *Cercocarpus montanus* is adapted to relatively dry environments; however, successful seedling establishment is often correlated with adequate soil moisture (Gucker 2006e), which may become more intermittent in future requiring an above-average annual precipitation year. This may significantly decrease seedling requirement on more xeric lower elevation sites.

Under these conditions this shrubland system is likely to increase rangewide at the expense of adjacent woodlands such as pinyon-juniper and ponderosa pine stands. With increasing average annual temperature, the number and severity of wildfires and insect outbreaks is expected to increase (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). Stevens-Rumann et al. (2017) documented a decrease in post-fire forest and woodland resilience during 2000-2015 when compared to 1985-1999 interval. Post-fire conversion of forests to non-forest vegetation such as fire-adapted shrublands because of tree regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017). Many stands of this ecological system occur in foothill zone of taller mountain ranges so it may be possible for the characteristic species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was low to moderate, with five ecoregions accounting for 63% of the potential distribution of this type having moderate sensitivity, and six ecoregions scoring low. Sensitivity scores were driven by a combination of fire regime departure and landscape condition.

Contributions to sensitivity from landscape condition were variable. Although scores were moderate across most ecoregions, they ranged to highly vulnerable in the High Plains to low in the Middle Rockies and Northwestern Great Plains. Landscape condition scores reflect areas where this type extends into areas near population centers (Wasatch Front, eastern front of the Colorado Rocky Mountains) and extends to valleys and plains with fragmentation and alteration from dryland agriculture. Away from these areas, moderate condition scores are associated with fragmentation from road networks, mining, and livestock grazing disturbance.

Fire regime departure was moderate or at the moderate range of high across all ecoregions. This reflects alteration of fire regime associated both with increased fire frequency associated with invasive grasses at lower elevations, and fire suppression at higher-elevation stands. However, this shrubland type is relatively tolerant to altered fire regimes in that it tends to occur at sites unsuitable for succession to high tree cover (xeric with shallow soils), and dominant shrub species have the ability to resprout following fire. Overall sensitivity from invasive annual grasses was low in all ecoregions.

Landscape fragmentation has resulted in changes to the structure of these shrublands that may interact with altered fire regimes, leading to an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is moderate across ecoregions. This moderate adaptive capacity is related to low scores in nine ecoregions and very low scores in two (High Plains and Southwestern Tablelands) for topoclimate variability. Although these shrublands can occur across a range of topographic conditions, stands often occur in foothill and plateau regions where local climates vary little within short distances, and limited options exist for species to move across these landscapes to adapt to changing climate conditions.

In terms of vulnerability related to functional species group diversity, scores were moderate for pollinator diversity, which may increase vulnerability of dominant shrubs and key forbs to loss of pollinator species from effects of climate change or disturbance. A high level of diversity of cool- and warm-season graminoids is a characteristic of this system, and the different photosynthetic pathways of these grasses (C3 and C4) may provide for species able to respond to a range of changed climatic conditions. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this shrubland system scores in the moderate range of overall climate change vulnerability. This is primarily due to low adaptive capacity associated with low topoclimate diversity, which can interact with contributions to sensitivity from altered landscape condition and fire regime departure.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 20. Climate change adaptation strategies relative to vulnerability scores for Rocky Mountain Lower Montane-Foothill Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soils, native seed dispersers, and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native grass and forb diversity and evaluate needs for restoring species providing other functional roles (cool season grasses, seed dispersers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, trends in soil moisture regime, and shrub regeneration.

High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, trends in soil moisture regime, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barnett and Crawford 1994, CNHP 2010, Comer et al. 2003*, Crawford et al. 2004, Dick-Peddie 1993, Drut et al. 1994, Ersch 2009, Garfin et al. 2014, Gregg and Crawford 2009, Gucker 2006e, Hess 1981, Hess and Wasser 1982, Hoffman and Alexander 1987, Knopf et al. 1990, LANDFIRE 2007a, Marriott and Faber-Langendoen 2000, McKenzie et al. 2004, McKenzie et al. 2008, Mueggler and Stewart 1980, Muldavin 1994, Muldavin et al. 2000b, Neely et al. 2001, Rising 1996, Roughton 1972, Sedgwick and Knopf 1987, Shiflet 1994, Stevens-Rumann et al. 2017, Thilenius et al. 1995, Welsh et al. 2008, Westerling et al. 2006

2.C.5.Nd. North American Western Interior Brackish Marsh, Playa & Shrubland

M082. Warm & Cool Desert Alkali-Saline Marsh, Playa & Shrubland

CES304.780 Inter-Mountain Basins Greasewood Flat

Figure 21. Photo of Inter-Mountain Basins Greasewood Flat. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs throughout much of the western U.S. in intermountain basins and extends onto the western Great Plains and into central Montana. It typically occurs near drainages on stream terraces and flats or may form rings around more sparsely vegetated playas. Sites typically have saline soils, a shallow water table and flood intermittently, but remain dry for most growing seasons. The water table remains high enough to maintain vegetation, despite salt accumulations. This system usually occurs as a mosaic of multiple communities, with open to moderately dense shrublands dominated or codominated by *Sarcobatus vermiculatus*. In high salinity areas, greasewood often grows in nearly pure stands, and on less saline sites, it commonly grows with other shrub species and typically has a grass understory. Other shrubs that may be present to codominant in some occurrences include *Atriplex canescens, Atriplex confertifolia, Atriplex gardneri, Atriplex parryi,* *Artemisia tridentata ssp. wyomingensis, Artemisia tridentata ssp. tridentata, Artemisia cana ssp. cana*, or *Krascheninnikovia lanata*. Occurrences are often surrounded by mixed salt desert scrub or big sagebrush shrublands. The herbaceous layer, if present, is usually dominated by graminoids. There may be inclusions of *Sporobolus airoides, Pascopyrum smithii, Distichlis spicata* (where water remains ponded the longest), *Calamovilfa longifolia, Eleocharis palustris, Elymus elymoides, Hordeum jubatum, Leymus cinereus, Poa pratensis, Puccinellia nuttalliana*, or herbaceous types. In more saline environments, *Allenrolfea occidentalis, Nitrophila occidentalis*, and *Suaeda moquinii* may be present.

Distribution: This system occurs throughout much of the western U.S. in Intermountain basins and extends onto the western Great Plains.

Nations: US

States/Provinces: AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY, ND, SD, NE

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Northwestern Glaciated Plains, Northwestern Great Plains, High Plains, Southwestern Tablelands, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Chihuahuan Desert, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is characterized by typically open shrublands dominated or codominated by the deciduous, facultative halophytic shrub *Sarcobatus vermiculatus*. Associated species vary with salinity, alkalinity, substrates, and depth to ground water and may create a mosaic of types or form rings surrounding a saline basin, depending on environmental variables. Stands are frequently surrounded by less saline mixed salt desert scrub or big sagebrush shrublands. In higher salinity areas, greasewood often grows in nearly pure stands or with halophytes *Allenrolfea occidentalis, Atriplex gardneri, Nitrophila occidentalis*, or *Suaeda moquinii* present to codominant, often with the salt-tolerant grass *Distichlis spicata* present in the understory. In less saline, often alkaline sites, it commonly grows mixed with upland shrub species *Atriplex canescens, Atriplex confertifolia, Atriplex parryi, Grayia spinosa, Krascheninnikovia lanata*, or *Picrothamnus desertorum*. In non-saline sites, *Artemisia tridentata ssp. wyomingensis, Artemisia tridentata ssp. tridentata*, and *Artemisia cana ssp. cana* may be present to codominant, and in highly disturbed areas, such as sand deposits over playas, disturbance-tolerant species such as *Ericameria nauseosa, Chrysothamnus* spp., or *Gutierrezia sarothrae* are abundant. Herbaceous layers range from absent to a moderately dense canopy of medium-tall to short bunchgrasses or sod grasses (0-25% cover). Species include *Bouteloua gracilis, Distichlis spicata, Eleocharis palustris, Elymus elymoides, Hordeum jubatum, Juncus arcticus ssp. littoralis (= Juncus balticus), Leymus cinereus, Pascopyrum smithii, Poa secunda (= Poa juncifolia), Puccinellia nuttalliana*, or *Sporobolus airoides*. Sand deposit sites may have *Achnatherum hymenoides (= Oryzopsis hymenoides)* or other psammophiles. Perennial forbs are typically sparse and often include *Achillea millefolium, Artemisia ludoviciana, Astragalus* spp., *Chenopodium fremontii, Glycyrrhiza lepidota, Grindelia squarrosa, Iva axillaris, Opuntia polyacantha*, and/or *Sphaeralcea coccinea*. Exotic species can be abundant on disturbed weedy sites and include such species as *Bassia scoparia (= Kochia scoparia), Bromus arvensis (= Bromus japonicus), Bromus rubens, Bromus tectorum, Descurainia* spp., *Halogeton glomeratus, Helianthus annuus, Lactuca serriola, Lepidium perfoliatum*, and/or *Poa pratensis*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: Low
Composition would be similar to cold desert playas described in Belnap et al. (2001) and Rosentreter and Belnap (2003) on poorly drained soils. Cyanobacteria (4): *Microcoleus* spp., *Nostoc commune, Nostoc flagelliforme*, and *Dermatocarpon miniatum*. Lichens: *Lecanora muralis*.

Halophytes; Species Diversity: Medium
Species in this group are adapted to saline and alkaline soil conditions common in the Western U.S. and dominate on substrates derived from marine shales, in internally drained basins, and in coastal areas. Shrubs: *Sarcobatus vermiculatus* (primary), *Allenrolfea occidentalis*, and *Suaeda moquinii*. Herbaceous: *Distichlis spicata, Nitrophila occidentalis*, and *Sporobolus airoides*.

Nitrogen Fixation; Species Diversity: Low
Greasewood shrublands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These shrublands typically have low to moderate herbaceous cover and low diversity. Species of Fabaceae (including species of *Astragalus*), some Poaceae (*Sporobolus airoides, Pascopyrum smithii, Distichlis spicata*), and a few Brassicaceae can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include species of *Nostoc*, such as *Nostoc commune* and *Nostoc flagelliforme* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa is moderate; however, within stand species diversity of nitrogen fixers is typically low.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this greasewood shrubland type.

Environment: This ecological system occurs throughout much of the intermountain western U.S. from the Mojave Desert and extends onto the western Great Plains and into central Montana. Elevation ranges from 100 to 2400 m. *Sarcobatus vermiculatus* commonly occurs in areas with a seasonally high-water table and is often the only green shrub in pluvial desert sites with available groundwater.

Climate: This system is tolerant of a wide range of climatic conditions: warm or cool, temperate, semi-arid and continental, but is most abundant in areas with hot, dry summers. Average annual precipitation ranges from 12.7 to 25.4 cm (5-10 inches).

Physiography/landform: Stands occur on dry, sunny, flat valley bottoms, on lowland floodplains, in ephemeral stream channels, at playa margins, on slopes and in sand dune complexes. Greasewood communities generally occur at lower elevations than moister sagebrush or shadscale zones. In high saline areas, greasewood often grows in nearly pure stands, although on less saline sites, it commonly grows with other shrub species and typically has a grass understory. It typically occurs near drainages on stream terraces and flats or may form rings around more sparsely vegetated playas. Some *Sarcobatus vermiculatus* stands occur on sandsheets when associated with a shallow water table such as near the Great Sand Dunes National Park and Preserve in Colorado.

Soil/substrate/hydrology: Sites typically have saline/alkaline soils, with a shallow or perched water table and flood intermittently, seasonally to semipermanently (West 1983b). The water table is usually within 5 m of surface, generally well within the root zone of greasewood and saltbush (Donovan et al. 1996). Sites can become dry for much of the growing season, or remain saturated due to poor drainage; however, the water table generally remains high enough to maintain vegetation, which can thrive despite salt accumulations (West 1983b, Knight 1994). Stands occur on floodplains, along the margins of perennial lakes, and in alkaline closed basins with low-gradient shorelines. Substrates are fine-textured saline or alkaline soils, or occasionally coarse-textured non-saline soils (USU 2002). Greasewood flats are typically subirrigated and rarely have open water except when associated with playas. As the water evaporates, salinity increases, affecting the biota.

Key Processes and Interactions: Greasewood flats are tightly associated with saline soils and groundwater that is near the surface. The primary ecological process that maintains greasewood flats is groundwater recharge, rather than surface water. *Sarcobatus vermiculatus* is a wetland obligate phreatophyte that tap into groundwater generally at less than 5 m, but taproots may reach great depth (>10 m). Hansen et al. (1995) reported that it can tolerate saturated soil conditions for up to 40 days. Like many facultative halophytes, greasewood is tolerant of alkaline and saline soil conditions that allow the species to occur in sites with less interspecific competition (Ungar et al. 1969, Branson et al. 1976).

Floristic variation within *Sarcobatus vermiculatus*-dominated vegetation varies with depth to water table, salinity and alkalinity, soil texture, and past land use or disturbance. Hanson (1929) described stands in south-central Colorado and found that pure stands of *Sarcobatus vermiculatus* and *Distichlis spicata* are more common on strongly saline/alkaline sites with fine-textured soil and shallow water tables, whereas stands with mixed shrubs such as *Chrysothamnus* or *Artemisia* are more common on drier, coarser-textured, low-alkaline sites. Understory dominated by *Sporobolus airoides* is found on dry, strongly alkaline sites, while stands dominated by *Pascopyrum smithii* are more common on less alkaline, moist sites in low-lying areas. The degree of salinity can vary seasonally as well as from year to year. During exceptionally wet years, the salt concentration drops, allowing less salt-tolerant species to appear, such as cattails (*Typha* spp.) or bulrushes (*Scirpus* and/or *Schoenoplectus* spp.) (Knight 1994). Some areas only flood during wet years, sometimes only once or twice in a decade. Others will have standing water every spring, except in the driest of years. As stands dry out, strong evaporation concentrates salt in the soils.

Fires are uncommon in this system because many stands are open and lack a continuous fuel layer (Sawyer et al. 2009). Severe hot fires can kill *Sarcobatus vermiculatus*, while after low- to moderate-severity fire it commonly sprouts after being top-killed (Anderson 2004b). Vigorously sprouting following fire can increase growth and stem density, growing up to 0.76 m (2.5 feet) in height within three years, with 90% of the plants surviving one year after burning (Daubenmire 1970, Anderson 2004b, Sawyer et al. 2009). Fire regime for greasewood communities is reported as generally less than a 100-year return interval (Anderson 2004b) although LANDFIRE (2007a) applied fire regime V (200+ years) and treated fire as a minor ecological driver within this system.

LANDFIRE (2007a) VDDT model for this system (BpS 2311530) has three classes:

A) Early Development 1 All Structures (5% of type in this stage): Shrub cover is 10-20%. Some grasses, with greasewood sprouts present. Some representation of other sprouting species may be present (creosotebush, rabbitbrush). Grass species vary geographically but include the following for Utah and Nevada: inland saltgrass, bottlebrush squirreltail, Sandberg bluegrass and alkali sacaton. Succession to class B after two years.

B) Mid Development 1 Open (30% of type in this stage): Shrub cover (21-60%): Greasewood shrubs are maturing, with a good mix of perennial grasses. Other shrub species that may be found with greasewood include creosotebush and rabbitbrush, and in transition zones to Mojave Desert, it may occur with various sagebrush species and salt desert shrub vegetation (shadscale, saltbushes, winterfat, budsage and spiny hopsage). Greasewood communities would stay in this class for 3-20 years, then succeed to class C. Vegetation will revert to class A with flooding (mean return interval of 75 years) or replacement fire (mean FRI of 200 years).

C) Late Development 1 Closed (65% of type in this stage): Shrubs (41-70%): Greasewood shrubs have reached maturity and will increase canopy closure. Perennial grasses will still be in the understory. Vegetation will revert to class A with replacement fire (mean FRI of 200 years). Flooding (mean return interval of 75 years) causes two transitions: to class A (50% of the time) or to class B (50% of the time).

There was some question in the model about whether flooding in class C (late-development) would send the entire system back to class A (early-development), or Class B (mid-development). As a compromise, flooding was attributed to take both pathways with equal probability.

ECOLOGICAL INTEGRITY

Change Agents: The major land uses that alter the natural processes of this system are associated with alteration of hydrology, livestock practices, annual exotic species invasion, fire regime alteration, and fragmentation (WNHP 2011). Any activity resulting in hydrological alterations, sedimentation, nutrient inputs, and/or physical disturbance may negatively shift species composition and allow for non-native species establishment. Declining water tables create perennially dry soils, stop surface salt accumulation, and allow salts to leach deeper and create a drier, less saline soil resulting in a change in vegetation composition and pattern (Cooper et al. 2006).

Although *Sarcobatus vermiculatus* is not ordinarily browsed by livestock, Daubenmire (1970) found that under heavy stocking rates, the shrubs will develop a compact canopy. Hansen et al. (1995) also reported browsing damage with heavy spring and summer grazing. *Sarcobatus vermiculatus* is noted to be important winter browse for domestic sheep, cattle, big game animals, as well as jackrabbits (Hanson 1929, Anderson 2004b). The shrub provides quality forage throughout the growing season although it contains soluble sodium and potassium oxalates that may cause poisoning and death in domestic sheep and cattle when it makes up too much of their diet (Anderson 2004b). Livestock grazing is reported to decrease small mammal numbers in *Sarcobatus vermiculatus / Distichlis spicata (= Distichlis stricta)* vegetation in Nevada and adjacent California (Page et al. 1978). *Distichlis spicata* is considered a grazing increaser. Grazing early when the upper part of the soil may be wet can sometimes cause compaction (WNHP 2011). Grazing and other disturbances can lead to biomass increases in the spring associated with an increase in *Bromus tectorum* and other fine fuel annuals which influence fire regime (Brown and Smith 2000).

The presence of invasive, exotic plant species such as *Acroptilon repens, Cardaria draba, Centaurea diffusa, Centaurea stoebe, Euphorbia esula, Lepidium latifolium, Linaria vulgaris*, and *Tamarix* spp. reduces habitat quality for numerous wildlife species, decreases forage for livestock, reduces ecosystem native species richness, increases soil erosion potential and decreases ecosystem resiliency and resistance to damage from impacts, including climate change. These non-native invasive species decrease the abundance of shorter native grasses and forbs and have the potential to alter structure and composition if they become dominant. The introduction of *Bromus tectorum* and other annual exotic species into these shrublands has altered fuel loads and fuel distribution allowing for increased fire frequency and severity (Anderson 2004b). Fire drastically alters the community composition because salt-desert shrubs are not adapted to periodic fire (WNHP 2011).

Human development has impacted many locations throughout the range of this system resulting in altered hydrologic regimes, fragmentation, altered fire regime, increased non-native plant species which reduces habitat quality for numerous wildlife species, decreases forage for livestock, reduces ecosystem native species richness, increases soil erosion potential and decreases ecosystem resiliency and resistance to damage from impacts, including climate change.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 21** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 22, left**) and sensitivity (**Figure 22, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

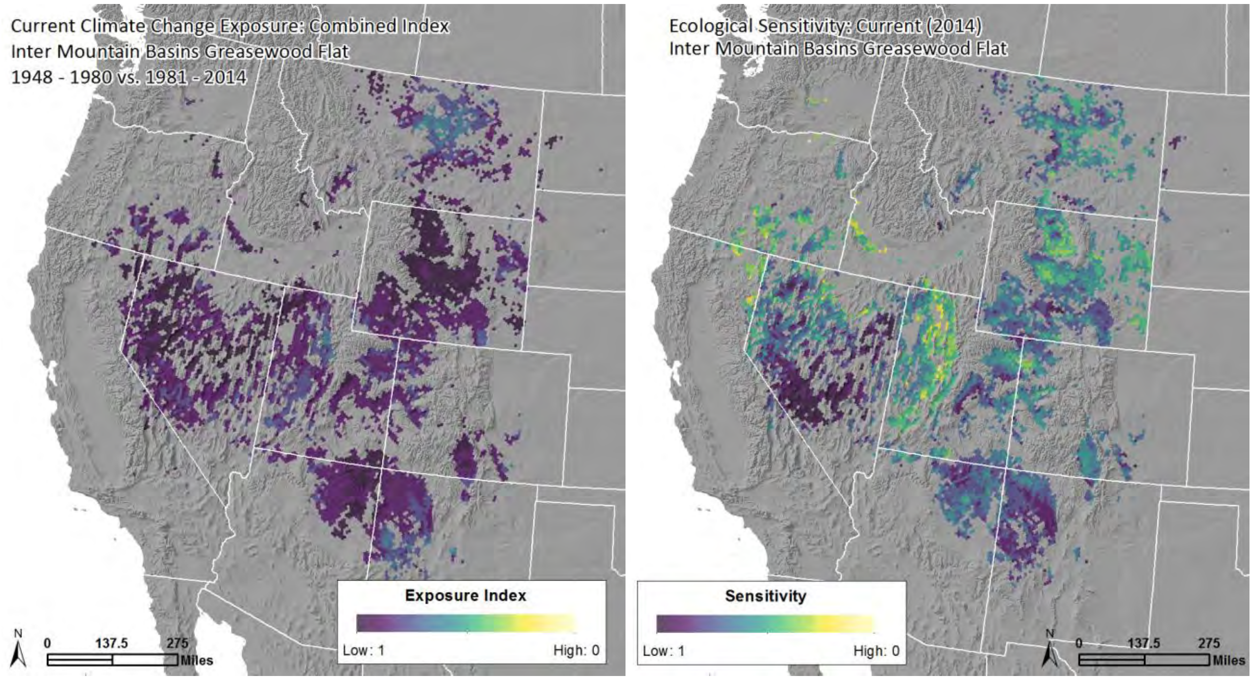

Figure 22. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Greasewood Flat. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 21. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Greasewood Flat by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Central Basin & Range	Arizona -New Mexico Plateau	Colorado Plateaus	Wyo-ming Basin	Northern Basin & Range	North-wester n Great Plains	North-western Glaciate d Plains	Eastern Cascades Slopes & Foothills	Middle Rockies	South-western Table-lands	Snake River Plain	Arizona -New Mexico Moun-tains	Wasatch & Uinta Moun-tains	South-ern Rockies	High Plains	Blue Moun-tains	Mojave Basin & Range	Columbia Plateau
	Sq miles within ecoregion	12,117	3,633	1,933	1,560	1,543	991	336	202	146	144	130	84	82	65	60	49	39	21
Contributions to Relative Vulnerability by Factor																			
Vulnerability from **Exposure (2014)**		**Mod** 0.62	**Mod** 0.62	**Mod** 0.61	**Mod** 0.65	**Mod** 0.64	**Mod** 0.61	**Mod** 0.59	**Mod** 0.66	**Mod** 0.64	**Mod** 0.59	**Mod** 0.65	**Mod** 0.59	**Mod** 0.61	**Mod** 0.62	**Mod** 0.68	**Mod** 0.68	**Mod** 0.60	**Mod** 0.63
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.64	0.63	0.41	0.66	0.56	0.59	0.46	0.38	0.19	0.62	0.15	0.72	0.26	0.54	0.25	0.09	0.65	0.15
	Fire Regime Departure	0.61	0.54	0.55	0.44	0.48	0.55	0.57	0.22	0.88	0.45	0.18	0.50	0.36	0.51	0.63	0.54	0.81	0.20
	Invasive Annual Grasses	0.86	0.98	0.90	0.86	0.50	0.64	0.90	0.63	0.98	1.00	0.79	1.00	0.99	0.98	0.52	0.87	0.69	0.75
	Sensitivity Average	**0.70**	**0.71**	**0.62**	**0.65**	**0.51**	**0.59**	**0.64**	**0.41**	**0.69**	**0.69**	**0.38**	**0.74**	**0.54**	**0.68**	**0.47**	**0.50**	**0.71**	**0.37**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.09	0.14	0.20	0.18	0.08	0.14	0.09	0.10	0.18	0.12	0.12	0.24	0.17	0.26	0.11	0.07	0.14	0.07
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.12**	**0.15**	**0.18**	**0.17**	**0.12**	**0.15**	**0.12**	**0.13**	**0.17**	**0.14**	**0.14**	**0.20**	**0.16**	**0.21**	**0.13**	**0.11**	**0.15**	**0.11**
Vulnerability from Measures of **Overall Resilience**		**High** 0.41	**High** 0.43	**High** 0.40	**High** 0.41	**High** 0.32	**High** 0.37	**High** 0.38	**High** 0.27	**High** 0.43	**High** 0.41	**High** 0.26	**High** 0.47	**High** 0.35	**High** 0.44	**High** 0.30	**High** 0.31	**High** 0.43	**Very High** 0.24
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**High**	**High**	**High**	**High**	**Mod**	**Mod**	**High**	**Mod**	**High**	**Mod**	**High**	**High**	**Mod**	**High**

Exposure Summary for 1981-2014 Timeframe: Across the distribution of this widespread shrubland system, exposure as of 2014 is moderate but does show some variation across ecoregions. An emerging pattern of changing climate appears in the Central Basin and Range, Arizona/New Mexico Plateau and Wyoming Basin ecoregions, where this system is most common, as increases of 0.55° to 0.67°C for Annual Mean Temperature for 54% to 82% of its distribution. In the other ecoregions where it is less common, similar increases are seen (up to 1°C of increase) over 45% of its distribution in those ecoregions. There are similar increases (up to 0.82°C) for Mean Temperature of the Warmest Quarter in three of the ecoregions where this system occurs for >40% to 89% of its distribution in those ecoregions.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating greasewood recruitment. Indirect effects of a warming climate with more frequent droughts could lower the shallow water table that these shrubs depend on causing widespread mortality. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate to low (higher scores) across the range of this type, but even in ecoregions scoring as low sensitivity (e.g., Central Basin and Range or Middle Rockies), the scores approach moderate. Sensitivity scores are particularly low (equating to higher sensitivity) in the Snake River Plain, Eastern Cascades, High Plains, Blue Mountains, and Columbia Plateau ecoregions, due to the combination of extensive agriculture and development fragmenting occurrences and altered fire regimes.

Landscape condition is generally moderate to poor (more development, lower scores); only in two ecoregions is landscape condition good (higher scores). Agriculture is likely to be a major factor for the poor landscape condition, since these greasewood communities occur in valley bottoms with high water tables, areas suitable for agriculture if ground-water pumping is employed. In all ecoregions, there are many small roads that fragment occurrences, along with many areas of urban, suburban and exurban development, especially along the Wasatch Front of Utah and in most areas of Colorado.

Risk of invasive grasses in this system is most pronounced in the Northern Basin and Range, Eastern Cascades, Northwestern Great Plains and High Plains ecoregions (**Figure 22**); these ecoregions include large areas of cheatgrass or other exotic grasses invasion. Elsewhere the risk of invasives grasses tends to be low. The low invasives risk may be a function of the high salinity of the soils which exclude non-saline-tolerant grass species. However, invasions of greasewood communities by exotic forb species is a known problem and those species are not represented in the invasive model used in this study.

Fire regime departure is moderate to high (indicated by lower scores); only 2 of the 18 ecoregions have low departure. Where invasive annual grasses are common, the departure can be explained by encroachment of these into greasewood stands, especially as water tables drop, shrub mortality increases and salts are leached deeper into the soils, which in turn allows these grasses to become abundant. This in turn allows fire to spread into greasewood stands under appropriate conditions. The increasing abundance of exotic forbs combined with mortality of the shrubs due to lowered water tables could also explain the moderate to high departure in areas where the annual grasses are less common.

The interactions of the stressors of fragmentation by development, hydrologic alterations, grazing, and invasive annual grass or exotic forb invasion have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across the entire range of this system. Both topoclimatic variability and diversity within functional species groups contribute to the low adaptive capacity. Topoclimatic variability is low, as these shrublands occur across generally flat landforms and topography such as valley bottoms, playas, and on the edges of floodplain terraces. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within two of the three identified functional species groups is also low. Within individual stands, nitrogen fixation is provided by only a few species and so their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability. Species of lichens and cyanobacteria that contribute to stabilizing soil crusts also have low within stand diversity. Halophytic species are adapted to saline or alkaline soil chemistry; greasewood is tolerant of alkaline and saline soil conditions that allow the species to occur or dominate in sites with less interspecific competition. Diversity within the halophytes functional group is moderate in this system.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Greasewood Flats score just into the moderate to high range of overall climate change vulnerability throughout its range. This is primarily due to their low scores for adaptive capacity, followed by moderate scores for exposure, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity cold desert types that naturally occupy extensive flat plains and valley bottoms. For a given increment of climate change, individual species would need to disperse longer distances per year as compared with those that occur in more rugged landscapes that naturally support higher microclimate diversity. Additionally, Greasewood Flats are dependent on shallow groundwater levels and are highly susceptible to invasive plants. Therefore, common effects of land use throughout the West, including groundwater pumping, surface disturbance from roads, and wildfire-induced expansion of invasive plant species, all have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type, especially for sensitivity measures that vary based on land use history across the range of the type. Below some of the major kinds of strategies that might be considered for this type are characterized.

Table 22. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Greasewood Flat

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Avoid alterations that could affect seasonal hydrology and limit impacts to ground-water. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (nitrogen fixers, etc.). Localize models for wildfire/hydrologic regimes and restore regimes where they have been severely altered from past groundwater pumping and diversions and/or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation, such as from mixed salt-desert scrub. Restore native herbaceous diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and other effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for hydrologic and/or wildfire regimes suitable to foreseen conditions of upcoming decades.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from native species from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Anderson 2004b, Belnap 2001, Belnap et al. 2001, Branson et al. 1976, Brown and Smith 2000, CNHP 2010, Comer et al. 2003*, Cooper et al. 2006, Daubenmire 1970, DeVelice and Lesica 1993, DeVelice et al. 1995, Donovan et al. 1996, Hansen et al. 1995, Hanson 1929, Knight 1994, LANDFIRE 2007a, Mozingo 1987, Page et al. 1978, Rosentreter and Belnap 2003, Sawyer et al. 2009, Shiflet 1994, USU 2002, Ungar et al. 1969, WNHP 2011, WNHP unpubl. data, West 1983b

3.A.2.Na. North American Warm Desert Scrub & Grassland

M086. Chihuahuan Desert Scrub

CES302.731 Chihuahuan Creosotebush Desert Scrub

Figure 23. Photo of Chihuahuan Creosotebush Desert Scrub. Photo credit: Patrick Alexander, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/aspidoscelis/

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This matrix ecological system is the common lower elevation *Larrea tridentata*-dominated desert scrub that occurs throughout much of the Chihuahuan Desert and has recently expanded into former lower elevation desert grasslands in the northern portion of its range. Stands typically occur in flat to gently sloping desert basins and on alluvial plains, extending up into lower to mid positions of piedmont slopes (bajada). Substrates range from coarse-textured loams on gravelly plains to finer-textured silty and clayey soils in basins. Soils are alluvial, typically loamy and non-saline, and frequently calcareous as they are often derived from limestone, and to a lesser degree igneous rocks. The vegetation is characterized by a moderate to sparse shrub layer (<10% cover on extremely xeric sites) that is typically strongly dominated by *Larrea tridentata* with *Flourensia cernua* often present to codominant. A few additional shrubs or succulents may also be present, such as *Agave lechuguilla, Parthenium incanum, Jatropha dioica, Koeberlinia spinosa, Lycium* spp., and *Yucca* spp. Additionally, *Flourensia cernua* can often be abundant and the sole dominant in silty basins which are included in this ecological system. In general, shrub diversity is low as this ecological system lacks thornscrub and other mixed desert scrub species that are common on the gravelly mid to upper piedmont slopes. However, on deeper soils and along minor drainages, shrub diversity and cover may increase with occasional *Atriplex canescens,* *Gutierrezia sarothrae*, or *Prosopis glandulosa*. Herbaceous cover is usually low and composed of grasses. Common species may include *Bouteloua eriopoda, Dasyochloa pulchella, Muhlenbergia porteri, Pleuraphis mutica, Scleropogon brevifolius*, and *Sporobolus airoides*. Included in this ecological system are *Larrea tridentata*-dominated shrublands with a sparse understory that occur on gravelly to silty, upper basin floors and alluvial plains. A pebbly desert pavement may be present on the soil surface.

Distribution: This extensive, lower elevation desert scrub ecological system occurs in the Chihuahuan Desert in broad desert basins and alluvial plains extending up into the lower bajada.

Nations: MX, US

States/Provinces: AZ, MXCH, MXSO?, NM, TX

CEC Ecoregions: High Plains, Southwestern Tablelands, Edwards Plateau, Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest, Arizona/New Mexico Plateau, Sonoran Desert, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz, L. Elliott and J. Teague

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This desert scrub is common on alluvial plains and is characterized by a moderate to sparse shrub layer (<10% cover on extremely xeric sites) that is typically strongly dominated by *Larrea tridentata* with *Flourensia cernua* often present to codominant (Brown 1982, MacMahon and Wagner 1985, Henrickson and Johnston 1986, MacMahon 1988, Dick-Peddie 1993). A few scattered shrubs or succulents may also be present such as *Agave lechuguilla, Parthenium incanum, Jatropha dioica, Koeberlinia spinosa, Lycium* spp., and *Yucca torreyi*. Additionally, *Flourensia cernua* will often strongly dominate in silty basins that are included in this ecological system. In general, shrub diversity is low as this ecological system lacks codominant thornscrub and other mixed desert scrub species that are common on the gravelly mid to upper piedmont slopes. However, shrub diversity and cover may increase locally where soils are deeper and along minor drainages with occasional *Atriplex canescens, Gutierrezia sarothrae, Parthenium incanum, Acacia constricta*, or *Prosopis glandulosa*. In Texas, succulents such as *Fouquieria splendens, Agave lechuguilla, Yucca torreyi, Opuntia* spp., and *Echinocereus* spp. may be conspicuous on particularly hot desert sites at low elevations. In the southern Chihuahuan Desert, stands are dominated by *Larrea tridentata* with *Agave parryi (= Agave scabra), Cylindropuntia kleiniae (= Opuntia kleiniae), Cylindropuntia imbricata (= Opuntia imbricata)*, and *Yucca filifera* (Huerta-Martinez et al. 2004). Herbaceous cover is usually low and composed of grasses. Common species may include *Bouteloua eriopoda, Dasyochloa pulchella (= Erioneuron pulchellum), Muhlenbergia porteri, Pleuraphis mutica, Scleropogon brevifolius*, and *Sporobolus airoides*. Included in this ecological system are *Larrea tridentata*-dominated shrublands with a sparse understory that occur on gravelly to silty, upper basin floors and alluvial plains. A pebbly desert pavement may be present on the soil surface.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soil crust plays many functions of holding the soil in place, retaining moisture, adding nutrients, and increasing the biodiversity at the species level. Biotic crusts increase the overall ecosystem productivity and provide micro-habitats for many small mammal and insect species. Chihuahuan Desert BSC diversity is based on Rosentreter and Belnap (2003). Species reflect the fact that soils are derived mostly (80%) from calcareous parent materials (limestone) with remaining soils

derived from volcanic materials. The dominance of calcareous soils results in higher diversity of lichens. Cyanobacteria (9): *Microcoleus vaginatus* is dominant, plus *Microcoleus paludosus, Nostoc commune, Oscillatoria* sp., *Phormidium* sp., *Plectonema nostocorum, Schizothrix californica, Schizothrix lamyi*, and *Scytonema hofmannii*. Lichens (13): *Collema coccophorum, Collema tenax, Catapyrenium squamulosum, Heppia lutosa, Peltula obscurans, Peltula richardsii* and *Clavascidium lacinulatum* dominate with *Psora rubiformis, Psora decipiens, Fulgensia desertorum, Fulgensia bracteata, Heppia* sp., and *Toninia sedifolia* common. Algal diversity is lower in warm desert regions with 8 common species: *Astasia* sp., *Chlorella* sp., *Chlorococcum* sp., *Fritschiella* sp., *Gonium* sp., *Navicula* sp., *Palmogloea protuberans*, and *Porphyrosiphon fuscus*. Common mosses (8+) include *Bryum* spp., *Crossidium aberrans, Ceratodon purpureus, Pseudocrossidium crinitum, Pterygoneurum ovatum, Syntrichia ruralis, Tortula atrovirens*, and *Weissia* spp. Common liverworts (2) include *Plagiochasma rupestre* and *Reboulia hemisphaerica*.

Biotic Pollination; Species Diversity: High
The dominant shrub *Larrea tridentata* is pollinated by insects. Cane et al. (2000) reported on insects captured in a creosotebush stand at Silverbell IBP site from 1994-1998. Results included 8 species of *Larrea tridentata* specialists and 22 other bees, many such as *Apis mellifera*, likely also pollinate *Larrea tridentata*. Insects: (*Larrea* specialists): *Ancylandrena larreae, Colletes clypeonitens, Colletes covilleae, Hesperapis larreae, Hoplitis biscutellae, Megandrena enceliae, Perdita punctulata*, and *Trachusa larreae*.

Nitrogen Fixation; Species Diversity: Low
Nitrogen fixers play an important role of providing nitrogen in a useable form to plants in ecosystems where usable nitrogen is limited. Nitrogen is a key element for plant growth and must be available in proportion with other nutrients for plant growth and vigorous productivity. Creosotebush shrublands occur in warm, arid and semi-arid climates often on substrates where soil nutrients such as nitrogen can be a significant constraint on plant growth (Schlesinger et al. 2006). These arid shrublands typically have low herbaceous cover and low diversity. Species of Fabaceae (*Acacia, Mimosa, Prosopis*), several Poaceae (*Bouteloua eriopoda, Bouteloua gracilis, Bouteloua ramosa, Dasyochloa pulchella, Muhlenbergia porteri, Pleuraphis mutica*, and *Scleropogon brevifolius*), and some Brassicaceae can fix nitrogen in this system. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Nostoc* and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa may be moderate; however, within stand species diversity of nitrogen fixers is typically low.

Xerophytes; Species Diversity: Low
Species in this group are adapted to frequent and extended drought and have evolved abilities and mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Larrea tridentata, Flourensia cernua*, and *Parthenium incanum*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this desert scrub type.

Environment: *Climate:* Climate is semi-arid to arid with annual precipitation ranging from 200-250 mm that falls mostly in the summer. Summers are hot and winters can be cold with freezing temperature occurring in the northern extent.

Physiography/landform: This ecological system is the common lower elevation desert scrub that occurs throughout much of the Chihuahuan Desert and has recently expanded into former desert grasslands in the northern portion of its range. Elevation ranges from 1000-2000 m. Stands typically occur in flat to gently sloping, desert basins and on alluvial plains, extending up into the lower to mid positions of piedmont slopes (bajada), sometimes on colluvium.

Soil/substrate/hydrology: Substrates range from coarse-textured loams on gravelly plains to finer-textured silty and clayey soils in basins. Soils are alluvial, typically loamy and non-saline, and frequently calcareous as they are often derived from limestone, and to a lesser degree igneous rocks (Brown 1982a, MacMahon and Wagner 1985, Henrickson and Johnston 1986, MacMahon 1988, Dick-Peddie 1993). In Texas, this system typically occurs on flat and gently rolling landforms, often on gravelly alluvial plains, outwash plains and intermountain basins. A pebbly desert pavement may be present on the soil surface.

Key Processes and Interactions: This is a stable ecosystem that is well suited to the hot, very dry basins and low hills where it occurs. The dominant and diagnostic species, *Larrea tridentata*, is a very long-lived species (some clones have been estimated to be over 10,000 years old). It is highly adapted to minimized evapotranspiration both daily and seasonally using stomatal regulation, resinous leaves, and a leaf structure and habit to minimize self-shading and maximize photosynthesis during favorable growing periods (Hamerlynck et al. 2002, Ogle and Reynolds 2002). *Larrea tridentata* is poorly adapted to fire because of its highly flammable, resinous leaves and limited sprouting ability after burning, although it may survive lower-intensity fires (Humphrey 1974, Brown and Minnich 1986, Marshall 1995, Paysen et al. 2000). McLaughlin and Bowers (1982) reported that burned individuals surviving a fire regained their former size in five years.

Historic fire regimes for Chihuahuan Creosotebush Desert Scrub are difficult to quantify but fires were rare with a fire-return interval (FRI) ranging from 300-1000 years and 500 years on average (from LANDFIRE BpS Model 2510740). The fire characteristics range from low- to moderate- to high-intensity, moderate-severity, stand-replacing crown fires that occur during spring, summer and fall seasons. Fires tend to be small or medium in size and need unusual conditions (e.g., a drought following an unusually wet year so there are adequate fine fuels that are available to carry a fire) (Brown and Minnich 1986, Paysen et al. 2000).

Weather stress such as drought also affects this community by reducing vegetation cover (especially grasses) every 80 years or so but does cause significant shrub mortality although shrubs may die back some (from LANDFIRE BpS Model 2510740) (Humphrey 1974). Drought is a relatively common occurrence in this desert scrub, generally occurring every 10-15 years and lasting 2-3 years with occasional long-term drought periods (10-15 years duration). *Larrea tridentata* and other shrubs have extensive root systems that allow them to exploit deep-soil water that is unavailable to shallower rooted grasses and cacti (Burgess 1995).

Biotic pollination by bees is important for creosotebush (Cane et al. 2000). Seed dispersal is primarily by wind and gravity as fruits are adapted for tumbling (Maddox and Carlquist 1985). However, seed burial by rodents may improve germination and survival of creosotebush (Chew and Chew 1970) so biotic dispersal may enhance regeneration especially in undisturbed, smooth desert pavement areas where seed burial is unlikely. Most seed germination requires between 80-150 mm (3-6 inches) of summer precipitation (Marshall 1995).

Herbivory by native herbivores in Chihuahuan Creosotebush Desert Scrub includes small mammals, reptiles and invertebrates. *Larrea* leaves are not edible to most animals; however, seeds are eaten by many small mammals (Paysen et al. 2000).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 2510740):

A) Early Development 1 All Structures (15% of type in this stage): Under natural conditions shrub cover generally represents <10% canopy cover and is likely not effected by disturbance. The grass community may be as low as 10% canopy cover after a combination of drought and fire. Little disturbance was considered in class A, modeled drought every 50 years on average keeping the class in A (option 2). In the historic condition where invasive annual grasses are absent, the fire-return interval is virtually nonexistent except for areas near the base of mountains experiencing locally higher rainfall and fine fuel buildup. After 100 years, class A transitions to class B. However, if the upper soil horizon and/or microbes are lost, then a longer recovery time is required. Or complete recovery is not possible.

B) Late Development 1 Open (85% of type in this stage): Typically <30% shrub canopy cover. Replacement fire followed by prolonged drought every 500 years (min-max: 300-1000 years) on average (Option 1). Wind/weather stress also affected this community on average every 80 years but did not cause a transition to class A. Class B is likely over-represented on the landscape today.

ECOLOGICAL INTEGRITY

Change Agents: Although Chihuahuan Creosotebush Desert Scrub is a widespread ecosystem that has increased in abundance at the expense of native desert grasslands, it is sensitive to altered fire regimes caused by invasive species, as well as anthropogenic disturbance such as mechanical/chemical shrub removal. Currently much of the extent in the U.S. of this desert scrub is the result of recent expansion of *Larrea tridentata* into former desert grasslands in the last 150 years from the combined effects of drought, overgrazing by livestock, and/or decreases in fire frequency over the last 70-250 years (Buffington and Herbel 1965, Ahlstrand 1979, Donart 1984, Dick-Peddie 1993, Gibbens et al. 2005). This system now includes vast areas of loamy plains that have been converted from *Pleuraphis mutica* and *Bouteloua eriopoda* desert grasslands to *Larrea tridentata* scrub. This system also includes expanding *Flourensia cernua* shrublands that occur in former (now degraded) tobosa (*Pleuraphis mutica*) flats and loamy plains. Presence of *Scleropogon brevifolius* is common on these degraded sites. Dick-Peddie (1993) suggested that absence of *Flourensia cernua* as codominant and presence of *Acourtia nana (= Perezia nana), Dasyochloa pulchella*, and *Yucca elata* may be indicators of recent conversion of desert grasslands into desert scrub, but more research is needed. Conversely, *Larrea tridentata* shrublands with a sparse understory on remnant early Holocene erosional surfaces (often with desert pavement) may indicate historical distributions of *Larrea tridentata* desert scrub in the Chihuahuan Desert (Stein and Ludwig 1979, Muldavin et al. 2000b).

Altered (uncharacteristic) fire regimes greatly influence ecosystem processes. The historical desert scrub has a very long fire-return interval (FRI) ranging from 300-1000 years (500 years on average) (from LANDFIRE BpS Model 2510740). *Larrea tridentata* and other desert scrub plant species did not evolve with fire and are sensitive to burning; most of them do not resprout after burning and are slow to recover, and therefore fires should be rare events to be avoided. Invasion of non-native grasses provides fine fuels that can increase fire frequency, intensity and severity. Fires in desert scrub are becoming more common, especially after a series of wet years when fine fuels from non-native herbaceous species build up enough to carry fire.

The impact of livestock grazing to the historical stands of desert scrub is expected to be relatively small because there is little forage available for them in this type, but where livestock grazing or other anthropomorphic disturbance occurs there may be increased soil erosion (Milchunas 2006).

Human development has impacted many locations throughout the ecoregion. These sites represent a poor-condition/non-functioning ecosystem that is highly fragmented, or much reduced in size from its historical extent; the surrounding landscape is in poor condition either with highly eroding soils, many non-native species or a large percentage of the surrounding landscape has been converted to pavement or disturbed by off-road vehicles; the biotic condition is at the limit or beyond natural range of variation, e.g., vegetation composition is altered and is not dominated by native shrubs such as *Larrea tridentata* and *Flourensia cernua*. Characteristic birds, mammals, reptiles, and insect species are not present at expected abundances or the ratio of species shows an imbalance of predator-to-prey populations; abiotic condition is poor with evidence of high soil erosion, rill and gullies present or exposed soil subhorizons. Non-native grass invasion provides fine fuels that may increase fire frequency, intensity and severity.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 23** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 22, left**) and sensitivity (**Figure 22, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

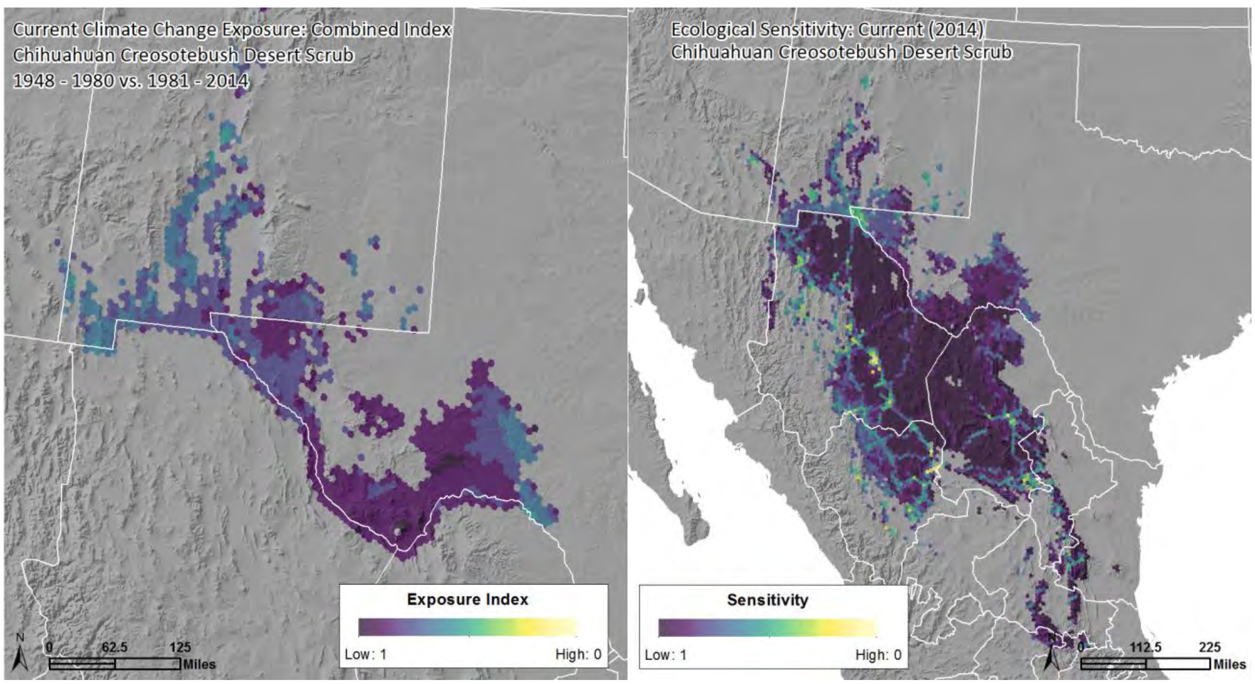

Figure 24. Climate exposure as of 2014 (left) and overall sensitivity (right) for Chihuahuan Creosotebush Desert Scrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 23. Resilience, exposure and vulnerability scores for Chihuahuan Creosotebush Desert Scrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Chihuahuan Desert	Piedmont & Plains (Mexico)	Sierra Madre Oriental	Southern Texas Plains-Interior Plains & Hills	Madrean Archipelago	Sierra Madre Occidental	Edwards Plateau	Arizona-New Mexico Plateau	High Plains	Arizona-New Mexico Mountains
	Sq miles within ecoregion	29,757	4,428	775	179	170	155	106	59	37	33
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Low** 0.80	**Low** 0.82	**Low** 0.86	**Low** 0.77	**Mod** 0.69	**Low** 0.83	**Mod** 0.70	**Mod** 0.68	**Low** 0.83	**Low** 0.80
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.89	0.76	0.82	0.82	0.83	0.73	0.58	0.47	0.57	0.91
	Fire Regime Departure	0.64	0.26	Null	0.58	0.38	Null	0.80	0.64	0.56	0.67
	Invasive Annual Grasses	0.96	0.99	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00
	Sensitivity Average	**0.83**	**0.67**	**0.91**	**0.80**	**0.74**	**0.83**	**0.79**	**0.70**	**0.71**	**0.86**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.18	0.19	0.38	0.21	0.19	0.34	0.13	0.14	0.08	0.35
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.17**	**0.18**	**0.27**	**0.18**	**0.18**	**0.25**	**0.15**	**0.15**	**0.12**	**0.25**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.50	**High** 0.42	**Mod** 0.59	**High** 0.49	**High** 0.46	**Mod** 0.54	**High** 0.47	**High** 0.43	**High** 0.41	**Mod** 0.56
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

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Exposure Summary for 1981-2014 Timeframe: Overall exposure in the U.S., as of 2014, for this widespread desert scrub system is mostly low, but moderate in the Madrean Archipelago, Arizona/New Mexico Plateau and Edwards Plateau ecoregions. An emerging pattern of changing climate appears as increases of 0.55°C for Annual Mean Temperature for 40% to 60% of its distribution in the Chihuahuan Desert, Arizona/New Mexico Plateau, and Southwest Tablelands ecoregions, but similar increases are seen for over 90% of its distribution in the Madrean Archipelago and Arizona/New Mexico Mountains ecoregions. In the Chihuahuan Desert and Madrean Archipelago ecoregions, for some 23% to 84% of its distribution in each, respectively, Precipitation of the Driest Month shows increases of about 0.9 mm, over the baseline average of 1.6 mm. In the High Plains ecoregion, Mean Temperature of the Driest Quarter shows an increase of 2.9°C for 87% of the type's distribution in that ecoregion.

Climate Change Effects: Potential climate change effects would likely include a loss of characteristic plants species, if climate change has the predicted effect of less available moisture with increasing mean temperature. Alteration of precipitation and evapotranspiration rates and timing may result in more frequent drought periods and higher intensity precipitation events, which following drought can cause significant erosion of topsoil (Finch 2012, Garfin et al. 2012). An unvegetated desert pavement could result.

Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced and possibly eliminated, effectively eliminating creosotebush recruitment. Indirect effects of a warming climate with more frequent droughts could lower the shallow water table that these shrubs depend on causing widespread mortality. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low to moderate across the range of this type; 6 of 10 ecoregions have low sensitivity (higher scores) and 4 ecoregions had moderate scores (**Table 23**).

Landscape condition is generally good (less development) with the majority of the extent (6 of 10 ecoregions) scored as good. This ecosystem occurs across vast and remote semi-arid and arid regions throughout its range with limited impacts. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, wind and solar energy development, transportation and transmission corridors, but only minor areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low (higher scores) in all ecoregions; although existing data are limited. However, flushes of annuals after an exceptionally wet year can sometimes create enough fuel to carry fire in this scrub. Fire regime departure is generally moderate with 5 of 10 ecoregions having moderate departure and 2 ecoregions with high departure. Two ecoregions that occur in Mexico were not scored; no fire regime departure data are available. The moderate to high departure is likely a reflection of increased fire frequency (more than once every 300 to 1000 years) and an increased proportion of early-seral stages from increased disturbance such as drought or mechanical disturbances, which affects the proportions of successional stages.

The interactions of the stressors of fragmentation by development, altered fire regime, and invasive annual grass invasion have resulted in changes to the composition and structure of this desert scrub. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is very low across the entire range of this system, in the U.S. and Mexico as well. Both topoclimatic variability and diversity within functional species groups contribute to the low adaptive capacity. These shrublands occur across generally flat landforms and topography such as flat to gently sloping desert basins and on alluvial plains, extending up into lower to mid positions of piedmont slopes (bajada). For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relative 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups scores very low overall; but varies from high to low among groups. Within individual stands, nitrogen fixation is provided by only a few species and so their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability. In addition, there are only a few species in the xerophytes functional group, primarily *Larrea tridentata*. Conversely, species of lichens and cyanobacteria that contribute to substrate developing soils crusts appear to be naturally diverse across the range of this type. Several species of bees and other insects provide a biotic pollination function, and the diversity within this group is high.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: As of 2014, this desert scrub type scores in the moderate level of vulnerability throughout its range. The moderate vulnerability is primarily due to low-moderate scores for exposure, low scores for adaptive capacity, and variable contributions from sensitivity measures that are limited overall. Inherent vulnerabilities are high for warm desert types that naturally occupy extensive flat plains and basins (low topoclimate variability). For a given increment of climate change, individual species would need to disperse longer distances per year as compared with those that occur in more rugged landscapes that naturally support higher microclimate diversity. Other vulnerabilities include low diversity within key functional species groups, such as nitrogen fixing species. Additionally, these desert scrub types are very sensitive to wildfire although they rarely burn except under extreme conditions. Fire regime departure is variable but generally moderate to low. Therefore, common effects of land use throughout the West, including surface disturbance from roads have direct and substantial impact, increasing the inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 24. Climate change adaptation strategies relative to vulnerability scores for Chihuahuan Creosotebush Desert Scrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, invasive plants, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation or outright loss of native species. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor trends in soil moisture regime, and for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely loss of native species or invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Consider creating new models for novel wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Ahlstrand 1979, Belnap 2001, Belnap et al. 2001, Brown 1982a, Brown and Minnich 1986, Buffington and Herbel 1965, Burgess 1995, Cane et al. 2000, Chew and Chew 1970, Comer et al. 2003*, Dick-Peddie 1993, Donart 1984, Elliott 2013, Evans and Belnap 1999, Finch 2012, Garfin et al. 2013, Gibbens et al. 2005, Hamerlynck et al. 2002, Henrickson and Johnston 1986, Huerta-Martínez et al. 2004, Humphrey 1974, LANDFIRE 2007a, MacMahon 1988, MacMahon and Wagner 1985, Maddox and Carlquist 1985, Marshall 1995a, McLaughlin and Bowers 1982, Milchunas 2006, Muldavin et al. 1998a, Muldavin et al. 2000b, Muldavin et al. 2002a, NRCS 2006a, Ogle and Reynolds 2002, Paysen et al. 2000, Rosentreter and Belnap 2003, Schlesinger et al. 2006, Stein and Ludwig 1979

CES302.734 Chihuahuan Mixed Desert and Thornscrub

Figure 25. Photo of Chihuahuan Mixed Desert and Thornscrub. Photo credit: Jasperdo, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/mytravelphotos

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is the widespread desert scrub that occurs on gravelly mid to upper bajadas, foothills and dissected gravelly alluvial fans in the Chihuahuan Desert and has recently expanded at the expense of desert grasslands in the northern portion of its range. It generally occurs on mid to upper piedmonts above the desert plains Chihuahuan Creosotebush Desert Scrub (CES302.731) and extends up to the chaparral zone. Soils are typically well-drained, non-saline, gravelly loams often with a petrocalic layer. Substrates are frequently derived from limestone although igneous rocks are common in some areas. In Texas, this system is best developed over limestone substrates. Vegetation is characterized by the presence of *Larrea tridentata*, typically mixed with thornscrub or other desert scrub such as *Agave lechuguilla, Aloysia wrightii, Baccharis pteronioides, Dasylirion leiophyllum, Flourensia cernua* (not bottomland), *Fouquieria splendens, Koeberlinia spinosa, Krameria erecta, Leucophyllum minus, Mimosa aculeaticarpa var. biuncifera, Mortonia scabrella, Opuntia engelmannii, Parthenium incanum, Prosopis glandulosa*, and *Rhus microphylla* (in drainages). Grasses are common but generally have lower cover than shrubs. Common species may include *Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Dasyochloa pulchella*, and *Muhlenbergia porteri*. Stands of *Acacia constricta-*, *Acacia neovernicosa-* or *Acacia greggii*-dominated thornscrub are included in this system, and limestone substrates appear important for at least these species. If present, *Prosopis glandulosa* has relatively low cover and does not strongly dominate the shrub layer.

This system also includes upper piedmont stands of desert scrub that are strongly dominated by *Larrea tridentata*, as wells as *Larrea tridentata* shrublands with a sparse understory that occur on gravelly piedmont slopes that may extend down gravelly upper basins.

In western Texas, this scrub is best developed over limestone substrates. *Acacia constricta, Agave lechuguilla, Condalia ericoides, Dasylirion leiophyllum, Larrea tridentata, Leucophyllum* spp., *Mimosa aculeaticarpa var. biuncifera, Parthenium incanum, Prosopis glandulosa, Viguiera stenoloba*, and *Yucca torreyi* are often present to dominant, but numerous shrub species may be present. The herbaceous cover is generally low with species such as *Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua ramosa, Bouteloua trifida, Dasyochloa pulchella*, and *Muhlenbergia setifolia*. Historically, much of this desert scrub was thought to be a more open steppe, characterized by perennial desert grasses (typically *Bouteloua eriopoda*) and an open creosotebush - mixed desert shrub layer. Remnant stands of this historic composition of *Larrea tridentata* desert scrub in the Chihuahuan Desert can be seen on remnant early Holocene erosional surfaces that can often have pebbly desert pavement on the soil surface.

Distribution: This system occurs in the Chihuahuan Desert (LANDFIRE 2007a).

Nations: MX, US

States/Provinces: AZ, MXCH, MXSO, NM, TX

CEC Ecoregions: High Plains, Southwestern Tablelands, Edwards Plateau, Southern Texas Plains/Interior Plains and Hills with Xerophytic Shrub and Oak Forest, Arizona/New Mexico Plateau, Sonoran Desert, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz, L. Elliott and J. Teague

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This mid to upper piedmont ecological system is characterized by the presence of *Larrea tridentata* typically mixed with thornscrub or other desertscrub such as *Agave lechuguilla, Aloysia wrightii, Baccharis pteronioides, Dasylirion leiophyllum, Flourensia cernua* (not bottomland), *Fouquieria splendens, Koeberlinia spinosa, Krameria erecta, Leucophyllum minus, Mimosa aculeaticarpa var. biuncifera, Mortonia scabrella (= Mortonia sempervirens ssp. scabrella), Opuntia engelmannii, Parthenium incanum, Prosopis glandulosa*, and *Rhus microphylla* (in drainages). Stands of *Acacia constricta*-, *Acacia neovernicosa*- or *Acacia greggii*-dominated thornscrub are included in this system, and limestone substrates appear important for at least these species. If present, *Prosopis glandulosa* has lower cover than other shrubs and does not strongly dominate the shrub layer. This system also includes upper piedmont stands of desert scrub that are strongly dominated by *Larrea tridentata*. In Texas, *Acacia constricta, Agave lechuguilla, Condalia ericoides, Dasylirion leiophyllum, Larrea tridentata, Leucophyllum* spp., *Mimosa aculeaticarpa var. biuncifera, Parthenium incanum, Prosopis glandulosa, Viguiera stenoloba*, and *Yucca torreyi* are often present to dominant, but numerous shrub species may be present. Grasses are common but generally have lower cover than shrubs. Common species may include *Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Dasyochloa pulchella*, and *Muhlenbergia porteri*. In Texas, herbaceous cover is generally low with species such as *Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua ramosa, Bouteloua trifida, Dasyochloa pulchella*, and *Muhlenbergia setifolia*. Also included in this ecological system are shrublands with a sparse understory of *Larrea tridentata* that occur on gravelly piedmont slopes that may extend down gravelly upper basins. A pebbly desert pavement may be present on the soil surface. This may indicate remnant erosional surfaces from the early Holocene that are thought to be some of the historic distribution of *Larrea tridentata* desert scrub in the Chihuahuan Desert (Muldavin et al. 2000b). Historically, much of this desert scrub was thought to be a steppe characterized by perennial desert grasses such as *Bouteloua eriopoda, Bouteloua ramosa, Muhlenbergia porteri, Bothriochloa barbinodis*, or *Digitaria californica* with an open creosotebush - mixed desert shrub layer.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Chihuahuan Desert BSC diversity is based on Rosentreter and Belnap (2003). Species reflect the fact that soils are derived mostly (80%) from calcareous parent materials (limestone) with remaining soils derived from volcanic materials. The dominance of calcareous soils results in higher diversity of lichens. Cyanobacteria (8): *Microcoleus vaginatus* is dominant, plus *Microcoleus paludosus, Nostoc commune, Oscillatoria* sp., *Phormidium* sp., *Plectonema nostocorum, Schizothrix californica, Schizothrix lamyi*, and *Scytonema hofmannii*. Lichens (13): *Collema coccophorum, Collema tenax, Catapyrenium squamulosum, Heppia lutosa, Peltula obscurans*, and *Peltula richardsii*, and *Placidium lacinulatum (= Catapyrenium lacinulatum)* dominate with *Lecidea rubiformis, Psora decipiens, Fulgensia desertorum, Fulgensia bracteata, Heppia* sp., and *Toninia sedifolia* common. Algal diversity is lower in warm desert regions with 8 common species: *Astasia* sp., *Chlorella* sp., *Chlorococcum* sp., *Fritschiella* sp., *Gonium* sp., *Navicula* sp., Palmogloea protuberans, and *Porphyrosiphon fuscus*. Common mosses (8+) include *Bryum* spp., *Crossidium aberrans, Ceratodon purpureus, Pseudocrossidium crinitum, Pterygoneurum ovatum, Syntrichia ruralis, Tortula atrovirens*, and *Weissia* spp. Common liverworts (2) include *Plagiochasma rupestre* and *Reboulia hemisphaerica*.

Biotic Pollination; Species Diversity: High
The dominant shrub *Larrea tridentata* is pollinated by insects. Cane et al. (2000) reported on insects captured in a creosotebush stand at Silverbell IBP site from 1994-1998. Results included 8 species of *Larrea tridentata* specialists and 22 other bees, many such as *Apis mellifera*, likely also pollinate *Larrea tridentata*. Insects: (*Larrea* specialists): *Ancylandrena larreae, Colletes clypeonitens, Colletes covilleae, Hesperapis larreae, Hoplitis biscutellae, Megandrena enceliae, Perdita punctulata*, and *Trachusa larreae*.

Nitrogen Fixation; Species Diversity: Medium
Creosotebush shrublands and thornscrub occur in warm, arid and semi-arid climates often on substrates where soil nutrients such as nitrogen can be a significant constraint on plant growth (Schlesinger et al.2006). These arid shrublands typically have moderate to low herbaceous cover and low diversity. Most species of Fabaceae (*Acacia constricta, Acacia greggii* (upland), *Acacia neovernicosa, Astragalus* spp., *Dalea* spp., *Mimosa aculeaticarpa var. biuncifera*, and *Prosopis glandulosa*), Rhamnaceae (*Condalia ericoides*), Rosaceae (*Petrophyton caespitosum*), many Poaceae *Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Dasyochloa pulchella, Muhlenbergia porter*, and *Muhlenbergia setifolia*), and some Brassicaceae can fix nitrogen in this mixed shrub system. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen, and carbon can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Nostoc* and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Xerophytes; Species Diversity: Medium
Species in this group are adapted to frequent and extended drought and have evolved abilities and

mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Acacia constricta, Acacia neovernicosa, Flourensia cernua, Fouquieria splendens, Hechtia texensis, Jatropha dioica var. graminea, Larrea tridentata, Lycium berlandieri, Parthenium incanum, Viguiera stenoloba*, and *Yucca torreyi*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this desert scrub type.

Environment: *Climate:* Climate is semi-arid with annual precipitation ranging from 200-250 mm that falls mostly in the summer.

Physiography/landform: This ecological system is the widespread desert scrub that occurs on gravelly mid to upper bajadas, foothills and dissected gravelly alluvial fans in the Chihuahuan Desert and has recently expanded into former desert grasslands in the northern portion of its range. It generally occurs on mid to upper piedmonts above the xeric basins and plains dominated by Chihuahuan Creosotebush Desert Scrub (CES302.731) and extends up to the chaparral zone.

Soil/substrate/hydrology: Soils are typically well-drained, non-saline, gravelly loams often with a petrocalic layer. Substrates are frequently derived from limestone, although igneous rocks are common in some areas (Brown 1982a, MacMahon and Wagner 1985, Henrickson and Johnston 1986, MacMahon 1988, Dick-Peddie 1993).

Key Processes and Interactions: In the U.S., much of this scrub is thought to be a result of recent expansion of *Larrea tridentata* into former desert grasslands and steppe in the last 150 years as a result of drought, overgrazing by livestock, and/or decreases in fire over the last 70-250 years (Buffington and Herbel 1965, Ahlstrand 1979, Donart 1984, Dick-Peddie 1993, Gibbens et al. 2005). This expansion has created challenges in determining ecologically historic stands from more recent ones. Dick-Peddie (1993) suggested that absence of *Flourensia cernua* as codominant and presence of *Dasyochloa pulchella, Acourtia nana*, and *Yucca elata* may be indicators of recent conversion of desert grasslands into desert scrub, but more research is needed. Conversely, sparse understory *Larrea tridentata* shrublands on remnant early Holocene erosional surfaces (often with shallow calcareous soils and a pebbly desert pavement) may indicate historic distributions of *Larrea tridentata* desert scrub in the Chihuahuan Desert (Stein and Ludwig 1979, Muldavin et al. 2000b).

Larrea tridentata, a dominant and diagnostic species, is very long-lived (some clones have been estimated to be over 10,000 years). It is highly adapted to minimized evapotranspiration both daily and seasonally using stomatal regulation, resinous leaves, and a leaf structure and habit to minimize self-shading and maximize photosynthesis during favorable growing periods (Hamerlynck et al. 2002, Ogle and Reynolds 2002). *Larrea tridentata* is poorly adapted to fire because of its highly flammable, resinous leaves and limited sprouting ability after burning although it may survive lower-intensity fires (Humphrey 1974, Brown and Minnich 1986, Marshall 1995, Paysen et al. 2000). McLaughlin and Bowers (1982) reported that burned individuals surviving a fire regained their former size in five years. Other dominant shrubs such as *Acacia constricta, Acacia greggii, Acacia neovernicosa, Fouquieria splendens, Flourensia cernua, Mimosa aculeaticarpa var. biuncifera, Mortonia scabrella*, and *Parthenium incanum* are generally top-killed by low- to moderate-severity fires, while severe fires may kill them. The nitrogen-fixing ability of *Acacia neovernicosa* and other leguminous shrubs in this system allow it to colonize harsh environments well (Muldavin et al. 1998a).

This system also includes invasive *Flourensia cernua* shrublands that occur in former (degraded) tobosa (*Pleuraphis mutica*) flats and loamy plains (Muldavin et al. 1998a). Presence of *Scleropogon brevifolius* is common in these invasive stands. *Flourensia cernua* is relatively shallow-rooted and therefore competes strongly with grasses for soil moisture (Muldavin et al. 1998a). Buffington and Herbel (1965) report that *Larrea tridentata* has displaced many stands of *Flourensia cernua* and cite that it may be because *Larrea tridentata* only competes with grasses during the shrub's seedling stage. Muldavin et al. (1998a) state that stands with no graminoid layer are unlikely to develop one; but stands with a graminoid layer are likely to maintain it if not overgrazed. Impermeable caliche and argillic horizons are not uncommon on these sites. These layers restrict deep percolation of soil-water and may favor the shallower root grasses and shrubs such as *Flourensia cernua* over more deeply rooted shrubs such as *Larrea tridentata* and *Prosopis* spp. (McAuliffe 1995).

Drought is a relatively common occurrence in this desert scrub, generally occurring every 10-15 years and lasting 2-3 years with occasional long-term drought periods (10-15 years duration). *Larrea tridentata* and other shrubs have extensive root systems that allow them to exploit deep-soil water that is unavailable to shallower rooted grasses and cacti (Burgess 1995).

LANDFIRE (2007a) developed three VDDT model for this system, all have two classes.

(1) Chihuahuan Mixed Desert and Thorn Scrub (BpS 2511001) occurs in basins, plains and into foothills in the Chihuahuan Desert. Substrates are generally fine-textured, saline soils. Does not do well in poorly aerated soils. Stands of *Acacia constricta*-, Acacia neovernicosa- or *Acacia greggii*-dominated thornscrub are included in this creosotebush system, and limestone substrates appear important for at least these species.

A) Early Development 1 All Structures (15% of type in this stage): Characterized by low shrub cover (typically 5-10%). Little disturbance was considered in Class A, except for replacement fire every 300 years on average. In the historic condition where invasive annual grasses are absent, the fire-return interval is virtually nonexistent except for areas near the base of mountains experiencing locally higher rainfall and fine fuel buildup from native annuals. After 100 years, class A transitions to class B.

B) Late Development 1 Closed (85% of type in this stage): Typically, >10% shrub cover and <10% grass and forb cover; associated with more productive soils. *Larrea tridentata* characteristically dominates shrub layer. *Acacia* species may dominate locally in patches. Few fine fuels are associated with this community, therefore the MFRIs for replacement fire and mixed-severity fire is 650 years (min-max: 300-1000 years). Wind/weather stress also affected this community on average every 80 years, but did not cause a transition to class A.

(2) Chihuahuan Mixed Desert Shrubland (BpS 2511002) a minor desert scrub that occurs on gravelly mid to upper bajadas, foothills and dissected gravelly alluvial fans in the Chihuahuan Desert and has recently expanded into former desert grasslands in the northern portion of its range. It generally occurs on mid to upper piedmonts above the desert plains Chihuahuan Creosotebush Desert Scrub (CES302.731) and extends up to the chaparral zone (LANDFIRE 2007a, BpS 2511002).

A) Early Development 1 Open (25% of type in this stage): Under natural conditions shrub cover represents <20% canopy cover and is likely not effected by disturbance. The grass community may be as low as 10% canopy cover after a combination of drought/fire. Little disturbance was considered in Class A, modeled drought every 50 years on average, resetting the age to zero (Option 2). In the historic condition where invasive annual grasses are absent, the fire-return interval is virtually nonexistent except for areas near the base of mountains experiencing locally higher rainfall and fine fuel buildup. After 100 years, class A transitions to class B. However, if the upper soil horizon and/or microbes are lost, then a longer recovery time is required or complete recovery is not possible.

B) Late Development 1 Open (75% of type in this stage): Typically, <40% shrub canopy cover and as much as 25% grass and forb canopy cover; associated with more productive soils. Shrubs characteristically dominate the upper layer. Replacement fire followed by prolonged drought every 500 years (min-max: 300-1000 years) on average (Option 1). Wind/weather stress also affected this community on average every 80 years, but did not cause a transition to class A.

(3) Chihuahuan Grama Grass-Steppe (BpS 2511003) a minor desert scrub steppe that occurs on the bajadas and into foothills in the Chihuahuan Desert. Substrates are generally coarse-textured, gravelly soils and may have a petrocalic layer. This site exhibits a high degree of topographic diversity, including limy uplands (LANDFIRE 2007a, BpS 2511003).

A) Early Development 1 Open (20% of type in this stage): Under natural conditions shrub cover represents <10% canopy cover and is likely not effected by disturbance. The grass community may be as low as 10% canopy cover after a combination of drought/fire. Little disturbance was considered in class A. Modeled drought every 50 years on average, resetting the age to zero (Option 2). In the historic condition where invasive annual grasses are absent, the fire-return interval is virtually nonexistent except for areas near the base of mountains experiencing locally higher rainfall and fine fuel buildup. After 100 years, class A transitions to class B. However, if the upper soil horizon and/or microbes are lost, then a longer recovery time is required. Or complete recovery is not possible.

B) Late Development 1 Open (80% of type in this stage): Typically, <10% shrub canopy cover and as much as 40% grass and forb canopy cover; associated with more productive soils. Grasses characteristically dominate shrub layer. Replacement fire followed by prolonged drought every 500 years (min-max: 300-1000 years) on average (Option 1). Wind/weather stress also affected this community on average every 80 years, but did not cause a transition to class A.

In the northern Chihuahuan Desert, this creosotebush mixed desert and thornscrub shrubland ecological system is thought to occur in presettlement conditions largely as mixed desert shrub-steppe on upper bajada gravelly soils and dissected gravelly alluvial fans (S. Yanoff pers. comm. 2006). This grama grass steppe with an open canopy of desert scrub species is a mostly historical grama grass steppe BpS that was described during LANDFIRE MZ25 BpS modeling workshops as Chihuahuan Grama Grass Creosote Steppe (LANDFIRE 2007a, BpS 2511003). It is distinct from creosotebush mixed shrublands on similar sites because it has an open shrub layer characterized by dense perennial grasses (typically black grama).

ECOLOGICAL INTEGRITY

Change Agents: Chihuahuan Mixed Desert and Thornscrub is a widespread, long-lived ecosystem that occurs above Chihuahuan Creosotebush Desert Scrub (CES302.731) in the xeric desert basin. Although thornscrub occurring on limestone rock outcrops is stable, other stands may be sensitive to altered fire regimes caused by invasive species, as well as anthropogenic disturbance such as mechanical/chemical shrub removal. Altered (uncharacteristic) fire regimes greatly influence ecosystem processes.

The historical desert scrub has a very long fire-return interval (FRI) ranging from 300-1000 years (500 years on average) (from LANDFIRE BpS Model 2510740). *Larrea tridentata* and other desert scrub plant species did not evolve with fire and are sensitive to burning; most of them do not resprout after burning and are slow to recover, and therefore fires should be rare events to be avoided. Invasion of non-native grasses provides fine fuels that can increased fire frequency, intensity and severity. Fires in desert scrub are becoming more common, especially after a series of wet years when fine fuels from non-native herbaceous species build up enough to carry fire.

The impact of livestock grazing to the historical stands of desert scrub is expected to be relatively small because there is little forage available for them in this type, but where livestock grazing or other anthropomorphic disturbance occurs there may be increased soil erosion (Milchunas 2006).

Human development has impacted many locations throughout the ecoregion. These sites represent a poor-condition/non-functioning ecosystem that is highly fragmented, or much reduced in size from its historical extent; the surrounding landscape is in poor condition either with highly eroding soils, many non-native species or a large percentage of the surrounding landscape has been converted to pavement or disturbed by off-road vehicles; the biotic condition is at the limit or beyond natural range of variation, e.g., vegetation composition is altered and is not dominated by native shrubs such as *Larrea tridentata* and *Flourensia cernua*. Characteristic birds, mammals, reptiles, and insect species are not present at expected abundances or the ratio of species shows an imbalance of predator-to-prey populations; abiotic condition is poor with evidence of high soil erosion, rill and gullies present or exposed soil sub horizons. Non-native grass invasion provides fine fuels that may increase fire frequency, intensity and severity.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 25** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 24, left**) and sensitivity (**Figure 24, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

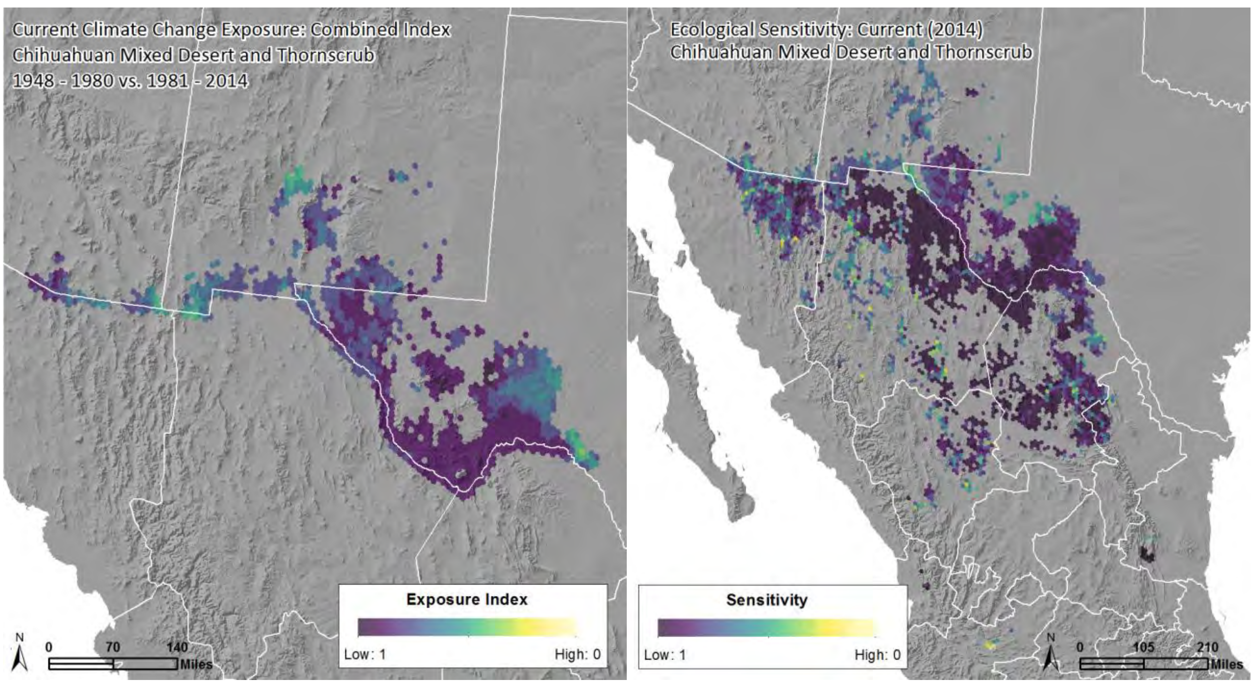

Figure 26. Climate exposure as of 2014 (left) and overall sensitivity (right) for Chihuahuan Mixed Desert and Thornscrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 25. Resilience, exposure and vulnerability scores for Chihuahuan Mixed Desert and Thornscrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Chihuahuan Desert	Madrean Archipelago	Piedmont & Plains (Mexico)	Southern Texas Plains-Interior Plains & Hills	Sierra Madre Occidental	Edwards Plateau	Arizona-New Mexico Mountains	Sinaloa & Sonora Hills & Canyons	Sierra Madre Oriental	Hills & Interior Plains (Mexico)
	Sq miles within ecoregion	6,161	796	393	286	211	63	47	28	25	20
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Low** 0.76	**Mod** 0.70	**Mod** 0.72	**Mod** 0.73	**Mod** 0.69	**Mod** 0.63	**Mod** 0.75	**Mod** 0.68	**Low** 0.91	**Low** 0.84
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.85	0.76	0.74	0.81	0.71	0.65	0.93	0.77	0.90	0.28
	Fire Regime Departure	0.75	0.27	0.24	0.56	Null	0.77	0.72	Null	Null	Null
	Invasive Annual Grasses	0.98	0.97	1.00	1.00	0.93	1.00	1.00	0.77	1.00	1.00
	Sensitivity Average	**0.86**	**0.67**	**0.66**	**0.79**	**0.82**	**0.81**	**0.88**	**0.77**	**0.95**	**0.64**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.18	0.26	0.20	0.16	0.26	0.17	0.36	0.28	0.32	0.17
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.34**	**0.38**	**0.35**	**0.33**	**0.38**	**0.33**	**0.43**	**0.39**	**0.41**	**0.34**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.60	**Mod** 0.52	**Mod** 0.50	**Mod** 0.56	**Mod** 0.60	**Mod** 0.57	**Mod** 0.65	**Mod** 0.58	**Mod** 0.68	**High** 0.49
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Low**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall exposure in the U.S., as of 2014, for this widespread desert scrub system is moderate to low. An emerging pattern of changing climate appears as increases of 0.52°C for Annual Mean Temperature for 32% of its distribution in the Chihuahuan Desert. Similar increases are seen for over 80% of its distribution in the Madrean Archipelago and Arizona/New Mexico Mountains ecoregions. In the Chihuahuan Desert and Madrean Archipelago ecoregions, for some 15% to 35% of its distribution in each, respectively, Precipitation of the Driest Month shows increases of about 0.9 mm over the baseline average of 1.6 mm. In the High Plains ecoregion, where it is peripheral, Mean Temperature of the Driest Quarter shows an increase of 2.9°C for 45% of the type's distribution in that ecoregion.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, or simply a loss of characteristic taxa, if climate change has the predicted effect of less available moisture with increasing mean temperature. Alteration of precipitation and evapotranspiration rates and timing may result in more frequent drought periods and higher intensity precipitation events, which following drought can cause significant erosion of topsoil (Finch 2012, Garfin et al. 2012).

Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced are possibly eliminated, effectively eliminating creosotebush recruitment. Indirect effects of a warming climate with more frequent droughts could lower the shallow water table that these shrubs depend on causing widespread mortality. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low to moderate across the range of this type; 7 of 10 ecoregions have low sensitivity (higher scores) (**Table 25**).

Landscape condition is generally good (less development) with 6 of 10 ecoregions scored as good and 3 peripheral ecoregions scored as moderate or poor (Hills and Interior Plains [Mexico]). This ecosystem occurs across extensive and remote semi-arid and arid regions throughout its range with limited impacts. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, wind and solar energy development, transportation and transmission corridors, but probably only minor areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low (higher scores) in all ecoregions; although data are limited for this measurement. However, flushes of annuals and perennial grasses after an exceptionally wet year can sometimes create enough fuel to carry fire in this open scrub. Fire regime departure is generally low to moderate, with 4 of 10 ecoregions having moderate departure and 2 ecoregions with high or very high departure. Two ecoregions that occur in Mexico were not scored; no fire regime departure data are available. The moderate to high departure is likely a reflection of increased fire frequency (i.e., introduction of novel fire regime) and an increased proportion of early seral stages from increased disturbance such as drought or mechanical disturbances, which affects the proportions of successional stages.

The interactions of the stressors of fragmentation by development, altered fire regime, and invasive annual grass invasion have resulted in changes to the composition and structure of this desert scrub. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity low range wide. Topoclimatic variability is very low or low in all ecoregions. These shrublands occur across generally flat to gently sloping landforms and topography such as mid to upper bajadas, foothills and dissected gravelly alluvial fans. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes.

Therefore, the relative 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups varies from moderate to high among groups. The most limiting functional role is that of nitrogen-fixation. Within individual stands, this is provided by only a moderate number of species, and so their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability. The xerophytes functional group also has moderate within-stand diversity, with sometimes as many as a dozen xerophytic shrubs found in any one stand. This contrasts with the Chihuahuan Creosotebush Desert Scrub system, where the xerophytic role is primarily represented by *Larrea tridentata*. Conversely, species of lichens and cyanobacteria that contribute to substrate developing soils crusts appear to be naturally diverse across the range of this type; calcareous substrates common in this system contribute to the high diversity of lichens. A number of bees and other insects provide a biotic pollination function, and the diversity within this group is high.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This desert scrub type scores in the moderate level of vulnerability throughout its range except the Sierra Madre Oriental (low exposure but contribution to vulnerability from resilience). The overall moderate vulnerability is primarily due to scores for exposure and adaptive capacity, and variable scores for sensitivity measures. Inherent vulnerabilities are high for warm desert types that naturally occupy extensive flat plains and alluvial fans (low topoclimate variability). Other vulnerabilities include moderate diversity within key functional species groups, such as nitrogen fixing species. Additionally, these desert scrub types are generally sensitive to wildfire although they rarely burn except under extreme conditions and at upper elevations where stands transition into chaparral and encinal. Therefore, common effects of land use throughout the West, including surface disturbance from roads have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 26. Climate change adaptation strategies relative to vulnerability scores for Chihuahuan Mixed Desert and Thornscrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, invasive plants, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation or outright loss of native species. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor trends in soil moisture regime, and for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely loss of native species or invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Consider creating new models for novel wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Ahlstrand 1979, Belnap 2001, Belnap et al. 2001, Brown 1982a, Brown and Minnich 1986, Buffington and Herbel 1965, Burgess 1995, Cane et al. 2000, Comer et al. 2003*, Dick-Peddie 1993, Donart 1984, Elliott 2012, Evans and Belnap 1999, Finch 2012, Garfin et al. 2013, Gibbens et al. 2005, Hamerlynck et al. 2002, Henrickson and Johnston 1986, Humphrey 1974, LANDFIRE 2007a, MacMahon 1988, MacMahon and Wagner 1985, Marshall 1995a, McAuliffe 1995, McLaughlin and Bowers 1982, Milchunas 2006, Muldavin et al. 1998a, Muldavin et al. 2000b, Muldavin et al. 2002a, NRCS 2006a, Ogle and Reynolds 2002, Paysen et al. 2000, Rosentreter and Belnap 2003, Schlesinger et al. 2006, Shiflet 1994, Stein and Ludwig 1979, Yanoff pers. comm.

M087. Chihuahuan Semi-Desert Grassland

CES302.735 Apacherian-Chihuahuan Semi-Desert Grassland and Steppe

Figure 27. Photo of Apacherian-Chihuahuan Semi-Desert Grassland and Steppe. Photo credit: Patrick Alexander, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/aspidoscelis/

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is a broadly defined desert grassland, mixed shrub-succulent steppe, or xeromorphic oak savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico (Apacherian region) but extends west to the Sonoran Desert, north into the Mogollon Rim in Arizona and up the Rio Grande Valley into central New Mexico. It also extends east into the Chihuahuan Desert. It is found on gently sloping alluvial erosional fans and piedmonts (bajadas) that lie along mountain fronts of the isolated basin ranges throughout the Sky Island mountain archipelago and on to foothill slopes up to 1670 m elevation in the Chihuahuan Desert. The vegetation in this mixed semi-desert grassland ecosystem is variable. It is characterized by the dominance of a typically diverse layer of warm-season, perennial grasses with scattered stem succulents and shrubs. Frequent species include the grasses *Aristida ternipes, Bouteloua barbata, Bouteloua chondrosioides, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Bouteloua repens, Bouteloua rothrockii, Dasyochloa pulchella, Digitaria californica, Eragrostis intermedia, Heteropogon contortus, Hilaria belangeri, Leptochloa dubia, Muhlenbergia porteri*, with *Muhlenbergia emersleyi, Muhlenbergia setifolia* at upper foothill elevation, rosettophyllous, often succulent species of *Agave, Dasylirion, Nolina, Opuntia*, and *Yucca*, and short-shrub species of *Calliandra*, and *Parthenium*. Tall-shrub/short-tree species of *Acacia, Prosopis, Juniperus, Mimosa*, and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica, Quercus oblongifolia*) may be present with low cover (usually <10%). *Pleuraphis mutica*-dominated semi-desert grasslands often with *Bouteloua eriopoda* or *Bouteloua* *gracilis* occurring on lowlands and loamy plains in the Chihuahuan Desert are classified as Chihuahuan Loamy Plains Desert Grassland (CES302.061). Many of the historical desert grassland and savanna areas have been converted through intensive grazing and other land uses, some to Apacherian-Chihuahuan Mesquite Upland Scrub (CES302.733) (*Prosopis* spp.-dominated).

Distribution: This system is found in the Borderlands of Arizona, New Mexico and northern Mexico (Apacherian region), extending to the Sonoran Desert and throughout much of the northern Chihuahuan Desert.

Nations: MX, US

States/Provinces: AZ, MXCH, NM, TX

CEC Ecoregions: Southern Rockies, High Plains, Southwestern Tablelands, Edwards Plateau, Arizona/New Mexico Plateau, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz and M.S. Reid

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The vegetation in this mixed semi-desert grassland ecosystem is variable. It is characterized by the dominance of a typically diverse layer of perennial grasses with scattered stem succulents and shrubs. Frequent species include the grasses *Aristida ternipes, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Bouteloua repens, Eragrostis intermedia, Heteropogon contortus, Muhlenbergia porteri*, with *Muhlenbergia emersleyi, Muhlenbergia setifolia* at upper foothill elevation, rosettophyllous, often succulent species of *Agave, Dasylirion, Nolina, Opuntia*, and *Yucca*, and short-shrub species of *Calliandra*, and *Parthenium*. Tall-shrub/short-tree species of *Acacia, Prosopis, Juniperus, Mimosa*, and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica, Quercus oblongifolia*) may be present with low cover.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Chihuahuan Desert BSC diversity is based on Rosentreter and Belnap (2003). Species reflect that soils are derived mostly (80%) from calcareous parent materials (limestone) with remaining soils derived from volcanic materials. The dominance of calcareous soils results in higher diversity of lichens. Cyanobacteria (8) (*Microcoleus vaginatus* is dominant, plus *Microcoleus paludosus, Nostoc commune*, Oscillatoria sp., *Phormidium* sp., *Plectonema nostocorum, Schizothrix californica, Schizothrix lamyi*, and *Scytonema hofmannii*; Lichens (13): *Collema coccophorum, Collema tenax, Catapyrenium lacinulatum, Catapyrenium squamulosum, Heppia lutosa, Peltula obscurans*, and *Peltula richardsii* dominate; *Psora rubiformis, Psora decipiens, Fulgensia desertorum, Fulgensia bracteata, Heppia* sp., and *Toninia sedifolia* are common. Algal diversity is lower in warm desert regions with 8 common species: *Astasia* sp., *Chlorella* sp., *Chlorococcum* sp., *Fritschiella* sp., *Gonium* sp., *Navicula* sp., *Palmogloea protuberans*, and *Porphyrosiphon fuscus*. Common mosses (8+) include *Bryum* spp., *Crossidium aberrans, Ceratodon purpureus, Pseudocrossidium crinitum, Pterygoneurum ovatum, Syntrichia ruralis, Tortula atrovirens*, and *Weissia* spp. Common liverworts (2) include *Plagiochasma rupestre* and *Reboulia hemisphaerica*.

Biotic Pollination; Species Diversity: Medium
Although the dominant species in this grassland system (graminoids) are wind-pollinated, there are

many forbs, cacti, shrubs, and stem succulents such as *Agave* and *Yucca* that need to be pollinated by organisms, especially insects, to fertilize ova to produce viable seed. Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. Insects are the primary pollinators. Insects: Bees (Apoidea), wasps and ants (Hymenoptera), butterflies and moths (Lepidoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially red tubular flowers) and certain bat pollinators such as the Mexican long-tongued bat (*Choeronycteris mexicana*) and endangered lesser long-nosed bat (*Leptonycteris yerbabuenae (= Leptonycteris curasoae yerbabuenae)*) migrate north to Arizona to feed on agaves. Some species such as yucca moths (*Tegeticula* spp.) and *Yucca* species have obligate mutualistic relationships, including *Tegeticula baccatella* and *Yucca baccata, Tegeticula carnerosanella* and *Yucca faxoniana, Tegeticula elatella* and *Yucca elata, Tegeticula maderae* and *Yucca* × *schottii*, and *Tegeticula yuccasella* and *Yucca glauca* (Whitford et al. 1995, Althoff et al. 2006).

Nitrogen Fixation; Species Diversity: Medium
Desert grasslands in Chihuahuan and Sonoran deserts occur in semi-arid climate often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. The semi-arid portions of this system typically have low to moderate herbaceous cover and low diversity of N-fixing species. Relatively mesic stands have higher cover and diversity of vascular plants, but lower cover and diversity of nonvascular N-fixing species. This grassland and steppe system typically has moderate to high herbaceous cover and moderate to high vascular species diversity. Most species of Fabaceae (including species of *Acacia, Astragalus, Calliandra, Mimosa, Dalea*, and *Prosopis*), many Poaceae, Rhamnaceae (*Condalia ericoides*), and some Brassicaceae fix nitrogen. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap 2001, Belnap et al. 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Nostoc, Plectonema, Schizothrix*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Warm-Season Graminoids; Species Diversity: High
Aristida arizonica, Aristida purpurea, Aristida ternipes, Bothriochloa barbinodis, Bouteloua chondrosioides, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua ramosa, Bouteloua repens, Bouteloua rothrockii, Dasyochloa pulchella, Digitaria californica, Eragrostis intermedia, Heteropogon contortus, Hilaria belangeri, Leptochloa dubia, Muhlenbergia emersleyi, Muhlenbergia pauciflora, Muhlenbergia porteri, Muhlenbergia setifolia, Panicum hallii, and *Schizachyrium cirratum*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. Black-tailed prairie dogs (*Cynomys ludovicianus*) in prairie grasslands (USFWS 1999). Historically, black-tailed prairie dogs may have functioned as a keystone species in the northern extent of Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (CES302.735); however, because of uncertainty of the prairie dog's role in this grassland system and the small portion of this system's range impacted by prairie dogs, it was not considered a keystone species for this system at this time.

Environment: This system is found on gently sloping alluvial erosional fans and piedmonts (bajadas) that lie along mountain fronts of the isolated ranges throughout the Sky Island mountain archipelago and on to foothill slopes from 1000 m to 1670 m and up to 1800 m elevation in the Chihuahuan Desert and up to 2200 m in lower montane grasslands.

Climate: Climate is semi-arid, warm-temperate with a highly variable, bimodally distributed precipitation. Approximately two-thirds of the 20-40 cm mean annual precipitation occurs in the late summer and early fall, usually as localized high-intensity thunderstorms.

Physiography/landform: Sites are typically gently sloping mesas and piedmonts (LANDFIRE 2007a).

Soil/substrate/hydrology: Substrates are variable, ranging from fine- to coarse-textured soils depending on site. However, most are typically deep, coarser-textured, gravelly soils derived from limestone, sandstone, conglomerate or igneous substrates such as tuff.

Key Processes and Interactions: Semi-desert grasslands are complex with many stands having a shrub or stem succulent component (*Agave* and *Yucca* spp.) under natural conditions (Burgess 1995). This woody component increases in density over time in the absence of disturbance such as fire (Burgess 1995, Gori and Enquist 2003, Schussman 2006a). Under historic natural conditions (also called natural range of variability or NRV), this ecosystem ranges from open perennial grasslands with low cover of shrubs to grasslands with a moderately dense shrub layer and succulent layer (Burgess 1995, Gori and Enquist 2003). An exception is that some stands with deep argillic horizons appear resistant to shrub and tree invasion without disturbance (McAuliffe 1995).

It is well-documented that frequent stand-replacing fire (fire-return interval (FRI) of 2.5 to 10 years) was a key ecological attribute of this semi-desert grassland ecosystem historically before 1890 (Wright 1980, Bahre 1985, McPherson 1995, Kaib et al. 1996). Other evidence of the importance of fire in maintaining desert grasslands includes the widespread conversion of grasslands to shrublands during the century of fire suppression (McPherson 1995) and the results of prescribed burning on decreasing shrub cover and increasing grass cover (Bock and Bock 1992, Robinett 1994). Additional evidence that frequent fire is a key ecological attribute of this ecosystem is that many common invasive shrubs, subshrubs and cacti are fire-sensitive and individuals are killed when top-burned, at least when they are young (<10 years old) (McPherson 1995), while native perennial grasses generally quickly recover from burning (Wright 1980, Martin 1983, Bock and Bock 1992).

Herbivory by native herbivores in the system is varied and ranges from invertebrates and rodents to pronghorn (Parmenter and Van Devender 1995, Whitford et al. 1995, Finch 2004). Soil-dwelling invertebrates include tiny nematodes and larger termites and ants, are important in nutrient cycling and affect soil properties, such as bulk density (Whitford et al. 1995). Above-ground invertebrates such as grasshoppers can significantly impact herbaceous cover when populations are high. Herbivory by native mammals also impacts these grasslands. Historically, populations of large mammals such as pronghorn (*Antilocarpa americana*) and mule deer (*Odocoileus hemionus*) were once abundant in this ecosystem (Parmenter and Van Devender 1995). Populations were greatly reduced and, in the case of pronghorn, extirpated during the 1800s and early 1900s, but effective game management has restored many populations, although habitat changes will limit restoration in other areas (Parmenter and Van Devender 1995). The historic impact of large native ungulates on this ecosystem is not known; however, in the case of wintering elk, it may have been significant locally. The current impact is assumed to be relatively small in this ecosystem.

Herbivory from native small mammals such as rodents is significant as they are the dominant mammals in the semi-desert grassland ecosystem. There is also high diversity of these rodents, especially ground-dwelling ones such as spotted ground squirrels (*Xerospermophilus spilosoma*), and bannertail and Ord kangaroo rats (*Dipodomys spectabilis* and *Dipodomys ordii*). These burrowing rodents have a substantial effect on vegetation composition, soil structure and nutrient cycling (Parmenter and Van Devender 1995, Finch 2004). Historically, black-tail prairie dogs (*Cynomys ludovicianus*) had extensive colonies in the Great Plains that extended west to southeastern Arizona but were greatly reduced. Although abundant in southeastern Arizona and southwestern New Mexico in the 1800s, the black-tailed prairie dog populations were decimated by 1930 and considered extirpated in Arizona by 1960 (Alexander 1932, Hoffman 1986, Parmenter and Van Devender 1995, Van Pelt 1999, Underwood and Van Pelt 2008). Although there have been several reintroductions of black-tailed prairie dogs, their numbers and impacts are still small in this region. Because of the nature of black-tail prairie dogs (large towns and major impacts to the local ecosystem), they may have historically functioned as a keystone species in lower elevation stands in the northern extent of Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (CES302.735). However, historically black-tailed prairie dogs were likely more abundant in the deeper soiled Chihuahuan Loamy Plains Desert Grassland (CES302.061) that occurs on lower elevation alluvial flats and plains. More research is needed to determine the role of black-tailed prairie dogs in these semi-grassland and steppe systems.

Invertebrate animals are also significant in semi-desert grassland. They are both abundant and extremely diverse, ranging from single-celled protozoans, bacterial and soil nematodes and mites to larger arachnids, millipedes, cockroaches, crickets, grasshoppers, ants, beetles, butterflies, moths, flies, bees, wasps, and true bugs (Whitford et al. 1995). Invertebrates are important for nutrient cycling and pollination, and subterranean species of ants and termites can impact soil properties such as bulk density, infiltration permeability and storage (Whitford et al. 1995). Grasshoppers feed on grasses and forbs and can consume significant amounts of forage when their populations are high. Many species of butterflies, flies, bees, and moths are important for pollination. Some species such as Yucca moths (*Tegeticula* spp.) and *Yucca* species have obligate/mutualistic relationships (Whitford et al. 1995, Althoff et al. 2006). In these grasslands, *Yucca* spp. are typically dependent on a single species of *Tegeticula* for pollination, which is usually dependent on a single *Yucca* host plant species for habitat and food for larvae, for example, *Tegeticula baccatella* and *Yucca baccata, Tegeticula carnerosanella* and *Yucca faxoniana, Tegeticula elatella* and *Yucca elata, Tegeticula maderae* and *Yucca x schottii*, and *Tegeticula yuccasella* and *Yucca glauca*. More study and review are needed to fully understand the many functional roles animals have within the semi-desert grassland ecosystem.

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 2711210).

A) Early Development 1 All Structures (20% of type in this stage): Herbaceous cover (0-20%). Grass and herbs, 0-5 years (predicated on moisture regime). Early-succession post-fire grass and herb community. This class encompasses the time period required to recover sufficient fuel loads to carry fire. Perennial bunchgrasses, annual grass, and herb community. Upper layer of shrubs, canopy cover less than 5%.

B) Mid Development 1 All Structures (35% of type in this stage): Perennial grass species dominate with 35-50% canopy cover; <0.5 m height. Shrub cover is 5-10% with shrubs 0-1 m tall. Grass with some low shrubs, 6-50 years old. Perennial bunchgrasses regenerated and young shrubs begin growing. Species are perennial bunchgrasses and shrubs. Canopy cover of shrubs is 5-10%. Maintenance disturbance is drought, occurring approximately every 30 years. Maintenance replacement fire is more frequent with less frequent replacement fire returning to class A. This was modeled to occur every 10 years on average, half the time causing a transition to class A, and half the time maintaining this class.

C) Late Development 1 All Structures (50% of type in this stage): Perennial grass species dominate with 10-35% canopy cover; 1-2 m height. Shrubs continue to increase in size and/or number of individuals. Species are perennial bunchgrasses and shrubs. Canopy cover of shrubs is 10-20%. (Shrub cover will be similar to species composition found in Apacherian-Chihuahuan Mesquite Upland Scrub (CES302.733)). Shrub species diversity increases. FRI=10 years, half are replacement (to class A) and half take class back to class B. The wind/weather stress in this model is drought, occurring approximately every 30 years. It is thought that this is the class that might result with lack of fire and that more would be present in this class currently versus historically.

In the LANDFIRE BpS 2611210 model, mixed-severity fire was modeled for MZ26; however, this was removed for MZ27, as it is thought that only patchy replacement fire would occur in this system (LANDFIRE 2007a). It was noted that the amount of moisture following fire has a significant impact on plant response/recovery. Because historical fire data in this system are lacking, there is uncertainty over the role fire plays in maintaining this system. Some modelers think fire has a major impact on control of woody species, whereas others think fire is less important in control of woody species than maintenance of perennial grass cover in this system (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: During the last century, the area occupied by this desert grassland and steppe decreased through conversion of desert grasslands as a result of drought, overgrazing and *Prosopis glandulosa* seed dispersion by livestock, and/or decreases in fire frequency (Buffington and Herbel 1965, Brown and Archer 1987). Conversion of this type has also commonly come from urban and exurban development near cities such as Sierra Vista, Arizona, altered hydrological regimes (water developments/reservoirs) (Cooke and Reeves 1976), and irrigated agriculture, especially hay meadows dominated by non-native forage grasses. Fire suppression has allowed succession and conversion to shrublands, desert scrub and woodlands, especially from oak, pinyon or juniper tree invasion (Gori and Enquist 2003). This grassland has also been converted to invasive non-native, perennial forage grasses *Eragrostis lehmanniana* and *Eragrostis curvula* (Cable 1971, Anable et al. 1992, Gori and Enquist 2003).

It is believed that mesquite formerly occurred in relatively minor amounts and was largely confined to drainages until cattle distributed seed upland into desert grasslands (Brown and Archer 1987, 1989). Shrublands dominated by *Prosopis* spp. have replaced large areas of desert grasslands, especially those formerly dominated by *Bouteloua eriopoda*, in Trans-Pecos Texas, southern New Mexico and southeastern Arizona (York and Dick-Peddie 1969, Hennessy et al. 1983). Studies on the Jornada Experimental Range suggest that combinations of drought, overgrazing by livestock, wind and water erosion, seed dispersal by livestock, fire suppression, shifting dunes, and changes in the seasonal distribution of precipitation have caused this recent, dramatic shift in vegetation physiognomy (Buffington and Herbel 1965, Herbel et al. 1972, Humphrey 1974, McLaughlin and Bowers 1982, Gibbens et al. 1983, Hennessy et al. 1983, Schlesinger et al. 1990, McPherson 1995).

These native mixed semi-desert grasslands are the dominant grassland type and range from open grasslands with low shrub canopy cover (less than 10% cover) to denser grassland with higher shrub and succulent cover. Over time without fire or other disturbance, stands become dominated by woody vegetation and convert to shrublands or woodlands (Gori and Enquist 2003). Conversion to juniper woodlands or mesquite shrublands is common when trees or mesquite exceed 15% cover (Gori and Enquist 2003). These grasslands were historically maintained as open grasslands with low shrub cover by fire-return intervals of 2.5 to 10 years (Wright 1980, Robinett 1994, McPherson 1995, Brown and Archer 1999). Both drought and livestock grazing interact with grass cover and fire-return intervals can affect the rate of shrub increase (Wright 1980, Robinett 1994, McPherson 1995, Brown and Archer 1999). Gori and Enquist (2003) found that after grassland conversion to shrubland there is a loss of perennial grasses and increases of bare ground. If not protected by surface rock, topsoil erosion can occur changing the site to be less suitable for grass recolonization (McAuliffe 1995).

Hydrological alterations also occurred in many semi-desert grasslands during early Anglo-American settlement time with a period of arroyo formation from 1865 to 1915 (Cooke and Reeves 1976). During this time many broad valley bottom drainages were incised, lowering water tables. This resulted in changes to more xeric vegetation because of decreased water availability, as well as increased sediment movement, altered hydrologic relationships, and loss of productive land (Cooke and Reeves 1976). Although there is debate of causes of these hydrologic changes (arroyo formation), Cooke and Reeves (1976) found strong evidence that arroyo formation was initiated by building ditches, canals, roads and embankments along channels that altered valley floor hydrology.

The introduction of the invasive non-native, perennial grasses *Eragrostis lehmanniana* and *Eragrostis curvula* has greatly impacted many semi-desert grasslands in this ecoregion (Cable 1971, Anable et al. 1992, Gori and Enquist 2003). Anable et al. (1992) and Cable (1971) found *Eragrostis lehmanniana* is a particularly aggressive invader and alters ecosystem processes, vegetation composition, and species diversity.

Common stressors and threats include fragmentation from housing and water developments, altered fire regime from fire suppression and indirect fire suppression from livestock grazing and fragmentation, introduction of invasive non-native species, and overgrazing by livestock which can lead to severe soil compaction and reduce vegetation cover exposing soils to erosion of topsoil, especially if soil surface does not significant rock cover.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 27** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 28, left**) and sensitivity (**Figure 28, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

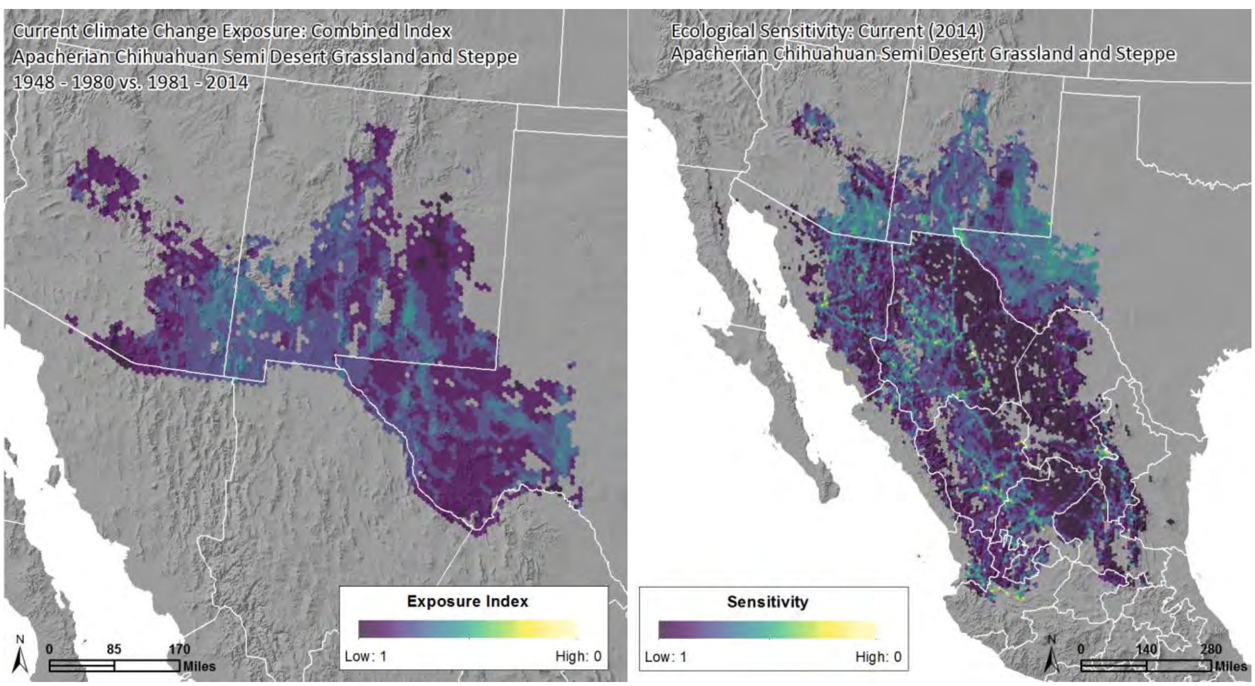

Figure 28. Climate exposure as of 2014 (left) and overall sensitivity (right) for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 27. Resilience, exposure and vulnerability scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Chihuahuan Desert	Piedmont & Plains (Mexico)	Madrean Archipelago	Sinaloa & Sonora Hills & Canyons	Sierra Madre Occidental	South-western Table-lands	Arizona-New Mexico Mountains	Sonoran Desert	Sierra Madre Oriental	High Plains	Arizona-New Mexico Plateau	Sinaloa Coastal Plain	Hills & Sierras (Mexico)	Edwards Plateau	Southern Texas Plains-Interior Plains & Hills	Hills & Interior Plains (Mexico)
	Sq miles within ecoregion	42,131	16,513	10,603	8,985	6,879	3,171	2,125	1,436	1,349	810	800	503	354	324	126	51
Contributions to Relative Vulnerability by Factor																	
Vulnerability from **Exposure (2014)**		Low 0.79	Low 0.76	Low 0.77	Mod 0.70	Low 0.77	Low 0.79	Low 0.76	Low 0.80	Low 0.89	Low 0.80	Low 0.79	Low 0.77	Low 0.83	Mod 0.68	Low 0.85	Low 0.85
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.83	0.72	0.70	0.79	0.77	0.82	0.77	0.80	0.81	0.56	0.65	0.80	0.67	0.61	0.91	0.69
	Fire Regime Departure	0.33	0.29	0.25	Null	Null	0.53	0.55	0.59	Null	0.22	0.41	Null	Null	0.28	0.75	Null
	Invasive Annual Grasses	0.95	0.95	0.99	0.71	0.81	1.00	0.98	0.92	1.00	0.96	1.00	0.88	1.00	1.00	1.00	1.00
	Sensitivity Average	**0.70**	**0.65**	**0.65**	**0.75**	**0.79**	**0.78**	**0.77**	**0.77**	**0.91**	**0.58**	**0.69**	**0.84**	**0.83**	**0.63**	**0.89**	**0.84**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.20	0.24	0.20	0.25	0.41	0.18	0.28	0.15	0.42	0.07	0.19	0.09	0.31	0.11	0.37	0.32
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.35**	**0.37**	**0.35**	**0.37**	**0.45**	**0.34**	**0.39**	**0.32**	**0.46**	**0.28**	**0.35**	**0.30**	**0.40**	**0.31**	**0.44**	**0.41**
Vulnerability from Measures of **Overall Resilience**		Mod 0.53	Mod 0.51	High 0.50	Mod 0.56	Mod 0.62	Mod 0.56	Mod 0.58	Mod 0.55	Mod 0.68	High 0.43	Mod 0.52	Mod 0.57	Mod 0.62	High 0.47	Mod 0.66	Mod 0.63
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Low	Mod	Mod	Mod	Mod	Mod	Low	Mod

Exposure Summary for 1981-2014 Timeframe: Overall exposure in the U.S., as of 2014, for this widespread grassland system is limited. In the Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains, Southwestern Tablelands, and Sonoran Desert ecoregions where it is most abundant, an emerging pattern of changing climate appears as increases of 0.52° to 0.69°C for Annual Mean Temperature for 34% of its distribution in the Chihuahuan Desert up to 99% in the Madrean Archipelago. Similar increases in the Mean Temperature of the Warmest Quarter occur in the Madrean Archipelago, Arizona/New Mexico Mountains, and Sonoran Desert ecoregions. Precipitation of the Driest Month shows increases ranging from 0.94 to 1.5 mm, as compared to baseline averages of 0.35 to 0.92 mm for this variable, in the Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains, across 15% to 25% of its distribution.

Climate Change Effects: Potential climate change effects could include a reduction in the current extent of the ecosystem and conversion to desert scrub, if climate change has the predicted effect of less available moisture with increasing mean temperature. Over time, potential climate change effects could also include a shift to species more common on hotter, drier sites and would likely result in a contraction of this grassland system at lower elevations and a possible limited migration of some species comprising the system to higher elevations in the future.

In general, the ecological consequences from such a warming climatic shift would be similar to extended drought. It will likely affect the composition and diversity of native animals and plants by impacting reproduction and survival of populations due to effects on the amount and season of water and food supply, and habitat availability. Populations of some exotics species better adapted to a warmer climate are projected to increase. Grassland bird populations currently impacted by habitat loss, fragmentation and degradation could experience significant shifts and reductions in their range through reduced nest success.

Some plants may be at risk of pollinator loss, especially those with obligate or near-obligate mutualistic relationships, such as certain nectiverous bats that migrate north to this system to feed on (and pollenate) widely dispersed agaves. Also, *Yucca* spp. and yucca moths (*Tegeticula* spp.) have obligate mutualistic relationships usually with a single species of yucca moth that may be vulnerable to impacts of climate change (Althoff et al. 2006). There are also concerns about climate change affecting the timing of anthesis in agaves, yuccas or other important species such that it does not match pollinator availability.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low across the range of this type with 9 of 16 ecoregions with low sensitivity (higher scores) and 7 of 16 ecoregions with moderate sensitivity (lower scores) (**Table 27**).

Landscape condition is generally good (less development) with 9 of 16 ecoregions scored and 7 ecoregions scored as moderate. This ecosystem occurs across extensive and remote semi-arid areas throughout its range with limited impacts. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, and areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low (higher scores) in all ecoregions; however, data are limited and it is known that in recent years, perennial invasive grasses are altering the fire regime. Fire regime departure is high to moderate all U.S ecoregions. Six ecoregions that occur in Mexico were not scored, as no fire regime departure data are available. The moderate to high departure is likely a reflection of decreased fire frequency due to grazing by livestock, which removes the fine fuels that carry fire. Fire suppression has also altered the composition and structure of this grassland allowing for increased invasions of cacti, desert scrub and trees such as species of *Acacia, Larrea, Juniperus, Pinus, Quercus*, and *Prosopis*. Overgrazing by livestock occurred historically in several ecoregions and contributed to conversion of many acres of this type to desert scrub.

The interactions of the stressors of fragmentation by development, direct and indirect fire suppression, and some invasion by exotic grasses have resulted in changes to the composition and structure of these semi-desert grasslands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Contribution to vulnerability from adaptive capacity is high across the range of this widespread system. Topoclimatic variability is low or very low in all of the 16 ecoregions, as these grasslands occur across generally flat landforms and topography such as gently sloping alluvial erosional fans and piedmonts (bajadas) and on to foothill slopes of desert mountain ranges. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups is moderate range-wide. Of the four functional species groups identified, two are moderately diverse (biotic pollination and nitrogen-fixers) and are the more limiting for the system's capacity to adapt to changing climate conditions. Bats, bees, wasps, ants, butterflies and moths, flies, beetles, and hummingbirds provide a critical function by pollinating the forbs, cacti, shrubs, and stem succulents such as *Agave* and *Yucca* that are important components of this system. A moderate within stand diversity of nitrogen fixers is provided by taxa in the Fabaceae and Rhamnaceae families of which most are nitrogen-fixers. Cyanobacteria are also important nitrogen-fixers in this system.

The other two functional species groups appear to have high within group diversity (soil crust forming taxa and warm-season graminoids). Species of lichens, algae and cyanobacteria that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type; calcareous and igneous substrates common in this system contribute to a high diversity of lichens. A diverse mix of warm-season graminoids is a characteristic of this system. Warm-season graminoid species use the less common C4 photosynthesis pathway to fix carbon that functions best at higher temperatures; this is most efficient pathway under low CO_2 concentrations, high light intensity and higher temperatures and is well-adapted to relatively warm, dry climates where this system occurs.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This semi-desert grassland type scores in the moderate level of vulnerability throughout its range, except for the Sierra Madre Orientale and Southern Texas Plans-Interior Plains and Hills ecoregions where it scores low. This moderate vulnerability is primarily due to the currently low climate exposure combined with High vulnerability from adaptive capacity scores. Inherent vulnerabilities are high for these grasslands that naturally occupy extensive flat to gently sloping desert plains, basins, alluvial fans, mesas, plateaus, and piedmont slopes (lower topoclimate variability). Additionally, these semi-desert grasslands have variable, but generally moderate to high fire regime departure scores and variable landscape condition scores with lowest scores in agricultural areas. Stands are highly susceptible to effects of extended drought, overgrazing, and long-term effects of fire regime alterations such as shrub and tree encroachment with fire suppression. Stands are also susceptible to invasive plants in the relatively mesic agricultural areas.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 28. Climate change adaptation strategies relative to vulnerability scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub invasion.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub invasion and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: AGFD 1999, ARPC 2001, Alexander 1932, Althoff et al. 2006, Anable et al. 1992, Bagne and Finch 2013, Bahre 1985, Belnap 2001, Belnap et al. 2001, Bock and Bock 1992, Brown 1982a, Brown and Archer 1987, Brown and Archer 1989, Brown and Archer 1999, Buffington and Herbel 1965, Burgess 1995, Cable 1971, Comer et al. 2003*, Cooke and Reeves 1976, Dick-Peddie 1993, Elliott 2013, Evans and Belnap 1999, Eyre 1980, Finch 2004, Gibbens et al. 1983, Gori and Enquist 2003, Hennessy et al. 1983, Herbel et al. 1972, Hoffman 1986, Humphrey 1974, Isely 1998, Kaib et al. 1996, LANDFIRE 2007a, Martin 1983, McAuliffe 1995, McLaughlin and Bowers 1982, McPherson 1995, Muldavin et al. 2000b, Muldavin et al. 2002a, NRCS 2006a, Parmenter and Van Devender 1995, Robinett 1994, Rosentreter and Belnap 2003, Schlesinger et al. 1990, Schussman 2006a, Shiflet 1994, TNC 2013, USFWS 1999, Underwood and Van Pelt 2008, Van Pelt 1999, Whitford et al. 1995, Wright 1980, York and Dick-Peddie 1969

M088. Mojave-Sonoran Semi-Desert Scrub

CES302.756 Sonora-Mojave Creosotebush-White Bursage Desert Scrub

Figure 29. Photo of Sonora-Mojave Creosotebush-White Bursage Desert Scrub. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system forms a desert scrub matrix blanketing broad valleys, lower bajadas, plains and low hills in the Mojave and lower Sonoran deserts. This desert scrub is characterized by a sparse to moderately dense layer (2-50% cover) of xeromorphic microphyllous and broad-leaved shrubs. *Larrea tridentata* and *Ambrosia dumosa* are typically dominants, but many different shrubs, dwarf-shrubs, and cacti may codominate or form typically sparse understories. Associated species may include *Atriplex canescens, Atriplex hymenelytra, Encelia farinosa, Ephedra nevadensis, Fouquieria splendens, Lycium andersonii*, and *Opuntia basilaris*. The herbaceous layer is typically sparse; but may have abundant seasonal ephemerals. Herbaceous species such as *Chamaesyce* spp., *Eriogonum inflatum, Dasyochloa pulchella, Aristida* spp., *Cryptantha* spp., *Nama* spp., and *Phacelia* spp. are common. This system can often appear as very open sparse vegetation, with the mostly barren ground surface being the predominant feature.

Distribution: This system occupies broad valleys, lower bajadas, plains and low hills in the Mojave and lower Sonoran deserts.

Nations: MX, US

States/Provinces: AZ, CA, MXBC, MXSO, NV, UT

CEC Ecoregions: Sierra Nevada, Wasatch and Uinta Mountains, Central Basin and Range, Arizona/New Mexico Plateau, Mojave Basin and Range, Sonoran Desert, Southern California/Northern Baja Coast, Southern and Baja California Pine-Oak Mountains, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This desert scrub system occurs as open to intermittent vegetation cover, with the mostly barren ground surface being the predominant feature (Sawyer et al. 2009). It is characterized by a sparse to moderately dense layer (2-50% cover) of xeromorphic microphyllous and broad-leaved shrubs that is typically dominated or codominated by *Larrea tridentata* usually with *Ambrosia dumosa*. However, several other shrubs may dominate or codominate this system, including *Atriplex* spp., *Ephedra viridis, Ephedra* spp., *Grayia spinosa*, or *Lycium* spp. Low-elevation stands typically have low cover and diversity, whereas in higher-elevation stands, many different shrubs, dwarf-shrubs, and cacti may be present to codominant or form sparse understories. Associated species may include *Atriplex canescens, Atriplex hymenelytra, Atriplex polycarpa, Croton californicus, Dalea* spp., *Echinocactus polycephalus, Encelia* spp., *Ephedra funerea, Ephedra nevadensis, Lycium andersonii, Opuntia basilaris, Krameria grayi, Krameria erecta, Psorothamnus arborescens, Psorothamnus fremontii, Salazaria mexicana, Senna armata*, and *Viguiera parishii*. Some common disturbance-related species include *Acamptopappus sphaerocephalus, Bebbia juncea, Cylindropuntia acanthocarpa (= Opuntia acanthocarpa), Ericameria teretifolia, Grayia spinosa*, or *Hymenoclea salsola* (Sawyer et al. 2009). If *Encelia farinosa* or *Yucca schidigera* is present, cover is generally low (< 1-2% cover). Occasional emergent *Fouquieria splendens* or *Yucca brevifolia* may be present with low cover. The herbaceous layer is typically sparse and intermittent, but may be seasonally abundant with ephemerals. Herbaceous species, such as *Chamaesyce* spp., *Eriogonum inflatum, Dasyochloa pulchella, Aristida* spp., *Cryptantha* spp., *Nama* spp., and *Phacelia* spp., are common. The vegetation description is based on several references, including Beatley (1976), Brown (1982a), Turner (1982), MacMahon (1988), Holland and Keil (1995), Marshall (1995), Reid et al. (1999), Barbour et al. (2007), Keeler-Wolf (2007), Schoenherr and Burk (2007), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
As elevation increases, lichen and moss flora becomes more diverse and approximates that found on the Colorado Plateau. Sonoran and Mojave Desert BSC diversity is based on Rosentreter and Belnap (2003). Species reflect the fact that soils are derived from mixed substrates, mostly from calcareous parent materials (limestone) and igneous parent materials (granite). Cyanobacteria (19): *Microcoleus vaginatus* is typically dominant in the Mojave Desert. There are many other common species in Sonoran and Mojave deserts such as *Anabaena variabilis, Calothrix castellii, Calothrix parietina, Lyngbya aestuarii, Microcoleus chthonoplastes, Microcoleus paludosus, Microcoleus sociatus, Nostoc commune, Nostoc microscopicum, Nostoc muscorum, Oscillatoria* sp., *Phormidium tenue, Plectonema nostocorum, Porphyrosiphon fuscus, Schizothrix calcicola, Schizothrix calcicola, Scytonema hofmannii*, and *Tolypothrix tenuis*. Lichens (15): *Catapyrenium squamulosum, Collema coccophorum, Collema tenax*, and *Catapyrenium squamulosum* are most common. *Acarospora strigata, Astasia* sp., *Fulgensia bracteata, Fulgensia desertorum, Heppia adglutinata, Heppia despreauxii, Heppia lutosa, Peltula patellata, Peltula richardsii, Psora decipiens*, and *Toninia*

sedifolia. Algal diversity is lower in warm desert regions with 12 common species: *Astasia* sp., *Chlorococcum infusionum, Chlorella vulgaris, Navicula* sp., *Nitzschia* sp., *Palmogloea protuberans, Pinnularia* sp., *Protococcus grevillea, Protococcus viridis, Rhizoclonium hieroglyphicum, Stichococcus subtilis, Trochiscia hirta*, and *Trichostomopsis australasiae (= Didymodon australasiae)*. Dominant mosses (18) include *Crossidium aberrans, Didymodon vinealis, Syntrichia caninervis, Pterygoneurum ovatum, Pterygoneurum subsessile*, and *Tortula inermis*, and other common mosses are *Bryum argenteum, Bryum caespiticium, Crossidium aberrans, Crossidium crassinerve, Desmatodon obtusifolius (= Tortula obtusifolia), Microbryum starkeanum, Pterygoneurum ovatum, Syntrichia ruralis, Tortula atrovirens, Tortula euryphylla*, and *Tortula plinthobia*. Common liverworts (4) include *Athalamia hyalina, Plagiochasma rupestre, Riccia sorocarpa*, and *Reboulia hemisphaerica*.

Biotic Pollination; Species Diversity: High
The dominant shrub *Larrea tridentata* is pollinated by insects. Cane et al. (2000) reported on insects captured in a creosotebush stand at Silverbell IBP site from 1994-1998. Results included 8 species of *Larrea tridentata* specialists and 22 other bees, many such as *Apis mellifera*, likely also pollinate *Larrea tridentata*. Insects: (*Larrea* specialists): *Ancylandrena larreae, Colletes clypeonitens, Colletes covilleae, Hesperapis larreae, Hoplitis biscutellae, Megandrena enceliae, Perdita punctulata*, and *Trachusa larreae*.

Nitrogen Fixation; Species Diversity: Low
This desert scrub occurs in warm, arid and semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These arid shrublands typically have low herbaceous cover and high shrub cover and diversity. Several species of Fabaceae, Poaceae, and Brassicaceae may fix nitrogen in this system. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Anabaena, Calothrix, Nostoc, Plectonema, Schizothrix*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema* or *Peltigera*, and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa may be low to moderate; however, within stand species diversity of nitrogen fixers is typically low.

Xerophytes; Species Diversity: Medium
Species in this group are adapted to frequent and extended drought and have evolved abilities and mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Ambrosia dumosa, Encelia farinosa, Ephedra nevadensis, Fouquieria splendens, Larrea tridentata, Lycium andersonii*, and *Opuntia basilaris*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this desert scrub type.

Environment: *Climate:* Climate is semi-arid to arid with hot summers and warm to cool winters depending on latitude and elevation.

Physiography/landform: This ecological system forms the vegetation matrix in broad valleys, lower bajadas, plains, flats and low hills in the lower Sonoran (Colorado) and Mojave deserts extending into the southeastern Great Basin where it forms the vegetation matrix. Other habitats include minor washes and rills, alluvial fans, and upland slopes. Elevation ranges from -75 to 1200 m. Adjacent ecological systems include Mojave Mid-Elevation Mixed Desert Scrub (CES302.742) above and Inter-Mountain Basins Playa (CES304.786) below.

Soil/substrate/hydrology: Substrates are typically well-drained, sandy soils derived from colluvium or alluvium, and are often calcareous with a caliche hardpan and/or a pavement surface that is derived from limestone and dolomite (Turner 1982b, Sawyer et al. 2009).

The environmental description is based on several references, including Beatley (1976), Brown (1982a), Turner (1982b), MacMahon (1988), Holland and Keil (1995), Marshall (1995), Reid et al. (1999), Barbour et al. (2007a), Keeler-Wolf (2007), Schoenherr and Burk (2007), and Sawyer et al. (2009).

Key Processes and Interactions: This system covers vast areas of sandy and gravelly alluvial fans and bajadas and rocky slopes in the northwestern Sonoran, Mojave and Colorado deserts (Keeler-Wolf 2007, Sawyer et al. 2009). The dominant shrub, *Larrea tridentata*, is very long-lived, with clones living >10,000 years (Keeler-Wolf 2007) and is very tolerant of drought and high temperatures. It is highly adapted to minimized evapotranspiration both daily and seasonally using stomatal regulation, resinous leaves, and a leaf structure and habit to minimize self-shading and maximize photosynthesis during favorable growing periods (Hamerlynck et al. 2002, Ogle and Reynolds 2002). It may die back during extreme drought but can sprout from the base (Meinzer et al. 1990). It has low recruitment and is slow to re-establish from seed (Keeler-Wolf 2007). *Larrea tridentata* is poorly adapted to fire because of its highly flammable, resinous leaves that burn hot such that fires usually kill the shrub. If the shrub is not killed, it has limited sprouting ability after low-intensity fires (Humphrey 1974, Brown and Minnich 1986, Marshall 1995, Paysen et al. 2000). McLaughlin and Bowers (1982) reported that burned individuals surviving a fire regained their former size in five years.

The main codominant shrub, *Ambrosia dumosa*, is short-lived with a relatively shallow root system, and tends to dominate sandy and rocky sites. It can quickly establish after disturbance or drought (Vasek 1980). Post fire, it also has a limited ability to sprout, but can readily re-establish from seed (Sawyer et al. 2009).

Fire-return interval is long for this open-canopied shrub system with typically discontinuous fuels (Sawyer et al. 2009). Fire occurs under extreme conditions often following a wet year when more fine fuels are available. When it burns, fires are usually of high intensity and moderate severity (Sawyer et al. 2009). Fires in historic creosote-bursage stands were thought to be infrequent except along the margins of the ecological system where it mixed with shrub-steppe containing greater grass fuel loading. Although bunchgrass species can fill in some of the interspaces between shrubs and provide fine fuels, their distribution is generally patchy and rarely provides fuel continuity sufficient to carry fire (Brooks et al. 2007). Periodic drought is occasionally sufficient to thin grass and shrub cover.

LANDFIRE developed a VDDT model for this system which has two classes (LANDFIRE 2007a, BpS 1310870):

A) Early Development 1 Open (15% of type in this stage): Dominant cover is herbaceous, 5-10% canopy cover. Creosotebush scrub is characterized by low cover 5-10%. Little disturbance was considered in class A, except for replacement fire every 300 years on average. Historical condition where invasive annual grasses are absent, the fire-return interval is virtually nonexistent except for areas near the base of mountains experiencing locally higher rainfall and fine fuel buildup from native annuals. After 100 years, class A transitions to class B.

B) Late Development 1 Closed (shrub-dominated - 85% of type in this stage): Greater than 15% shrub cover and 20-40% grass and forb cover; associated with more productive soils. Less fine fuel is associated with this community, therefore the FRIs for replacement fire and mixed-severity fire is 650 years (min-max: 300-1000 years). Wind/weather stress also affected this community on average every 80 years, but did not cause a transition to class A.

LANDFIRE modelers emphasized that pre-settlement fire conditions in warm desert plant communities are not known. However, it is thought that fires in creosotebush scrub were absent to rare events in presettlement desert habitats, because fine fuels from winter annual plants were probably sparse, only occurring in large amounts during the spring following exceptionally wet winters (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: Primary land uses that alter natural processes of this system directly affect vegetation and soil surface with disturbance and fragmentation, and annual non-native species invasion. Excessive stress to the system occurs through soil disturbance from off-road vehicle (ORV) use, and heavy grazing that alters the species composition by reduction of perennial species and increases native disturbance-driven increaser species as well as non-native annual grasses. Fine fuels from non-native annual grasses, such as *Bromus madritensis, Bromus tectorum*, and *Schismus* spp., currently represents the most important fuel bed component in creosotebush scrub and can substantially increase the fire frequency. In years of good moisture, non-native annual grasses can comprise 66-97% of the total annual biomass in this system (LANDFIRE 2007a, BpS model 1310870). In contrast to native annuals, non-native annual plants produce fine fuel beds that persist throughout the summer and greatly increase the continuity of fuels for much of the fire season (Brooks et al. 2007). Historic year-round livestock grazing has contributed to the deterioration of this system.

Human development has impacted many locations throughout the distribution of this system. High- and low-density urban and industrial developments have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 29** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 30, left**) and sensitivity (**Figure 30, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

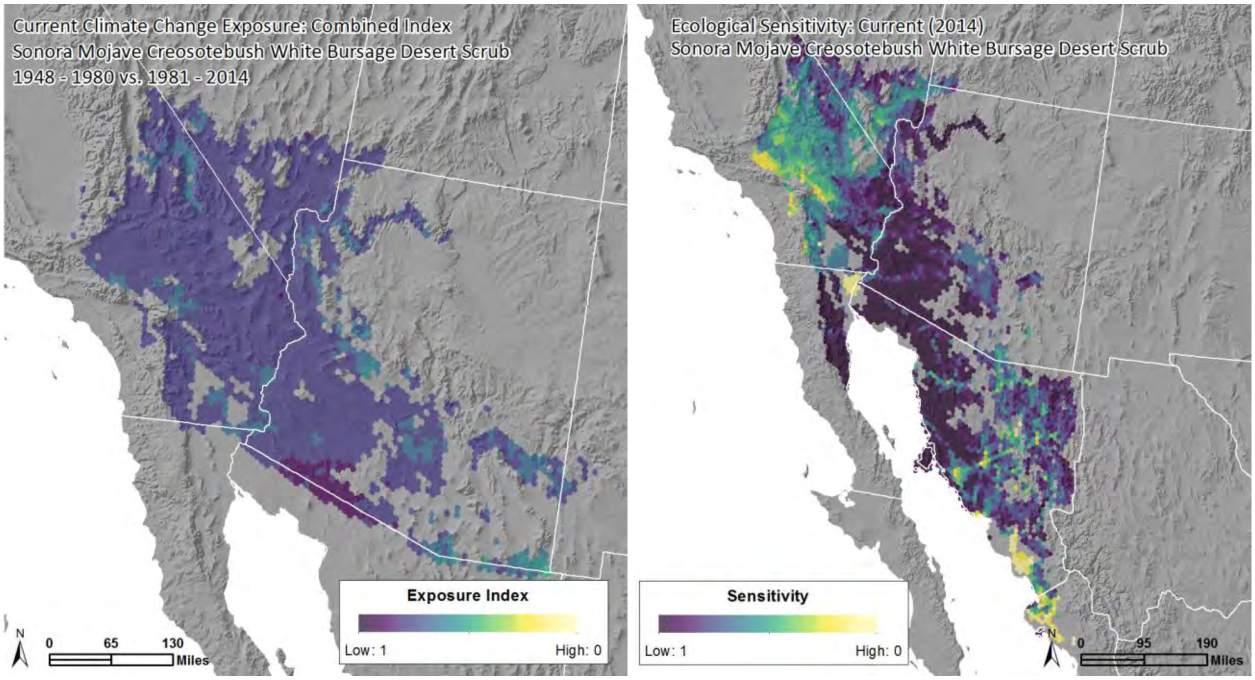

Figure 30. Climate exposure as of 2014 (left) and overall sensitivity (right) for Sonora-Mojave Creosotebush-White Bursage Desert Scrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 29. Resilience, exposure and vulnerability scores for Sonora-Mojave Creosotebush-White Bursage Desert Scrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Sonoran Desert	Mojave Basin & Range	Madrean Archipelago	Sinaloa & Sonora Hills & Canyons	Sinaloa Coastal Plain	Central Basin & Range	Sierra Madre Occidental	Arizona-New Mexico Plateau	California Coastal Sage, Chaparral, & Oak Woodlands	Arizona-New Mexico Mountains	Southern & Baja California Pine-Oak Mountains
	Sq miles within ecoregion	18,526	14,288	1,082	539	309	176	174	80	69	28	20
Contributions to Relative Vulnerability by Factor												
Vulnerability from **Exposure (2014)**		**Mod** 0.72	**Mod** 0.74	**Mod** 0.60	**Mod** 0.64	**Mod** 0.69	**Mod** 0.73	**Mod** 0.64	**Mod** 0.71	**Mod** 0.75	**Mod** 0.75	**Mod** 0.74
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.74	0.72	0.72	0.69	0.40	0.84	0.77	0.84	0.19	0.69	0.35
	Fire Regime Departure	0.90	0.56	0.25	Null	Null	0.60	Null	0.88	0.44	0.92	0.69
	Invasive Annual Grasses	0.97	0.66	0.95	0.81	0.97	0.98	0.59	0.98	0.47	0.92	0.53
	Sensitivity Average	**0.87**	**0.65**	**0.64**	**0.75**	**0.69**	**0.81**	**0.68**	**0.90**	**0.37**	**0.84**	**0.52**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.08	0.18	0.23	0.13	0.03	0.19	0.38	0.33	0.15	0.26	0.27
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.12**	**0.17**	**0.19**	**0.14**	**0.10**	**0.18**	**0.27**	**0.24**	**0.16**	**0.21**	**0.22**
Vulnerability from Measures of **Overall Resilience**		**High** 0.50	**High** 0.41	**High** 0.42	**High** 0.45	**High** 0.39	**High** 0.49	**High** 0.47	**Mod** 0.57	**High** 0.26	**Mod** 0.53	**High** 0.37
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall exposure in the U.S., as of 2014, for this widespread desert scrub system is moderate. An emerging pattern of changing climate appears in the Sonoran Desert, Mojave Basin and Range, Madrean Archipelago, Central Basin and Range, Arizona/New Mexico Plateau, and California Coastal Sage as increases ranging from 0.57° to 0.76°C for Annual Mean Temperature throughout its distribution in these ecoregions. Similar increases are seen for Mean Temperature of the Warmest Quarter over >35% of its distribution in these ecoregions. Minimum Temperature of the Coldest Month shows increases ranging from 1.1° to 1.4°C in several ecoregions, generally for <10% of its distribution in each ecoregion.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, or outright loss of native taxa, if climate change has the predicted effect of less available moisture with increasing mean temperature. Alteration of precipitation and evapotranspiration rates and timing may result in more frequent drought periods and higher intensity precipitation events, which following drought can cause significant erosion of topsoil (Finch 2012, Garfin et al. 2012) and transition it desert pavement conditions.

Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced are possibly eliminated, effectively eliminating creosotebush recruitment. Indirect effects of a warming climate with more frequent droughts could lower the shallow water table that these shrubs depend on causing widespread mortality. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low to moderate across the range of this type; with high sensitivity scores in the California Coastal Sage, Chaparral, & Oak Woodlands ecoregion on the periphery of the range (**Table 29**). In two of the ecoregions moderate sensitivity is a result of the interactions between invasive annual grasses and fire regime departure.

Vulnerability from degraded landscape condition is generally low (i.e., less development) or moderate with 8 of 11 ecoregions. Three ecoregions score in the low or very low range; likely fragmented by development. This system generally occurs across vast and remote semi-arid and arid regions throughout its range with limited impacts. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, wind and solar energy development, transportation and transmission corridors, and areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low (higher scores) in 7 of 11 ecoregions. However, wildfire has been introduced to this system. Invasive annual grasses can flush after exceptionally wet years and can sometimes create enough fuel to carry fire. Fires are devastating in this ecosystem, which has a long fire-return interval (+650 years) and is dominated by fire-sensitive shrubs that are killed when burned. Fire regime departure is mixed with 3 of 11 ecoregions having low departure (higher scores), three have moderate departure, one has high and one has very high contributions from departure. Four ecoregions that occur in Mexico (where no fire regime departure data are available). In addition, the effects of historic overgrazing and current grazing by livestock impact the limited herbaceous component and biological soil crusts.

The interactions of the stressors of fragmentation by development, altered fire regime, and invasion by annual grasses have resulted in changes to the composition and structure of this desert scrub. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is very low across the entire range of this system, in the U.S. and Mexico as well. Both topoclimatic variability and diversity within functional species groups contribute to the very low adaptive capacity. These shrublands occur across generally flat landforms and topography such as broad valleys, lower bajadas, plains and low hills in the Mojave and lower Sonoran deserts. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relative 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups varies from high to low among groups; but scores as very low overall. Within individual stands, the most limiting functional role is that of nitrogen fixation, which is provided by only a few species and so their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability. The xerophytes functional group has moderate within-stand diversity, with sometimes as many as a dozen xerophytic shrubs found in any one stand. This contrasts with the Chihuahuan Creosotebush Desert Scrub system, where the xerophytic role is primarily represented by *Larrea tridentata*. Conversely, species of lichens, algae and cyanobacteria that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type; calcareous and igneous substrates common in this system contribute to a high diversity of lichens. A number of bees and other insects provide a biotic pollination function, and the diversity within this group is also high.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This desert scrub type scores in the moderate level of vulnerability throughout its range. This is primarily due to its very low scores for adaptive capacity and current moderate scores for exposure. Inherent vulnerabilities are high for warm desert types that naturally occupy extensive flat plains and valley bottoms (low topoclimate variability). Other vulnerabilities include low diversity within key functional species groups, such as nitrogen fixing species. Additionally, this desert scrub is highly susceptible to invasive plants and their interactions with introduced wildfires. Therefore, common effects of land use throughout the West, including surface disturbance from roads, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 30. Climate change adaptation strategies relative to vulnerability scores for Sonora-Mojave Creosotebush-White Bursage Desert Scrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, invasive plants, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation or outright loss of native species. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor trends in soil moisture regime, and for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely loss of native species or invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Consider creating new models for novel wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barbour and Major 1977, Barbour and Major 1988, Barbour et al. 2007a, Beatley 1976, Belnap 2001, Belnap et al. 2001, Brooks et al. 2007, Brown 1982a, Brown and Minnich 1986, Cane et al. 2000, Comer et al. 2003*, Evans and Belnap 1999, Finch 2012, Garfin et al. 2013, Hamerlynck et al. 2002, Holland and Keil 1995, Humphrey 1974, Keeler-Wolf 2007, LANDFIRE 2007a, MacMahon 1988, Marshall 1995a, McLaughlin and Bowers 1982, Meinzer et al. 1990, Ogle and Reynolds 2002, Paysen et al. 2000, Reid et al. 1999, Rosentreter and Belnap 2003, Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Schoenherr and Burk 2007, Shiflet 1994, Thomas et al. 2004, Turner 1982b, Vasek 1980

CES302.761 Sonoran Paloverde-Mixed Cacti Desert Scrub

Figure 31. Photo of Sonoran Paloverde-Mixed Cacti Desert Scrub. Photo credit: Kevin Schraer, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/coyotecreek

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs on hillsides, mesas and upper bajadas in southern Arizona and extreme southeastern California. The vegetation is characterized by a sparse emergent tree layer of *Carnegiea gigantea* (3-16 m tall) and/or a sparse to moderately dense canopy of xeromorphic deciduous and evergreen tall shrubs codominated by *Parkinsonia microphylla* and *Larrea tridentata*, with *Prosopis* sp., *Olneya tesota*, and *Fouquieria splendens* less prominent. Other common shrubs and dwarf-shrubs include *Acacia greggii, Ambrosia deltoidea, Ambrosia dumosa* (in drier sites), *Calliandra eriophylla, Jatropha cardiophylla, Krameria erecta, Lycium* spp., *Menodora scabra, Simmondsia chinensis*, and many cacti, including *Ferocactus* spp., *Echinocereus* spp., and *Opuntia* spp. (both cholla and prickly-pear). The sparse herbaceous layer is composed of perennial grasses and forbs with annuals seasonally present and occasionally abundant. Outliers of this succulent-dominated ecological system occur as "Cholla Gardens" in transitional areas in the southern and eastern Mojave Desert ecoregion. In this area, the system is characterized by *Cylindropuntia bigelovii, Senna armata*, and other succulents, but it lacks the *Carnegiea gigantea* and *Parkinsonia microphylla* which are typical farther east. *Fouquieria splendens* is present in increasingly diminishing amounts in the system where it occurs further west and north.

Distribution: This system is found primarily in southwestern Arizona and western Sonora, Mexico, extending east of the Colorado River in southeastern California where locally there is enough summer precipitation (Whipple Mountains).

Nations: MX, US

States/Provinces: AZ, CA, MXBC, MXSO, NV?

CEC Ecoregions: Arizona/New Mexico Plateau, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, Southern and Baja California Pine-Oak Mountains, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The vegetation is characterized by a diagnostic sparse, emergent tree layer of *Carnegiea gigantea* (3-16 m tall) and/or a sparse to moderately dense canopy codominated by xeromorphic deciduous and evergreen tall shrubs *Parkinsonia microphylla* and *Larrea tridentata*, with *Prosopis* sp., *Olneya tesota*, and *Fouquieria splendens* less prominent. Other common shrubs and dwarf-shrubs include *Acacia greggii, Ambrosia deltoidea, Ambrosia dumosa* (in drier sites), *Calliandra eriophylla, Jatropha cardiophylla, Krameria erecta, Lycium* spp., *Menodora scabra, Simmondsia chinensis*, and many cacti, including *Ferocactus* spp., *Echinocereus* spp., and *Opuntia* spp. (both cholla and prickly-pear). The sparse herbaceous layer is composed of perennial grasses and forbs with annuals seasonally present and occasionally abundant. On slopes, plants are often distributed in patches around rock outcrops where suitable habitat is present. Outliers of this succulent-dominated ecological system occur as "Cholla Gardens" in transitional areas in the southern and eastern Mojave Desert ecoregion. In this area, the system is characterized by *Cylindropuntia bigelovii (= Opuntia bigelovii), Senna armata*, and other succulents, but it lacks the *Carnegiea gigantea* and *Parkinsonia microphylla* which are typical farther east. *Fouquieria splendens* is present in increasingly diminishing amounts as the system occurs further west and north.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
As elevation increases, lichen and moss flora are more diverse and approximate that found on the Colorado Plateau. Sonoran Desert BSC diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (15): *Calothrix parietina, Microcoleus paludosus, Microcoleus sociatus, Microcoleus vaginatus, Nostoc commune, Nostoc microscopicum, Nostoc muscorum, Schizothrix calcicola*, and *Scytonema hofmannii* are most common, plus *Lyngbya aestuarii, Oscillatoria* sp., *Plectonema nostocorum, Phormidium* sp., *Porphyrosiphon fuscus*, and *Tolypothrix tenuis*. Soil lichens (9) are patchy in Sonoran Desert. *Collema coccophorum, Collema tenax*, and *Catapyrenium squamulosum* are most common. *Acarospora strigata, Heppia adglutinata, Heppia despreauxii, Heppia lutosa, Peltula patellata*, and *Peltula richardsii* are often present. Algal diversity is lower in warm desert regions with 8 common species: *Chlorella vulgaris, Navicula* sp., *Nitzschia* sp., *Palmogloea protuberans, Pinnularia* sp., *Protococcus grevillea, Stichococcus subtilis*, and *Trochiscia hirta*. Common mosses (8) include *Bryum argenteum, Bryum caespiticium, Crossidium aberrans, Desmatodon obtusifolius (= Tortula obtusifolia), Pterygoneurum ovatum, Syntrichia ruralis, Tortula euryphylla*, and *Tortula plinthobia*.

Biotic Pollination; Species Diversity: High
Many shrubs are pollinated by insects in this desert scrub system. Cane et al. (2000) reported on insects captured in a Creosotebush *Larrea tridentata* stand at Silverbell IBP site from 1994-1998. Results included 8 species of *Larrea tridentata* specialists and 22 other bees, many such as

introduced *Apis mellifera*, likely also pollinate shrubs and cacti such as *Acacia* spp., *Calliandra eriophylla, Larrea tridentata, Mimosa* spp., *Parkinsonia* spp. (Turner et al. 1995). Insects: (*Larrea* specialists): *Ancylandrena larreae, Colletes clypeonitens, Colletes covilleae, Hesperapis larreae, Hoplitis biscutellae, Megandrena enceliae, Perdita punctulata*, and *Trachusa larreae*. Additionally, species of bats, such as lesser long-nosed bat (*Leptonycteris yerbabuenae*) and Mexican long-tongued bat (*Choeronycteris mexicana*), pollinate large night-blooming saguaro cacti. (Alcorn et al. 1961, Chambers and Gray 2004). Before the introduction of the honey bees (*Apis mellifera*) by Europeans, an intermittent lack of native pollinators may have limited seed set in saguaro and other species (Schmidt and Buchman 1986, Turner et al. 1995).

Nitrogen Fixation; Species Diversity: Medium
This desert scrub occurs in warm, arid and semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These arid shrublands typically have low herbaceous cover and high shrub cover and diversity. Most species of Fabaceae (*Acacia, Calliandra, Mimosa, Olneya, Parkinsonia, Prosopis*, and *Senna*), several Poaceae, and some Brassicaceae can fix nitrogen in this system. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen, and carbon can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Calothrix, Nostoc, Plectonema, Schizothrix*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema* or *Peltigera*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Xerophytes; Species Diversity: Medium
Species in this group are adapted to frequent and extended drought and have evolved abilities and mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Acacia greggii, Ambrosia deltoidea, Calliandra eriophylla, Carnegiea gigantea, Fouquieria splendens, Jatropha cardiophylla, Larrea tridentata, Parkinsonia microphylla, Prosopis* sp., and *Simmondsia chinensis*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this desert scrub type.

Environment: *Climate:* Climate is arid to semi-arid, continental with mild winters and hot summers (Niering and Lowe 1984). Precipitation has a bimodal distribution with rain in the winter (December-February) and a summer monsoon (July-September). Extended periods of drought or episodes of extreme cold limit this type. Specifically, establishment of dominant species is constrained by decadal or longer periods of below-average precipitation (Turner et al. 1995). Twenty-four hours of below-freezing temperature causes nearly total mortality of the dominant plants. At the southern end of the system's range, competition from more mesic species may constrain distribution of this system (Turner et al. 1995).

Physiography/landform: This succulent desert scrub ecological system occurs on hillsides, mesas and upper bajadas in southern Arizona and extreme southeastern California. Stands are typically found below 1200 m elevation, with rare occurrences up to 1400 m. Landforms range from steep, rocky slopes of desert mountains to upper and lower bajadas extending out on to alluvial flats. With decreasing elevation, the system typically occurs in xeroriparian habitats (edges of channels and washes) and on rock outcrops.

Soil/substrate/hydrology: At higher elevations of bajadas and on steeper surfaces, the system is found on coarse soils that may be associated with poorly developed geomorphic (aka frequently eroded) surfaces; at lower elevations (bottom of bajadas and alluvial fans far from risk of flooding), it is found on very stable geomorphic surfaces. The soils are often underlain by an impervious caliche layer.

Key Processes and Interactions: Complex ecological factors determine the occurrence of characteristic species *Carnegiea gigantea*. Major range-limiting factors are cold winters and dry summers. According to Benson (1982), *Carnegiea gigantea* is killed by extended frosts and does not occur above 1370 m elevation. Its seeds germinate and seedlings and adults grow mostly during the summer monsoon season, so the lack summer moisture further west restricts it from the Mojave Desert. Seedlings require shade from rocks or shrubs called "nurse" plants for seed germination and seedling establishment. The nurse plant protects seedlings from drying out in the intense desert sun, and possibly from frost and predation (Benson 1982, Brown 1982a). As it grows, *Carnegiea gigantea* may inhibit the nurse plant and cause dieback in these shrubs or possibly damage itself significantly (Brown 1982a). In Arizona, north slopes are generally too cold for *Carnegiea gigantea* to germinate; therefore, the best sites are mesic microsites on warm exposures where there is shade and a slight depression to concentrate precipitation. Bats such as lesser long-nosed bat (*Leptonycteris yerbabuenae*) and Mexican long-tongued bat (*Choeronycteris mexicana*) pollinate these large night-blooming cacti. Once the fruit ripens in June, lesser long-nosed bat, white-winged dove (*Zenaida asiatica*), Gila woodpecker (*Melanerpes uropygialis*), and other birds or mammals consume the fleshy red pulp and disperse the seeds, which pass through their guts intact (Pavek 1993b). Seed dispersal beneath nurse plant shrub canopies such as *Parkinsonia microphylla* is primarily done by frugivorous birds and is a major factor in saguaro establishment (McAuliffe 1988, 1993). *Carnegiea gigantea* are vulnerable to fire with smaller individuals (<2-4 m tall) generally killed, especially if large amounts of fuel are present at the plant base, but larger individuals may survive (McLaughlin and Bowers 1982, Pavek 1993b).

This system is not thought to have supported fuel loads to sustain large fires prior to European habitation of the region. Historically, fires in the Sonoran Desert were usually low intensity and uncommon with fire-return interval greater than 250 years because of limited fuel loads (McLaughlin and Bowers 1982, Thomas 1991). Natural fires are associated with dry lightning coincident with monsoonal storms following years when previous winter precipitation was sufficient to create a thick fine-fuel bed of annual plants to carry fire. These fires tend to be patchy due to heavier fuel in microsites, or linear when high winds were associated with convection storms (LANDFIRE 2007a). Replacement fires were very rare or absent (average FRI of 100-1000 years, and perhaps longer) (LANDFIRE 2007a). If they occurred, they did so only during conditions of extreme fire behavior after consecutive years of above-average winter precipitation when necessary fine fuels accumulate. These rare fires - which may or may not have occurred - had tremendous influence on community structure because the dominant overstory plants are extremely susceptible to fires, even those of low intensity (McLaughlin and Bowers 1982, Esque et al. 2004).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 1411090):

A) Early Development 1 Open (5% of type in this stage): Shrub cover is11-50%. Initial post-disturbance community dominated by bursage. Duration 20 years with succession to class B.

B) Mid Development 1 Open (shrub-dominated - 20% of type in this stage): Dominated by bursage and early-seral shrubs such as *Encelia farinosa*. Perennial warm-season grasses are scattered, and dominant succulents and woody plants have established beneath bursage plants. Duration 50-100 years with succession to class C unless infrequent replacement fire or climatic event (drought, frost) returns vegetation to class A. Lethal freeze and drought are listed as Wind/Weather/Stress in model.

C) Late Development 1 Closed (shrub-dominated - 75% of type in this stage): Succulent- and small tree-dominated community. Persists until infrequent replacement fire or climatic event (drought, frost) returns vegetation to class A. Lethal freeze and drought are listed as Wind/Weather/Stress in model.

Prolonged weather-related stress (drought or frost) thinned dominant overstory plants and, in rare cases, led to stand replacement. It is speculated that these events occurred with similar frequency as stand-replacing fires (LANDFIRE 2007a). Cold stress is more common in stands at the northern extent and at higher elevations on desert mountain ranges. Large (presumably old) saguaro plants are also susceptible to windthrow, particularly after rainstorms saturate the soil (LANDFIRE 2007a). LANDFIRE modelers note there is much uncertainty in model parameters, particularly with respect to the return interval of fire, drought and lethal cold temperatures (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: Primary land uses that alter natural processes of this system directly affect vegetation and soil surface through disturbance and fragmentation, and annual non-native species invasion. Recent conversion of this type has commonly come from installation of irrigated agriculture near rivers and forage production sites in northern Sonora, Mexico, and southern Arizona where desert is cleared and *Pennisetum ciliare* is planted for forage production.

Altered fire regime from encroachment by invasive non-native grasses such as *Bromus rubens, Schismus barbatus*, and perennial *Pennisetum ciliare* are serious threats and stressors to this ecosystem. Annual invasive non-native grasses such as *Bromus rubens* and *Schismus barbatus* and other annuals can build up enough litter (fine fuels) after a couple wet years to carry fire and cause massive destruction to fire-sensitive desert species. These invasive non-native species have greatly increased the incidence and extent of fires in the Sonoran Desert as these grasses carry fire between shrub interspaces and generally increase fuel loads, fire extent and severity.

Excessive stresses to the system through soil disturbance from off-road vehicle (ORV) use and heavy grazing can alter the composition of perennial species and increase the establishment of native disturbance-increasers and exotic annual grasses. *Pennisetum ciliare*, a fire-adapted perennial forage grass introduced from the African savanna, has gained a foothold in central and southern Arizona and is expanding its range. It can grow in dense stands that crowd out native plants and can fuel devastating fires in the Sonoran Desert. In addition, competition for water can weaken and kill desert plants, even larger trees and cacti, while dense roots and ground shading prevent germination of native seeds. Additional conversion from urban and exurban development near larger metropolitan areas is also significant (LANDFIRE 2007a). Development, including urbanization, suburban, and energy development, continue to convert or degrade existing stands. Losses around large metropolitan areas such as Phoenix and Tucson are significant, especially in northern Phoenix in this mid-elevation ecosystem. Residential development has significantly impacted locations within commuting distance to urban areas (LANDFIRE 2007a). Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Additionally, massive dust from development likely negatively impacts vegetation and habitat quality for wildlife as this dust is a significant health hazard to humans. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

Energy development from large-scale solar and, to a lesser extent, wind farms is becoming more common in the desert southwest. These projects span thousands of acres of land. The BLM designated a Solar Energy Zone in California called the "Riverside East Zone" and it contains Sonoran palo verde - mixed cacti scrub. While the BLM and USFWS try to have developers design projects to avoid impacts to the desert dry wash woodland, this results in corridors of washes surrounded by graded and bladed land. Because of these changes in vegetation, landform and soil structure surrounding the corridors, these areas often flood during summer monsoon rains, causing severe erosion and changes their original function in the ecosystem (S. Dashiell pers. comm.). There are some landscape-scale planning processes that attempt to minimize impacts to microphyll woodland: Restoration Design Energy Project in Arizona and BLM's Solar Energy Program and Desert Renewable Energy Conservation Plan (in preparation) (S. Dashiell pers. comm.).

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 31** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 32, left**) and sensitivity (**Figure 32, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

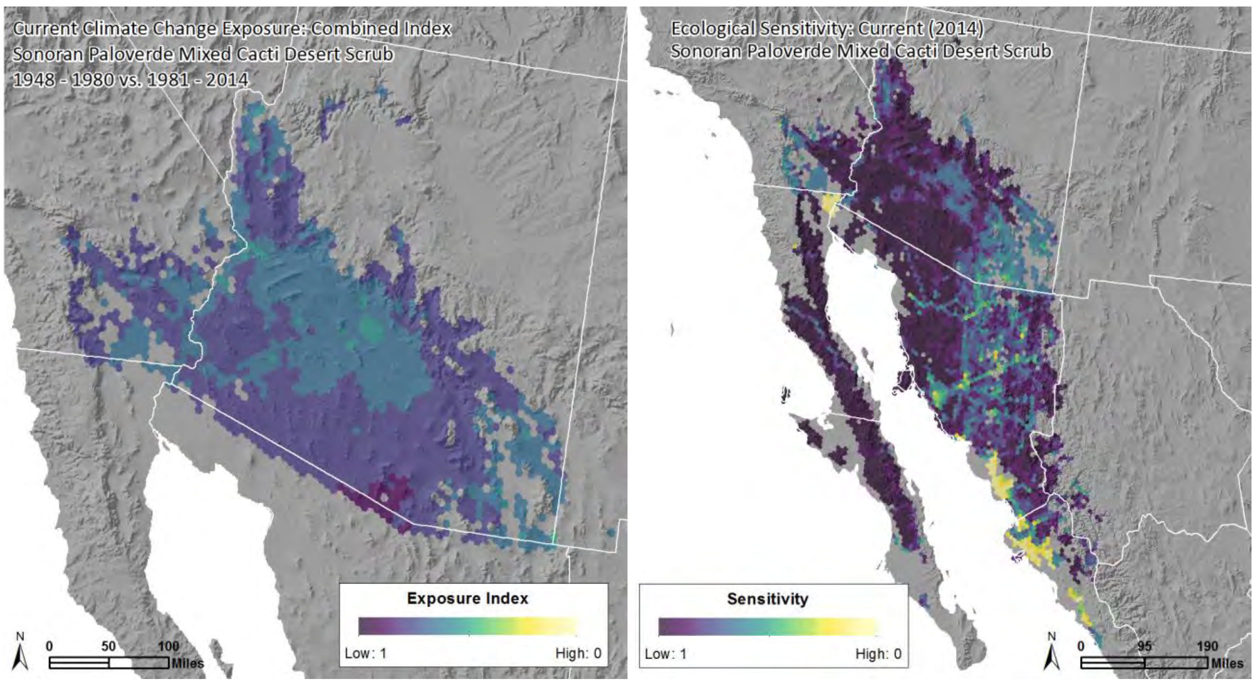

Figure 32. Climate exposure as of 2014 (left) and overall sensitivity (right) for Sonoran Paloverde-Mixed Cacti Desert Scrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 31. Resilience, exposure and vulnerability scores for Sonoran Paloverde-Mixed Cacti Desert Scrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Sonoran Desert	Baja Californian Desert	Sinaloa & Sonora Hills & Canyons	Madrean Archipelago	Arizona-New Mexico Mountains	Sinaloa Coastal Plain	Mojave Basin & Range	Sierra Madre Occidental	Arizona-New Mexico Plateau	California Coastal Sage, Chaparral, & Oak Woodlands
	Sq miles within ecoregion	36,964	3,979	3,477	3,230	1,231	985	575	227	57	42
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Mod** 0.69	**Mod** 0.59	**Mod** 0.57	**Mod** 0.71	**Mod** 0.71	**Mod** 0.60	**Mod** 0.70	**Mod** 0.66	**Mod** 0.72	**Mod** 0.67
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.76	0.95	0.78	0.74	0.80	0.48	0.66	0.81	0.83	0.95
	Fire Regime Departure	0.96	Null	Null	0.32	0.97	Null	0.78	Null	0.91	0.95
	Invasive Annual Grasses	0.98	1.00	0.71	0.97	0.95	0.98	0.81	0.65	0.97	0.86
	Sensitivity Average	**0.90**	**0.98**	**0.74**	**0.67**	**0.91**	**0.73**	**0.75**	**0.73**	**0.90**	**0.92**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.12	0.18	0.15	0.22	0.26	0.05	0.18	0.30	0.28	0.18
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.31**	**0.34**	**0.33**	**0.36**	**0.38**	**0.27**	**0.34**	**0.40**	**0.39**	**0.34**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.60	**Mod** 0.66	**Mod** 0.53	**Mod** 0.52	**Mod** 0.64	**Mod** 0.50	**Mod** 0.55	**Mod** 0.57	**Mod** 0.65	**Mod** 0.63
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, as of 2014, exposure for this widespread desert scrub system is moderate. An emerging pattern of changing climate appears in the Sonoran Desert, Madrean Archipelago, Arizona/New Mexico Mountains, Mojave Basin and Range, and California Coastal Sage ecoregions as increases ranging from 0.65° to 0.85°C for Annual Mean Temperature throughout its distribution in these ecoregions. Similar increases are seen for Mean Temperature of the Warmest Quarter over >50% of its distribution in these ecoregions. In the Sonoran Desert, Arizona/New Mexico Mountains, Mojave Basin and Range, and California Coastal Sage ecoregions, Minimum Temperature of the Coldest Month shows increases ranging from 1.2° to 1.4°C across some 15% of its distribution in each ecoregion.

Climate Change Effects: Potential climate change effects could include a shift to species more common on hotter, drier sites such as the often adjacent and more widespread creosote-bursage desert scrub, if climate change has the predicted effect of increasing mean temperature. The Sonoran Desert may warm by an average of 2-4°F over the next 50 years. Precipitation is less predictable. Persistent drought is currently common in this system and likely to become more common in future as climate warms, becoming a more significant threat and stressor that may cause ecosystem collapse. However, the latest IPCC report states that monsoonal storms are likely to intensify (IPCC 2013b) because of changes in the Pacific monsoon which will affect this ecosystem (IPCC 2013b). If precipitation increases significantly, this may change the timing or magnitude of peak and low streamflows, which may be beneficial to some species and detrimental to others. Given the higher probability of warming, the stress on component species is high for a drought- and heat-intolerant species. Thomas et al. (2012) analyzed predicted changes in suitable habitat for dominant plants in the southwestern U.S. for two future time periods and three emission scenarios. Results show significant losses in modern-day suitable habitat for key species such as *Carnegiea gigantea, Olneya tesota*, and *Parkinsonia microphylla*, with limited potential for increases in future suitable habitat for this ecosystem.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low across the range of this type; all 10 ecoregions have low sensitivity (higher scores), although a few ecoregions approach moderate sensitivity (**Table 31**).

Landscape condition is generally good (less development) with 9 of 10 ecoregions having good condition (higher scores). Generally, this type occurs across vast and remote semi-arid and arid regions throughout its range with limited impacts. However, in the Sinaloa Coastal Plain landscape condition is poor, likely due to fragmentation by development, and in the Madrean Archipelago, urban and exurban development in the vicinity of Phoenix and Tucson has impacted this system. This system typically does not occur on sites conducive to agriculture, so overall these scores are likely a reflection of fragmentation due to many small roads, mining operations, wind and solar energy development, transportation and transmission corridors, and areas of urban, suburban and exurban development. However, in the Sonoran Desert ecoregion large areas of irrigated agriculture in southeastern California have also impacted this system.

Risk of invasive annual grasses is low (higher scores) in 8 of 10 ecoregions with the relatively minor Sinaloa & Sonora Hills & Canyons Sierra Madre Occidental ecoregion having moderate risk. Invasive annual grasses can flush after exceptionally wet years and can sometimes create enough fuel to carry fire. However, in the range of this type invasive perennial grasses are likely to be a more important risk; they are not included in the invasives model used in this study. Fire regime departure is generally low (higher scores) in 5 of 10 ecoregions, although the Madrean Archipelago ecoregion has high departure (low score). Scores are null for 4 ecoregions that occur in Mexico, where no fire regime departure data are available. When they do occur, fires are devastating in this ecosystem, which has a long fire-return interval and is dominated by fire-sensitive scrub and cacti that are killed when burned.

The interactions of the stressors of fragmentation by development, altered fire regime, and invasive annual grass invasion have resulted in changes to the composition and structure of this desert scrub.

Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across the range of this system, in the U.S. and Mexico as well. Topoclimatic variability is very low in nearly all ecoregions. These shrublands occur across gently sloping to steeper landforms and topography such as steep, rocky slopes of desert mountains and upper and lower bajadas extending out on to alluvial flats. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups varies from moderate to high among groups; with an overall score as moderate. Within individual stands, the most limiting functional role is that of nitrogen fixation, which is provided by a moderate number of species, as this system has many taxa in the *Fabaceae* family of which most are nitrogen-fixers. The xerophytes functional group also has moderate within-stand diversity, with sometimes as many as a dozen xerophytic shrubs found in any one stand. Conversely, species of lichens, algae and cyanobacteria that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type; calcareous and igneous substrates common in this system contribute to a high diversity of lichens. Bats and a number of bees and other insects provide a biotic pollination function, and the diversity within this group is also high.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This desert scrub type currently scores in the moderate level of vulnerability throughout its range. This is primarily due to its moderate scores for exposure and low scores for adaptive capacity. Inherent vulnerabilities are high for warm desert types that naturally occupy extensive flat plains and valley bottoms. Additionally, these desert scrub types are highly susceptible to invasive plants and their interactions with introduced wildfires. Therefore, common effects of land use throughout the West, including surface disturbance from roads, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 32. Climate change adaptation strategies relative to vulnerability scores for Sonoran Paloverde-Mixed Cacti Desert Scrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, invasive plants, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation or outright loss of native species. Restore native herb diversity and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor trends in soil moisture regime, and for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely loss of native species or invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Consider creating new models for novel wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Alcorn et al. 1961, Belnap 2001, Belnap et al. 2001, Benson 1982, Bowers and McLaughlin 1987, Brown 1982a, Cane et al. 2000, Chambers and Gray 2004, Comer et al. 2003*, Esque et al. 2004, Evans and Belnap 1999, IPCC 2013b, LANDFIRE 2007a, LANDFIRE 2007b, MacMahon 1988, McAuliffe 1988, McAuliffe 1993, McLaughlin and Bowers 1982, Niering and Lowe 1984, Pavek 1993b, Pavek 1994a, Robichaux

1999, Rosentreter and Belnap 2003, Schmidt and Buchman 1986, Shiflet 1994, Shreve and Wiggins 1964, TNC 2013, Thomas 1991, Thomas et al. 2012, Turner et al. 1995, USFS 2002b

3.B.1.Ne. Western North American Cool Semi-Desert Scrub & Grassland

M093. Great Basin Saltbush Scrub

CES304.783 Inter-Mountain Basins Mat Saltbush Shrubland

Figure 33. Photo of Inter-Mountain Basins Mat Saltbush Shrubland. Photo credit: Andrey Zharkikh, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs on gentle slopes and rolling plains in the northern Colorado Plateau and Uinta Basin on Mancos shale and arid, windswept basins and plains across parts of Wyoming. It is also found in eastern Wyoming in Great Plains areas and may extend north into Montana and Canada. These landscapes typically support dwarf-shrublands composed of relatively pure stands of *Atriplex* spp., such as *Atriplex corrugata* (in Colorado and Utah), *Atriplex gardneri* (Wyoming and Montana into Canada), or *Atriplex falcata* (Columbia Plateau and northern Great Basin). Other dominant or codominant dwarf-shrubs may include *Artemisia longifolia, Artemisia pedatifida* (very important in Wyoming, rare in Colorado stands), or *Picrothamnus desertorum*, sometimes with other low shrubs, such as *Krascheninnikovia lanata* or *Tetradymia spinosa*. *Atriplex confertifolia* or *Atriplex canescens* may be present but do not codominate. *Artemisia tridentata ssp. wyomingensis* can occur in local patches within this system. The herbaceous layer is typically sparse. Scattered perennial forbs occur, such as *Oenothera* spp., *Phacelia* spp., *Sphaeralcea grossulariifolia, Stanleya pinnata*, and *Xylorhiza glabriuscula*; perennial grasses *Achnatherum hymenoides, Bouteloua gracilis* (not in Wyoming), *Distichlis spicata, Elymus elymoides, Elymus lanceolatus ssp. lanceolatus, Pascopyrum smithii, Pleuraphis jamesii, Poa secunda*, or *Sporobolus airoides* may comprise the herbaceous layer. In less saline areas, there may be inclusions of grassland patches dominated by *Hesperostipa comata, Leymus salinus, Pascopyrum smithii*, or *Pseudoroegneria spicata*. Substrates are shallow, typically saline, alkaline, fine-textured soils developed from shale or alluvium and may be associated with shale badlands. Infiltration rate is typically low. In Wyoming and possibly elsewhere, inclusions of non-saline, gravelly barrens or rock outcrops dominated by cushion plants such as *Arenaria hookeri* and *Phlox hoodii* without dwarf-shrubs may be present (these are not restricted to this system). Annuals are seasonally present and may include *Eriogonum inflatum, Monolepis nuttalliana, Plantago tweedyi*, and the introduced annual grass *Bromus tectorum*. In Montana, *Atriplex gardneri* also occurs associated with Great Plains badlands, and determining which system it falls into may be difficult.

Distribution: This system occurs on gentle slopes and rolling plains in the northern Colorado Plateau and Uinta Basin on Mancos shale and arid, windswept basins and plains across parts of Wyoming, and possibly into Montana and Canada.

Nations: US

States/Provinces: AZ, CO, MT, NM, UT, WY

CEC Ecoregions: Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Northwestern Great Plains, High Plains, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This ecological system typically supports dwarf-shrublands composed of relatively pure stands of *Atriplex* spp., such as *Atriplex corrugata* or *Atriplex gardneri*. Other dominant or codominant dwarf-shrub may include *Artemisia longifolia, Artemisia pedatifida*, or *Picrothamnus desertorum*, sometimes with a mix of other low shrubs, such as *Krascheninnikovia lanata* or *Tetradymia spinosa*. *Atriplex confertifolia* or *Atriplex canescens* may be present but do not codominate. The herbaceous layer is typically sparse. Scattered perennial forbs occur, such as *Xylorhiza glabriuscula* and *Sphaeralcea grossulariifolia*, and the perennial grasses *Achnatherum hymenoides, Bouteloua gracilis, Elymus elymoides, Elymus lanceolatus ssp. lanceolatus, Pascopyrum smithii*, or *Sporobolus airoides* may dominate the herbaceous layer. In less saline areas, there may be inclusions of grasslands dominated by *Hesperostipa comata, Leymus salinus, Pascopyrum smithii*, or *Pseudoroegneria spicata*. In Wyoming and possibly elsewhere, vegetation dominated by cushion plants such as *Arenaria hookeri* and *Phlox hoodii* without dwarf-shrubs may be present and occurs on inclusions of non-saline, gravelly barrens or rock outcrops. Annuals are seasonally present and may include *Eriogonum inflatum, Plantago tweedyi*, and the introduced annual grass *Bromus tectorum*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: Low
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems of the western U.S. (Belnap and Lange 2003). Species composition would be similar to cold desert playas occurring on poorly drained soils as described in Belnap et al. (2001) and Rosentreter and Belnap (2003). Cyanobacteria (4): *Microcoleus* spp., *Nostoc commune, Nostoc flagelliforme*, and *Dermatocarpon miniatum*. Lichens: *Lecanora muralis*.

Halophytes; Species Diversity: Low
Species in this group are adapted to saline and alkaline soil conditions common in the Western U.S. and dominate on substrates derived from marine shales, in internally drained basins, and in coastal areas. Shrubs: *Atriplex corrugata, Atriplex falcata, Atriplex gardneri, Artemisia longifolia*, or *Artemisia pedatifida*. Herbaceous: *Distichlis spicata* and *Sporobolus airoides*. Although the diversity of shrubs for this system is moderate range-wide, a given stand is typically depauperate with one shrub species and a few herbaceous species.

Nitrogen Fixation; Species Diversity: Low
Mat and Gardner saltbush dwarf-shrublands occur in semi-arid climates often on harsh saline substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid dwarf-shrublands typically have low to very low herbaceous cover and low diversity. Species of Fabaceae (including species of *Astragalus* and *Lupinus*) and some Poaceae (e.g., *Achnatherum hymenoides, Distichlis spicata, Elymus elymoides, Elymus lanceolatus ssp. lanceolatus, Pascopyrum smithii, Pleuraphis jamesii, Poa secunda*, or *Sporobolus airoides*), and a few Brassicaceae can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Nostoc* and *Nostoc*-containing species of *Collema* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa is moderate; however, within stand species diversity of nitrogen fixers is typically low.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this saltbush shrubland type.

Environment: *Climate:* Climate is temperate and semi-arid. Summers are generally hot, and freezing temperatures are common in the winter. Mean annual precipitation ranges from 13-33 cm. In Montana and Wyoming, approximately two-thirds of the annual precipitation falls in spring and early summer. In Colorado and Utah, over half the precipitation occurs in the late summer monsoons as high-intensity thunderstorms.

Physiography/landform: This ecological system occurs in the intermountain western U.S. on gentle slopes and rolling plains on semi-arid, windswept plains and basins. Elevation ranges from 1150-2200 m. Stands occur on shale outcrops and plains and are nearly flat to moderately steep.

Soils/substrate/hydrology: Substrates are shallow to moderately deep, typically saline, alkaline, poorly developed, fine-textured soils but range from sandy loam to clay and may be gravelly. Soil are developed from shale, alluvium, and bentonite and may be associated with shale badlands. Infiltration rate is typically low and erosion rates are high because of poor infiltration and high runoff. In Wyoming and possibly elsewhere, inclusions of non-saline, gravelly barrens or rock outcrops may be present.

Key Processes and Interactions: These are highly saline-tolerant and drought-tolerant shrublands. *Atriplex corrugata*- and *Atriplex gardneri*-dominated shrublands are the most saline-tolerant of the Mancos shale plant communities studied by Branson et al. (1976). Gardner's saltbush has an extensive, highly branched root system, and tolerates poor site conditions (Reed 1993b). Stands are characterized by bare ground and young to mature shrubs that have re-sprouted or established from nearby seed. Although very slow-growing, these shrubs can completely dominate these extremely saline sites (Branson et al. 1976). They are true evergreen dwarf-shrubs retaining leaves for several years. This plant utilizes winter soil moisture, beginning new growth in March when the soils are relatively warm and moist. It flowers in April and by mid-July fruits are shattered (Branson et al. 1976). If the soils dry out in midsummer, it can go dormant until the late summer monsoon rains begin. Disturbance is characterized by very wet periods that contribute to high shrub mortality every 100 years on average.

Shrub cover may be patchy and discontinuous, but cover is higher than Inter-Mountain Basin Shale Badland (CES304.789). These shrublands typically occur on flatter slopes with less severe erosion than those occupied by badland communities. This system does not have a fire regime due to discontinuous fuel (LANDFIRE 2007a). Fire can occur in conjunction with wet years possibly once every 100 years on average. Most species of *Atriplex* sprout after fire, recovering fully within 2 to 3 years from root sprouts (Wright 1980).

LANDFIRE developed a VDDT model for this system which has two classes (LANDFIRE 2007a, BpS 2310660):

A) Early Development 1 All Structures (10% of type in this stage): Shrub cover is 0-5%. Characterized by bare ground and young shrubs that have re-sprouted or established from nearby seed. May find some ephemeral forbs or grasses at this stage. Disturbance is characterized by very wet periods that contribute to high shrub mortality every 100 years on average. Succession to class B after 12 years.

B) Late Development 1 All Structures (90% of type in this stage): Characterized by mature shrubs (10-20% cover). Typically lacks understory vegetation. Sites at this stage are very patchy with discontinuous shrubs. Same disturbance as in class A.

ECOLOGICAL INTEGRITY

Change Agents: The naturally sparse plant cover along with fine-grained salt soils make these shrublands particularly vulnerable to water and wind erosion, especially where vegetation has been depleted by grazing or disturbances (CNHP 2010). The dwarf-shrub *Atriplex gardneri* is very resilient and has been used to stabilize soils and to reclaim disturbed sites. It had one of the highest survival rates of all shrubs planted on processed oil shale in the Uinta Basin in Utah and was one of only two species to establish on coal mine spoils in Wyoming (Reed 1993b). Sites are arid and harsh with high winds and substrates that are typically highly erodible, saline, alkaline clays and silty clay soils low in phosphorous, nitrogen, and potassium. Sites are susceptible to accelerated erosion and soil loss. Sites are harsh and few other species can grow on them.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 33** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 34, left**) and sensitivity (**Figure 34, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

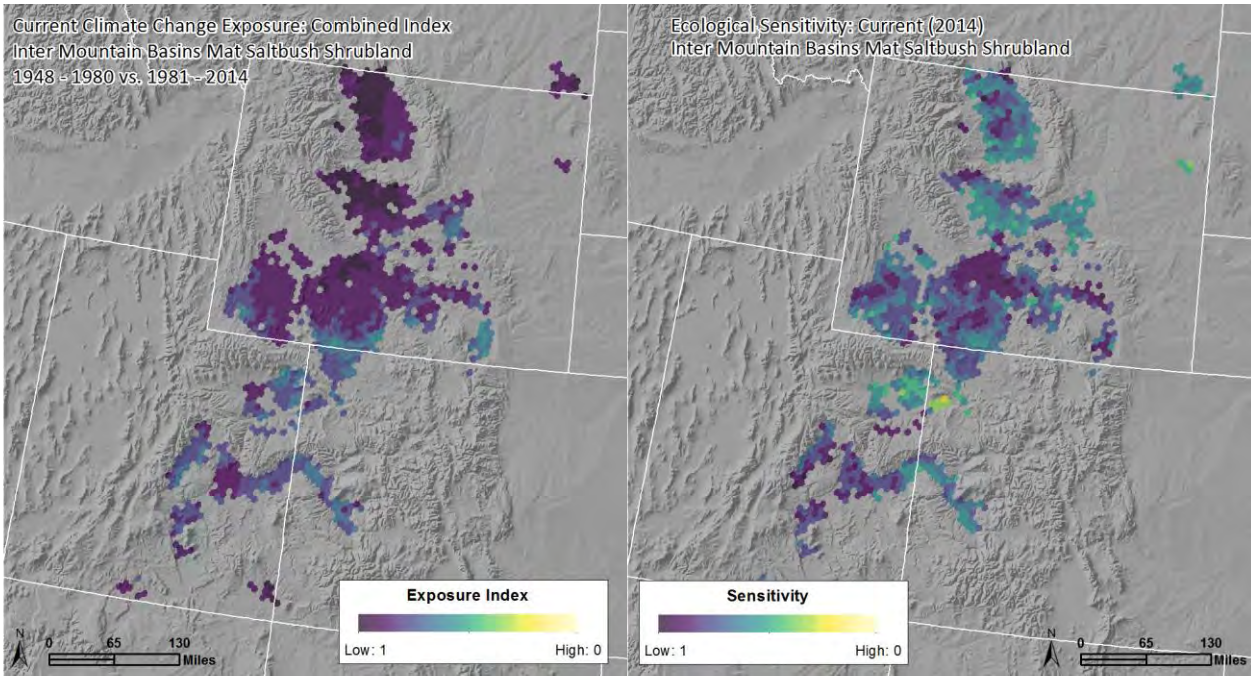

Figure 34. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Mat Saltbush Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 33. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Mat Saltbush Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Wyoming Basin	Colorado Plateaus	Northwestern Great Plains
	Sq miles within ecoregion	2,906	1,268	42
Contributions to Relative Vulnerability by Factor				
Vulnerability from **Exposure (2014)**		**Mod** 0.63	**Mod** 0.55	**Mod** 0.63
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.67	0.45	0.69
	Fire Regime Departure	0.72	0.77	0.48
	Invasive Annual Grasses	0.83	0.90	0.51
	Sensitivity Average	**0.74**	**0.71**	**0.56**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.17	0.18	0.16
	Diversity within Functional Species Groups	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null
	Adaptive Capacity Average	**0.16**	**0.17**	**0.16**
Vulnerability from Measures of **Overall Resilience**		**High** 0.45	**High** 0.44	**High** 0.36
Climate Change Vulnerability Index		**Mod**	**High**	**High**

Exposure Summary for 1981-2014 Timeframe: This dwarf saltbush scrub system is common in the Wyoming Basin and Colorado Plateau ecoregions, where it currently scores in the moderate range for climate exposure. An emerging pattern of climate change is seen as increases in Annual Mean Temperature of 0.67°C across 75% to 41% of its distribution, respectively. In the Northwest Great Plains ecoregion, 91% of its distribution shows an increase of 0.7°C. Mean Temperature of the Warmest Quarter shows a similar increase in the Wyoming Basin and Colorado Plateau ecoregions across smaller proportions of distribution (ranging from 58% to 28%, respectively).

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, or outright loss of characteristic taxa, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating saltbush recruitment. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals. Given the extreme saline and fine-textured soil characteristics, another likely effect would be conversion of some areas from saltbush scrub to badlands with little to no vegetation cover.

Ecosystem Resilience: Sensitivity: This desert scrub type has sensitivity to climate change scoring as moderate (higher scores) in all three ecoregions. In the Northwestern Great Plains ecoregion it is the combination of moderate risk of invasive annual grasses and high fire regime departure (low scores) that is reflected in the sensitivity score.

Landscape condition is good (less development, higher scores) in the Wyoming Basin and Northwestern Great Plains ecoregions, and moderate in the Colorado Plateaus. However, even in the two ecoregions with good landscape condition, the scores indicate that development is a factor. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, oil and gas development associated with shale deposits, transmission corridors, and areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low in two ecoregions (Wyoming Basin and Colorado Plateaus) and moderate in the third. This system is not highly vulnerable to cheatgrass invasion due to the typically highly saline soils and extremely dry climate regime. Even so, the results for the invasive grass risk suggests annual grasses may be gaining a foothold in some areas of this system's distribution, particularly in the Northwestern Great Plains. Fire regime departure follows a pattern that probably reflects an interaction with the invasive grasses; departure is highest in the Northwestern Great Plains ecoregion. Fire is not an important disturbance in this system, except perhaps in extended wet periods, due to the sparse vegetation and low cover of grasses which can serve as fine fuels. With the introduction of invasive annual grasses, in years of sufficient moisture, fire can spread into occurrences from surrounding ecosystem types due to a more continuous cover of fine fuels, altering the structure and composition in occurrences.

The interactions of the stressors of fragmentation due to development, invasive annual grass invasion, and introduction of fire have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system in some areas to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is very low across the entire range of this system. Both topoclimatic variability and diversity within functional species groups contribute to the low adaptive capacity. Topoclimatic variability is very low, as these shrublands occur across generally flat landforms and topography such as windswept plains and basins. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within the three identified functional species groups also score very low. Within individual stands, nitrogen fixation is provided by only a few species and so their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability. Species of lichens and cyanobacteria that contribute to stabilizing soil crusts also have low within-stand diversity. Halophytic species are adapted to saline or alkaline soil chemistry; mat saltbushes (*Atriplex corrugata* and *Atriplex gardneri*) are saline-tolerant and this allows them to occur or dominate in sites with less interspecific competition. Only a couple of herbaceous species have tolerance for these saline conditions. Diversity within the halophytes functional group is low in this system.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Inter-Mountain Basins Mat Saltbush Shrubland currently scores in the moderate to high range of overall climate change vulnerability throughout its range. This vulnerability is primarily due to moderate scores for exposure, but low adaptive capacity scores. Inherent vulnerabilities are high for low-diversity, cool desert scrub types that naturally occupy extensive flat to undulating plains and basins (low topoclimate variability). Additionally, these dwarf-shrublands have low diversity within key functional species groups, such as with nitrogen fixing species, biological soil crust and halophyte species. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 34. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Mat Saltbush Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Blaisdell and Holmgren 1984, Branson et al. 1976, CNHP 2010, Comer et al. 2003*, Knight 1994, LANDFIRE 2007a, Potter et al. 1985, Reed 1993b, Rosentreter and Belnap 2003, Shiflet 1994, Welsh 1957, Wright 1980

CES304.784 Inter-Mountain Basins Mixed Salt Desert Scrub

Figure 35. Photo of Inter-Mountain Basins Mixed Salt Desert Scrub. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This extensive ecological system includes open-canopied shrublands of typically saline basins, alluvial slopes and plains across the Intermountain western U.S. This type also extends in limited distribution into the southern Great Plains. Substrates are often saline and calcareous, medium- to fine-textured, alkaline soils, but include some coarser-textured soils. The vegetation is characterized by a typically open to moderately dense shrubland composed of one or more *Atriplex* species, such as *Atriplex confertifolia, Atriplex canescens, Atriplex obovata, Atriplex polycarpa*, or *Atriplex spinifera*. Other shrubs present to codominant may include *Artemisia tridentata ssp. wyomingensis, Chrysothamnus viscidiflorus, Ericameria nauseosa, Ephedra nevadensis, Grayia spinosa, Krascheninnikovia lanata, Lycium* spp., *Picrothamnus desertorum*, or *Tetradymia* spp. Northern occurrences may lack *Atriplex* species and are typically dominated by *Grayia spinosa, Krascheninnikovia lanata*, and/or *Picrothamnus desertorum*. In Wyoming, occurrences are typically a mix of *Atriplex confertifolia, Grayia spinosa, Artemisia tridentata ssp. wyomingensis, Sarcobatus vermiculatus, Krascheninnikovia lanata*, and various *Ericameria* or *Chrysothamnus* species. Some places are a mix of *Atriplex confertifolia* and *Artemisia tridentata ssp. wyomingensis*. In the Great Basin, *Sarcobatus vermiculatus* is generally absent but, if present, does not codominate. The herbaceous layer varies from sparse to moderately dense and is dominated by perennial graminoids such as *Achnatherum hymenoides, Bouteloua gracilis, Elymus lanceolatus ssp. lanceolatus, Pascopyrum smithii, Pleuraphis jamesii, Pleuraphis rigida, Poa secunda*, or *Sporobolus airoides*. Various forbs are also present.

Distribution: This system occurs in the intermountain western U.S., extending in limited distribution into the southern Great Plains. In the Great Basin, this ecological system occupies sites west of the Wasatch Mountains, east of the Sierra Nevada, south of the Idaho batholith and north of the Mojave Desert. In Wyoming, this system occurs in the Great Divide and Bighorn basins.

Nations: US

States/Provinces: AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY

CEC Ecoregions: Eastern Cascades Slopes and Foothills, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Great Plains, High Plains, Southwestern Tablelands, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, Southern California/Northern Baja Coast, Southern and Baja California Pine-Oak Mountains, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: R. Crawford, M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The vegetation is characterized by a typically open to moderately dense shrubland composed of one or more *Atriplex* species, such as *Atriplex confertifolia, Atriplex canescens, Atriplex polycarpa*, or *Atriplex spinifera*. *Grayia spinosa* tends to occur on coppice dunes that may have a silty component to them. Northern occurrences lack *Atriplex* species and are typically dominated by *Grayia spinosa* and *Krascheninnikovia lanata*. Other shrubs present to codominant may include *Artemisia tridentata ssp. wyomingensis, Chrysothamnus viscidiflorus, Ericameria nauseosa, Ephedra nevadensis, Grayia spinosa, Lycium* spp., *Picrothamnus desertorum*, or *Tetradymia* spp. In Wyoming, occurrences are typically a mix of *Atriplex confertifolia, Grayia spinosa, Artemisia tridentata ssp. wyomingensis, Sarcobatus vermiculatus, Krascheninnikovia lanata*, and various *Ericameria* or *Chrysothamnus* species. In the Great Basin, *Sarcobatus vermiculatus* is generally absent but, if present, does not codominate. The herbaceous layer varies from sparse to moderately dense and is dominated by perennial graminoids such as *Achnatherum hymenoides, Bouteloua gracilis, Elymus lanceolatus ssp. lanceolatus, Pascopyrum smithii, Pleuraphis jamesii, Pleuraphis rigida, Poa secunda*, or *Sporobolus airoides*. The vegetation description is based on several references, including Beatley (1976), Campbell (1977), Brown (1982), West (1979, 1983b), Knight et al. (1987), Knight (1994), Shiflet (1994), Holland and Keil (1995), Reid et al. (1999), Ostler et al. (2000), Barbour et al. (2007), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems of the western U.S. (Belnap and Lange 2003). In general biological soil crust species composition of this diverse, wide-ranging system would be similar to cold desert found in the Colorado Plateau playas described in Belnap et al. (2001) and Rosentreter and Belnap (2003). Cyanobacteria (16): *Microcoleus vaginatus* is strongly dominant with *Scytonema myochrous* and

Nostoc commune common. Other species include *Anabaena variabilis, Calothrix parietina, Chroococcus turgidus, Gloeothece linearis, Lyngbya limnetica, Nostoc paludosum, Oscillatoria geminata, Phormidium minnesotense, Phormidium tenue, Plectonema radiosum, Schizothrix calcicola*, and *Tolypothrix tenuis*. Lichens are similar to those in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia bracteata, Fulgensia desertorum, Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora cerebriformis, Psora decipiens, Squamarina lentigera*, and *Toninia* spp. Algal diversity is high (>40) but biomass is low in the Colorado Plateau, although higher than warm desert regions. Common mosses (14) include *Syntrichia caninervis* and *Syntrichia ruralis* with *Bryum* spp., *Ceratodon purpureus, Crossidium aberrans, Didymodon* spp., *Funaria hygrometrica, Pterygoneurum* spp., and *Tortula* spp. frequently present. Liverworts are uncommon.

Halophytes; Species Diversity: Medium
Species in this group are adapted to saline and alkaline soil conditions common in the Western U.S. and dominate on substrates derived from marine shales, in internally drained basins, and in coastal areas. Shrubs: *Atriplex confertifolia, Atriplex canescens, Atriplex obovata, Atriplex polycarpa, Atriplex spinifera, Krascheninnikovia lanata, Sarcobatus vermiculatus*, or *Tidestromia carnosa*. Herbaceous: *Distichlis spicata, Leymus salinus*, and *Sporobolus airoides*. Mixed-shrub stands would likely have moderate diversity whereas single-shrub dominant stands would likely be low.

Nitrogen Fixation; Species Diversity: Medium
Saltbush shrublands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low herbaceous cover and low diversity. Several species of Fabaceae (including species of *Astragalus, Dalea, Lupinus*, and *Psorothamnus fremontii*), Rosaceae (*Coleogyne, Prunus, Purshia*) and some Poaceae (*Achnatherum hymenoides, Bouteloua gracilis, Distichlis spicata Elymus lanceolatus, Leymus salinus, Pascopyrum smithii, Pleuraphis jamesii, Pleuraphis rigida, Poa secunda, Sporobolus airoides*, and *Sporobolus cryptandrus*), and a few Brassicaceae may fix nitrogen within this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2003). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa is moderately high; and within stand species diversity of nitrogen fixers is typically moderate.

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
This widespread system occurs in both winter-dominated and bimodal-distribution precipitation. Cool-season graminoids: *Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Festuca idahoensis, Leymus salinus, Muhlenbergia porteri, Poa secunda*, and *Pseudoroegneria spicata*. Warm-season graminoids: *Aristida purpurea, Muhlenbergia asperifolia, Pleuraphis jamesii, Pleuraphis mutica, Scleropogon brevifolius, Sporobolus airoides, Sporobolus cryptandrus*, and *Sporobolus wrightii*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this sagebrush shrubland type.

Environment: *Climate:* This is a semi-arid system of extreme climatic conditions, with warm to hot summers and cold winters. Annual precipitation ranges from approximately 13-33 cm. In much of this shrubland's distribution the season of greatest moisture is mid to late summer, although in the more northern areas a moist period is to be expected in the winter and spring. Precipitation is extremely irregular in the southern part of its distribution, such that long-term seasonal or monthly averages do not convey the full story (Blaisdell and Holmgren 1984).

Physiography/landform: This salt desert shrubland system is a matrix system in the Intermountain West. This system occurs on lowland and upland sites usually at elevations between 1520 and 2200 m (4987-7218 feet). Sites can be found on all aspects and include valley bottoms, alluvial and alkaline flats, mesas and plateaus, playas, drainage terraces, washes and interdune basins, bluffs, and gentle to moderately steep sandy or rocky slopes. Slopes are typically gentle to moderately steep but are sometimes unstable and prone to surface movement. Many areas within this system are degraded due to erosion and may resemble "badlands." Soil surface is often very barren in occurrences of this system. The interspaces between the characteristic plant clusters are commonly covered by a biological soil crust (West 1982).

Soils/substrates/hydrology: Soils are shallow to moderately deep, poorly-developed, and often alkaline or saline. The soils of much of the area are poorly-developed Entisols, a product of an arid climate. Vegetation within this system is tolerant of these soil conditions but not restricted to it. Other sites include level pediment remnants where coarse-textured and well-developed soil profiles have been derived from sandstone gravel and are alkaline, or on Mancos shale badlands, where soil profiles are typically fine-textured and non-alkaline throughout (West and Ibrahim 1968). They can also occur in alluvial basins where parent materials from the other habitats have been deposited over Mancos shale and the soils are heavy-textured and saline-alkaline throughout the profile (West and Ibrahim 1968). The environmental description is based on several other references, including Branson et al. (1967, 1976), Beatley (1976), Campbell (1977), Brown (1982), West (1983b), Knight et al. (1987), Knight (1994), Shiflet (1994), Holland and Keil (1995), Reid et al. (1999), Ostler et al. (2000), Barbour et al. (2007), and Sawyer et al. (2009).

Key Processes and Interactions: West (1982) stated that "salt desert shrub vegetation occurs mostly in two kinds of situations that promote soil salinity, alkalinity, or both. These are either at the bottom of drainages in enclosed basins or where marine shales outcrop." However, salt-desert shrub vegetation may also occur in climatically extremely dry, non-saline sites, as well as physiologically dry (saline) soils (Blaisdell and Holmgren 1984). Not all salt desert shrub soils are saline, and their hydrologic characteristics may often be responsible for the associated vegetation (Naphan 1966). That is, they are flooded or wetted enough to mobilize but not flush soil salt content, and therefore the ephemeral hydrology precipitates and concentrates salts. Species of the salt desert shrub complex have different degrees of tolerance to salinity and aridity, and they tend to sort themselves out along a moisture/salinity gradient (West 1982). Thus these saltbush shrublands are dependent on a certain amount of ephemeral flooding and warm temperatures causing evaporation. The effects of these physical, chemical, moisture, and topographic gradients on species and communities occur through complex relations that are not well understood and are in need of further study (Blaisdell and Holmgren 1984). In northern, cool desert locations of this system, soil moisture accumulation and storage within this system typically occur in the winter months. There is generally at least one good snowstorm per season that will provide sufficient moisture to the vegetation. The winter moisture accumulation amounts will affect spring plant growth. Plants may grow as little as a few inches to 1 m. Unless more rains come in the spring, the soil moisture will be depleted in a few weeks, growth will slow and ultimately cease, and the perennial plants will assume their various forms of dormancy (Blaisdell and Holmgren 1984). If effective rain comes later in the warm season, some of the species will renew their growth from the stage at which it had stopped. Others, having died back, will start over as if emerging from winter dormancy (Blaisdell and Holmgren 1984). *Atriplex confertifolia* shrubs often develop large leaves in the spring, which increase the rate of photosynthesis. As soil moisture decreases, the leaves are lost, and the plant takes on a dead appearance. During late fall, very small overwintering leaves appear which provide some photosynthetic capability through the remainder of the year (Reid et al. 1999).

The variation of plant communities found within this ecological system is maintained by intra- or inter-annual cycles of flooding followed by extended drought, which favor accumulation of transported salts. The moisture supporting these intermittently flooded communities is usually derived off-site, and they are dependent upon natural watershed function for persistence (Reid et al. 1999). As a result, these desert communities of perennial plants are dynamic and changing. The composition within this system may change dramatically and may be both cyclic and unidirectional. Superimposed on the compositional change is great variation from year to year in growth of all the vegetation, the sum of varying growth responses of individual species to specific conditions of different years (Blaisdell and Holmgren 1984). Desert plants grow when temperature is satisfactory, but only if soil moisture is available at the same time. Because the amount of moisture is variable from year to year and because different species flourish under different seasons of soil moisture, seldom do all components of the vegetation thrive in the same year (Blaisdell and Holmgren 1984).

Insects are an important component of many shrub steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square mile. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

Disturbance scale was variable during presettlement. Droughts and extended wet periods could be region-wide, or more local. A series of high water years or drought could affect whole basins. Mormon cricket disturbances could affect hundreds to perhaps thousands of acres for a few years to 1-2 decades (LANDFIRE 2007a).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 2310810):

A) Early Development 1 All Structures (25% of type in this stage): Shrub cover is 0-5%. Dominated by continuous grass with widely scattered shrubs and relatively younger shrubs than in classes B and C. Over 10 years, vegetation moves to class B as the primary succession pathway. Replacement fire occurs every 300 years on average, and will set back succession to year zero. Extended wet periods (every 35 years) will also have a stand-replacing effect. During a drought (mean return interval of 35 years), vegetation will follow an alternative succession pathway to class C.

B) Mid Development 1 Open (45% of type in this stage): Characterized by mature shrubs (5-20% cover). Discontinuous grass patches and higher shrub canopy cover than in class A. Extended wet periods (every 35 years on average) will cause a stand-replacing transition to class A. During extended drought periods (every 35 years), vegetation will shift to class C. Replacement fire is rare (mean FRI of 500 years). Class B will be maintained in the absence of disturbance.

C) Mid Development 2 Open (30% of type in this stage): Characterized by mature shrubs (21-30% cover). Grass is lacking and shrub canopy cover is even higher than class B. During extended wet periods (35 years), vegetation will transition to class A. After 20 years, vegetation moves back to class B through succession. Drought (mean return interval of 35 years) will maintain vegetation in class C. Fire would not carry in this class and is not modeled.

Under reference conditions disturbances were unpredictable, but flooding, drought, insects and fire may all occur in this system. Extended wet periods were modeled as occurring every 35 years, and drought periods every 35 years. Extended wet periods tended to favor perennial grass development, while extended drought tended to favor shrub development. Fire was rare and limited to more mesic sites (and moist periods) with high grass productivity. Mixed-severity fire was modeled as occurring with a mean FRI of 500-1000 years (LANDFIRE 2007a).

In summary, desert communities of perennial plants are dynamic and changing. The composition within this system may change dramatically over time and may be both cyclic and unidirectional. Superimposed on the compositional change is great variation from year to year in growth of all the vegetation - the sum of varying growth responses of individual species to specific conditions of different years (Blaisdell and Holmgren 1984). Desert plants grow when temperature is satisfactory, but only if soil moisture is available at the same time. Because amount of moisture is variable from year to year and because different species flourish under different seasons of soil moisture, seldom do all components of the vegetation thrive in the same year (Blaisdell and Holmgren 1984).

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from invasive annual plant species, which displace natural composition and provide fine fuels that significantly increase spread of catastrophic fire. The primary land uses that alter the natural processes of this system are associated with livestock grazing and introduction of exotic annual grasses. Some of the salt desert shrub species are more palatable; *Atriplex canescens, Kochia americana, Krascheninnikovia lanata*, and *Picrothamnus desertorum* are at greater risk of overuse by livestock (West 1983b). There is evidence that palatable grasses such as *Achnatherum hymenoides, Elymus elymoides, Pleuraphis jamesii*, and *Sporobolus cryptandrus* may have been more abundant before grazing (West 1983). Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual species, particularly *Bromus madritensis, Bromus tectorum, Schismus* spp., and other exotic annual grasses. The introduction of exotic annual grasses has altered many stands by increasing the amount of fine fuels present that can substantially increase fire frequency and intensity which reduces the cover of shrubs (Sawyer et al. 2009).

When grasshopper and Mormon cricket populations reach outbreak levels, they cause significant economic losses for ranchers and livestock producers, especially when accompanied by a drought (USDA-APHIS 2003, 2010). Both rangeland forage and cultivated crops can be consumed by grasshoppers. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is the Federal agency responsible for controlling economic infestations of grasshoppers on western rangelands with a cooperative suppression program. They work with federal land managing agencies to conduct grasshopper suppression. The goal of APHIS's grasshopper program is not to eradicate them but to reduce outbreak populations to less economically damaging levels (USDA-APHIS 2003). This APHIS effort dampens the natural ecological outbreak cycles of grasshoppers and Mormon crickets, but does not eradicate the species.

Human development has impacted many locations throughout the range of this type. High- and low-density urban and industrial developments have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 35** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 36, left**) and sensitivity (**Figure 36, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

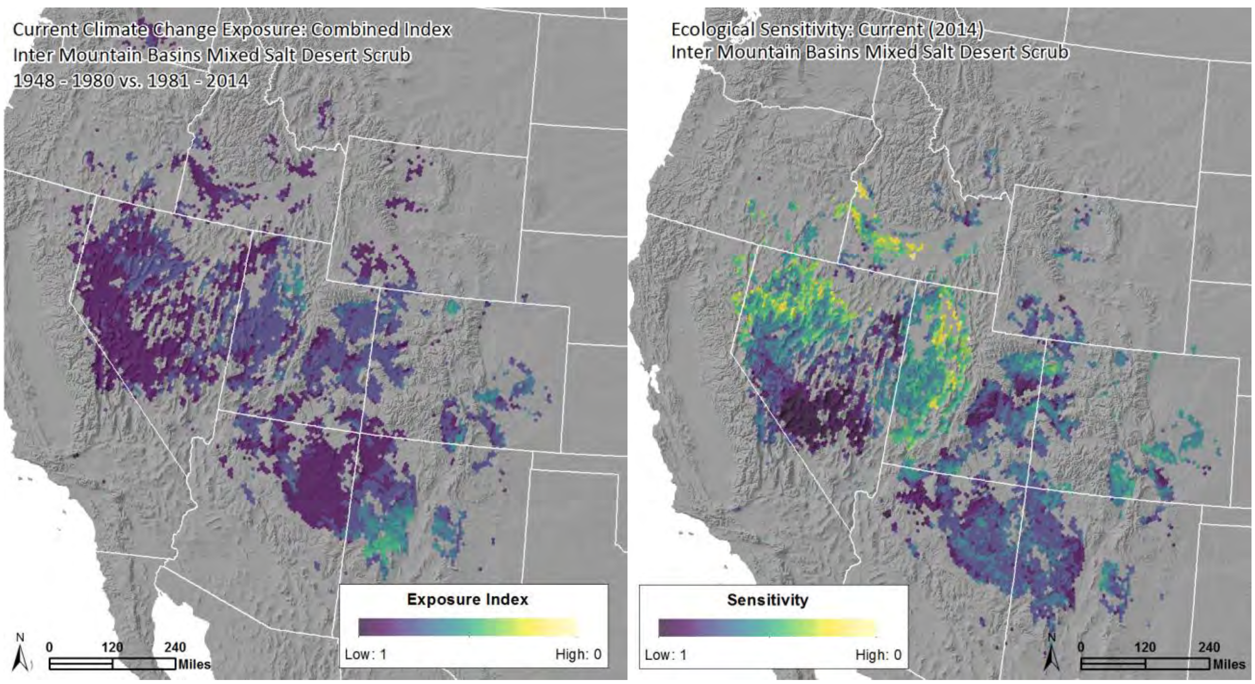

Figure 36. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Mixed Salt Desert Scrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 35. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Mixed Salt Desert Scrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Central Basin & Range	Arizona-New Mexico Plateau	Colorado Plateaus	South-western Table-lands	Arizona-New Mexico Moun-tains	Snake River Plain	Northern Basin & Range	Wyoming Basin	Columbia Plateau	Middle Rockies	Southern Rockies	High Plains	Mojave Basin & Range	Wasatch & Uinta Moun-tains	Eastern Cascades Slopes & Foothills
	Sq miles within ecoregion	22,215	8,416	3,332	794	662	617	518	355	133	101	82	72	66	57	32
Contributions to Relative Vulnerability by Factor																
Vulnerability from **Exposure (2014)**		Mod 0.58	Mod 0.55	Mod 0.55	High 0.49	Mod 0.55	Mod 0.60	Mod 0.58	Mod 0.58	Mod 0.64	Mod 0.63	High 0.46	Mod 0.53	Mod 0.60	Mod 0.53	Mod 0.61
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.67	0.71	0.57	0.57	0.73	0.39	0.66	0.71	0.34	0.25	0.63	0.45	0.78	0.22	0.52
	Fire Regime Departure	0.47	0.51	0.59	0.30	0.55	0.51	0.51	0.65	0.28	0.83	0.33	0.40	0.71	0.34	0.47
	Invasive Annual Grasses	0.79	0.99	0.93	1.00	1.00	0.66	0.39	0.83	0.28	0.98	1.00	0.99	0.89	1.00	0.23
	Sensitivity Average	**0.64**	**0.73**	**0.70**	**0.62**	**0.76**	**0.52**	**0.52**	**0.73**	**0.30**	**0.69**	**0.65**	**0.61**	**0.79**	**0.52**	**0.41**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.16	0.16	0.23	0.12	0.20	0.13	0.19	0.22	0.17	0.18	0.25	0.11	0.26	0.18	0.22
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.33**	**0.33**	**0.36**	**0.31**	**0.35**	**0.31**	**0.35**	**0.36**	**0.33**	**0.34**	**0.37**	**0.31**	**0.38**	**0.34**	**0.36**
Vulnerability from Measures of **Overall Resilience**		High 0.49	Mod 0.53	Mod 0.53	High 0.47	Mod 0.55	High 0.42	High 0.43	Mod 0.54	High 0.32	Mod 0.51	Mod 0.51	High 0.46	Mod 0.59	High 0.43	High 0.38
Climate Change Vulnerability Index		Mod	Mod	Mod	High	Mod	Mod	Mod	Mod	High	Mod	High	High	Mod	High	High

Exposure Summary for 1981-2014 Timeframe: Overall, across the distribution of this widespread shrubland system, exposure as of 2014 is moderate or high across ecoregions. An emerging pattern of changing climate appears in most ecoregions where this system occurs as increases of 0.55° to 0.78°C for Annual Mean Temperature and Mean Temperature of the Warmest Quarter for 35% of its distribution in the Colorado Plateau up to 99% of its distribution in the Mojave Basin and Range. Small areas (<5% of distribution) of similar change in these variables is seen in the Northern Basin and Range, Snake River Plain and Middle Rockies ecoregions. In the Central Basin and Range, where this system is most abundant, the Mean Diurnal Range is decreasing by 0.57°C across 15% of the distribution; this variable is the difference between the monthly mean maximum temperature and the monthly mean minimum temperature, suggesting the difference between day-time maximums and night-time minimums is decreasing.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating saltbush recruitment. With extended drought, the herbaceous layer would be eliminated except for ephemeral annuals.

Ecosystem Resilience: Sensitivity: This widespread desert scrub type has sensitivity ranging from high (low scores) to low across all reported ecoregions. In the ecoregions with moderate to high scores it tends to be the combination of poor/low landscape condition and moderate to high fire regime departure, although in 3 ecoregions invasive annual grass risk is a contributing factor.

Landscape condition is generally moderate to poor (more development, lower scores); only in 1 ecoregions is landscape condition very good (very higher scores). Particular concentrations of poor landscape condition due to development activity include the Middle Rockies, Columbia Plateau, High Plains, Wasatch and Uinta Mountains, and the Snake River Plain ecoregions. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, oil and gas development, transmission corridors, and areas of urban, suburban and exurban development.

Risk of invasive annual grasses is high in 2 ecoregions: Northern Basin and Range and Columbia Plateau, and very high in the Eastern Cascades. Risk scored low in the remaining ecoregions, but there are concentrations of higher risk in the Central Basin and Range, Snake River Plain and Wyoming Basin ecoregions. Fire regime departure is moderate to high in all ecoregions. Fire is not an important disturbance in this system, except in more mesic sites or in extended wet periods, due to the generally sparse vegetation and low cover of grasses which can serve as fine fuels. With the introduction of invasive annual grasses, in years of sufficient moisture, fire can spread due to a more continuous cover of fine fuels, altering the structure and composition in occurrences.

The interactions of the stressors of fragmentation due to development, overgrazing, invasive annual grass invasion, and introduction of fire have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Vulnerability from poor adaptive capacity is high across the range of this type. Topoclimatic variability is very low everywhere, as these shrublands occur across generally very flat landforms and topography such as valley bottoms, alluvial and alkaline flats, mesas and plateaus, playas, drainage terraces, washes and interdune basins, or bluffs. They predominately occur where local climates vary little within short distances. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within the identified functional species groups varies from high to moderate among groups; with an overall score of moderate. Within individual stands, nitrogen fixation is the most limiting and appears to be provided by only a few species; their individual vulnerabilities to factors such as drought and human disturbance suggests increased overall vulnerability for the system. In contrast, species of lichens, algae and cyanobacteria that contribute to stabilizing soil crusts have high within-stand diversity. Perennial cool-season graminoids have moderate within stand diversity. These herbaceous species use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. Halophytes are species adapted to saline soil conditions, and in this system the diversity of halophytic species is moderate.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Inter-Mountain Basins Mixed Salt Desert Scrub currently scores in the moderate to high range of overall climate change vulnerability throughout its range. This is primarily due to its moderate scores for exposure, low adaptive capacity scores, and moderate sensitivity measures. Inherent vulnerabilities are high for low-diversity, cool desert scrub types that naturally occupy extensive flat to undulating plains, terraces, alluvial slopes and saline basins (low topoclimate variability). Additionally, these shrublands have moderate diversity within key functional species groups, such as with nitrogen fixing species, halophyte species, and perennial cool-season/warm-season graminoids. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 36. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Mixed Salt Desert Scrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (nitrogen fixers, perennial cool-season/warm-season graminoids, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson and Porter 1994, Barbour and Major 1977, Barbour and Major 1988, Barbour et al. 2007a, Beatley 1976, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Benson 1969, Blaisdell and Holmgren 1984, Branson et al. 1967, Branson et al. 1976, Brown 1982a, CNHP 2010, Campbell 1977, Comer et al. 2003*, Cornely et al. 1992, Degenhardt et al. 1996, Francis 1986, Franklin 2005, Grismer 2002, Hammerson 1999, Hoffman et al. 1969, Holland and Keil 1995, INPS 1993, Knight 1994, Knight et al. 1987, LANDFIRE 2007a, Naphan 1966, Nussbaum et al. 1983, Ostler et al. 2000, Reid et al. 1999, Rosentreter and Belnap 2003, Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Shiflet 1994, Stebbins 2003, USDA-APHIS 2003, USDA-APHIS 2010, WNHP unpubl. data, Weber 1987, Welsh et al. 1993, Welsh et al. 2003, West 1979, West 1982, West 1983b, West 1983c, West and Ibrahim 1968, Williams 1984

M171. Great Basin-Intermountain Dry Shrubland & Grassland
CES304.763 Colorado Plateau Blackbrush-Mormon-tea Shrubland

Figure 37. Photo of Colorado Plateau Blackbrush-Mormon-tea Shrubland. Photo credit: J Brew, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/brewbooks

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in the Colorado Plateau on benchlands, colluvial slopes, pediments or bajadas. Elevation ranges from 560-1650 m. Substrates are shallow, typically calcareous, non-saline and gravelly or sandy soils over sandstone or limestone bedrock, caliche or limestone alluvium. It also occurs in deeper soils on sandy plains where it may have invaded desert grasslands. This is an evergreen, microphyllous scrub with succulents, half-shrubs, and scattered deciduous shrubs. The vegetation is characterized by extensive open shrublands dominated by *Coleogyne ramosissima* often with *Ephedra viridis, Ephedra torreyana*, or *Grayia spinosa*. Sandy portions may include *Artemisia filifolia, Eriogonum leptocladon, Poliomintha incana*, or *Quercus havardii var. tuckeri* (relict populations) as codominant. The herbaceous layer is sparse and composed of graminoids such as *Achnatherum hymenoides, Pleuraphis jamesii*, or *Sporobolus cryptandrus*.

Distribution: Occurs in the Colorado Plateau on benchlands, colluvial slopes, pediments or bajadas. Elevation ranges from 560-1600 m.

Nations: US

States/Provinces: AZ, CO, NM, UT

CEC Ecoregions: Wasatch and Uinta Mountains, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Mojave Basin and Range, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This ecological system is dominated by sparse to moderately dense shrubs. Dominant shrubs include *Coleogyne ramosissima, Ephedra nevadensis*, and *Ephedra viridis* (which may codominate with *Grayia spinosa, Salvia dorrii*, and *Lycium andersonii*). There is usually a sparse herbaceous layer with some perennial grasses and forbs. Annual grasses and forbs are present seasonally. Some characteristic species associated with this system include the shrubs *Gutierrezia sarothrae, Chrysothamnus viscidiflorus, Yucca baccata*, and *Krameria grayi*, succulents such as *Ferocactus cylindraceus (= Ferocactus acanthodes), Opuntia* spp., *Echinocereus* spp., *Echinocactus* spp., and *Agave* spp., the graminoid *Pleuraphis rigida*, and perennial forbs such as *Machaeranthera pinnatifida* and *Sphaeralcea ambigua*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and are critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems in the western U.S. (Belnap and Lange 2003). Colorado Plateau crust diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (16): *Microcoleus vaginatus* is strongly dominant with *Scytonema myochrous* and *Nostoc commune* common. Other species include *Anabaena variabilis, Calothrix parietina, Chroococcus turgidus, Gloeothece linearis, Lyngbya limnetica, Nostoc paludosum, Oscillatoria geminata, Phormidium minnesotense, Phormidium tenue, Plectonema radiosum, Schizothrix calcicola*, and *Tolypothrix tenuis*. Lichens are similar to those in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia bracteata, Fulgensia desertorum, Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora cerebriformis, Psora decipiens, Squamarina lentigera*, and *Toninia* spp. Algal diversity is high (>40) but biomass is low in the Colorado Plateau, although higher than warm desert regions. Common mosses (14) include *Syntrichia caninervis* and *Syntrichia ruralis* with *Bryum* spp., *Ceratodon purpureus, Crossidium aberrans, Didymodon* spp., *Funaria hygrometrica, Pterygoneurum* spp., and *Tortula* spp. frequently present. Liverworts are uncommon.

Nitrogen Fixation; Species Diversity: Medium
Blackbrush shrublands occur in warm, semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low herbaceous cover and low diversity. Several species of Fabaceae (including species of *Astragalus, Dalea*, and *Psorothamnus*), Rosaceae (*Coleogyne, Purshia*), a few Poaceae, and some Brassicaceae may fix nitrogen within this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across

its range, diversity of nitrogen-fixing taxa is moderate; however, within stand species diversity of nitrogen fixers is typically moderate.

Seed Dispersal; Species Diversity: High
Coleogyne ramosissima fruits are large and heavy and dispersed via animal activity and storm runoff (Anderson 2001a). Kangaroo rats are their main dispersers collecting and burying large amounts of seeds in caches, but many other species utilize and cache seeds. These rodents eat blackbrush seeds and inadvertently disperse seeds in caches or have viable seeds pass through gut. List is from West (1983d) and Meyer and Pendleton (2005). Mammals that disperse seeds (15): Chisel-toothed kangaroo rat (*Dipodomys microps*), Merriam's kangaroo rat (*Dipodomys merriami*), Ord's kangaroo rat (*Dipodomys ordii*), Panamint kangaroo rat (*Dipodomys panamintinus*), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*), long-tailed pocket mouse (*Chaetodipus formosus*), desert woodrat (*Neotoma lepida*), southern grasshopper mouse (*Onychomys torridus*), little pocket mouse (*Perognathus longimembris*), cactus mouse (*Peromyscus eremicus*), plains pocket mouse (*Perognathus flavescens*), deer mouse (*Peromyscus maniculatus*), pinyon mouse (*Peromyscus truei*), western harvest mouse (*Reithrodontomys megalotis*), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), and southern pocket gopher (*Thomomys umbrinus*).

Xerophytes; Species Diversity: Low
Species in this group are adapted to frequent and extended drought and have evolved abilities and mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Coleogyne ramosissima* (dominant - often monoculture), *Ephedra viridis* and *Ephedra torreyana*, or *Grayia spinosa* (codominants).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this shrubland type.

Environment: This shrubland ecological system occurs in the Colorado Plateau at elevations ranging from 580 to 1650 m (1903-5413 feet) (Bowns and West 1976). *Climate:* This shrubland system occurs in an arid to semi-arid climate with annual precipitation in the form of summer monsoons and winter storms is generally less than 30 cm, averaging approximately 20 cm.

Physiography/landform: Stands occur on gentle to steep, bouldery or rocky colluvial and alluvial slopes of mountains, plateaus, canyons, washes, valley bottoms, and mesas with varying aspects (Anderson 2001a).

Soils/substrates/hydrology: Substrates are shallow, well-drained, typically calcareous, non-saline and gravelly or sandy soils over sandstone or limestone bedrock, caliche or limestone alluvium, but may include other parent materials such as shale, gneiss, quartzites, and igneous rocks (Anderson 2001a). Effective soil moisture appears to be primarily controlled by regolith depth and position in relation to the water table. This brushland system occupies most sites where regolith is uniformly shallow. In association with blackbrush (*Coleogyne ramosissima*) sites, the soil moisture is concentrated on top of impermeable bedrock at a shallow depth. This perching effect allows for gradual uptake of moisture by the plants roots (Loope and West 1979). This permits growth of plants with more mesic habitat requirements (Warren et al. 1982). On sites with deep soil, blackbrush may occur in almost pure occurrences with only a few associated species (Warren et al. 1982). Dark-colored biological soil crusts, composed of lichens, mosses, fungi, and algae, are often present in this system in fairly undisturbed areas. Sandy soils may have more biological soil crusts than clayish or silty soil surfaces.

Key Processes and Interactions: Blackbrush is a slow-growing, long-lived, drought-tolerant, evergreen shrub with a diffuse and shallow root system (Bowns 1973, Anderson 2001a). It may lose older leaves during the dry summer season (drought-deciduous) to reduce water stress and become dormant during dry periods. Unlike many rosaceous species, *Coleogyne ramosissima* is wind-pollinated and largely selfincompatible (Pendleton et al. 1995, Pendleton and Pendleton 1998). Blackbrush is a mast species. The resulting fruit crop is a function of available stored energy, producing abundant crops of seeds every few to several years (Pendleton and Meyer 2004).

In general, seed germination and establishment are rare as seedings are uncommon (Anderson 2001a). The germination rate is low, except after a wet spring when soils remain moist for two weeks (Lei 1997). Seeds also require cold stratification (6 weeks) without light to break dormancy (Lei 1997, Meyer and Pendleton 1990). Seeds appear to remain viable for a long time in seed bank. Meyer and Pendleton (2005) observed 80% germination from 15-year-old seeds. Abundant seedlings have been observed in clumps from rodent caches (Bowns and West 1976, Lei 1997) or after heavy spring rains, which suggests adaptions to seed caching by small mammals or large runoff events that bury seeds. Kangaroo rats are the main seed dispersers, caching large numbers during mast years (Meyer and Pendleton 2005). Fruits are large and require small mammals or large storm runoff for dispersal (Anderson 2001a).

Blackbrush also provides fair forage for desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*) during the winter, and it can tolerate heavy browsing (USFS 1937, Mozingo 1986, Anderson 2001a). Herbaceous forage from understory is generally low.

Fire does not appear to play a role in maintenance of shrublands within this system. Topographic breaks dissect the landscape, and isolated pockets of vegetation are separated by rock walls or steep canyons that protect it from spreading fire. Blackbrush is fire-intolerant (Loope and West 1979). It does not sprout after fire and is slow to re-colonized burned sites (Wright 1972). In shallow regolith situations, secondary succession, in the sense of site preparation by seral plants, may not occur at all (Loope and West 1979). In *Coleogyne ramosissima* mixed shrub stands, fire will favor more fire-tolerant shrubs such as *Artemisia filifolia, Ephedra viridis, Grayia spinosa, Quercus havardii var. tuckeri*, or ruderal species (Tirmenstein 1999j, Anderson 2001a, 2001b, Gucker 2006d).

Biological soil crusts associated with the system are negatively effected by fire, as burning reduced biological soil crusts from 9% cover to less than 1% of total cover, and there was little evidence of recovery postburn after 19 years (Callison et al. 1985). Biological soil crusts are critically important for soil fertility, soil moisture, and soil stability in the many semi-arid ecosystems in the western U.S. (Belnap and Lange 2003). Biological soil crusts fix large amounts of soil nitrogen (mostly by cyanobacteria) and soil carbon, they protect soils from wind erosion, and rough surface texture slows runoff and allows for more infiltration (Evans and Belnap 1999, Belnap et al. 2001, Belnap and Lange 2003, Johansen 2001). Fires in desert scrub are typically patchy and vary in severity, leaving patches of biological crust organisms to recolonize. Recover rates for biological soil crust organisms vary, e.g., green algae (2 years), cyanobacteria (2-6 years), mosses (3-8 years); however, lichens may take decades (Johansen 2001).

Burning blackbrush stands should be minimized because of the unpredictability of successive vegetation, accelerated soil erosion, long-term or permanent removal of blackbrush, and damage to biological soil crusts (Wright 1980, West 1983d, 1988, Callison et al. 1985).

LANDFIRE (2007a) VDDT model for this system (BpS 2310780) has three classes:

A) Early Development 1 Open (5% of type in this stage): Shrub cover is 0-5%. Dominated by grasses, shrub seedlings and post-fire associated forbs. This type typically occurs where fires burn relatively hot in classes B and C. Shrubs (*Coleogyne ramosissima, Ephedra viridis, Ephedra torreyana*, and *Grayia spinosa*) will generally be re-established after 20-30 years.

B) Late Development 2 Closed (shrub-dominated - 30% of type in this stage): Shrub cover (*Coleogyne ramosissima, Ephedra viridis, Ephedra torreyana*, and *Grayia spinosa*) 21-100%. Greater than 15% shrub cover and 10-20% herb cover; generally associated with more productive soils. Effects of cumulative drought can cause a shift from this class to class C.

C) Late Development 1 Closed (shrub-dominated - 65% of type in this stage): Shrubs (*Coleogyne ramosissima, Ephedra viridis, Ephedra torreyana*, and *Grayia spinosa*) are the dominant lifeform with canopy cover of 10-20%. Less than 15% shrub cover and <10% herb cover generally associated with less productive cobbly and gravelly soils. Effects of cumulative drought can cause a shift from class B to this class.

LANDFIRE modelers emphasized that blackbrush is fire-intolerant, may be slow to re-establish following fire such that grasses may dominate immediately following fire. Invasion of non-native annual grasses following fire is likely under current conditions (LANDFIRE 2007a). LANDFIRE modelers state that generally, the mean fire interval is approximately 75 years with high variability due to annual variation in drying of shrub foliage, shrub mortality and grass and forb production related to drought and moisture cycles (LANDFIRE 2007a). There is also high variation in ignitions and associated fire weather (LANDFIRE 2007a). Fire years are typically correlated with wet years that produce high herbaceous biomass/fine fuel amounts. In areas with high summer moisture from monsoon season rains there are many chances for lightning strikes (LANDFIRE 2007a). Fire-return intervals would have been much longer in drier geographic areas with return intervals over 200 years (LANDFIRE 2007a). Fire size would have been small because of the discontinuous fuel; frequent topographic breaks that dissect the landscape creating isolated pockets of vegetation are separated by rock walls or steep canyons (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: Altered fire regime and invasive species are the biggest threats to this system. These are brought on by activities that disturb vegetation and biological soil crusts and include livestock grazing, mining, utility rights-of-way, ORVs and other dispersed recreation. Conversion of this type has commonly come from burning. Burning blackbrush stands is not recommended due to the unpredictability of successive vegetation, accelerated soil erosion, long-term or permanent removal of blackbrush, and damage to biological soil crusts (Wright 1980, West 1983d, 1988, Callison et al. 1985). Following fires, these communities are often colonized by non-native grasses, such as *Bromus rubens* and *Bromus tectorum* which serve to encourage recurrent fires and delay shrub regeneration. Where non-native annual grasses have invaded, fire may be much more frequent than the reference condition and can cause a rapid decline in ecological function (and a higher Fire Regime Condition Class) (LANDFIRE 2007a).

Human development and land use have impacted many areas. Fragmentation from transportation infrastructure (roads, railways, pipelines and transmission lines) leads to dispersal of invasive non-native species and altered hydrological processes such as surface flow when excessive runoff from roads creates gullies. Additionally, increased mortality from road kill affects wildlife populations. Other developments that have large impacts include high- and low-density urban and industrial such as energy (renewable wind/solar, oil/gas), mining and landfills. Human land-use impacts from recreation (ORVs, mountain biking, hiking) and agriculture (livestock grazing/browsing) can also be significant (West 1983d).

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 37** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 38, left**) and sensitivity (**Figure 38, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

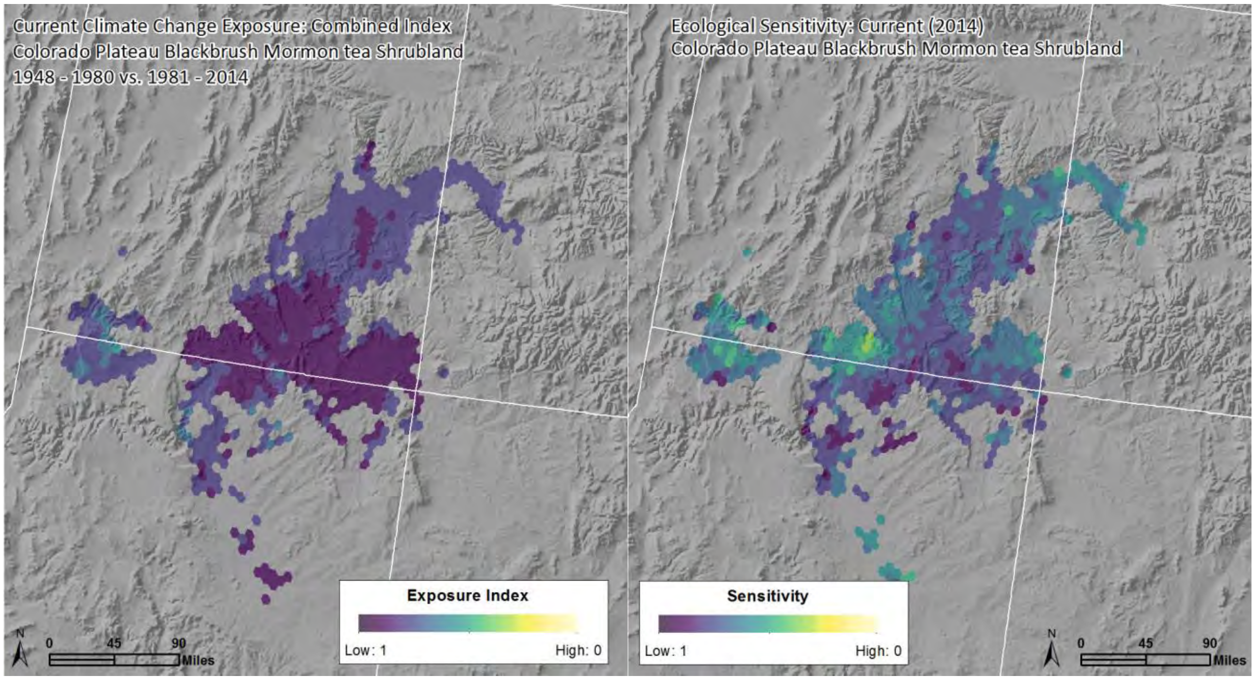

Figure 38. Climate exposure as of 2014 (left) and overall sensitivity (right) for Colorado Plateau Blackbrush-Mormon-tea Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 37. Resilience, exposure and vulnerability scores for Colorado Plateau Blackbrush-Mormon-tea Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Colorado Plateaus	Arizona-New Mexico Plateau
	Sq miles within ecoregion	2,812	449
Contributions to Relative Vulnerability by Factor			
Vulnerability from **Exposure (2014)**		Mod 0.57	Mod 0.55
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.64	0.66
	Fire Regime Departure	0.50	0.54
	Invasive Annual Grasses	0.94	0.98
	Sensitivity Average	**0.69**	**0.72**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.22	0.21
	Diversity within Functional Species Groups	0.50	0.50
	Keystone Species Vulnerability	Null	Null
	Adaptive Capacity Average	**0.36**	**0.35**
Vulnerability from Measures of **Overall Resilience**		Mod 0.53	Mod 0.54
Climate Change Vulnerability Index		Mod	Mod

Exposure Summary for 1981-2014 Timeframe: This is a common shrubland system in the Colorado Plateau and Arizona/New Mexico Plateau ecoregions, and climate exposure as of 2014 is moderate in both ecoregions. For the distribution of this shrubland, an emerging pattern of changing climate appears as increases of 0.65°C for Annual Mean Temperature throughout both ecoregions. Mean Temperature of the Warmest Quarter has similar increases (up to 0.7°C) across about 25% of its distribution in these ecoregions.

Climate Change Effects: Blackbrush is long-lived and drought-tolerant so blackbrush-dominated shrublands may be able to resist the effects of climate change if the climate trends have the predicted effect of less available moisture with increasing mean temperature. Under current climate conditions there are many barriers to successful regeneration of blackbrush. The ecological consequences from such a climate shift would be similar to more frequent and extended drought. Successful dispersal, germination, and seedling establishment and survival would be reduced, effectively eliminating blackbrush recruitment. With eventual loss of blackbrush, sandy sites would likely blow out and become active dunes. Sites on other substrates may be colonized by more drought-tolerant shrubs such as species of *Atriplex* that are adapted to droughty saline/alkaline sites. Indirect effects of a warming climate may result in more frequent fires from drier fuels, and rapid loss of blackbrush, at least for denser stands that could carry a fire. However, it may be possible to retain blackbrush on Colorado Plateau sites using climate-adapted seeds from Mojave Desert populations or possibly assist with its long-term migration to higher/cooler elevation sites on the Colorado Plateau.

Ecosystem Resilience: Sensitivity: Sensitivity to climate change is moderate across the limited range of this shrubland system. These results reflect fire regime departure combined with moderate landscape condition in both ecoregions.

Landscape condition is moderate (some development) (**Table 37**). This system often occurs on remote plateaus and in canyonlands away from infrastructure development. However, there are some significant transportation corridors and some localized development of urban, suburban and exurban areas. Cropland agriculture is not a significant factor in the Colorado Plateau; however, there are effects of ranching operations and many small roads that fragment occurrences for recreation use, mining operations, and oil and gas development. In the Grand Valley of western Colorado, irrigated agriculture has impacted some areas where this system occurs.

Risk of invasive annual grasses is low overall. However, fire regime departure is moderate across the range of this system with some areas of high departure in south-central Utah near Bryce Canyon National Park. Although risk of annual grass invasion is low, other stressor interactions such as livestock use, ORVs, and other activities disturb the soils crusts, leading to increased erosion and susceptibility of blackbrush stands to mortality of the shrubs. Blackbrush is fire-sensitive, so any fires that do occur result in the loss of these shrubs which can take long time periods to re-establish.

The interactions of the stressors of overgrazing, fragmentation by roads and other development have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low end of the scale (at 0.36). Topoclimatic variability is very low, as these shrublands occur across a limited variety of landforms and topography. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within the three identified functional species groups varies from high to moderate among groups. Within individual stands, nitrogen fixation is the least diverse group, but the function is provided by several species and so their individual vulnerabilities to factors such as drought and human disturbance suggests a moderate overall vulnerability for the system. Conversely, seed dispersal and substrate developing soils crusts appear to be naturally diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This desert scrub type currently scores in the moderate level of overall vulnerability throughout its range. This is primarily due to its moderate scores for exposure and adaptive capacity scores that are on the lower end of the moderate range. Inherent vulnerabilities are high for types that naturally occupy extensive flat to gently sloping benchlands, alluvial fans, and colluvial slopes (low topoclimate variability). Additionally, these desert scrub types are susceptible to invasive plants and their interactions with introduced wildfires. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 38. Climate change adaptation strategies relative to vulnerability scores for Colorado Plateau Blackbrush-Mormon-tea Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). If a natural wildfire regime was historically characteristic, localize models for wildfire regimes, and restore regimes where they have been severely altered from introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including regeneration in primary xerophytic species.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor for invasive plant expansion and effects of climate stress, including regeneration in primary xerophytic species, and loss/gain of neighboring species. If applicable, update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for invasive plant expansion and effects of climate stress, including regeneration in primary xerophytic species, and loss/gain of neighboring species. If applicable, create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson 2001a, Anderson 2001b, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Bowns 1973, Bowns and West 1976, Callison et al. 1985, Comer et al. 2003*, Evans and Belnap 1999, Gucker 2006d, Johansen 2001, LANDFIRE 2007a, Lei 1997, Loope and West 1979, McWilliams 2003a, Meyer and Pendleton 1990, Meyer and Pendleton 2005, Mozingo 1987, Pendleton and Meyer 2004, Pendleton and Pendleton 1998, Pendleton et al. 1995, Rondeau 1999, Rosentreter and

Belnap 2003, Shiflet 1994, Thatcher 1975, Tirmenstein 1999j, Tuhy and MacMahon 1988, Tuhy et al. 2002, USFS 1937, Warren et al. 1982, West 1983d, West 1988, Wright 1972, Wright 1980

CES304.787 Inter-Mountain Basins Semi-Desert Grassland

Figure 39. Photo of Inter-Mountain Basins Semi-Desert Grassland. Photo credit: Marion Reid.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This widespread ecological system includes the driest grasslands throughout the intermountain western U.S. It occurs on xeric sites over an elevation range of approximately 1450 to 2320 m (4750-7610 feet) on a variety of landforms, including swales, playas, mesas, alluvial flats, and plains. This system may constitute the matrix over large areas of intermountain basins, and also may occur as large patches in mosaics with shrubland systems dominated by *Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis, Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Gutierrezia sarothrae*, or *Krascheninnikovia lanata*. Grasslands in areas of higher precipitation, at higher elevation, typically belong to other systems. Substrates are often well-drained sandy or loam soils derived from sedimentary parent materials but are quite variable and may include fine-textured soils derived from igneous and metamorphic rocks. The dominant perennial bunchgrasses and shrubs within this system are all drought-resistant plants. Dominant or codominant species are *Achnatherum hymenoides, Aristida* spp., *Bouteloua gracilis, Hesperostipa comata, Muhlenbergia* spp., *Pleuraphis jamesii*, or *Sporobolus* spp. Scattered shrubs and dwarf-shrubs often are present, especially *Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis, Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Ericameria* spp., *Gutierrezia sarothrae*, and *Krascheninnikovia lanata*. This system is typically composed of cool-season grasses in the western portion of its range where winter precipitation dominates, and a mix of cool- and warm-season grasses where precipitation occurs during both winter and summer seasons (Colorado Plateau). Grasslands in the basins of south-central and southwestern Wyoming, dominated by *Pseudoroegneria spicata* and *Poa secunda* and containing cushion-form forbs and other species typical of dry basins, are included in this system.

Distribution: This system occurs throughout the intermountain western U.S. on dry plains and mesas, at approximately 1450 to 2320 m (4750-7610 feet) elevation. In the Bighorn Basin of north-central Wyoming, there may be some desert grasslands, but this is uncertain.

Nations: US

States/Provinces: AZ, CA, CO, ID, MT?, NM, NV, OR, UT, WA, WY

CEC Ecoregions: North Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Great Plains, Southwestern Tablelands, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: NatureServe Western Ecology Team

Description Author: G.P. Jones and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This grassland system may constitute the matrix over large areas of intermountain basins and may also occur as large patches in mosaics with shrubland systems dominated by *Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis, Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Gutierrezia sarothrae*, or *Krascheninnikovia lanata*. The dominant perennial bunchgrasses and shrubs within this system are all drought-resistant plants. Dominant or codominant species are *Achnatherum hymenoides, Aristida* spp., *Bouteloua gracilis, Hesperostipa comata, Muhlenbergia* spp., or *Pleuraphis jamesii*. Additional perennial warm-season grasses found in this system include *Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Muhlenbergia asperifolia, Muhlenbergia pungens, Muhlenbergia richardsonis, Muhlenbergia torreyi, Pleuraphis rigida, Sporobolus airoides, Sporobolus contractus*, and *Sporobolus cryptandrus*. Scattered shrubs and dwarf-shrubs often are present, especially *Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis, Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Gutierrezia sarothrae*, and *Krascheninnikovia lanata*. Grasslands in the basins of south-central and southwestern Wyoming, dominated by *Pseudoroegneria spicata* and *Poa secunda* and containing cushion-forming forbs and other species typical of dry basins, are included in this system. In the Columbia Plateau, this semi-desert ecological system does not include *Pseudoroegneria spicata*-dominated or -codominated associations such as *Pseudoroegneria spicata - Achnatherum hymenoides* Grassland (CEGL001674) or *Pseudoroegneria spicata - Poa secunda* Grassland (CEGL001677). Additionally, *Poa cusickii* Marsh (CEGL001655) is restricted to relatively mesic sites there and does not occur in this semi-desert system as it occurs in the Columbia Plateau, but may be found in this system in Wyoming. The vegetation description is based on several other references, including Barbour and Major (1977), Brown (1982), West (1983e), Knight (1994), Reid et al. (1999), West and Young (2000), Tuhy et al. (2002), Barbour et al. (2007), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Soil crust is not as important in sites with high vascular cover and lower cover of bare ground in relative mesic sites (Belnap et al. 2001). The biological soil crust diversity metric assumes a generally open grassland. Great Basin crust diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (17) (*Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp.); lichens are similar to those in the Colorado Plateau in the southern Great Basin (21) (*Collema tenax* and *Collema coccophorum* dominate sandy/silty sites; other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp.), plus additional species (14) in the northern Great Basin (*Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*). Algal diversity is higher in the Great Basin then warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp.

Nitrogen Fixation; Species Diversity: Medium
These grasslands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea*, and *Psoralidium)* and many Poaceae (*Bouteloua gracilis, Hesperostipa comata, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata)*, and some Brassicaceae, can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap 2001, Belnap et al. 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this systems include *Anabaena, Nostoc* and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema* or *Peltigera* and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Perennial Cool-Season Graminoids (12): *Achnatherum hymenoides, Achnatherum lettermanii, Achnatherum nelsonii, Achnatherum speciosum, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Leymus cinereus, Pascopyrum smithii, Poa cusickii, Poa secunda*, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this semi-desert grassland type.

Environment: This widespread semi-arid ecological system consists of lower-elevation dry grasslands found on plains, mesas and foothills throughout the intermountain western U.S. Elevation ranges from approximately 1450 to 2320 m (4750-7610 feet).

Climate: Climate usually includes hot summers and cold winters with freezing temperatures and snow common. Annual precipitation is usually from 20-40 cm (7.9-15.7 inches). A significant portion of the precipitation falls in July through October during the summer monsoon storms, with the rest falling as snow during the winter and early spring months (bimodal precipitation). However, precipitation in the western portion of this system's range occurs primarily in the winter.

Physiography/landform: These grasslands occur on a variety of aspects, slopes and landforms, including swales, playas, mesas, alluvial flats, plains and hillslopes. Stands are found in lowland and upland areas usually on xeric sites. Grasslands in areas of higher precipitation, at higher elevation, typically belong to other systems.

Soil/substrate/hydrology: Substrates range from deep to shallow, frequently well-drained sandy or loam soils derived from sandstone or shale parent materials but are quite variable and may include fine-textured soils derived from igneous and metamorphic rocks. Some occurrences on sandy soils have a high cover of cryptogams on the soil surface. These cryptogams tend to increase the stability of the highly erodible sandy soils of these grasslands during torrential summer rains and heavy wind storms (Kleiner and Harper 1977). *Muhlenbergia*-dominated grasslands which flood temporarily, combined with high evaporation rates in this dry system, can have accumulations of soluble salts in the soil. Soil salinity depends on the nature of the parent material and on the amount and timing of precipitation and flooding. Growth-inhibiting salt concentrations are diluted when the soil is saturated, allowing the growth of less salt-tolerant species. As the saturated soils dry, the salt concentrates until it precipitates out on the soil surface (Dodd and Coupland 1966, Ungar 1968). The environmental description is based on several other references, including Barbour and Major (1977), Brown (1982), West (1983e), Knight (1994), Reid et al. (1999), West and Young (2000), Tuhy et al. (2002), Barbour et al. (2007), and Sawyer et al. (2009).

Key Processes and Interactions: Disturbance dynamics in this semi-arid grassland system are variable because of variation in the composition; however, most are dominated by perennial bunchgrasses that are adapted to low- to medium-frequency (<30 to <100 years) and low- to medium-intensity fires (Howard 1997a, b, Tirmenstein 1999e, Zlatnik 1999a, b, Johnson 2000c, Simonin 2000a, b, c, Anderson 2003a, Sawyer et al. 2009). Most of the species are classified as resistant or tolerant of fire; with the exception of *Bouteloua eriopoda*, which is classified as sensitive, but will recover quickly if there is adequate summer moisture (Simonin 2000a). Season of burn is also important for predicting post-burn recovery.

The majority of characteristic grass species, such as *Achnatherum hymenoides, Aristida* spp., *Bouteloua eriopoda, Bouteloua gracilis, Hesperostipa comata, Pleuraphis jamesii, Poa secunda, Pseudoroegneria spicata, Sporobolus airoides*, and *Sporobolus cryptandrus*, will be top-killed after burning, then resprout from rootcrowns unless the fire was very severe (Howard 1997a, b, Tirmenstein 1999e, Zlatnik 1999a, b, Johnson 2000c, Simonin 2000a, b, c, Anderson 2003a, Sawyer et al. 2009). This grassland system is maintained by fires that kill or reduce cover of the more fire-sensitive shrub species.

The dominant perennial grass species are well-adapted to the semi-arid conditions. *Achnatherum hymenoides* is one of the most drought-tolerant, cool-season grasses in the western U.S. (USFS 1937, Tirmenstein 1999e). It is also a valuable forage grass in arid and semi-arid regions. *Hesperostipa comata* is a deep-rooted, cool-season grass that uses soil moisture below 0.5 m depth during the dry summers. It is prone to litter accumulations at plant bases, which can increase intensity of fire, making it more susceptible to mortality (Zlatnik 1999a). *Bouteloua gracilis* is a drought- and very grazing-tolerant warm-season grass that generally forms a short sod. *Pleuraphis jamesii*, also a warm-season grass, is only moderately palatable to grazers, but decreases when heavily utilized during drought and in the more arid portions of its range where it is the dominant grass (West et al. 1972). This grass reproduces extensively from scaly rhizomes, which make the plant resistant to trampling by large wildlife or livestock and have good soil-binding properties (Weaver and Albertson 1956, West 1972).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2,000 square miles. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

LANDFIRE developed this VDDT model for this system for the Great Basin using two classes (LANDFIRE 2007a, BpS 1211350).

A) Early Development 1 Open (grass-dominated - 20% of type in this stage): Dominated by grasses (*Achnatherum hymenoides, Hesperostipa comata*) and post-fire-associated forbs, and remnant *Artemisia tridentata*. Perennial grasses and forbs dominate (generally 25-40% cover) where woody shrub canopy has been top-killed/removed by wildfire. Shrub cover is less than 5%. Replacement fire occurs every 120 years on average. Succession to class B after 20 years.

B) Mid Development 1 Open (grass with shrubs - 80% of type in this stage): Dominated by grasses (*Achnatherum hymenoides, Hesperostipa comata*) and *Artemisia tridentata*. Shrubs compose the upper layer lifeform (5-25% cover) with diverse perennial grass and forb understory dominant. Mean fire-return interval (FRI) is 75 years with 80% replacement fire (mean FRI of 94 years) and 20% mixed-severity fire (mean FRI of 375 years). Mixed-severity fire, insect/disease (return interval of 75 years), and weather-related stress (return interval of 100 years) maintain vegetation in class B.

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from the combination of heavy livestock use and drought, which can push these grassland communities over thresholds that are often irreversible because of soil loss and arroyo formation. Relatively intact sites will have both native perennial grasses and intact biological soil crusts. Conversions occur as biological soil crusts decrease, shrubs increase, and non-native species begin to invade, such as *Bromus rubens, Bromus tectorum, Centaurea solstitialis, Hypericum perforatum*, and *Poa pratensis*. The final endpoint on severely altered sites is non-native grasses and severe soil loss. This has been well established on both the Colorado Plateau and Great Basin.

The primary land uses that alter the natural processes of this system are associated with livestock practices, invasive annual plant invasion, fire regime alteration, direct soil surface disturbance, and fragmentation (WNHP 2011). Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers including *Aristida* spp., *Ericameria* spp., and *Gutierrezia sarothrae*, and annual grasses, particularly *Bromus tectorum* and other exotic annual bromes. Persistent grazing will further diminish perennial grass cover, expose bare ground, increase exotic annuals, and may lead to higher density of *Ericameria* spp. or *Gutierrezia sarothrae*. Fire further stresses livestock-altered vegetation by increasing exposure of bare ground to erosion and consequent increases in exotic annuals and decrease in perennial bunchgrasses. The introduction of *Bromus tectorum* into these communities has altered fuel loads and fuel distribution. More frequent fire favors cool-season annuals that complete their life cycles in early spring, leaving abundant fine fuels that burn hot and damage and kill perennial grasses. Fragmentation of grasslands by agriculture also increases cover of annual grass, annual/biennial forbs, bare ground, decreases cover of perennial forbs and biological soil crusts, and reduces obligate insects (Quinn 2004), obligate birds and small mammals (Vander Haegen et al. 2001).

When grasshopper and Mormon cricket populations reach outbreak levels, they cause significant economic losses for ranchers and livestock producers, especially when accompanied by a drought (USDA-APHIS 2003, 2010). Both rangeland forage and cultivated crops can be consumed by grasshoppers. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is the federal agency responsible for controlling economic infestations of grasshoppers on western rangelands with a cooperative suppression program. They work with federal land managing agencies to conduct grasshopper suppression. The goal of APHIS's grasshopper program is not to eradicate them but to reduce outbreak populations to less economically damaging levels (USDA-APHIS 2003). This APHIS effort dampens the natural ecological outbreak cycles of grasshoppers and Mormon crickets but does not eradicate the species.

Human development has impacted many locations throughout the range of this system. High- and low-density urban and industrial developments can have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

Common stressors and threats include fragmentation from roads, ORV use (LANDFIRE 2007a, WNHP 2011), altered fire regime from too frequent fires caused by build ups of fine fuels from invasion of non-native annual grasses (Pellant 1990, 1996), altered fire regime from active fire suppression and indirect fire suppression from livestock grazing and fragmentation, and introduction of invasive non-native species (WNHP 2011). The most serious current threat is from the interaction between livestock grazing and long-term drought, which together exceed the resilience of system and leads to degradation and conversion.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 39** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 40, left**) and sensitivity (**Figure 40, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

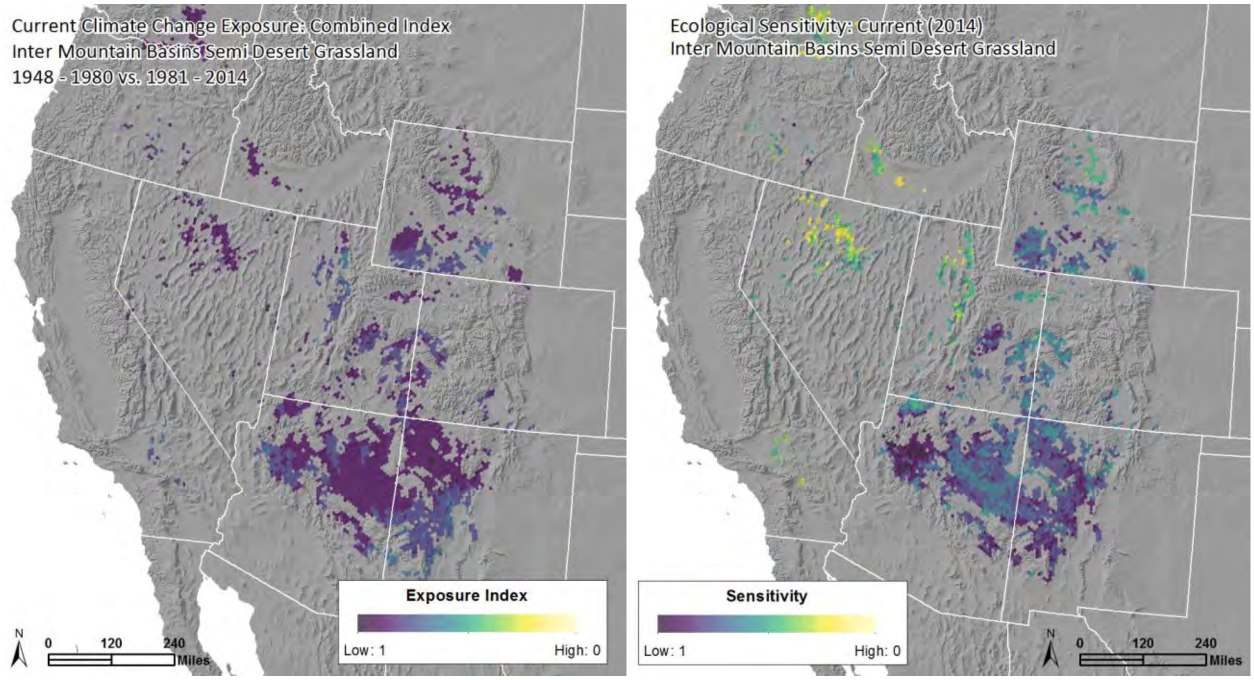

Figure 40. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Semi-Desert Grassland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 39. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Semi-Desert Grassland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Arizona-New Mexico Plateau	Arizona-New Mexico Mountains	Colorado Plateaus	Columbia Plateau	Wyoming Basin	Central Basin & Range	Northern Basin & Range	Snake River Plain	Southern Rockies	Mojave Basin & Range
	Sq miles within ecoregion	5,355	1,330	550	511	448	286	59	57	42	21
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Mod** 0.59	**Mod** 0.56	**Mod** 0.58	**Mod** 0.62	**Mod** 0.58	**Mod** 0.59	**Mod** 0.58	**Mod** 0.62	**Mod** 0.59	**Mod** 0.52
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.71	0.73	0.54	0.16	0.63	0.36	0.58	0.27	0.70	0.37
	Fire Regime Departure	0.50	0.59	0.47	0.16	0.44	0.24	0.63	0.21	0.43	0.43
	Invasive Annual Grasses	0.99	1.00	0.89	0.66	0.87	0.57	0.39	0.69	1.00	0.60
	Sensitivity Average	**0.74**	**0.77**	**0.63**	**0.33**	**0.64**	**0.39**	**0.53**	**0.39**	**0.71**	**0.47**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.16	0.19	0.19	0.07	0.18	0.19	0.19	0.10	0.31	0.11
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.33**	**0.35**	**0.34**	**0.28**	**0.34**	**0.34**	**0.34**	**0.30**	**0.40**	**0.30**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.53	**Mod** 0.56	**High** 0.49	**High** 0.31	**High** 0.49	**High** 0.37	**High** 0.44	**High** 0.34	**Mod** 0.55	**High** 0.39
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**High**	**Mod**	**High**	**Mod**	**High**	**Mod**	**High**

Exposure Summary for 1981-2014 Timeframe: Overall exposure as of 2014 for this widespread grassland system is moderate. In all ecoregions where it occurs, except the Columbia Plateau and Snake River Plain, an emerging pattern of climate change is seen in increases in Annual Mean Temperature ranging from 0.52° to 0.74°C for 24% of its distribution in the Northern Basin and Range up to 97% of its distribution in the Arizona/New Mexico Mountains. Similar increases are seen in the Mean Temperature of the Warmest Quarter, up to 0.77°C in most ecoregions and for over 25% of its distribution in each.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. If significant precipitation occurred during the summer, warm-season grasses may increase as cool-season species decrease. Many stands of this ecological system occur in basins surrounded by mountain ranges, so it may be possible for species in this system to move into foothill zones as suitable climate is diminished at lower elevations.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be moderate to high, but in the Arizona-New Mexico Mountains ecoregion it is low (high numerical score). This moderate to high sensitivity in 9 out of 10 ecoregions is a result of interactions between fire regime departure and landscape condition, with invasive grass risk being a factor in about half of the ecoregions.

Landscape condition is moderate to poor indicating roads and other signs of development is a factor. In the Columbia Plateau ecoregion, condition is scored very low, a reflection of intensive agricultural activity combined with other infrastructure around remaining occurrences of this type. Throughout its range, there are many small roads that fragment occurrences, and development of residential exurban areas is significant in some locations. Mining operations and transmission corridors are other impacts.

Risk of invasive annual grasses varies from low (higher scores) to moderate; but high in the Northern Basin and Range. Vulnerability from fire regime departure is moderate to very high (lowest numerical scores) across the entire range of this system. Livestock grazing of these semi-desert grasslands has diminished the cover of the native perennial grasses, disturbed the soil crust and allowed establishment of native disturbance-increasers, primarily rabbitbrush (*Ericameria* sp.) and snakeweed (*Gutierrezia sarothrae*), along with invasive annual grasses in some areas where cheatgrass is especially prevalent. The result is many occurrences of these grasslands have shifted to a shrub-dominance, which in turn alters the fire regime.

The interactions of the stressors of fragmentation by roads, ORV use, and other development, overgrazing, invasion by exotics, and fire suppression have resulted in changes to the composition and structure of these grasslands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns in some of the ecoregions where it occurs.

Ecosystem Resilience: Adaptive Capacity: Vulnerability from adaptive capacity scores is high range wide. Topoclimatic variability is low throughout its range, as these grasslands occur across generally flat landforms and topography such as swales, playas, mesas, alluvial flats, plains and hillslopes. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within each of the three identified functional species groups is moderate. Within individual stands, species of lichens, algae and cyanobacteria that contribute to stabilizing soil crusts have high within-stand diversity. The other functional species groups, nitrogen fixation and perennial cool-season graminoids have moderate within-stand diversity. Perennial cool-season graminoids use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This semi-desert grassland type scores in the moderate to high level of vulnerability throughout its range. This is primarily due to its moderate scores for current exposure combined with moderate to high contributions to vulnerability from overall resilience measures. Inherent vulnerabilities are high for these grasslands that naturally occupy extensive on flat to gently sloping swales, playas, mesas, alluvial flats, and plains. Additionally, these semi-desert grasslands have moderate to high fire regime departure scores and variable landscape condition scores with lowest scores in agricultural areas. Stands are highly susceptible to effects of extended drought, overgrazing, and long-term effects of fire regime alterations such as shrub and tree encroachment with fire suppression. In their western extent, stands are highly susceptible to invasive plants and their interactions with increased wildfires.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 40. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Semi-Desert Grassland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for effects of climate stress, like trends in cool season graminoids, nitrogen fixers, and invasive plant expansion.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for effects of climate stress, like trends in cool season graminoids, nitrogen fixers, and invasive plant expansion, and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, like trends in cool season graminoids, nitrogen fixers, and invasive plant expansion, and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson 2003a, Anderson 2009, Barbour and Major 1977, Barbour et al. 2007a, Bell et al. 2009, Belnap 2001, Belnap et al. 2001, Betts 1990, Brown 1982a, CNHP 2010, Cable 1967, Cable 1969, Cable 1975b, Comer et al. 2003*, Degenhardt et al. 1996, Dodd and Coupland 1966, Greene 1999, Hammerson 1999, Howard 1997a, Howard 1997b, Johnson 2000c, Kleiner and Harper 1977, Knight 1994, LANDFIRE 2007a, Mast et al. 1997, Mast et al. 1998, McClaran and Van Devender 1995, Pellant 1990, Pellant 1996, Quinn 2004, Reid et al. 1999, Rosentreter and Belnap 2003, Saab and Marks 1992, Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Shiflet 1994, Simonin 2000a, Simonin 2000b, Simonin 2000c, Stebbins 2003, TNC 2013, Tennant 1984, Tirmenstein 1999b, Tirmenstein 1999c, Tirmenstein 1999e, Tuhy et al. 2002, USDA-APHIS 2003, USDA-APHIS 2010, USFS 1937, USFWS 2004b, Ungar 1968, Vander Haegen et al. 2001, WNHP 2011, WNHP and BLM 2005, WNHP unpubl. data, Weaver and Albertson 1956, West 1983e, West and Young 2000, West et al. 1972, Zlatnik 1999a, Zlatnik 1999b

CES302.742 Mojave Mid-Elevation Mixed Desert Scrub

Figure 41. Photo of Mojave Mid-Elevation Mixed Desert Scrub. Photo credit: Laura Camp, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/lauracamp

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is an extensive desert scrub dominated by *Yucca brevifolia* and/or *Coleogyne ramosissima*. It is found in the transition zone between *Larrea tridentata - Ambrosia dumosa* desert scrub and lower montane woodlands (700-1800 m elevations) that occur in the eastern and central Mojave Desert, and in southern Great Basin. The vegetation in this ecological system is quite variable. Major communities include *Yucca brevifolia* and *Coleogyne ramosissima* scrub. Dominant and diagnostic species include *Coleogyne ramosissima, Ericameria parryi, Ericameria teretifolia, Eriogonum fasciculatum, Ephedra nevadensis, Grayia spinosa, Lycium* spp., *Menodora spinescens, Nolina* spp., *Cylindropuntia acanthocarpa, Salazaria mexicana, Viguiera parishii, Yucca brevifolia*, or *Yucca schidigera*. Less common are stands with scattered Joshua trees and a saltbush short-shrub layer dominated by *Atriplex canescens, Atriplex confertifolia*, or *Atriplex polycarpa*, or occasionally *Hymenoclea salsola*. In some areas in the western Mojave, *Juniperus californica* is common with the yuccas. Desert grasses, including *Achnatherum hymenoides, Achnatherum speciosum, Muhlenbergia porteri, Pleuraphis jamesii, Pleuraphis rigida*, or *Poa secunda*, may form an herbaceous layer. Scattered *Juniperus osteosperma* or desert scrub species may also be present.

Distribution: This system is found in the eastern and central Mojave Desert and on lower piedmont slopes in the transition zone into the southern Great Basin.

Nations: MX?, US

States/Provinces: AZ, CA, NV, UT

CEC Ecoregions: Sierra Nevada, Wasatch and Uinta Mountains, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Mojave Basin and Range, Sonoran Desert, California Coastal Sage, Chaparral, and Oak Woodlands, Southern California/Northern Baja Coast, Southern and Baja California Pine-Oak Mountains, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The vegetation in this ecological system is quite variable. Major alliances include *Yucca brevifolia* and *Coleogyne ramosissima* scrub. Dominant and diagnostic species include *Coleogyne ramosissima, Ephedra nevadensis, Ericameria parryi, Ericameria teretifolia, Eriogonum fasciculatum, Grayia spinosa, Krameria* spp., *Lycium* spp., *Nolina* spp., *Cylindropuntia acanthocarpa (= Opuntia acanthocarpa), Peucephyllum schottii, Salazaria mexicana, Viguiera parishii, Yucca brevifolia*, or *Yucca schidigera* (Sawyer et al. 2009). Less common are stands with scattered (*Yucca brevifolia* and a saltbush short-shrub layer dominated by *Atriplex canescens, Atriplex confertifolia, Atriplex polycarpa*, or occasionally *Hymenoclea salsola*. In some areas in the western Mojave, *Juniperus californica* is common with *Yucca brevifolia*. Desert grasses, including *Achnatherum hymenoides, Achnatherum speciosum, Muhlenbergia porteri, Pleuraphis jamesii, Pleuraphis rigida*, or *Poa secunda*, may form an herbaceous layer. Scattered *Juniperus osteosperma* or desert scrub species may also be present. Stands dominated by *Ericameria parryi, Eriogonum fasciculatum, Nolina bigelovii, Nolina parryi, Lycium andersonii, Menodora spinescens*, or *Viguiera parishii* occur on rocky ridges, outcrops, and dry washes and may be too sparse to burn except under extreme conditions (Sawyer et al. 2009). The vegetation description is based on several references, including Beatley (1976), Brown (1982), Turner (1982), MacMahon (1988), Holland and Keil (1995), Reid et al. (1999), Ostler et al. (2000), Anderson (2001c), Gucker (2006a, 2006b), Barbour et al. (2007), Keeler-Wolf (2007), Sawyer et al. (2009), and NatureServe Explorer (2011).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
As elevation increases, lichen and moss flora are more diverse and approximate that found on the Colorado Plateau. Mojave Desert BSC diversity is based on Rosentreter and Belnap (2003). Species reflect fact that soils are derived mixed substrates mostly from calcareous parent materials (limestone) and igneous parent materials (granite). Cyanobacteria (9): *Microcoleus vaginatus* is typically dominant in Mojave Desert (but otherwise similar to Sonoran). Other cyanobacteria include *Anabaena variabilis, Calothrix castellii, Microcoleus chthonoplastes, Nostoc commune, Nostoc muscorum, Phormidium tenue, Schizothrix calcicola*, and *Scytonema hofmannii*. Lichens (10): *Catapyrenium squamulosum, Collema coccophorum*, and *Collema tenax* are most common. Other common species include *Acarospora strigata, Fulgensia bracteata, Fulgensia desertorum, Heppia lutosa, Peltula patellata, Psora decipiens*, and *Toninia sedifolia*. Algal diversity is lower in warm desert regions with 4 common species: *Chlorococcum infusionum, Chlorella vulgaris, Protococcus viridis*, and *Rhizoclonium hieroglyphicum*. Dominant Mojave Desert soil crust mosses (11) include *Crossidium aberrans, Didymodon vinealis, Syntrichia caninervis, Pterygoneurum ovatum, Pterygoneurum subsessile, Tortula inermis*, and *Trichostomopsis australasiae (= Didymodon australasiae)*. Other common mosses are *Bryum argenteum, Crossidium crassinerve, Microbryum starkeanum*, and *Tortula atrovirens*.

Biotic Pollination; Species Diversity: High
Many of the dominant shrubs are wind-pollinated; however, other taxa such as *Encelia farinosa, Eriogonum fasciculatum, Ericameria* spp., *Larrea tridentata, Lycium* spp., *Opuntia* spp., and *Psorothamnus fremontii* are insect pollinated by many generalist pollinators, including honey bees and many species of small native bees, flies, wasps, and beetles (Francis 2004). However, a few characteristic species such as *Yucca brevifolia* and *Yucca schidigera* are dependent on moths within *Tegeticula yuccasella* species complex for pollination (Althoff et al. 2006). *Tegeticula mojavella* and *Tegeticula californica* pollinate *Yucca schidigera, Tegeticula synthetica* pollinates *Yucca brevifolia*, and *Tegeticula antithetica* pollinates *Yucca brevifolia var. jaegeriana* in the eastern and northeastern extent of this system (Pellmyr and Segraves 2003).

Nitrogen Fixation; Species Diversity: Medium
This desert scrub occurs in warm, arid and semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These arid shrublands typically have low herbaceous cover and low diversity. Most species of Fabaceae (*Acacia, Dalea, Psorothamnus*), Rosaceae (*Coleogyne, Purshia*), several Poaceae, and several Brassicaceae can fix nitrogen in system. Common grasses for this system include *Achnatherum hymenoides, Achnatherum speciosum, Muhlenbergia porteri, Pleuraphis jamesii, Pleuraphis rigida*, or *Poa secunda*. Cyanobacteria (especially *Nostoc*) and cyanolichens fix large amounts of soil nitrogen, and carbon can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in Mojave Desert soil crusts include *Anabaena, Calothrix, Nostoc, Schizothrix*, and *Scytonema* (6 spp.). Common N-fixing soil lichens include *Nostoc*-containing species of *Collema* or *Peltigera*, and *Scytonema*-containing species (4 spp.) of *Heppia* (Belnap 2001).

Xerophytes; Species Diversity: Medium
Species in this group are adapted to frequent and extended drought and have evolved abilities and mechanisms to survive, such as sclerophyllous leaves, C4/CAM photosynthetic pathways, waxy cuticles, water storage structures, and drought-deciduous leaves and seeds. Shrubs: *Coleogyne ramosissima, Ericameria parryi, Ericameria teretifolia, Eriogonum fasciculatum, Ephedra nevadensis, Lycium* spp., *Menodora spinescens, Nolina* spp., *Cylindropuntia acanthocarpa, Salazaria mexicana, Viguiera parishii, Yucca brevifolia*, and *Yucca schidigera*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this desert scrub type.

Environment: This ecological system is found in the Mojave Desert and in the transition zone into the southern Great Basin. It represents the extensive mid-elevation desert scrub in the transition zone above the lower elevation creosotebush desert scrub and generally below the foothill and lower montane woodlands (700-1850 m elevations (Sawyer et al. 2009). Adjacent ecological systems include Great Basin Pinyon-Juniper Woodland (CES304.773) and Inter-Mountain Basins Big Sagebrush Shrubland (CES304.777) above and Sonora-Mojave Creosotebush-White Bursage Desert Scrub (CES302.756) below.

Climate: Climate is semi-arid with hot summers and cool winters. Annual precipitation is low, averaging between 4 and 25 cm. However, year-to-year precipitation variability can be quite large with drought common and rare wet years producing a bloom of desert annuals.

Physiography/landform: Stands occur on upper bajada and lower piedmont slopes with smaller patches occurring on rocky ridges and outcrops. Slopes are gentle to moderate. Aspect is variable with higher elevation stands found on warmer south- to west-facing slopes.

Soil/substrate/hydrology: Substrates are a mixture of alluvium and colluvium and are variable, ranging from silt to loam to coarse sand, but often shallow, well-drained, sandy and rocky. Many stands occur on alkaline, calcareous substrates and often have biological crusts and a shallow caliche layer (Sawyer et al. 2009). The environmental description is based on several references, including Beatley (1976), Brown (1982a), Turner (1982b), MacMahon (1988), Holland and Keil (1995), Reid et al. (1999), Ostler et al. (2000), Anderson (2001c), Gucker (2006a, 2006b), Barbour et al. (2007a), Keeler-Wolf (2007), and Sawyer et al. (2009).

Key Processes and Interactions: This system occurs on extremely xeric sites and is well-adapted to prolonged drought and heat stress. Growth slows or stops in winter due to cold and is inhibited at other times by heat. Winter rains are sometimes sufficient to allow ephemeral herbs to flower in the spring. Late summer thunderstorms also contribute moisture.

Disturbance dynamics in this system are variable because of variation in structure and composition, being dominated by open- to closed-canopy scrub to desert grasslands dominated by *Pleuraphis rigida* (<1400 m elevation) and *Pleuraphis jamesii* (>1400 m elevation) sometimes with a *Yucca brevifolia* overstory (Sawyer et al. 2009). Except for the relatively few stands with an herbaceous layer, fire-return intervals (FRI) also tend to be long because the open stands only burn under extreme conditions. Older *Yucca brevifolia* individuals can tolerate low-severity fires due to fire-resistant bark, and both *Yucca brevifolia* and *Yucca schidigera* can sprout if burned (Gucker 2006a, b).

LANDFIRE developed a VDDT model for this system which has two classes (LANDFIRE 2007a, BpS 1410820):

A) Early Development 1 Open (25% of type in this stage): Shrub cover is 0-50%. Historically, fire was relatively uncommon in this vegetation. The average FRI for replacement fire was 400 years. When burned, the fire-tolerant/crown-sprouting shrubs such as spiny menodora, horsebrush and snakeweed will dominate the site. At higher elevations of mesic blackbrush, a big sagebrush-desert bitterbrush community typically replaces blackbrush for a protracted period. This class can express itself for over a hundred years with varying amounts of blackbrush gradually establishing after decades and eventually succeeding to class B. A few examples of this that have been observed in the field are believed to be over 60+ years. The ground cover varies by elevation and moisture regime with mesic sites being generally 10-35% with some sites only capable of 10% cover. The thermic sites are generally 10-15% ground cover with exception going as high as 35%.

B) Late Development 2 Closed (shrub-dominated - 30% of type in this stage): This community class seems to be stable and occurs after a threshold is crossed. Composition is 50-70% blackbrush-dominated. Other species are perennial grasses of desert needlegrass, Indian ricegrass, galleta grass, fluff grass, and threeawn. Lesser shrub composition includes Nevada ephedra, turbinella oak, desert bitterbrush, fourwing saltbush, and Anderson's wolfberry in mesic sites and Nevada ephedra, creosotebush, Mojave buckwheat, snakeweed, prickly pear, white bursage, and spiny menodora in thermic sites. There are other shrubs also. The FRI for replacement fire is 400 years, which causes a rare transition to class A.

Fire-sensitive shrub species such as the long-lived *Coleogyne ramosissima, Menodora spinescens, Nolina bigelovii*, or *Nolina parryi* will convert to early-seral and intermediate shrublands dominated by *Hymenoclea salsola, Grayia spinosa, Gutierrezia sarothrae, Ericameria teretifolia, Ephedra nevadensis, Menodora spinescens, Cylindropuntia acanthocarpa, Salazaria mexicana, Tetradymia* spp., or *Yucca schidigera* which have shorter FRIs (Anderson 2001c, Keeler-Wolf 2007, Sawyer et al. 2009). LANDFIRE modelers emphasized that blackbrush is fire-intolerant, may be slow to re-establish following fire, and grasses may dominate immediately following fire. Invasion of non-native annual grasses following fire is likely under current conditions (LANDFIRE 2007a).

Some species such as yucca moths (*Tegeticula* spp.) and *Yucca* species have obligate mutualistic relationships (Baker 1986b, Althoff et al. 2006). *Yucca* sp. are typically dependent on one or sometimes two species of *Tegeticula* for pollination, which is usually dependent on one to several *Yucca* host plant species for habitat and food for larvae; for example, *Tegeticula mojavella* and *Tegeticula californica* pollinate *Yucca schidigera*, and *Tegeticula antithetica* and *Tegeticula synthetica* pollinate *Yucca brevifolia*. More study and review are needed to fully understand the many functional roles animals have within this ecosystem.

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of this system are associated with livestock practices, annual exotic species introduction, fire regime alteration, direct soil surface disturbance, and fragmentation. Excessive grazing stresses the system through soil disturbance (also from ORV use), diminishing or eliminating the biological soil crust, altering the plant species composition by loss of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus madritensis* and other non-native annual bromes.

Natural fire regimes may have been altered because of grazing by livestock and fire suppression over the last 100 years. This may allow the presence of relatively fire-intolerant species such as *Artemisia tridentata, Coleogyne ramosissima*, or *Larrea tridentata* in stands of this system in relatively mesic sites (Keeler-Wolf and Thomas 2000). In sites throughout the range of this system, annual grass invasion has also substantially altered the fire frequency. Fine fuel adjacency from alien annual grasses, such as *Bromus madritensis, Bromus tectorum*, and *Schismus* spp., currently represents the most important fuel bed component in desert scrub and can substantially increase the fire frequency. After a year of moderate to high rainfall, the annual vegetation converts into fine fuels that can carry fire through these open scrub stands, killing fire-sensitive species with moderate to long fire-return intervals and converting to exotic annual grasslands (Keeler-Wolf et al. 1998).

Human development has impacted many locations throughout the ecoregion. High- and low-density urban and industrial developments also have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 41** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 42, left**) and sensitivity (**Figure 42, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

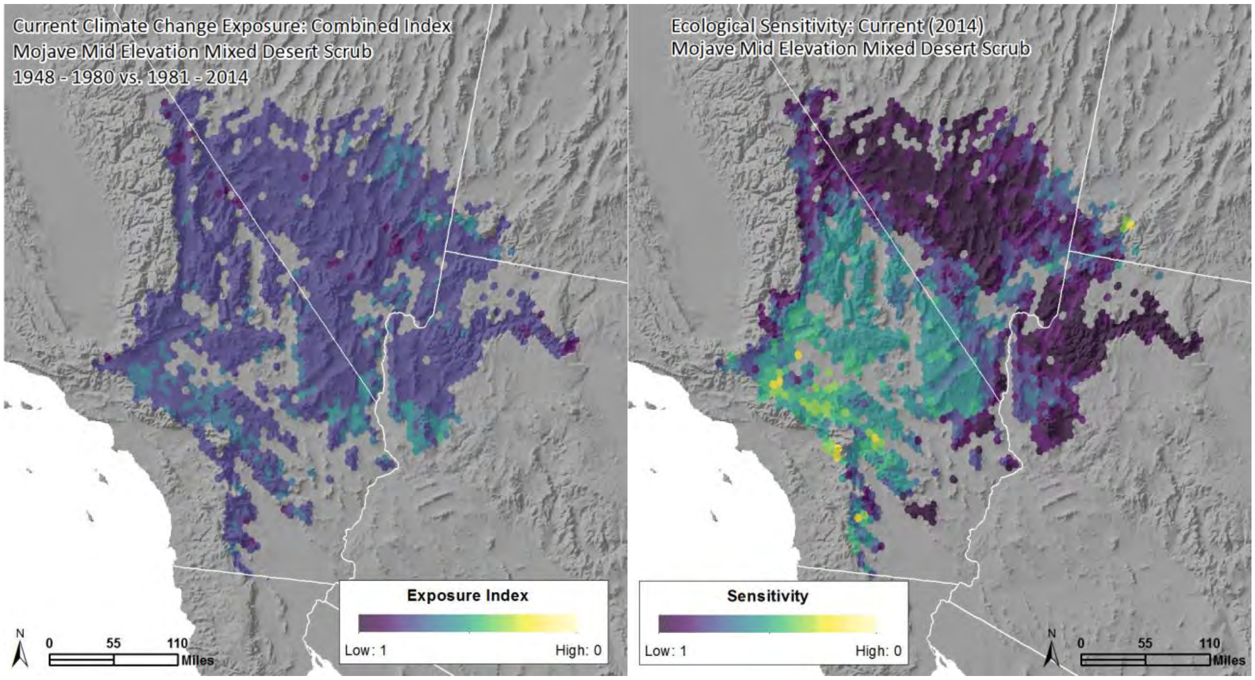

Figure 42. Climate exposure as of 2014 (left) and overall sensitivity (right) for Mojave Mid-Elevation Mixed Desert Scrub. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 41. Resilience, exposure and vulnerability scores for Mojave Mid-Elevation Mixed Desert Scrub by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Mojave Basin & Range	Central Basin & Range	Arizona-New Mexico Plateau	Sonoran Desert	Southern & Baja California Pine-Oak Mountains	Colorado Plateaus
	Sq miles within ecoregion	15,466	4,043	1,015	423	209	22
Contributions to Relative Vulnerability by Factor							
Vulnerability from **Exposure (2014)**		Mod 0.52	Mod 0.53	Mod 0.52	High 0.48	High 0.49	Mod 0.50
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.77	0.84	0.81	0.76	0.50	0.67
	Fire Regime Departure	0.74	0.87	0.94	0.83	0.75	0.75
	Invasive Annual Grasses	0.62	0.95	0.92	0.85	0.47	0.93
	Sensitivity Average	**0.71**	**0.89**	**0.89**	**0.81**	**0.57**	**0.78**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.28	0.26	0.32	0.24	0.32	0.28
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.39**	**0.38**	**0.41**	**0.37**	**0.41**	**0.39**
Vulnerability from Measures of **Overall Resilience**		Mod 0.55	Mod 0.63	Mod 0.65	Mod 0.59	High 0.49	Mod 0.59
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	High	Mod

Exposure Summary for 1981-2014 Timeframe: Overall exposure as of 2014 for this desert scrub system is moderate. But trending into the high range in two ecoregions. An emerging pattern of changing climate appears as increases ranging from 0.58° to 0.82°C for Annual Mean Temperature and Mean Temperature of the Warmest Quarter throughout its distribution in all ecoregions. The Minimum Temperature of the Coldest Month has increased by over 1.1°C for >45% of its distribution in the California Coastal Sage, and Southern and Baja California Mountains ecoregions, while similar increases are seen for over 5% to 10% of its distribution in the other ecoregions where it occurs. In the Mojave Basin and Range and Central Basin and Range ecoregions, the Mean Diurnal Ranges has decreased by 0.5°C for about 25% of its distribution, suggesting that the difference between day-time maximums and night-time minimums is decreasing.

Climate Change Effects: Many of the desert scrub species such as *Coleogyne ramosissima* (blackbrush) are long-lived and drought-tolerant so blackbrush-dominated scrub may to some degree be able to resist the effects of less available moisture with increasing mean temperature. The ecological consequences from such a climate shift would be similar to more frequent and extended drought. Successful dispersal, germination, and seedling establishment and survival would be reduced, effectively eliminating seedling recruitment for many scrub species. Indirect effects of a warming climate may result in more frequent fires from drier fuels, and rapid loss of fire-intolerant shrubs such as *Artemisia tridentata, Coleogyne ramosissima*, or *Larrea tridentata*, at least for stands with enough fuel to carry a fire.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low across the range of this type; 4 of 6 ecoregions have low sensitivity (higher numerical scores) (**Table 41**).

Landscape condition is generally good (less development) with 4 of 6 ecoregions having good condition. This ecosystem generally occurs across extensive and remote semi-arid regions throughout its range with limited impacts. This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, mining operations, wind and solar energy development, transportation and transmission corridors, and areas of urban, suburban and exurban development especially in the western Mojave.

Risk of invasive annual grasses is low (higher numerical scores) in 4 of 6 ecoregions. However, the Mojave Basin and Range and Southern and Baja California Pine-Oak Mountains ecoregions have moderate risk and high these ecoregions, respectively, contain 74% of the extent of this system. Flushes of annuals (and perennial grasses) after exceptionally wet years can sometimes create enough fuel to carry fire. Fire has been introduced to this system by invasive annual grasses, as historically fire was not important in this type. Although fire regime departure is low to moderate across the range, but when burned, there are significant compositional changes. Fire-tolerant/crown-sprouting shrubs will dominate burned sites and replace the longer-lived fire-sensitive shrub species for the next 60+ years. In addition, the effects of historic overgrazing and current grazing by livestock impact herbaceous composition and biological soil crusts.

The interactions of the stressors of overgrazing, fragmentation, and other disturbances have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Contributions to vulnerability from adaptive capacity is high (low numerical scores) range wide. Topoclimatic variability is low to very low, as these shrublands occur across a limited variety of landforms and topography, such as on upper bajada and lower piedmont slopes. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within functional species groups varies from medium among groups and contributes to a higher adaptive capacity than might be expected when just looking at topo-climate variability. Medium diversity is found within the functional species groups of nitrogen-fixers and xerophytic species, whereas there appears to be high diversity within the biotic pollinators and biological soil crust functional groups, which may enhance the system's ability to adapt to climate change.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: This desert scrub type currently scores as having moderate overall vulnerability throughout 5 of the 6 ecoregion of its range. It currently scores as high vulnerability in the Southern & Baja California ecoregion. This is primarily due to its moderate to high exposure and mostly moderate scores for overall resilience. Inherent vulnerabilities are high for desert types that naturally occupy extensive gently sloping alluvial fans and lower piedmont slopes (low topoclimate variability). Additionally, these desert scrub types are highly susceptible to invasive plants and their interactions with introduced wildfires. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 42. Climate change adaptation strategies relative to vulnerability scores for Mojave Mid-Elevation Mixed Desert Scrub

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and prevent introduced fire. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native shrub and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (pollinators, nitrogen fixers, etc.). If a natural wildfire regime was historically characteristic, localize models for wildfire regimes, and restore regimes where they have been severely altered from introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species and biotic pollinators. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. If applicable, update and modify models for wildfire regimes suitable to forecasted future conditions.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. If applicable, create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Althoff et al. 2006, Anderson 2001c, Baker 1986b, Barbour and Major 1977, Barbour and Major 1988, Barbour et al. 2007a, Beatley 1976, Belnap 2001, Belnap et al. 2001, Brown 1982a, Comer et al. 2003*, Evans and Belnap 1999, Francis 2004, Gucker 2006a, Gucker 2006b, Holland and Keil 1995, Keeler-Wolf 2007, Keeler-Wolf and Thomas 2000, Keeler-Wolf et al. 1998a, LANDFIRE 2007a, MacMahon 1988, Ostler et al. 2000, Pellmyr and Segraves 2003, Reid et al. 1999, Rondeau 1999, Rosentreter and Belnap 2003, Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Shiflet 1994, Thomas et al. 2004, Turner 1982b, West 1983d, West 1988

M170. Great Basin-Intermountain Dwarf Sagebrush Steppe & Shrubland

CES304.762 Colorado Plateau Mixed Low Sagebrush Shrubland

Figure 43. Photo of Colorado Plateau Mixed Low Sagebrush Shrubland. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in the Colorado Plateau, Tavaputs Plateau and Uinta Basin in canyons, gravelly draws, hilltops, and dry flats at elevations generally below 1800 m. Soils are often rocky, shallow, and alkaline. This type extends across northern New Mexico into the southern Great Plains on limestone hills. It includes open shrublands and steppe dominated by *Artemisia nova* or *Artemisia bigelovii* sometimes with *Artemisia tridentata ssp. wyomingensis* codominant. Semi-arid grasses such as *Achnatherum hymenoides, Aristida purpurea, Bouteloua gracilis, Hesperostipa comata, Pleuraphis jamesii*, or *Poa fendleriana* are often present and may form a graminoid layer with over 25% cover.

Distribution: Occurs in the Colorado Plateau, Tavaputs Plateau and Uinta Basin in canyons, gravelly draws, hilltops, and dry flats at elevations generally below 1800 m.

Nations: US

States/Provinces: AZ, CO, NM, UT

CEC Ecoregions: Wasatch and Uinta Mountains, Southern Rockies, Southwestern Tablelands, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These shrublands are dominated by *Artemisia nova* or *Artemisia bigelovii*, sometimes with *Artemisia tridentata ssp. wyomingensis* codominant. Other shrubs that may be present include *Atriplex canescens, Chrysothamnus viscidiflorus, Ephedra* spp., *Ericameria* spp., *Gutierrezia sarothrae, Lycium* spp., and *Yucca* spp. The herbaceous layer ranges from sparse to moderately dense and is composed of semi-arid grasses such as *Achnatherum hymenoides, Aristida purpurea, Bouteloua gracilis, Hesperostipa comata, Pleuraphis jamesii*, or *Poa fendleriana* forming a graminoid layer sometimes with over 25% cover. The floristic description is based on several other references, including Jameson et al. (1962), Brown (1982), West (1983a), Baker and Kennedy (1985), Francis (1986), Dick-Peddie (1993), West and Young (2000), Howard (2003), Fryer (2009), and NatureServe Explorer (2011).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and are critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems in the western U.S. (Belnap and Lange 2003). Colorado Plateau crust diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (16): *Microcoleus vaginatus* is strongly dominant with *Scytonema myochrous* and *Nostoc commune* common. Other species include *Anabaena variabilis, Calothrix parietina, Chroococcus turgidus, Gloeothece linearis, Lyngbya limnetica, Nostoc paludosum, Oscillatoria geminata, Phormidium minnesotense, Phormidium tenue, Plectonema radiosum, Schizothrix calcicola*, and *Tolypothrix tenuis*. Lichens are similar to those in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia bracteata, Fulgensia desertorum, Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora cerebriformis, Psora decipiens, Squamarina lentigera*, and *Toninia* spp. Algal diversity is high (>40) but biomass is low in the Colorado Plateau, although higher than warm desert regions. Common mosses (14) include *Syntrichia caninervis* and *Tortula ruralis* with *Bryum* spp., *Ceratodon purpureus, Crossidium aberrans, Didymodon* spp., *Funaria hygrometrica, Pterygoneurum* spp., and *Tortula* spp. frequently present. Liverworts are uncommon.

Nitrogen Fixation; Species Diversity: Medium
Dwarf-sagebrush stands occur in warm, semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid dwarf-shrublands typically have low herbaceous cover and low diversity with a given stand but can be quite variable across is range. Possible nitrogen-fixing plants include species of Fabaceae (including species of *Astragalus, Dalea*, and *Lupinus*), Rosaceae (*Amelanchier, Purshia*), several Poaceae species (such as *Achnatherum hymenoides, Aristida purpurea, Bouteloua gracilis, Elymus elymoides, Hesperostipa comata, Koeleria macrantha, Pleuraphis jamesii, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*), and a few Brassicaceae species. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap

2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
This system is adapted to a bimodal precipitation pattern with both warm-season summer and cool-season winter precipitation. Local stands have a low to moderately diverse mixture of warm- and cool-season graminoids such as:

Cool-season graminoids: *Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Koeleria macrantha, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*.

Warm-season graminoids: *Aristida purpurea, Bouteloua gracilis, Bouteloua eriopoda*, and *Pleuraphis jamesii*.

Keystone Species: Keystone species provide an important vital role in the function of an ecosystem relative to their abundance and would be identified by analysis of functional species groups. No keystone species were identified for this shrubland type.

Environment: This ecological system occurs in the Colorado Plateau, Tavaputs Plateau and Uinta Basin in canyons, gravelly draws, hilltops, mesatops and dry flats at elevations generally below 1800 m. This type extends across northern New Mexico into the southern Great Plains on limestone hills and sandstone breaks. Soils are often rocky, shallow and alkaline. Adjacent upland systems include Colorado Plateau Pinyon-Juniper Woodland (CES304.767) and Inter-Mountain Basins Montane Sagebrush Steppe (CES304.785) (deeper soils) at higher elevations and Inter-Mountain Basins Mixed Salt Desert Scrub (CES304.784) at lower elevations. The environmental description is based on several other references, including Jameson et al. (1962), Brown (1982), West (1983a), Baker and Kennedy (1985), Francis (1986), Dick-Peddie (1993), West and Young (2000), Howard (2003), Fryer (2009), and NatureServe Explorer (2011).

Key Processes and Interactions: The diagnostic species of this system, *Artemisia nova* or *Artemisia bigelovii*, grow in more xeric sites than other *Artemisia* shrublands (Hironaka et al. 1983). This dwarf-shrubland system is associated with shallow, rocky soils which experience extreme drought in summer. The plants are low and widely spaced, which tends to decrease the risk of fire. Fire is uncommon on drier sites because of discontinuous and low fuel buildup on the generally unproductive sites (Fryer 2009). Fire effects on *Artemisia bigelovii* is not known but assumed to be similar to *Artemisia nova* (Howard 2003), with fire-return intervals (FRI) ranging from 35 to over 100 years for xeric, low-productivity sagebrush communities of the Great Basin (Fryer 2009). In general, most sites are thought to have relatively long fire-return intervals (100-200 years) according to LANDFIRE models developed by experts (Fryer 2009). Stands in the western Great Plains typically have higher herbaceous cover (Shaw et al. 1989) which may decrease FRI. These shrubs are fire-sensitive and rarely sprout after burning. They reproduce from light wind-dispersed seeds from adjacent unburned areas to disturbed areas (Howard 1999, 2003, Fryer 2009). It generally takes around 30 years for a burned *Artemisia nova* stand to recover to pre-fire density (Hironaka et al. 1983, Fryer 2009). *Artemisia tridentata ssp. wyomingensis* may be present to codominant and shares similar ecological characteristics on these relatively xeric sites (Howard 1999).

Scattered trees may be present in some stands of this system. Fire reduces sagebrush abundance in both sagebrush and pinyon-juniper systems. Where these systems are adjacent, periodic fire likely prevents establishment of juniper and pinyon trees in sagebrush stands (Wright et al. 1979). In order to maintain dominance of sagebrush, fire-return interval must be long enough to permit sagebrush stands to mature, but short enough to prevent establishment and growth of trees in these sites. Fire-return intervals of 150-250 years for stand-replacing fire will likely maintain these shrublands. Expansion and contraction of trees into sagebrush shrublands are regulated by a combination of climate, fire, and bark beetle infestations with trees seedlings establishing during wetter periods (Wright et al. 1979, Paysen et al. 2000).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square mile. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2310640). These are summarized as:

A) Early Development 1 All Structures (shrub-dominated - 10% of type in this stage): Early-seral community dominated by herbaceous vegetation; less than 6% sagebrush canopy cover; up to 24 years post-disturbance. Replacement fire occurs every 250 years on average. Succession to class B after 24 years.

B) Late Development 1 Open (shrub-dominated - 70% of type in this stage): Shrub cover is 0-10%. Mid-seral community with a mixture of herbaceous and shrub vegetation; 6-10% sagebrush canopy cover present; between 20-59 years post-disturbance. Replacement fire (FRI of 240 years) causes a transition to class A, whereas mixed-severity fire (FRI of 100 years) maintains the site in its present condition. In the absence of fire for 120 years, the site will follow an alternative succession path to class C. Otherwise, succession and mixed-severity fire keeps site in class B.

C) Late Development 1 Open (conifer-dominated - 20% of type in this stage): Shrub cover is 10-30%. Late-seral community with a mixture of herbaceous and shrub vegetation; >10% sagebrush canopy cover present; 75+ years post-disturbance. Replacement fire is every 200 years on average (transition to class A), whereas mixed-severity fire happens on average every 140 years due to a diminished herbaceous component compared to class B. Mixed-severity fire causes a transition to class B. Succession will keep the site in class C without fire.

Black sagebrush generally supports more fire than other dwarf sagebrushes. This type generally burns with mixed severity (average FRI of 100-140 years) due to relatively low fuel loads and herbaceous cover. Bare ground acts as a micro-barrier to fire between low-statured shrubs. Oils and resins present in the foliage and stems of sagebrush allow fire to spread. Stand-replacing fires (average FRI of 200-240 years) can occur in this type when successive years of above-average precipitation are followed by an average or dry year. Stand-replacement fires dominate in the late-succession class where the herbaceous component has diminished. Fires may or may not be wind-driven and only cover small areas. This type fits into Fire Regime Groups IV and III LANDFIRE 2007a, BpS 1210310).

Grazing by wild ungulates occurs in this type due to the high palatability of *Artemisia nova* compared to other browse. Native browsing tends to open up the canopy cover of shrubs but does not often change the succession stage (LANDFIRE 2007a, BpS 1210310).

Prolonged drought may reduce the foliar and basal covers of graminoids but not that of shrubs. Reduced foliar cover of graminoids will affect fire behavior. This effect is assumed minor and not included in the model (LANDFIRE 2007a, BpS 1210310).

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of this system are associated with livestock grazing and introduction of exotic annual grasses. *Artemisia bigelovii* and *Artemisia nova* are utilized by livestock to a much greater degree than other species of *Artemisia*, resulting in low, pruned plants (West 1983a, Howard 2003d, Fryer 2009). Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus tectorum* and other exotic annuals. The introduction of exotic annual grasses has altered many stands by increasing the amount of fine fuels present that can substantially increase fire frequency and intensity which reduces the cover of fire-sensitive shrubs such as *Artemisia bigelovii* and *Artemisia nova* (Howard 2003d, Fryer 2009).

When grasshopper and Mormon cricket populations reach outbreak levels, they cause significant economic losses for ranchers and livestock producers, especially when accompanied by a drought (USDA-APHIS 2003, 2010). Both rangeland forage and cultivated crops can be consumed by grasshoppers. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is the Federal agency responsible for controlling economic infestations of grasshoppers on western rangelands with a cooperative suppression program. They work with federal land managing agencies to conduct grasshopper suppression. The goal of APHIS's grasshopper program is not to eradicate them but to reduce outbreak populations to less economically damaging levels (USDA-APHIS 2003). This APHIS effort dampens the natural ecological outbreak cycles of grasshoppers and Mormon crickets but does not eradicate the species.

Human development has impacted many locations throughout the ecoregion. High- and low-density urban and industrial developments also have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 43** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 44, left**) and sensitivity (**Figure 44, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

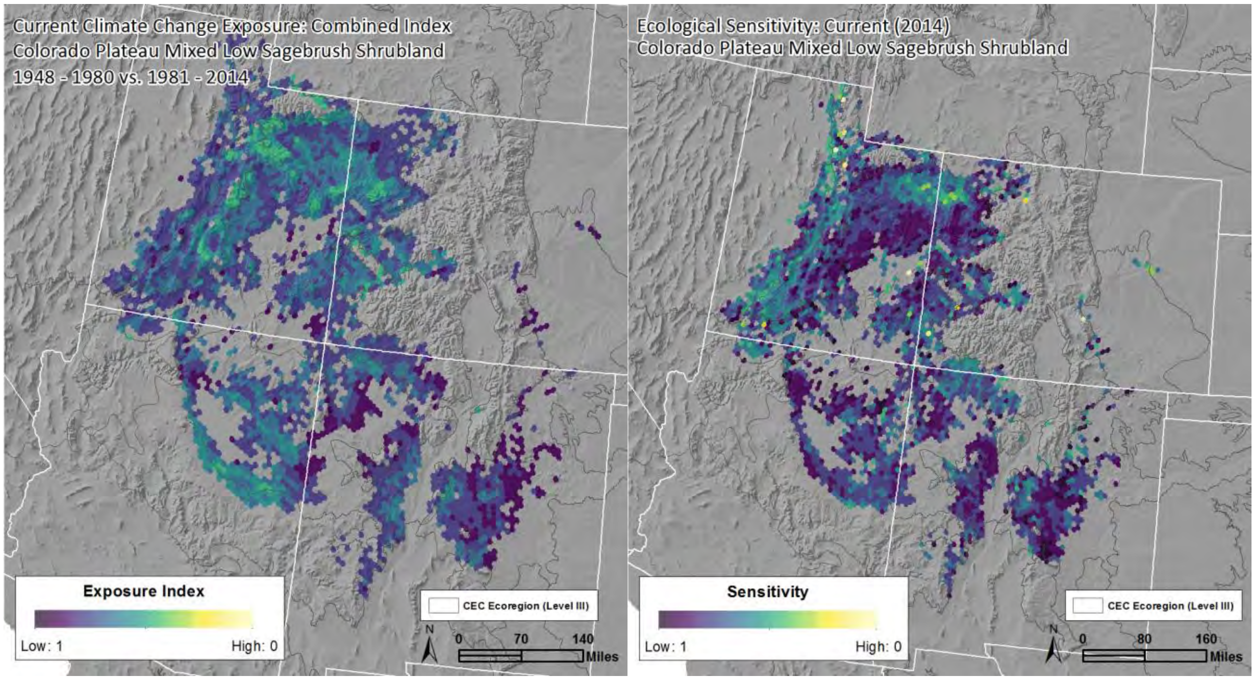

Figure 44. Climate exposure as of 2014 (left) and overall sensitivity (right) for Colorado Plateau Mixed Low Sagebrush Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 43. Resilience, exposure and vulnerability scores for Colorado Plateau Mixed Low Sagebrush Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that ecoregion, e.g., no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system, with yellow (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Wasatch & Uinta Mountains	Colorado Plateaus	Arizona-New Mexico Plateau	Southwestern Tablelands	Central Basin & Range	Arizona-New Mexico Mountains	Southern Rockies
	Potential square miles within ecoregion	682	506	169	112	105	40	37
Contributions to Relative Vulnerability by Factor								
Vulnerability from **Exposure (2014)**		**Mod** 0.64	**Mod** 0.64	**Mod** 0.68	**Mod** 0.71	**Mod** 0.73	**Mod** 0.62	**Mod** 0.69
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.48	0.72	0.79	0.67	0.40	0.78	0.44
	Fire Regime Departure	0.69	0.56	0.55	0.66	0.42	0.59	0.48
	Invasive Annual Grasses	1.00	0.99	1.00	1.00	0.99	1.00	1.00
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.72**	**0.76**	**0.78**	**0.77**	**0.60**	**0.79**	**0.64**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.29	0.30	0.24	0.14	0.26	0.25	0.21
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.40**	**0.40**	**0.37**	**0.32**	**0.38**	**0.37**	**0.36**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.56	**Mod** 0.58	**Mod** 0.57	**Mod** 0.55	**High** 0.49	**Mod** 0.58	**High** 0.50
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: The exposure as of 2014 for this shrubland system is moderate across all ecoregions.

Annual mean temperature has increased between 0.5° and 0.7°C across substantial portions of all seven ecoregions (26-93% of each region). Annual temperature increases are reflected in summer temperature increases of 0.6°C characterizing 40-80% of six ecoregions.

Climate Change Effects: Climate change can affect vegetation communities by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks. In the southwestern U.S., including the Colorado Plateau where this system is common, the average annual temperature is projected to continue to increase with more frequent droughts, and the annual snowpack and streamflow are predicted to decline (Garfin et al. 2014). Characteristic dominant species *Artemisia bigelovii* and *Artemisia nova* are adapted to semi-arid environments, and highly drought-tolerant as mature plants (Howard 2003d, Fryer 2009). Information on seedling establishment and survival is limited. In addition, these shrubs are not fire-adapted and must re-establish from seed post-fire. Ecological consequences from a warming climate could increase fire frequency which would likely reduce its extent because of relatively slow post-fire recovery. However, with increasing average annual temperatures, the number and severity of wildfires in adjacent areas is expected to increase (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). In these areas this shrubland system may increase at the expense of dry woodlands such as pinyon-juniper stands, which may fail to re-establish post-fire. The net result of climate change is not known.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was moderate to low, with four ecoregions accounting for 50% of the potential distribution of this type having low sensitivity, and three ecoregions characterized by moderate sensitivity. Sensitivity scores were driven by a combination of fire regime departure and landscape condition.

Contributions to sensitivity from landscape condition were variable, ranging from high in the Wasatch and Uinta Mountains, Central Basin and Range, and Southern Rockies, to low in the Arizona-New Mexico Plateaus and Mountains ecoregions. Portions of the range with lower landscape condition scores reflect conversion to agriculture (e.g., hay and alfalfa), grazing, and fragmentation from suburban and exurban development.

Fire regime departure was moderate across five ecoregions, and high in two ecoregions (Central Basin and Range and Southern Rockies). This reflects alteration of fire regime associated with invasive grasses, which have led to increased fire frequency and declines of sagebrush cover. Overall sensitivity from invasive annual grasses was low in all ecoregions. However, flushes of annuals and perennial grasses can create enough fuel to carry fire in this open shrubland.

Overall, landscape fragmentation and fire regime departure have resulted in changes to the structure of these shrublands, leading to an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across all ecoregions of this system. This low adaptive capacity is related to low to very low scores for topoclimate variability. These reflect a low level of topoclimate variability associated with the hilltops, mesatops and dry flats characterizing much of the shrubland type. Therefore, stands occur where local climates vary little within short distances, and limited options exist for species to move across these landscapes to adapt to changing climate conditions.

In terms of vulnerability related to functional species groups, scores were moderate across ecoregions. This shrubland type scores high for biological crusts which can contribute to soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems. However, scores were moderate in terms of nitrogen fixers and perennial cool- and warm-season grasses. No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, this shrubland system scores in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure and landscape condition, and low adaptive capacity associated with low topoclimate diversity. Additionally, these shrublands are highly susceptible to effects of grazing and increased fire frequency associated with invasive grasses.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 44. Climate change adaptation strategies relative to vulnerability scores for Colorado Plateau Mixed Low Sagebrush Shrubland.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids, and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids, and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Baker and Kennedy 1985, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Brown 1982a, Comer et al. 2003*, Dick-Peddie 1993, Francis 1986, Fryer 2009, Garfin et al.

2014, Gucker 2006e, Hironaka et al. 1983, Howard 1999, Howard 2003a, Howard 2003d, Jameson et al. 1962, LANDFIRE 2007a, McKenzie et al. 2004, McKenzie et al. 2008, NatureServe Explorer 2011, Paysen et al. 2000, Rising 1996, Rosentreter and Belnap 2003, Shaw et al. 1989, Shiflet 1994, USDA-APHIS 2003, USDA-APHIS 2010, West 1983a, West and Young 2000, Westerling et al. 2006, Wright et al. 1979

CES304.080 Columbia Plateau Low Sagebrush Steppe

Figure 45. Photo of Columbia Plateau Low Sagebrush Steppe. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system can form the matrix of the landscape and is composed of sagebrush dwarf-shrub-steppe that occurs in a variety of shallow-soil habitats throughout eastern Oregon, northern Nevada and southern Idaho. *Artemisia arbuscula ssp. arbuscula* and close relatives (*Artemisia arbuscula ssp. longiloba* and occasionally *Artemisia nova*) form stands that typically occur on mountain ridges and flanks and broad terraces, ranging from 1000 to 3000 m in elevation. Substrates are shallow, fine-textured soils, poorly drained clays that occur in thin-soil areas and are frequently very stony. Other shrubs and dwarf-shrubs present may include *Purshia tridentata, Eriogonum* spp., and other species of *Artemisia*. Common graminoids include *Festuca idahoensis, Koeleria macrantha, Poa secunda*, and *Pseudoroegneria spicata*. Many forbs also occur and may dominate the herbaceous vegetation, especially at the higher elevations. Isolated individuals of *Juniperus occidentalis* and *Cercocarpus ledifolius* can often be found in this system. This ecological system is closely related to the concept of shallow-dry sagebrush in the resistance-resilience framework.

Distribution: This system is found throughout the basins of eastern Oregon and southern Idaho, south into northern Nevada and northeastern California.

Nations: US

States/Provinces: CA, ID, MT?, NV, OR, WA, WY?

CEC Ecoregions: Columbia Mountains/Northern Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Wasatch and Uinta Mountains, Idaho Batholith, Northwestern Great Plains, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Snake River Plain

Primary Concept Source: J. Kagan

Description Author: J. Kagan and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Artemisia arbuscula ssp. arbuscula* and close relatives (*Artemisia arbuscula ssp. longiloba* and occasionally *Artemisia nova*) form stands. Other shrubs and dwarf-shrubs present may include *Purshia tridentata, Eriogonum* spp., and other species of *Artemisia*. Common graminoids include *Festuca idahoensis, Koeleria macrantha, Pseudoroegneria spicata*, and *Poa secunda*. Many forbs also occur and may dominate the herbaceous vegetation, especially at the higher elevations. Isolated individuals of *Juniperus occidentalis* (western juniper) and *Cercocarpus ledifolius* (mountain-mahogany) can often be found in this system.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and are critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems the western U.S. (Belnap and Lange 2003). Ecological systems in the Columbia Plateau are assumed to have similar biological soil crust species richness as in the Great Basin. Great Basin crust diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin than warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp.

Nitrogen Fixation; Species Diversity: Medium
These shrublands occur in semi-arid climates on rocky substrates with limited soil depth and soil nutrients, such as nitrogen are likely a significant constraint on plant growth. These semi-arid shrublands typically have low herbaceous cover and low diversity. Several species of Fabaceae (including species of *Astragalus* and *Lupinus*), Poaceae (e.g., *Festuca idahoensis, Koeleria macrantha, Poa secunda, Pseudoroegneria spicata*), species of Rosaceae (*Purshia tridentata*), and a few species of Brassicaceae may fix nitrogen within this system. Cyanobacteria and cyanolichens can be important sources of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, or *Peltigera*- and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa is moderate; within stand species diversity of nitrogen fixers is typically moderate.

Perennial Cool-Season Graminoids; Species Diversity: Medium
Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Koeleria macarantha, Leymus cinereus, Pascopyrum smithii, Poa fendleriana, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this black and low sagebrush shrubland type.

Environment: This system occurs on shallow-soil habitats, ranging from 1000 to 3000 m in elevation.

Climate: Climate is semi-arid with a large proportion of the 20-30 cm of annual precipitation falling as winter snow. The temperature regime is continental, with cold winters, warm summers, a large diurnal temperature range, and a short frost-free season.

Physiography/landform: Stands typically occur on mountain ridges and flanks and broad terraces, but may be associated with flats, depressions, and slopes with soils that are either very shallow or quite poorly drained. In the Columbia River Basin, the vegetation in this system occupies the driest habitats of all the *Artemisia*-dominated stands.

Soil/substrate/hydrology: Substrates are generally fine-textured, usually poorly drained clays that occur in shallow-soiled areas, which are almost always very stony and characterized by recent rhyolite or basalt. Beetle and Johnson (1982) report that *Artemisia arbuscula ssp. arbuscula* grows in soils with a high volume of gravel (even though soil may be in clay textural class or contain a clay-rich layer that impedes drainage), and that *Artemisia arbuscula ssp. longiloba* grows in clay soils, often alkaline, that contain no gravels. Soils dominated by *Artemisia nova* are typically alkaline and calcareous.

Key Processes and Interactions: The diagnostic species of this system, *Artemisia arbuscula ssp. arbuscula, Artemisia arbuscula ssp. longiloba*, or *Artemisia nova*, grow in more xeric sites than other *Artemisia* shrubs (Hironaka et al. 1983), and are highly drought-tolerant. *Artemisia arbuscula* tends to grow where claypan layers exist in the soil profile and soils are often saturated during a portion of the year, while *Artemisia nova* tends to grow where there is a root-limiting layer in the soil profile (LANDFIRE 2007a). This shrubland system is associated with shallow, rocky soils which experience extreme drought in summer. The plants are low and widely spaced, which tends to decrease the risk of fire (Chappell et al. 1997).

Fire influences the density and distribution of shrubs. In general, fire increases the abundance of herbaceous perennials and decreases the abundance of woody plants (WNHP 2011). The fire interval for this system is 110 years (LANDFIRE 2007a). Anecdotal observations indicate that these patches often are not burned during surrounding forest fires. Fire is uncommon because of discontinuous and low fuel buildup on the generally unproductive sites (Young and Palmquist 1992, Fryer 2009, Sawyer et al. 2009). Most sites are thought to have relatively long fire-return intervals (100-200 years) according to

LANDFIRE models developed by experts (LANDFIRE 2007a). These shrubs are fire-sensitive and rarely sprout after burning.

The dominant shrub species can easily colonize burns via wind-dispersed seeds from adjacent unburned areas into disturbed areas (Howard 1999, Steinberg 2002a, Fryer 2009). It generally takes around 30 years for a burned stand to recover to pre-fire shrub density (Zamora and Tueller 1973, Hironaka et al. 1983, Howard 1999, Steinberg 2002a, Fryer 2009). However, recovery of this system after fire may take up to 325-450 years (Baker 2006).

Grazing by wild ungulates occurs in this shrubland system. Native browsing tends to open the canopy cover of shrubs but does not often change the successional stage (LANDFIRE 2007a).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square miles. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 0811240 and BpS 0911240). Dominant shrub is *Artemisia arbuscula*. Dominant herbaceous species are *Poa secunda* and *Pseudoroegneria spicata*.

A) Early Development 1 All Structures (10% of type in this stage): Zero to 1% low sagebrush cover. Herbaceous cover of bunchgrasses and forbs would fill to about 20-30% cover within a few years.

B) Mid Development 1 Open (40% of type in this stage): Dominant lifeform is herb. Minimum cover = 20%, maximum cover = 40%. Minimum height for herbs is 0.6 m. Scattered and usually small low sagebrush is present, but perennial grasses and forbs continue to dominate. The general formation is that of a shrub savanna. Sagebrush cover is usually 1-5% in this stage.

C) Late Development 1 Open (50% of type in this stage): Sagebrush is codominant with perennial grasses and forbs. Sagebrush and herbaceous cover can be variable depending on site productivity. Bare ground and rock in the interspaces increase on less productive sites. The general formation is that of a shrubland. Expected composition is 50-60% grass; 5-10% forbs; 20-40% shrubs. Windswept ridges with thinner soils may be still more open.

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of this system are associated with livestock practices, annual exotic species invasion, fire regime alteration, direct soil surface disturbance, and fragmentation. Barbour and Major (1988) report that *Artemisia nova* is utilized by livestock to a much greater degree than other species of *Artemisia*, resulting in low, pruned plants (West 1983a). Both *Artemisia arbuscula* and *Artemisia nova* are considered a valuable browse plant during the spring, fall, and winter months and are often grazed by native ungulates (elk and mule deer) and domestic livestock. Prolonged livestock use can cause a decrease in the abundance of native, perennial bunchgrasses and increase in the cover of shrubs and non-native grass species, such as *Poa bulbosa* and *Poa pratensis*.

Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus madritensis, Bromus tectorum, Schismus* spp., and other exotic annual grasses. The introduction of exotic annual grasses has altered many stands by increasing the amount of fine fuels present that can substantially increase fire frequency and intensity which reduces the cover of fire-sensitive shrubs such as *Artemisia nova* (Fryer 2009, Sawyer et al. 2009).

Direct and indirect fire suppression are a threat to this system where stands are adjacent to pinyon-juniper woodlands. Over the long term, heavy grazing by livestock removes the fine fuels that carry fire that indirectly leads to a reduction in fire frequencies, which can lead to pinyon-juniper encroachment with subsequent loss of shrub and herbaceous understory (LANDFIRE 2007a).

Human development has impacted many locations throughout the range of this ecological system. High- and low-density urban and industrial developments also have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirect through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 45** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 46, left**) and sensitivity (**Figure 46, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

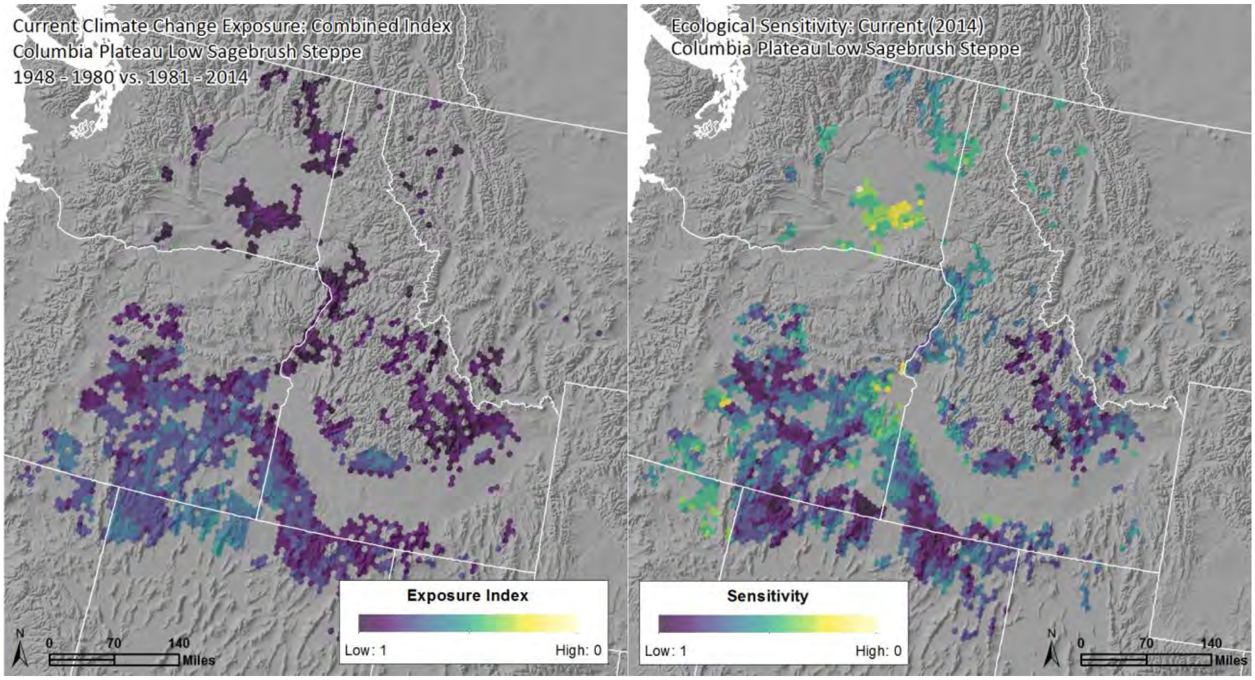

Figure 46. Climate exposure as of 2014 (left) and overall sensitivity (right) for Columbia Plateau Low Sagebrush Steppe. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 45. Resilience, exposure and vulnerability scores for Columbia Plateau Low Sagebrush Steppe by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Northern Basin & Range	Blue Moun-tains	Middle Rockies	Columbia Plateau	Snake River Plain	Eastern Cascades Slopes & Foothills	Central Basin & Range	Columbia Mountains-Northern Rockies	Idaho Batholith
	Sq miles within ecoregion	5,469	947	518	502	363	204	179	162	120
Contributions to Relative Vulnerability by Factor										
Vulnerability from **Exposure (2014)**		Mod 0.56	Mod 0.62	Mod 0.66	Mod 0.68	Mod 0.58	Mod 0.55	Mod 0.60	Mod 0.68	Mod 0.64
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.81	0.68	0.61	0.19	0.59	0.72	0.77	0.17	0.61
	Fire Regime Departure	0.84	0.68	0.58	0.27	0.81	0.38	0.66	0.36	0.72
	Invasive Annual Grasses	0.68	0.79	0.99	0.67	0.76	0.51	0.80	1.00	0.92
	Sensitivity Average	**0.78**	**0.72**	**0.73**	**0.38**	**0.72**	**0.54**	**0.74**	**0.51**	**0.75**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.25	0.27	0.26	0.12	0.15	0.15	0.41	0.15	0.49
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.38**	**0.39**	**0.38**	**0.31**	**0.32**	**0.32**	**0.45**	**0.32**	**0.49**
Vulnerability from Measures of **Overall Resilience**		Mod 0.58	Mod 0.55	Mod 0.55	High 0.34	Mod 0.52	High 0.43	Mod 0.60	High 0.42	Mod 0.62
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	High	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of these steppe shrublands, exposure as of 2014 is moderate. Areas of this system's distribution show an emerging pattern of change in Annual Mean Temperature in the Central Basin and Range, Eastern Cascades Slopes and Blue Mountains ecoregions. The increases are in the range of 0.5° to 0.6°C, over 30% of its distribution in those regions. The Mean Diurnal Range is decreasing by some 0.6°C in the Central Basin and Range and Columbia Plateau ecoregions, again across small areas (18% and 7%, respectively), suggesting the difference between day-time maximums and night-time minimums is decreasing. In the Central Basin and Range, the decrease in diurnal range exceeds 2 standard deviations from the 1948-1980 baseline mean, so the change is approaching being outside of the range of variability seen in the mid-century baseline years.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating sagebrush recruitment.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change varies from low to high, but in 6 of 9 ecoregion, scores in the moderate range. Sensitivity is greatest in the Columbia Plateau, Eastern Cascades and Columbia Mountains ecoregions, due to the combination of extensive agriculture and development fragmenting occurrences and concentrations of invasive annual grasses, which in turn alters fire regimes.

Landscape condition varies from good (less development, higher scores) to poor (more development) (**Table 45**), as the ecosystem occurs across extensive basins and areas where agriculture is a significant factor (e.g., Snake River Plain, Columbia Plateau, Columbia Mountains-Northern Rockies and Middle Rockies). Infrastructure development throughout its range is also a factor; there are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive plants is limited in 6 ecoregions and moderate in 3 ecoregions. Fire regime departure is moderate to high in 7 of 9 ecoregions (**Figure 46**); this is likely a reflection of fire suppression which can lead to invasion of juniper into these shrubland, changing the structure and composition of the occurrences. In the Eastern Cascades/Modoc Plateau, invasive grasses contribute to fine-fuels and alter the fire regime.

The interactions of the stressors of fragmentation by development, overgrazing, fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Vulnerability from adaptive capacity is high across the range of this system. Topoclimatic variability is low or very low, as these dwarf-shrublands often occur on low-relief landforms and topography, such as mountain ridges and flanks, broad terraces, flats, depressions, and gentle slopes. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within each of the three identified functional species groups varies from moderate to high; with an overall score of moderate. Nitrogen-fixation and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae*, *Rosaceae*, and *Poaceae* families, along with cyanobacteria and cyanolichens. Cool-season perennial graminoids are characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. Species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Columbia Plateau Low Sagebrush Steppe scores in the moderate range of overall climate change vulnerability throughout most of its range, except in the east Cascades Slopes and Foothills ecoregion where it scored as highly vulnerable. This high vulnerability is primarily due to the low to limited adaptive capacity and the variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity, cool desert steppe types that naturally occupy extensive flat terraces, basins and gently rolling hills (low topoclimate variability). Additionally, these dwarf-shrub steppes have moderate diversity within key functional species groups, such as with nitrogen fixing species and perennial cool-season graminoids species. Sensitivity measures are variable with some ecoregions with moderate to high fire regime departure and poor landscape condition. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 46. Climate change adaptation strategies relative to vulnerability scores for Columbia Plateau Low Sagebrush Steppe

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.

Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Baker 2006, Barbour and Major 1988, Beetle and Johnson 1982, Bell et al. 2009, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Blackburn and Tueller 1970, Chappell et al. 1997, Comer et al. 2003*, Fryer 2009, Hironaka et al. 1983, Howard 1999, Johnston 2001, LANDFIRE 2007a, Rosentreter and Belnap 2003, Sawyer et al. 2009, Shiflet 1994, Steinberg 2002a, USDA-APHIS 2003, USDA-APHIS 2010, WNHP 2011, WNHP unpubl. data, West 1983a, Young and Palmquist 1992, Zamora and Tueller 1973

CES304.770 Columbia Plateau Scabland Shrubland

Figure 47. Photo of Columbia Plateau Scabland Shrubland. Photo credit: Thayne Tuason, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/thaynet

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is found in the Columbia Plateau region and consists of extensive low shrublands. These xeric shrublands occur under relatively extreme soil-moisture conditions. Substrates are typically shallow lithic soils with limited water-holding capacity over fractured basalt. Because of poor drainage through basalt, these soils are often saturated from fall to spring by winter precipitation but typically dry out completely to bedrock by midsummer. Vegetation cover is typically low, generally less than 50% and often much less than that. Vegetation is characterized by an open dwarf-shrub canopy dominated by *Artemisia rigida* along with other shrub and dwarf-shrub species, particularly

Eriogonum compositum, Eriogonum douglasii, Eriogonum microthecum, Eriogonum niveum, Eriogonum sphaerocephalum, Eriogonum strictum, Eriogonum thymoides, and/or *Salvia dorrii*. Other shrubs are uncommon in this system; mixes of *Artemisia rigida* and other *Artemisia* species typically belong to different ecological systems than this. Low cover of perennial bunchgrasses, such as *Danthonia unispicata, Elymus elymoides, Festuca idahoensis*, or primarily *Poa secunda*, as well as scattered forbs, including species of *Allium, Antennaria, Balsamorhiza, Lomatium, Phlox*, and *Sedum*, characterize these sites. Individual sites can be dominated by grasses and semi-woody forbs, such as *Nestotus stenophyllus*. Annuals may be seasonally abundant, and cover of moss and lichen is often high in undisturbed areas (1-60% cover).

Distribution: This system occurs in the Columbia Plateau region of southern Idaho, eastern Oregon and eastern Washington, and extreme northern Nevada.

Nations: US

States/Provinces: ID, NV, OR, WA

CEC Ecoregions: Columbia Mountains/Northern Rockies, North Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Idaho Batholith, Columbia Plateau, Northern Basin and Range, Snake River Plain

Primary Concept Source: J. Kagan

Description Author: M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Total vegetation cover is typically low, generally less than 50% and often much less than that. Vegetation is characterized by an open dwarf-shrub canopy dominated by *Artemisia rigida* along with other shrub and dwarf-shrub species, particularly *Eriogonum* spp. Other shrubs are uncommon in this system; mixes of *Artemisia rigida* and other *Artemisia* species typically belong to different ecological systems than this. Low cover of perennial bunchgrasses, such as *Danthonia unispicata, Elymus elymoides, Festuca idahoensis*, or primarily *Poa secunda*, as well as scattered forbs, including species of *Allium, Antennaria, Balsamorhiza, Lomatium, Phlox*, and *Sedum*, characterize these sites. Individual sites can be dominated by grasses and semi-woody forbs, such as *Nestotus stenophyllus (= Stenotus stenophyllus)*. Annuals may be seasonally abundant, and cover of moss and lichen is often high in undisturbed areas (1-60% cover).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and are critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems the western U.S. (Belnap and Lange 2003). Ecological systems in the Columbia Plateau are assumed to have similar biological soil crust species richness as in the Great Basin. Biological soil crust diversity is based on Belnap et al. (2001) and Rosentreter and Belnap (2003). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp.,

Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin and Columbia Plateau: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin than warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum, Syntrichia ruralis*, and *Tortula* spp. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp.

Nitrogen Fixation; Species Diversity: Low
Scabland shrublands occur in semi-arid climates on rocky substrates with limited soil depth and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid shrublands typically have low herbaceous cover and low diversity. Several species of *Fabaceae* (*Trifolium macrocephalum*), Poaceae (e.g., *Festuca idahoensis, Poa secunda, Pseudoroegneria spicata*), and a few species of *Brassicaceae* may fix nitrogen in this ecosystem. Cyanobacteria and cyanolichens can be important sources of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, or *Peltigera*- and *Scytonema*-containing species of *Heppia* (Belnap 2001). Across its range, diversity of nitrogen-fixing taxa is moderate; however, within stand species diversity of nitrogen fixers is typically low.

Perennial Cool-Season Graminoids; Species Diversity: Low
Danthonia unispicata, Elymus elymoides, Festuca idahoensis, Hesperostipa comata, Poa secunda, and *Pseudoroegneria spicata*. Across its range, diversity of perennial cool-season graminoid taxa is moderate; however. within stand species diversity is typically low.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this shrubland type.

Environment: This open, low shrubland ecological system is characteristic of the scablands in the Columbia Basin and portions of the Snake River plain. Elevations range from 190-1830 m.

Climate: Climate is semi-arid and temperate with a winter precipitation peak. Mean annual precipitation ranges from 25-50 cm and occurs primarily in the winter as snow or rain.

Physiography/landform: Stands are found on flat to undulating to rolling plateaus, plains, ridgetops and brows. Sites are nearly level to moderately sloping (to 30%). It occurs on all aspects, but is more common on southern slopes, although given that most sites are flat, aspect is not very significant.

Soil/substrate/hydrology: These xeric shrublands occur under relatively extreme soil-moisture conditions. Substrates are typically shallow lithic soils (7-30 cm) with a high percentage of rock fragments (10-70%), limited water-holding capacity over fractured basalt. This moisture is stored in the soil profile and utilized during the typically dry summers. Because of poor drainage through basalt, these soils are often saturated from fall to spring by winter precipitation but typically dry out completely to bedrock by midsummer. The soils are non-calcareous, sandy to clay loams, with pH of 6.3-6.6. Parent material is restricted to colluvium and residuum derived from basalt and acidic lava. Soil surface is mostly rock, erosion pavement (pebble surface), bare ground, and moss. Litter accumulates under the scattered *Artemisia rigida* plants forming moss-covered mounds up to 20 cm deep. These hummocks persist several years after the death of the dwarf-shrub (Daubenmire 1970, 1992). Moss and lichen cover a significant amount of the ground surface, often with up to 50% cover.

Key Processes and Interactions: This xeric shrubland ecological system is driven by its tolerance of extreme low soil-moisture conditions and very thin soils that can be easily disturbed or eroded. Stands in this system are generally considered to be late-seral with species composition controlled by the harsh edaphic conditions of the site (Daubenmire 1970, Johnson and Simon 1987). While these soils are often saturated from fall to spring by the winter precipitation, they typically dry out completely to bedrock by midsummer (Daubenmire 1970, 1992, Johnson and Simon 1987). *Poa secunda*, a typical dominant graminoid, is well-adapted to these conditions because it starts growing early in the spring and completes its reproductive cycle early while there is still moisture in the soil (Daubenmire 1970, 1992, Johnson and Simon 1987). Also, if there is late summer or early fall precipitation, dormant *Poa secunda* can respond quickly and green up. Daubenmire (1970) and Johnson and Simon (1987) suggest that the basalt bedrock present under these dwarf-shrub/grassland stands is fractured enough to support deeper-rooted dwarf-shrubs. Moss does well in this habitat because of seasonally moist conditions. *Artemisia rigida* is favored winter browse for elk and deer, and moderately palatable to livestock (Johnson and Clausnitzer 1992).

Frost heaving may be severe, causing local soil disturbance in the winter when these thin, saturated soils freeze and push soil and plants up out of the ground. Pedestalled *Artemisia rigida* plants and bunchgrasses are common (Daubenmire 1970, Hironaka et al. 1983).

Fire is thought to be unimportant because it is unlikely that the sparse vegetation in these stands could carry a fire. However, if it does occur the *Artemisia rigida* plants are not tolerant and would be killed (Johnson and Simon 1987, Daubenmire 1992, Johnson and Clausnitzer 1992).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 0810650). This model includes sites where there is potential for pinyon (*Pinus monophylla*) and/or juniper (*Juniperus osteosperma*) establishment in classes C and D.

A) Early Development 1 All Structures (5% of type in this stage): Shrub cover is 0-10%. This class is dominated by sprouting buckwheats and other hemi-shrubs, surviving perennial grasses and forbs and annual forbs. Plant cover is typically extremely low. Sagebrush will be absent and patch size is very small in this class. Rock dominates the visual appearance and may dominate satellite imagery. Succession to class B after 10 years.

B) Mid Development 1 Open (5% of type in this stage): Shrub cover is 0-10%. Young stiff sagebrush appears while the other species reach their more-or-less mature sizes. Plant cover remains low but denser patches are now present, composed mostly of the hemi-shrubs and perennial grasses and forbs. Rock is less dominant visually but may still dominate satellite imagery. Succession to class C after 20 years.

C) Late Development 1 Open (90% of type in this stage): Shrub cover is 0-10%. Stiff sagebrush is fully mature and visually dominates the scene, particularly after spring leaf out and flowering. Total vegetation cover rarely exceeds 25% and is often <15%. Plant height rarely exceeds 0.5 m.

Replacement fire was modeled as mean fire-return interval = 250 years in all three classes, with no other disturbances modeled. Severe droughts can temporarily reduce herbaceous vegetation; however, all the species that occupy this BpS are very drought-tolerant (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: The biggest threat is exotic invasive plants (Tisdale 1986, Daubenmire 1992). Common exotics include annual grasses, especially *Bromus tectorum*, and other annual exotic graminoids such as *Bromus arvensis, Bromus briziformis*, and *Taeniatherum caput-medusae*; annual forbs such as *Epilobium brachycarpum, Erodium cicutarium, Holosteum umbellatum, Lactuca serriola*, and *Tragopogon dubius*; and the perennial forb *Hypericum perforatum*. *Bromus tectorum* is moderately dense on some stands and may become abundant during wet years and possibly be dense enough to carry a fire, which would kill fire-sensitive shrubs *Artemisia rigida* (Bunting et al. 1987, Daubenmire 1992, McWilliams 2003b).

Disturbance from heavy use by livestock or vehicles, particularly on dry soils, disrupts the moss/lichen layer and increases exposed rock and bare ground, increasing the threat of invasion by exotic plants (WNHP 2011). The saturated spring soils are vulnerable to trampling, but the rocky soils discourage livestock (Daubenmire 1992). In areas excluded from grazing entirely, *Pseudoroegneria spicata* and *Festuca idahoensis* may dominate with *Artemisia rigida* in some areas, also growing in rock fractures. In addition to drought tolerance, *Poa secunda* is also tolerant of grazing and trampling by livestock (Daubenmire 1970, Ganskopp 1979). With disturbance, such as livestock impacts, comes an increase in erosion pavement and bare ground, and a decrease in moss and lichen cover (Daubenmire 1970, Johnson and Simon 1987).

In addition, large-scale wind and solar power development is becoming more common in the region of the system, potentially increasing fragmentation and facilitating establishment of invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 47** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 48, left**) and sensitivity (**Figure 48, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

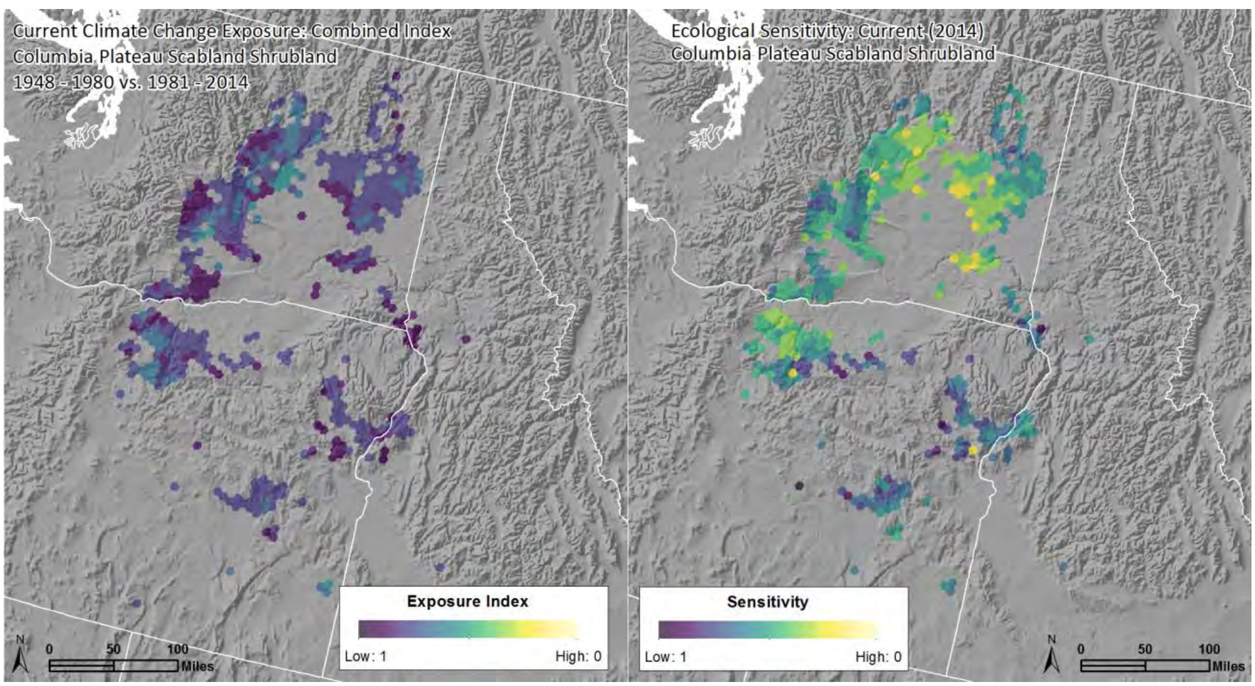

Figure 48. Climate exposure as of 2014 (left) and overall sensitivity (right) for Columbia Plateau Scabland Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 47. Resilience, exposure and vulnerability scores for Columbia Plateau Scabland Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Columbia Plateau	Blue Mountains	Columbia Mountains-Northern Rockies	Northern Basin & Range
	Sq miles within ecoregion	1,080	283	79	54
Contributions to Relative Vulnerability by Factor					
Vulnerability from **Exposure (2014)**		**Mod** 0.75	**Mod** 0.75	**Mod** 0.74	**Mod** 0.72
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.36	0.60	0.08	0.74
	Fire Regime Departure	0.55	0.52	0.55	0.67
	Invasive Annual Grasses	0.59	0.80	1.00	0.37
	Sensitivity Average	**0.50**	**0.64**	**0.54**	**0.59**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.16	0.27	0.11	0.21
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null	Null
	Adaptive Capacity Average	**0.16**	**0.21**	**0.13**	**0.18**
Vulnerability from Measures of **Overall Resilience**		**High** 0.33	**High** 0.43	**High** 0.34	**High** 0.39
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of these uncommon shrublands, exposure as of 2014 is moderate. The emerging pattern of climate change is a decrease in Mean Diurnal Range by 0.4°C in the Columbia Plateau ecoregion, where it is most abundant, over 19% of its distribution in that ecoregion. This suggests the difference between day-time maximums and night-time minimums is decreasing. In the Blue Mountains, where it is less common, the Annual Mean Temperature shows an increase of 0.6°C over 21% of the type's distribution.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be significantly reduced, effectively eliminating *Artemisia rigida* recruitment.

Ecosystem Resilience: Sensitivity: Sensitivity to climate change is moderate in 3 of 4 ecoregions and tipping into high within the Columbia Plateau. This is due to the combination of agriculture and development fragmenting occurrences and localized concentrations of invasive annual grasses, which in turn alters fire regimes.

Landscape condition scores vary across ecoregions (**Table 47**); only in the Northern Basin and Range ecoregion is landscape condition on the upper end of the moderate range. Agriculture is a significant factor in the Columbia Plateau, whereas in the Blue Mountains and Columbia Mountains-Northern Rockies ecoregions infrastructure development is more of a factor, e.g., there are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive plants is currently low in two ecoregions, moderate in one, and high in one (Northern Basin and Range). Fire regime departure is moderate across all four ecoregions (**Figure 48**); this is likely a reflection of fire being introduced to this system by invasive annual grasses, as historically fire was not important in these sparsely-vegetated scablands. Invasive grasses contribute to fine fuels, and if dense enough can carry a fire, introducing a fire-regime.

The interactions of the stressors of overgrazing, invasive annual grass invasion, and introduction of fire have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is very low across the entire range of this edaphically-controlled ecological system. Both topoclimatic variability and diversity within functional species groups contribute to the very low adaptive capacity. Topoclimatic variability is very low, as these shrublands occur across generally flat landforms and topography such as flat to undulating to rolling plateaus, plains, ridgetops and brows. Sites are nearly level to moderately sloping (to 30%). For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within two of the three identified functional species groups is very low. Nitrogen-fixation and the diversity of cool-season perennial graminoids are the most limiting, with low within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae* and *Poaceae* families, along with cyanobacteria and cyanolichens. Cool-season perennial graminoids are characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. The third functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Columbia Plateau Scabland Shrubland scores in the moderate range of overall climate change vulnerability throughout its range. This moderate vulnerability is primarily due to moderate climate exposure, very low adaptive capacity, and the variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity, cool desert scrub types that naturally occupy extensive flat to undulating to rolling plateaus, plains, ridgetops (low topoclimate variability). Additionally, these dwarf-shrublands have low diversity within key functional species groups, such as both nitrogen fixing species and perennial cool-season graminoids species. Sensitivity measures are variable, but generally moderate. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 48. Climate change adaptation strategies relative to vulnerability scores for Columbia Plateau Scabland Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids, and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration, nitrogen fixers and cool-season graminoids, and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Bunting et al. 1987, Comer et al. 2003*, Copeland 1980a, Daubenmire 1970, Daubenmire 1992, Ganskopp 1979, Hall 1973, Hironaka et al. 1983, Johnson and Clausnitzer 1992, Johnson and Simon 1985, Johnson and Simon 1987, LANDFIRE 2007a, McWilliams 2003b, Poulton 1955, Rosentreter and Belnap 2003, Shiflet 1994, Tisdale 1986, Tyler 2006, WNHP 2011, WNHP unpubl. Data

CES304.794 Wyoming Basins Dwarf Sagebrush Shrubland and Steppe

Figure 49. Photo of Wyoming Basins Dwarf Sagebrush Shrubland and Steppe. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This windswept ecological system is composed of dwarf sagebrush shrubland and shrub-steppe that forms matrix vegetation and large patches on the margins of high-elevation basins in central and southern Wyoming. Typical sites are gently rolling hills and long, gently sloping pediments and fans. These sites are very windy and have shallow, often rocky soils (*Artemisia nova* and *Artemisia tripartita ssp. rupicola*) or have shallow, poorly drained, fine-textured soils (*Artemisia arbuscula*). The distinguishing feature of this system is a short-shrub stratum in which dwarf-shrubs (<30 cm tall) contribute at least two-thirds of the woody canopy. Four sagebrush taxa may dominate the shrub stratum: *Artemisia tripartita ssp. rupicola, Artemisia nova, Artemisia arbuscula ssp. longiloba*, and wind-dwarfed

Artemisia tridentata ssp. wyomingensis. Two or more of these sagebrushes often codominate, but any of them may occur alone. Where graminoids are common and tall, the vegetation often has the appearance of grassland without shrubs; the presence of shrubs is obvious only when the vegetation is viewed up close. Where graminoids contribute less cover, the vegetation is a compact shrubland. The herbaceous component of the vegetation includes both rhizomatous and bunch-form graminoids, cushion plants, and other low-growing forbs. *Bouteloua gracilis*, a common species of Inter-Mountain Basins Big Sagebrush Steppe (CES304.778) in Wyoming, is absent.

Distribution: This system occurs throughout the basins of central and southern Wyoming, extending south into adjacent portions of Colorado. It also occurs on the eastern side of the Continental Divide in Montana, where *Artemisia nova* shrublands are found on calcareous substrates.

Nations: US

States/Provinces: CO, MT, WY

CEC Ecoregions: Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Northwestern Great Plains, Wyoming Basin

Primary Concept Source: K.A. Schulz

Description Author: M.S. Reid, G.P. Jones and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system includes dwarf-shrublands dominated by one of four species: *Artemisia tripartita ssp. rupicola, Artemisia nova, Artemisia arbuscula ssp. longiloba*, and wind-dwarfed *Artemisia tridentata ssp. wyomingensis* that characterize different sites. Two or more of these sagebrushes often codominate, but any of them may occur alone. Other often wind-dwarfed shrubs, such as *Artemisia frigida, Chrysothamnus viscidiflorus, Ericameria nauseosa, Gutierrezia sarothrae*, or *Purshia tridentata*, may be present and occasionally abundant. Where graminoids are common and tall, the vegetation often has the appearance of grassland without shrubs; the presence of shrubs is obvious only when the vegetation is viewed up close. Where graminoids contribute less cover, the vegetation is open to a moderately dense canopy of compact shrubs <30 cm tall. The herbaceous component of the vegetation typically includes cool-season rhizomatous and bunch-form graminoids, cushion plants, and other low-growing forbs. Common graminoids species include *Achnatherum hymenoides (= Oryzopsis hymenoides), Achnatherum speciosum (= Stipa speciosa), Achnatherum thurberianum (= Stipa thurberiana), Elymus elymoides, Elymus lanceolatus, Festuca idahoensis, Hesperostipa comata (= Stipa comata), Koeleria macrantha, Leucopoa kingii, Pascopyrum smithii, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*. Forb cover is typically minor and includes *Antennaria microphylla, Cerastium arvense, Heterotheca villosa, Packera multilobata (= Senecio multilobatus), Phlox hoodii, Senecio integerrimus, Sphaeralcea coccinea*, and *Stenotus armerioides*.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems of the western U.S. (Belnap and Lange 2003). Biological Soil Crust (BSC) diversity is based on Muscha and Hild (2006). Cyanobacteria: *Microcoleus vaginatus* is dominant, plus several other species. Lichens (26): *Acarospora schleicheri, Aspicilia reptans, Aspicilia* sp., *Caloplaca jungermanniae, Caloplaca lactea, Caloplaca tiroliensis, Caloplaca tominii, Candelariella*

terrigena, Cladonia pocillum, Collema coccophorum, Collema tenax, Diploschistes muscorum, Endocarpon pusillum, Lecanora sp., *Peltigera ponojensis, Placidium lachneum, Placidium squamulosum, Psora decipiens, Psora montana, Psora tuckermanii, Rhizoplaca haydenii, Toninia sedifolia, Xanthoparmelia chlorochroa, Xanthoparmelia neochlorochroa, Xanthoparmelia norchlorochroa, Xanthoparmelia wyomingica*. Mosses (7): *Bryum argenteum, Bryum caespiticium, Bryum* sp., *Desmatodon convolutus, Pterygoneurum ovatum, Tortula caninervis, Tortula ruralis*.

Nitrogen Fixation; Species Diversity: Medium
These shrublands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea, Lupinus, Oxytropis*, and *Trifolium*), Rosaceae (*Purshia*), some Poaceae (e.g., *Elymus elymoides, Elymus lanceolatus, Festuca idahoensis, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*), and several Brassicaceae can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Nostoc*. Common N-fixing soil lichens include *Nostoc*-containing species of *Peltigera* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Carex filifolia, Elymus lanceolatus, Festuca idahoensis, Poa fendleriana, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this short sagebrush shrubland type.

Environment: *Climate:* Climate is semi-arid with 20-30 (45) cm of annual precipitation. The temperature regime is continental, with cold winters, warm summers, large diurnal ranges, and a short frost-free season.

Physiography/landform: This windswept ecological system of dwarf sagebrush shrubland and shrub-steppe occurs from 1500 to 3200 m elevation. These sites are very windy, gently rolling hills and long, gently sloping pediments and fans, broad ridgetops, the ridges of low mountains and the margins of high-elevation basins.

Soil/substrate/hydrology: Soils are variable but are often shallow and rocky. *Artemisia nova* generally occupies medium- to coarse-textured soils, often with a large volume of rock fragments and frequently calcareous. *Artemisia arbuscula*-dominated stands have poorly drained, very heavy, montmorillonite (smectite) clay soils with some coarse fragments, usually effectively very shallow to a hard clay pan, not deep enough to support either big sagebrush or deep-rooted grasses. Those two sagebrushes do grow together sometimes. *Artemisia tripartita ssp. rupicola*-dominated stands have coarse-textured (gravelly), well-drained shallow soils.

Key Processes and Interactions: The key ecological factors for this system are the harsh, windswept, semi-arid climate with a short growing season and shallow soils. *Artemisia nova* and *Artemisia tripartita ssp. rupicola* dwarf-shrublands are associated with shallow, rocky soils which experience extreme drought in summer, whereas *Artemisia arbuscula*-dominated stands occur on shallow, poorly drained, fine-textured soils.

Fire is not important in this ecosystem, because it occurs very infrequently. Plants are low and widely spaced so there is little fuel to carry a fire. Replacement fire is predicted to occur every 300 years (LANDFIRE 2007a). Fire effects are variable depending on dominant species. *Artemisia arbuscula ssp. longiloba, Artemisia nova*, and *Artemisia tridentata ssp. wyomingensis* are generally killed by burning and do not resprout, so fire impacts can be severe (Young 1983, Howard 1999, Steinberg 2002a, Fryer 2009). However, *Artemisia tripartita ssp. rupicola* shrubs can sprout from the stump after being top-killed by fire and will reproduce both by seed and by layering (Tirmenstein 1999k). Hironaka et al. (1983) notes that some populations may have variation in this ability.

LANDFIRE developed a VDDT model for this system which has two classes (LANDFIRE 2007a, BpS 2210720):

A) Early Development 1 All Structures (herbaceous-dominated-30% of type in this stage): Grass-and-forb-dominated site for approximately 125 years. Black/low sagebrush seedlings are young and begin to establish towards the end of this seral period. Replacement fire occurs every 300 years

B) Late Development 1 Open (shrub-dominated-70% of type in this stage): Black/low sagebrush with mid-height late-seral grasses (150 or more years).

Soil erosion caused by native ungulates sometimes can occur in these stands when they trail across them, especially in spring and fall when the sites are wet. The sites are resilient and resistant to trampling in summer and winter, when they are dry or frozen (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: The primary threats that alter the natural processes of this system are poor livestock practices, annual exotic species invasion, fire regime alteration, direct soil surface disturbance, and fragmentation. Barbour and Major (1988) report that *Artemisia nova* is utilized by livestock to a much greater degree than other species of *Artemisia*, resulting in low, pruned plants (West 1983a). Both *Artemisia arbuscula* and *Artemisia nova* are considered a valuable browse plant during the spring, fall, and winter months and are often grazed by native ungulates (elk and mule deer) and domestic livestock. While grazing appears to have little effect on shrub densities, it does tend to decrease the abundance of tall bunchgrasses and increase the cover of forbs such as *Arenaria congesta* (Johnston 2001). Shrubs are favored in overgrazed ranges because heavy grazing may deplete the perennial graminoid layer leaving only a shrub layer that may increase at the expense of grass cover (Hironaka et al. 1983). Grazing also favors non-native, grazing-tolerant grass species such as *Poa bulbosa* and *Poa pratensis*.

Excessive grazing also stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus tectorum*, and other exotic annual grasses. The introduction of exotic annual grasses has altered many stands by increasing the amount of fine fuels present that can substantially increase fire frequency and intensity which reduces the cover of fire-sensitive shrubs such as *Artemisia nova* (Fryer 2009).

Direct and indirect fire suppression are a threat to this system where stands are adjacent to pinyon-juniper woodlands. Over the long term, heavy grazing by livestock removes the fine fuels that carry fire that indirectly leads to a reduction in fire frequencies, which can lead to pinyon-juniper encroachment with subsequent loss of shrub and herbaceous understory (LANDFIRE 2007a).

Human development has impacted many locations throughout Wyoming. High- and low-density urban and industrial developments have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining or oil and gas operations can drastically impact natural vegetation. Large-scale wind power development is expanding in this system, fragmenting the habitat and facilitating establishment of invasive species. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 49** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 50, left**) and sensitivity (**Figure 50, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

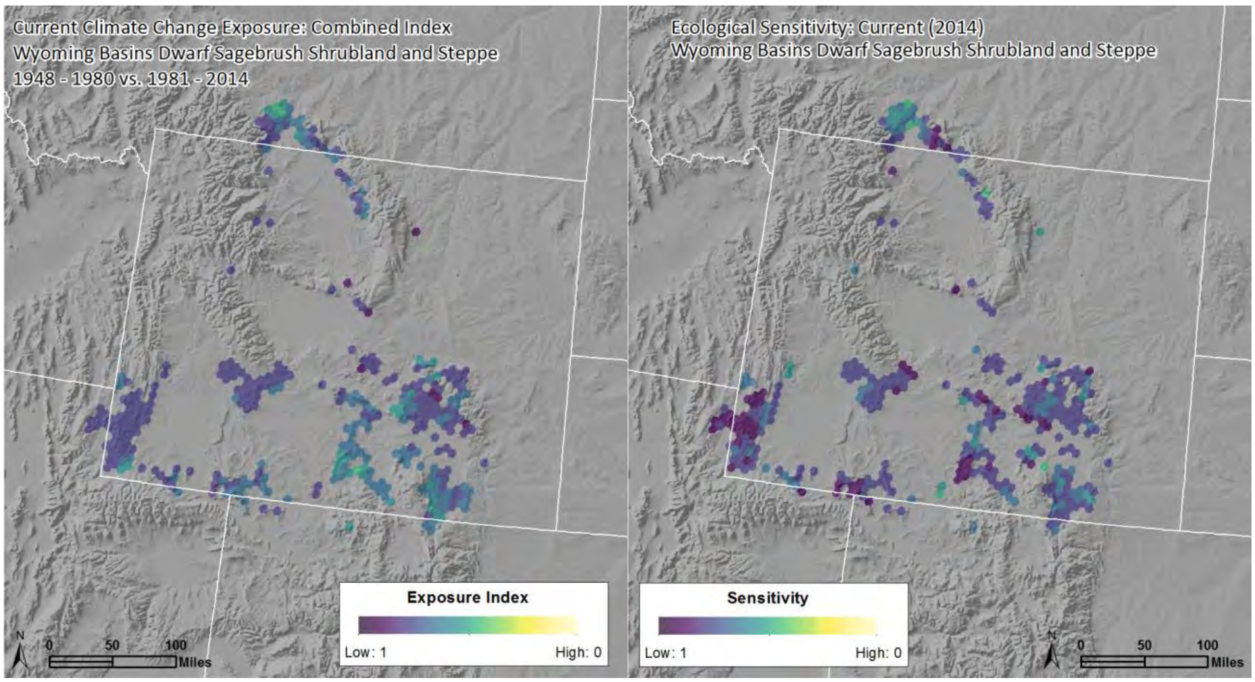

Figure 50. Climate exposure as of 2014 (left) and overall sensitivity (right) for Wyoming Basins Dwarf Sagebrush Shrubland and Steppe. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 49. Resilience, exposure and vulnerability scores for Wyoming Basins Dwarf Sagebrush Shrubland and Steppe by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Wyoming Basin	Northwestern Great Plains	Southern Rockies
	Sq miles within ecoregion	352	81	72
Contributions to Relative Vulnerability by Factor				
Vulnerability from **Exposure (2014)**		Mod 0.71	Mod 0.64	Mod 0.70
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.73	0.39	0.72
	Fire Regime Departure	0.52	0.47	0.48
	Invasive Annual Grasses	0.96	0.99	0.99
	Sensitivity Average	**0.74**	**0.61**	**0.73**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.30	0.20	0.31
	Diversity within Functional Species Groups	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null
	Adaptive Capacity Average	**0.40**	**0.35**	**0.41**
Vulnerability from Measures of **Overall Resilience**		Mod 0.57	High 0.48	Mod 0.57
Climate Change Vulnerability Index		Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall for this relatively uncommon sagebrush system, exposure as of 2014 is moderate. An emerging pattern of changing climate appears as increases of 0.65° to 0.77°C for Annual Mean Temperature and Mean Temperature of the Warmest Quarter, across >50% of its distribution in each of the ecoregions.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating sagebrush recruitment.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be moderate. Sensitivity is highest in the Northwestern Great Plains ecoregion, due to the combination of extensive agriculture and development fragmenting occurrences and apparent fire regime departure.

Landscape condition varies from moderate (more development) to poor (fragmented) (**Table 49**). Much of the range of the ecosystem occurs across vast basins and plains with few roads where agriculture is limited. However, development impacts are expanding in this system, such as mining or oil and gas operations, which can impact natural vegetation; large-scale wind power development, transportation corridors and power transmission lines continue to fragment vegetation and provide vectors for invasive species. In the Northwestern Great Plains, the poor landscape condition score reflects some agricultural activity near stands of this system, along with many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive plants scored low in throughout the range of this system. However, fire regime departure in moderate to high ranges suggest decreased fire frequency due to grazing by livestock, which removes the fine fuels that carry fire, and fire suppression that has altered the structure of this dwarf-shrubland. These changes are probably making them vulnerable to catastrophic, stand-replacing fires.

The interactions of the stressors of fragmentation by development, direct and indirect fire suppression, and some invasive annual grass invasion have resulted in changes to the composition and structure of these dwarf-shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity low across the range of this uncommon dwarf-shrubland system. Topoclimatic variability scored low to very low, as these dwarf-shrublands occur across generally low-relief landforms and topography, such as gently rolling hills and long, gently sloping pediments and fans, broad ridgetops, the ridges of low mountains and the margins of high-elevation basins. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within two of the three identified functional species groups is moderate. Nitrogen-fixation and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae, Rosaceae*, and *Poaceae* families, along with cyanobacteria and cyanolichens. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. The third functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Wyoming Basins Dwarf Sagebrush Shrubland and Steppe scores in the moderate range of overall climate change vulnerability throughout its range. This moderate vulnerability is primarily due to moderate climate exposure, low adaptive capacity scores, and the moderate contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity semi-arid types that naturally occupy extensive flat plains, basins, and gently rolling hills and long, gently sloping alluvial fans (low topoclimate variability). Additionally, these dwarf-shrublands and steppe have moderate fire regime departure throughout much of their range. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 50. Climate change adaptation strategies relative to vulnerability scores for Wyoming Basins Dwarf Sagebrush Shrubland and Steppe

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barbour and Major 1988, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Comer et al. 2003*, Fryer 2009, Hironaka et al. 1983, Howard 1999, Johnston 2001, Jones 1992b, Knight 1994, Knight et al. 1987, LANDFIRE 2007a, Muscha and Hild 2006, Rosentreter and Belnap 2003, Shiflet 1994, Steinberg 2002a, Tirmenstein 1999k, West 1983a, Young 1983

M169. Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland

CES304.083 Columbia Plateau Steppe and Grassland

Figure 51. Photo of Columbia Plateau Steppe and Grassland. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This system occurs throughout much of the Columbia Plateau. It is a bunchgrass-dominated grassland or steppe that is similar floristically to big sagebrush-dominated steppe, but is defined by a more frequent fire regime and the absence or low cover of shrubs over large areas. These are large, extensive grasslands, not grass-dominated patches within the sagebrush shrub-steppe ecological system. Soils are variable, ranging from relatively deep, fine-textured often with coarse fragments, and non-saline often with a microphytic crust, to stony volcanic-derived clays to alluvial sands. This grassland is dominated by perennial bunchgrasses and forbs (>25% cover), sometimes with a sparse (<10% cover) shrub layer. Associated graminoids include *Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus ssp. lanceolatus, Hesperostipa comata, Festuca idahoensis, Koeleria macrantha, Poa secunda*, and *Pseudoroegneria spicata*. Common forbs are *Phlox hoodii, Arenaria* spp., and *Astragalus* spp. Shrubs such as *Chrysothamnus viscidiflorus, Ericameria nauseosa, Tetradymia* spp., or *Artemisia* spp. are often present in disturbed stands. Areas with deeper soils are rare because of conversion to other land uses. The rapid fire-return regime of this ecological system maintains a grassland structure by retarding shrub invasion, and landscape isolation and fragmentation limit seed dispersal of native shrub species. Fire frequency is presumed to be less than 20 years. Through isolation from a seed source, combined with repeated burning, these are "permanently" (more than 50 years) converted to grassland.

Distribution: This system occurs throughout the Columbia Plateau region, from north-central Idaho, south and west into Washington, Oregon, southern Idaho, and northern Nevada. Whether it also occurs in northeastern California, in the western ranges of Wyoming, or the central Wyoming Basins is unclear.

Nations: US

States/Provinces: CA?, ID, MT?, NV, OR, UT?, WA, WY?

CEC Ecoregions: Columbia Mountains/Northern Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Klamath Mountains, Idaho Batholith, Columbia Plateau, Northern Basin and Range, Central Basin and Range, Snake River Plain

Primary Concept Source: R. Crawford

Description Author: R. Crawford, M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This grassland is dominated by perennial bunchgrasses and forbs (>25% cover), sometimes with a sparse (<10% cover) shrub layer; *Chrysothamnus viscidiflorus, Ericameria nauseosa, Tetradymia* spp., or *Artemisia* spp. may be present in disturbed stands. Associated graminoids include *Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus ssp. lanceolatus, Hesperostipa comata, Festuca idahoensis, Koeleria macrantha, Poa secunda*, and *Pseudoroegneria spicata*. Common forbs are *Phlox hoodii, Arenaria* spp., and *Astragalus* spp.

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems of the western U.S. (Belnap and Lange 2003). Ecological systems in the Columbia Plateau are assumed to have similar biological soil crust species richness as in the Great Basin. Great Basin crust diversity is based on Rosentreter and Belnap (2003). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin than warm desert regions with over 72 species. Common

mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp.

Biotic Pollination; Species Diversity: Medium
Although graminoids and many of the shrubs in this system (*Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis* and/or *Artemisia tripartita*) are self- or wind-pollinated, most forbs and other shrubs (*Chrysothamnus viscidiflorus, Ericameria nauseosa, Tetradymia canescens*) need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Howard 1999, Tirmenstein 1999c, Scher 2001). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for sage grouse (Barnett and Crawford 1994, Drut et al. 1994, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds important for certain species. Insects: Bees (*Apoidea*), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially for red tubular flowers).

Nitrogen Fixation; Species Diversity: Medium
This steppe and grassland system occurs in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid grasslands and shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea, Lupinus, Penstemon, Psoralidium*, and *Trifolium*), some Poaceae (*Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Festuca idahoensis, Koeleria macrantha, Poa secunda*, and *Pseudoroegneria spicata*), and several Brassicaceae can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema* or *Peltigera*- and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Festuca idahoensis, Koeleria macrantha, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this steppe and grassland type.

Environment: These are large extensive grassland ecosystems, not grass-dominated patches within sagebrush shrub-steppe ecological system. This system occurs throughout much of the Columbia Plateau and is found at slightly higher elevations farther south. Soil depth and soil texture within precipitation zones largely drive the distribution of shrub-steppe and grassland (WNHP 2011). Geographically (climatically), this steppe system is associated with Inter-Mountain Basins Big Sagebrush Steppe (CES304.778), rings the driest portion of the basin that supports the big sagebrush shrubland and the semi-desert shrub-steppe systems, and is bounded by montane woodlands and the Palouse prairie. It is found in landscapes that favor frequent ignition sources and fuels that spread fire, and few natural firebreaks. Biological soil crust is very important in this ecological system (WNHP 2011).

Climate: Climate is semi-arid, cool temperate with annual precipitation ranging from 18-40 cm and high inter-annual variation. Much of the precipitation falls as snow or spring rain; however, growing-season drought is characteristic. Temperatures are continental with large annual and diurnal variation. Winter precipitation dominates and promotes cool-season grasses.

Physiography/landform: Stands occur on valley floors, alluvial fans, floodplains, stabilized dunes, mesic uplands, swales, and rocky slopes. Slopes are variable from gentle to very steep.

Soil/substrate/hydrology: Soils are variable, ranging from relatively deep, fine-textured often with coarse fragments, and non-saline often with a biological soil crust, to stony volcanic-derived clays to alluvial sands. Burrowing animals and their predators likely played important roles in creating small-scale patch patterns (WNHP 2011).

Key Processes and Interactions: In the Columbia Plateau this grassland ecosystem occurs in a mosaic with sagebrush steppe vegetation and includes sagebrush steppe habitats where fire has removed the sagebrush; thus, due to change in fire regime, this type has expanded at the expense of sagebrush steppe (LANDFIRE 2007a).

Columbia Plateau ecosystems are more sensitive to grazing than grasslands in the Great Plains as they did not evolve with the same duration, seasonality, and severity of large native ungulate grazing (Mack and Thompson 1982, Burkhart 1996). In general, native ungulate grazing was dispersed and occurred during the winter and spring when forage was available.

These grasslands are defined by a more frequent fire regime and the absence or low cover of shrubs over large areas, occasionally entire landforms. The historic frequency was 30-100 years (LANDFIRE 2007a). The natural fire regime of this ecological system likely maintains a patchy distribution of shrubs so the general aspect of the vegetation is a grassland. Post-fire shrub recruitment is limited and rate is estimated to be 25 acres in 50 years under ideal conditions for *Artemisia tridentata* (WNHP 2011). These shrubs produce large quantities of small seeds beginning at age 3-4 years of which 90% of the seed is dispersed within 9 m (30 feet) of the parent and few seeds are carried more than 30 m (100 feet) (Tirmenstein 1999c). Biological soil crust is very important in this ecological system (LANDFIRE 2007a).

LANDFIRE developed a somewhat different VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 0911230):

A) Early Development 1 All Structures (herbaceous-dominated - 5% of type in this stage): Herbaceous cover is variable (10-50%). Grassland having just burned. Young, green vegetation. Lasts one year before natural succession to class B.

B) Mid Development 1 Open (herbaceous-dominated - 80% of type in this stage): Herbaceous cover 51-90%. Perennial bunchgrass with solid cryptogam cover, large bluebunch wheatgrasses, lower *Poa secunda* and forb cover, greater forb diversity. Patches are anywhere from 2-50 years old. Replacement fire is the primary disturbance (MFR=50 years).

C) Late Development 1 Closed (herbaceous-dominated - 15% of type in this stage): Herbaceous cover 51-90%. Shrub cover is 0-30%. Native grassland with shrubs beginning to get a foothold, or small pockets of remnants from the original fire expanding into the grassland. It equals the early-seral states in Wyoming big sagebrush steppe ecological system. Patches within this matrix die back due to competition/maintenance, but this does not have a profound effect on class condition. Replacement fire occurs every 16-17 years on average.

Shrubs may increase following heavy grazing and/or with fire suppression, particularly in moist portions in the northern Columbia Plateau where it forms a landscape mosaic pattern with shallow-soil scabland shrublands.

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from conversion to invasive non-native species such as *Bromus tectorum, Centaurea solstitialis, Hypericum perforatum*, and *Poa pratensis*. These invasive species increase post disturbance including long-term excessive grazing by livestock, or direct soil disturbance from severe trampling by livestock and roads. Altered fire regimes such as repeated, high-frequency fire has eliminated shrubs and created extensive grasslands dominated by non-native invasive annual grass *Bromus tectorum* and other non-native annual species (Pellant 1990, 1996).

Additionally, in some places fire suppression has allowed succession and conversion to shrublands (LANDFIRE 2007a, WNHP 2011). The primary land uses that alter the natural processes of this system are associated with livestock practices, annual exotic species, fire regime alteration, direct soil surface disturbance, and fragmentation from roads and agriculture (WNHP 2011).

Ecosystems in the Columbia Basin are more sensitive to livestock grazing than grasslands in the Great Plains as they did not evolve with the same duration, seasonality, and severity of large native ungulate grazing (Mack and Thompson 1982, Burkhart 1996). In the early 1900s, heavy sheep and cattle grazing led to an increase of shrubs into much of the area. Excessive grazing stresses the system through soil disturbance, trampling and displacing the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and exotic annual grasses, particularly *Bromus tectorum* (Pellant 1990, 1996). Persistent grazing will further diminish perennial cover, expose bare ground, and increase exotic annuals. Currently, fire further stresses livestock-altered vegetation by increasing exposure of bare ground and consequent increases in exotic annuals and decrease in perennial bunchgrass. In more mesic steppe, fire is not as important in maintenance of perennial grasses and forbs. Fescue dominates more heavily on north aspects and moist sites, which have a lower fire frequency (LANDFIRE 2007a). Shrubs may increase with fire suppression, particularly in moist portions in the northern Columbia Plateau where it forms a landscape mosaic pattern with shallow-soil scabland shrublands.

Any disturbances to soil and bunchgrass layers, such as vehicle tracks and chaining shrubs, will increase the probability of alteration of vegetation structure and composition and response to fire as discussed above. Johnson and Swanson (2005) note that *Festuca idahoensis* decreases following fire, but following a flush of annuals, these sites regain pre-fire cover after a few years. Repeated, high-frequency fire has eliminated the sagebrush and the seed sources of sagebrush, creating extensive grasslands (LANDFIRE 2007a). Currently, cheatgrass and other introduced grasses often invade these habitats after fire. Too much fire has turned steppe into annual grasslands in many areas and has turned large areas of shrubland into grasslands (LANDFIRE 2007a).

Fragmentation of shrub-steppe by agriculture increases cover of annual grass, total annual/biennial forbs, bare ground, decreases cover of perennial forbs and biological soil crusts, and reduces obligate insects (Quinn 2004), obligate birds and small mammals (Vander Haegen et al. 2000, 2001). These fragmentation responses are similarly expected in steppe vegetation (WNHP 2011).

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 51** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 52, left**) and sensitivity (**Figure 52, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

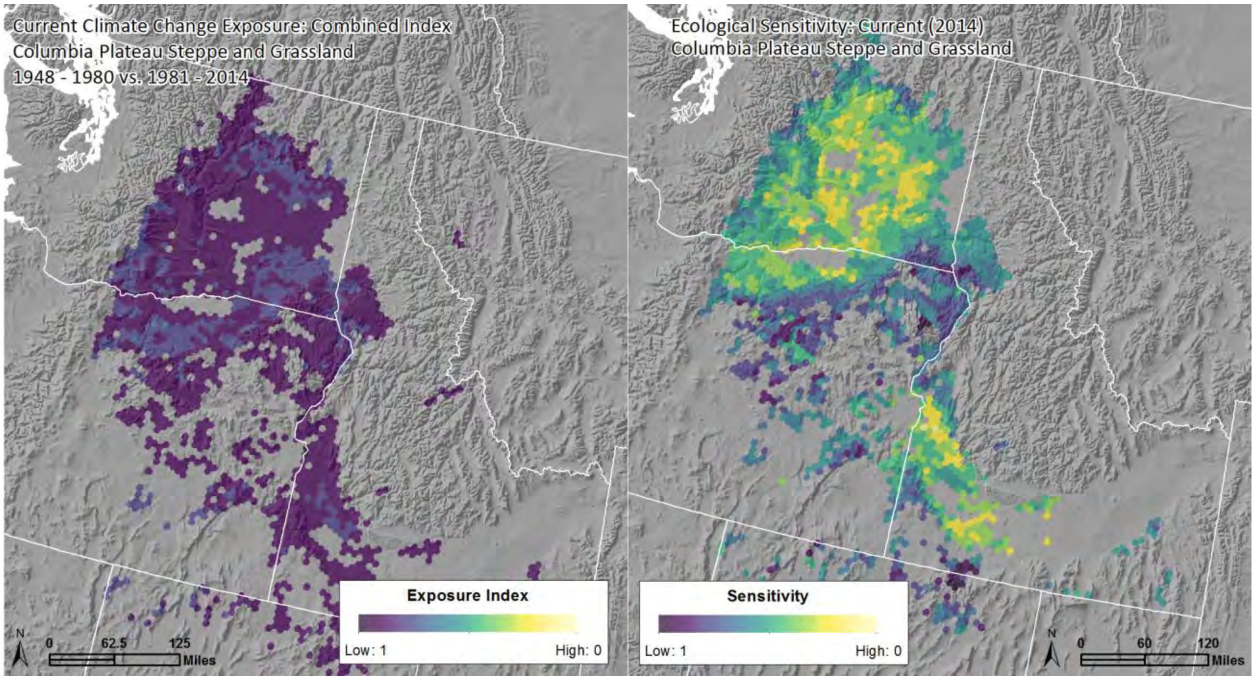

Figure 52. Climate exposure as of 2014 (left) and overall sensitivity (right) for Columbia Plateau Steppe and Grassland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 51. Resilience, exposure and vulnerability scores for Columbia Plateau Steppe and Grassland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Columbia Plateau	Blue Mountains	Snake River Plain	Northern Basin & Range	Columbia Mountains-Northern Rockies	Eastern Cascades Slopes & Foothills	North Cascades	Idaho Batholith	Central Basin & Range
	Sq miles within ecoregion	5,628	2,136	540	430	238	226	104	25	24
Contributions to Relative Vulnerability by Factor										
Vulnerability from **Exposure (2014)**		Low 0.81	Low 0.83	Low 0.82	Low 0.83	Low 0.84	Low 0.80	Low 0.82	Low 0.85	Low 0.87
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.29	0.56	0.26	0.66	0.18	0.23	0.36	0.43	0.56
	Fire Regime Departure	0.40	0.62	0.37	0.53	0.52	0.41	0.43	0.60	0.72
	Invasive Annual Grasses	0.70	0.90	0.69	0.48	0.97	0.92	0.92	0.72	0.70
	Sensitivity Average	**0.46**	**0.69**	**0.44**	**0.55**	**0.56**	**0.52**	**0.57**	**0.58**	**0.66**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.17	0.31	0.11	0.24	0.24	0.26	0.34	0.41	0.27
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.34**	**0.41**	**0.31**	**0.37**	**0.37**	**0.38**	**0.42**	**0.45**	**0.39**
Vulnerability from Measures of **Overall Resilience**		High 0.40	Mod 0.55	High 0.37	High 0.46	High 0.46	High 0.45	High 0.50	Mod 0.52	Mod 0.52
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of this steppe ecological system, exposure as of 2014 is low. Where it is most abundant, in the Blue Mountains ecoregion, Annual Mean Temperature shows an increase of 0.6°C over 42% of its distribution there.

Climate Change Effects: Potential climate change effects could include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Regeneration of establishment and survival of characteristic cool season perennial bunchgrasses would be greatly reduced, effectively eliminating recruitment.

Additionally, warmer/drier fuels from invasive, exotic annual grasses such as *Bromus tectorum* and ruderal shrubs such as *Ericameria nauseosa* may result in more frequent fires that could increase rate of loss of mature stands through conversion to annual grasslands or shrublands that are adapted to frequent fire.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be moderate to high across the range of this type. More sensitivity appears to be due to a combination of extensive agriculture and development fragmenting occurrences and altered fire regimes.

Landscape condition varies from moderate (some development) to low, to very low (e.g., in the Columbia Mountains-Northern Rockies and East Cascades Slopes & Foothills ecoregions) (**Table 51**). Agriculture is a significant factor in the Columbia Plateau and Snake River Plain, whereas in all other ecoregions, infrastructure and development of various kinds play a role. There are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive grasses appears to vary across ecoregions, with moderate to high risk scores in 5 of 9 ecoregions. Fire regime departure is moderate to high in all ecoregions. Fire suppression has led to conversion to sagebrush shrublands, and extensive livestock grazing historically resulted in the removal of the bunchgrass component. Together these factors result in an altered fire regime.

The interactions of the stressors of fragmentation by development, overgrazing, fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these grasslands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across the range of this steppe and grassland system. Topoclimatic variability is low to very low across all ecoregions. These steppe grasslands occur across generally low-relief landforms and topography, such as valley floors, alluvial fans, floodplains, stabilized dunes, mesic uplands, swales, and rocky slopes. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within three of the four identified functional species groups is moderate. Nitrogen-fixation, biotic pollination, and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae*, *Brassicaceae* and *Poaceae* families, along with cyanobacteria and cyanolichens. Insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system. Within-stand diversity for this functional group is moderate. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

The fourth functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Columbia Plateau Steppe and Grassland scores in the moderate range of overall climate change vulnerability throughout most of its range. This moderate vulnerability is primarily due to low scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity cold desert types that naturally occupy extensive dry flats, plateaus, plains, basins, gently sloping alluvial fans, hillslopes and ridges (low topoclimate variability). Additionally, these grasslands and steppes often occur in agriculture areas and have moderate to poor landscape condition, moderate fire regime departure, and are susceptible to invasive plants. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 52. Climate change adaptation strategies relative to vulnerability scores for Columbia Plateau Steppe and Grassland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, pollinators, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native grass and herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barnett and Crawford 1994, Belnap and Lange 2003, Belnap et al. 2001, Burkhardt 1996, Comer et al. 2003*, Daubenmire 1970, Drut et al. 1994, Ersch 2009, Gregg and Crawford 2009, Howard 1999, Johnson and Swanson 2005, LANDFIRE 2007a, Mack and Thompson 1982, Pellant 1990, Pellant 1996, Quinn 2004, Shiflet 1994, TNC 2013, Tirmenstein 1999c, Vander Haegen et al. 2000, Vander Haegen et al. 2001, WNHP 2011, WNHP unpubl. data

CES304.774 Great Basin Xeric Mixed Sagebrush Shrubland

Figure 53. Photo of Great Basin Xeric Mixed Sagebrush Shrubland. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in the Great Basin on dry flats and plains, alluvial fans, rolling hills, rocky hillslopes, saddles and ridges at elevations between 1000 and 2600 m. Sites are dry, often exposed to desiccating winds, with typically shallow, rocky, non-saline soils. Shrublands are dominated by *Artemisia nova* (mid and low elevations), *Artemisia arbuscula ssp. longicaulis*, or *Artemisia arbuscula ssp. longiloba* (higher elevation) and may be codominated by *Artemisia tridentata ssp. wyomingensis* or *Chrysothamnus viscidiflorus*. Other shrubs that may be present include *Atriplex confertifolia, Ephedra* spp., *Ericameria* spp., *Grayia spinosa, Lycium shockleyi, Picrothamnus desertorum*, and *Tetradymia* spp. The herbaceous layer is likely sparse and composed of perennial bunchgrasses, such as *Achnatherum hymenoides, Achnatherum speciosum, Achnatherum thurberianum, Elymus elymoides*, or *Poa secunda*.

Distribution: This system occurs in the Great Basin on dry flats and plains, alluvial fans, rolling hills, rocky hillslopes, saddles and ridges at elevations between 1000 and 2600 m.

Nations: US

States/Provinces: CA, ID?, NV, OR, UT, WY

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Idaho Batholith, Northern Basin and Range, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Sonoran Desert, Southern and Baja California Pine-Oak Mountains

Primary Concept Source: K.A. Schulz

Description Author: M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These shrublands are dominated by *Artemisia nova* (mid and low elevations), *Artemisia arbuscula ssp. longicaulis* (lower elevations), or *Artemisia arbuscula ssp. longiloba* (higher elevations) and may be codominated by *Artemisia tridentata ssp. wyomingensis* or *Chrysothamnus viscidiflorus*. Other shrubs that may be present include *Atriplex confertifolia, Ephedra* spp., *Ericameria* spp., *Grayia spinosa, Lycium shockleyi, Picrothamnus desertorum, Purshia tridentata, Sarcobatus vermiculatus*, and *Tetradymia* spp. The herbaceous layer is likely sparse and composed of perennial bunchgrasses, such as *Achnatherum hymenoides, Achnatherum speciosum, Achnatherum thurberianum, Elymus elymoides, Festuca idahoensis, Hesperostipa comata, Poa fendleriana, Poa secunda*, or *Pseudoroegneria spicata*. The floristic description is based on several other references, including Blackburn and Tueller (1970), Zamora and Tueller (1973), Hironaka et al. (1983), West (1983a), Barbour and Major (1988), Chappell et al. (1997), Howard (1999), Steinberg (2002), Barbour et al. (2007), Fryer (2009), Sawyer et al. (2009), and NatureServe Explorer (2011).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Biological soils crusts are composed of cyanobacteria, lichens, microfungi, algae, mosses, and liverworts and critically important for soil fertility, soil moisture, and soil stability in arid and semi-arid ecosystems of the western U.S. (Belnap and Lange 2003). Great Basin crust diversity is based on Rosentreter and Belnap (2003). Late-successional sagebrush lichen diversity is based on Belnap et al. (2001). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii,*

Phormidium spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin than warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp. Late-successional sagebrush lichen (5): *Acarospora schleicheri, Massalongia carnosa, Fuscopannaria cyanolepra (= Pannaria cyanolepra), Trapeliopsis wallrothii*, and *Texosporium sancti-jacobi*.

Nitrogen Fixation; Species Diversity: Medium
Black and low sagebrush shrublands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea, Lupinus*, and *Psoralidium*), Rosaceae (*Purshia tridentata*) and some Poaceae (e.g., *Achnatherum hymenoides, Bouteloua gracilis, Elymus elymoides, Hesperostipa comata, Leymus cinereus, Pleuraphis jamesii, Poa fendleriana, Poa secunda*, and *Pseudoroegneria spicata*), and several Brassicaceae can fix nitrogen in this system. Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap et al. 2001, Belnap 2001). Heterocystic genera (specialized N-fixing type of cyanobacteria) found in soil crusts for this system include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, or *Peltigera*- and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Achnatherum hymenoides, Elymus elymoides, Elymus lanceolatus, Hesperostipa comata, Leymus cinereus, Pascopyrum smithii, Poa fendleriana, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this sagebrush shrubland type.

Environment: *Climate:* Climate is semi-arid with 20 to 30 cm of annual precipitation and warm summers and cold winters.

Physiography/landform: This ecological system is widely distributed in the interior Great Basin of the western United States on dry flats and plains, alluvial fans, rolling hills and foothills, saddles and ridges at elevations between 1000 and 2600 m. Sites are xeric, flat to steep, and often exposed to desiccating winds or with typically shallow, rocky, non-saline soils. It occupies flat to steeply sloping upland sites, on a wide variety of topographic positions. Sloping sites tend to have southerly aspects.

Soil/substrate/hydrology: Sites with low slope tend to have deeper soils, while those with steeper slopes have shallow to moderately deep soils that are well-drained. Soil texture is loam, sandy loam, or clay loam (Hansen and Hoffman 1988), and there is often a significant amount of coarse fragments in the soil profile. Hironaka et al. (1983) reported that most of the habitat occurred on calcareous soils, often with a cemented duripan. Low sagebrush tends to grow where claypan layers exist in the soil profile and soils are often saturated during a portion of the year; black sagebrush tends to grow where there is a root-limiting layer in the soil profile, whereas Wyoming sagebrush and basin big sagebrush generally occur on moderately deep to deep soils that are well-drained (LANDFIRE 2007a). The environmental description is based on several other references, including Blackburn and Tueller (1970), Zamora and Tueller (1973), Hironaka et al. (1983), West (1983a), Barbour and Major (1988), Chappell et al. (1997), Howard (1999), Steinberg (2002a), Barbour et al. (2007a), Fryer (2009), and Sawyer et al. (2009).

Key Processes and Interactions: The diagnostic species of this system, *Artemisia nova, Artemisia arbuscula ssp. longicaulis*, or *Artemisia arbuscula ssp. longiloba*, grow in more xeric sites than other *Artemisia* shrublands (Hironaka et al. 1983). This shrubland system is associated with shallow, rocky soils which experience extreme drought in summer. The plants are low and widely spaced, which tends to decrease the risk of fire (Chappell et al. 1997). Fire is uncommon because of discontinuous and low fuel buildup on the generally unproductive sites (Young and Palmquist 1992, Fryer 2009, Sawyer et al. 2009). Most sites are thought to have relatively long fire-return intervals (100-200 years) according to LANDFIRE models developed by experts (LANDFIRE 2007a). These shrubs are fire-sensitive and rarely sprout after burning. They reproduce from light wind-dispersed seeds from adjacent unburned areas into disturbed areas (Howard 1999, Steinberg 2002a, Fryer 2009). It generally takes around 30 years for a burned stand to recover to pre-fire density (Zamora and Tueller 1973, Hironaka et al. 1983, Howard 1999, Steinberg 2002a, Fryer 2009). *Artemisia tridentata ssp. wyomingensis* may be present to codominant and shares similar ecological characteristics on these relatively xeric sites (Howard 1999).

Scattered trees may be present in some stands of this system. Fire reduces sagebrush abundance in both sagebrush and pinyon-juniper systems. Where these systems are adjacent, periodic fire likely prevents establishment of juniper and pinyon trees in sagebrush stands (Wright et al. 1979). Blackburn and Tueller (1970) noted rapid invasion of these communities by *Juniperus osteosperma* and *Pinus monophylla* at some sites in Nevada. In order to maintain dominance of sagebrush, fire-return interval must be long enough to permit sagebrush stands to mature, but short enough to prevent establishment and growth of trees in these sites. Fire-return intervals of 150-250 years for stand-replacing fire will likely maintain these shrublands. Expansion and contraction of trees into sagebrush shrublands are regulated by a combination of climate, fire, and bark beetle infestations with trees seedlings establishing during wetter periods (Wright et al. 1979, Clifford et al. 2008).

The black and low sagebrush type tends to occur adjacent to Inter-Mountain Basins Big Sagebrush Shrubland (CES304.777). The Wyoming big sagebrush and basin big sagebrush types create a mosaic within the black and low sagebrush types. These big sagebrush types have a different fire regime that acts to carry the fire, with black and low sagebrush serving as firebreaks most of the time (LANDFIRE 2007a).

Black sagebrush (*Artemisia nova*) generally supports more fire than other dwarf sagebrushes (LANDFIRE 2007a). This type generally burns with mixed severity (average FRI of 100-140 years) due to relatively low fuel loads and herbaceous cover (LANDFIRE 2007a). Bare ground acts as a micro-barrier to fire between low-statured shrubs. Stand-replacing fires (average FRI of 200-240 years) can occur in this type when successive years of above-average precipitation are followed by an average or dry year (LANDFIRE 2007a). Stand-replacement fires dominate in the late-successional class where the herbaceous component has been diminished or where trees dominate (LANDFIRE 2007a). This type fits best into Fire Regime Group IV (LANDFIRE 2007a).

Grazing by wild ungulates occurs in this shrubland system. Native browsing tends to open up the canopy cover of shrubs but does not often change the successional stage (LANDFIRE 2007a).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square mile. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

LANDFIRE developed a VDDT model for this system which has three classes (LANDFIRE 2007a, BpS 1210790). This model includes sites where there is potential for pinyon (*Pinus monophylla*) and/or juniper (*Juniperus osteosperma*) establishment in classes C and D.

A) Early Development 1 All Structures (15% of type in this stage): Shrub cover is 0-5%. Early-seral community dominated by herbaceous vegetation; less than 6% sagebrush canopy cover; up to 24 years post-disturbance. Fire-tolerant shrubs (green/low rabbitbrush) are first sprouters after stand-replacing, high-severity fire. Replacement fire (mean FRI of 250 years) maintains vegetation in class A. Prolonged drought every 200 years on average maintains vegetation in class A. Succession to class B after 25 years.

B) Mid Development 1 Open (60% of type in this stage): Mid-seral community with a mixture of herbaceous and shrub vegetation; 6-25% sagebrush (sagebrush/brush) canopy cover present; between 20-59 years post-disturbance. Drought every 200 years causes two transitions: 50% of times drought thins shrubs while maintaining vegetation in class B, whereas 50% of times drought causes a stand-replacing event. Replacement fire (FRI of 250 years) causes a transition to class A, whereas mixed-severity fire (FRI of 100 years) maintains the site in its present condition. In the absence of fire for at least 120 years, the site will follow an alternative successional path to class C. Otherwise, succession and mixed-severity fire keeps site in class B.

C) Late Development 1 Open (15% of type in this stage): Late-seral community with a mixture of herbaceous and shrub vegetation; 10-25% sagebrush canopy cover present; and dispersed conifer seedlings and saplings established at less than 6% cover (*Juniperus osteosperma* and/or *Pinus monophylla*). Insects attack the vegetation in this state every 60 years on average but does not cause a transition to another state. Severe droughts (return interval of 200 years) cause two thinning disturbances: to class B (50% of times) and within class C. Replacement fire is every 200 years on average, whereas mixed-severity fire is less frequent than in class B (FRI of 130 years). Succession is to class D after 75 years.

D) Late Development 1 Closed (10% of type in this stage): Late-seral community with a closed canopy of conifer trees (6-40% cover). The degree of tree canopy closure differs depending on whether it is a low sagebrush (maximum 15%) or black sagebrush (maximum 40%) community. In low sagebrush communities a mixture of herbaceous and shrub vegetation with >10% sagebrush canopy cover would still be present. In black sagebrush communities the herbaceous and shrub component would be greatly reduced (<1%). When Ips beetle outbreaks occur the pinyon pine component is reduced (return interval of 60 years): 75% of times thinning is not intense enough to cause a transition whereas in 25% of cases a transition to class C will occur. The only fire is replacement (FRI of 150 years) and driven by a greater amount of woody fuel than in previous states. Prolonged droughts have the same effect as before.

ECOLOGICAL INTEGRITY

Change Agents: The primary land uses that alter the natural processes of this system are associated with livestock grazing and introduction of exotic annual grasses. Barbour and Major (1988) report that *Artemisia nova* is utilized by livestock to a much greater degree than other species of *Artemisia*, resulting in low, pruned plants (West 1983a). Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus madritensis, Bromus tectorum, Schismus* spp., and other exotic annual grasses. The introduction of exotic annual grasses has altered many stands by increasing the amount of fine fuels present that can substantially increase fire frequency and intensity which reduces the cover of fire-sensitive shrubs such as *Artemisia nova* (Fryer 2009, Sawyer et al. 2009).

Direct and indirect fire suppression are a threat to this system where stands are adjacent to pinyon-juniper woodlands. Over the long term, heavy grazing by livestock removes the fine fuels that carry fire that indirectly leads to a reduction in fire frequencies, which can lead to pinyon-juniper encroachment with subsequent loss of shrub and herbaceous understory (LANDFIRE 2007a).

When grasshopper and Mormon cricket populations reach outbreak levels, they cause significant economic losses for ranchers and livestock producers, especially when accompanied by a drought (USDA-APHIS 2003, 2010). Both rangeland forage and cultivated crops can be consumed by grasshoppers. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is the Federal agency responsible for controlling economic infestations of grasshoppers on western rangelands with a cooperative suppression program. They work with federal land managing agencies to conduct grasshopper suppression. The goal of APHIS's grasshopper program is not to eradicate them but to reduce outbreak populations to less economically damaging levels (USDA-APHIS 2003). This APHIS effort dampens the natural ecological outbreak cycles of grasshoppers and Mormon crickets but does not eradicate the species.

Human development has impacted many locations throughout the range of this system. High- and low-density urban and industrial developments also have large impacts. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 53** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 54, left**) and sensitivity (**Figure 54, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

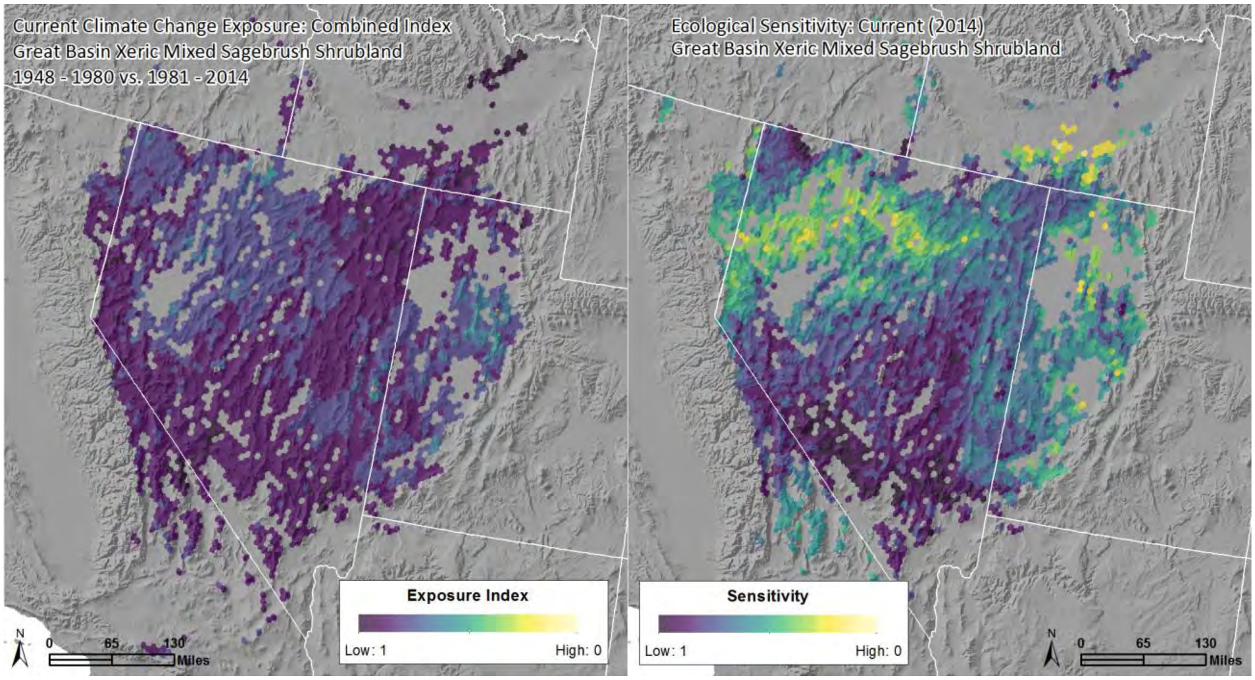

Figure 54. Climate exposure as of 2014 (left) and overall sensitivity (right) for Great Basin Xeric Mixed Sagebrush Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 53. Resilience, exposure and vulnerability scores for Great Basin Xeric Mixed Sagebrush Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Central Basin & Range	Northern Basin & Range	Mojave Basin & Range	Eastern Cascades Slopes & Foothills	Snake River Plain	Blue Mountains	Middle Rockies
	Sq miles within ecoregion	19,570	3,587	536	129	53	51	50
Contributions to Relative Vulnerability by Factor								
Vulnerability from **Exposure (2014)**		**Mod** 0.59	**Mod** 0.59	**Mod** 0.63	**Mod** 0.58	**Mod** 0.66	**Mod** 0.65	**Mod** 0.68
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.78	0.82	0.83	0.80	0.27	0.47	0.70
	Fire Regime Departure	0.43	0.56	0.63	0.50	0.25	0.58	0.62
	Invasive Annual Grasses	0.83	0.60	0.79	0.42	0.54	0.80	0.99
	Sensitivity Average	**0.68**	**0.66**	**0.75**	**0.57**	**0.35**	**0.61**	**0.77**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.34	0.31	0.50	0.24	0.15	0.27	0.20
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.42**	**0.41**	**0.50**	**0.37**	**0.32**	**0.39**	**0.35**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.55	**Mod** 0.53	**Mod** 0.63	**High** 0.47	**High** 0.34	**Mod** 0.50	**Mod** 0.56
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**High**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Rangewide, exposure as of 2014 is moderate. In the Central Basin and Range ecoregion, where it is most abundant, an emerging pattern of climate change is seen as increases in Annual Mean Temperature and Temperature of the Warmest Quarter of 0.58° and 0.72°C, respectively, for 60% of its distribution in the ecoregion. In the Mojave Basin and Range, where it is much less common, these same variables show similar increases of 0.7°C but for 90% of the distribution in that ecoregion. In both ecoregions, the Mean Diurnal Range is decreasing by 0.5°C for about 18% of the type's distribution in each ecoregion, suggesting the difference between day-time maximums and night-time minimums is decreasing.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be greatly reduced, effectively eliminating sagebrush recruitment. A warming climate with more frequent droughts weakens sagebrush shrubs and eliminates recruitment. Additionally, warmer/drier fuels may result in more frequent fires that could increase rate of loss of mature stands through conversion of these shrublands to annual grasslands that are adapted to frequent fire (Chambers et al. 2013).

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change varies from low (higher numerical scores) to moderate or high across the range of this type. Sensitivity scores are particularly low (equating to higher sensitivity) in the Snake River Plain ecoregion, due to the combination of extensive agriculture and development fragmenting occurrences and concentrations of invasive annual grasses, which in turn alters fire regimes.

Landscape condition is generally good (less fragmentation, higher scores); however, in the Snake River Plain and Blue Mountains ecoregions, it scored as moderate. Agriculture and other infrastructure development are factors in these ecoregions. Elsewhere there are many small roads that fragment occurrences, along with some development of urban, suburban and exurban areas, especially along the Wasatch Front of Utah.

Risk of invasive grasses in this system is most pronounced in the Northern Basin and Range, Snake River Plain and Eastern Cascades ecoregions (**Figure 54**); these ecoregions include large areas of cheatgrass invasion. Elsewhere the risk of invasives grasses tends to be low. Fire regime departure is moderate to high (indicated by lower scores), and very high in the Snake River Plain, with the effects of fire suppression and fine-fuels introduction by invasive grasses interacting. Grazing by livestock removes the fine fuels that carry fire, which indirectly leads to a reduction in fire frequencies, which can lead to pinyon-juniper encroachment into these xeric sage shrublands.

The interactions of the stressors of fragmentation by development, overgrazing, fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low to moderate across the range of this somewhat widespread shrubland system but is lowest in the Snake River Plain ecoregion. Topoclimatic variability is generally low or very low, but is moderate in the Mojave Basin & Range ecoregion. These xeric shrublands tend to occur across low-relief landforms and topography, such as dry flats and plains, alluvial fans, rolling hills, rocky hillslopes, saddles and ridges. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within two of the three identified functional species groups is moderate. Nitrogen-fixation and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae, Rosaceae*, and *Poaceae* families, along with cyanobacteria and cyanolichens. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration. The third functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Great Basin Xeric Mixed Sagebrush Shrublands score in the moderate range of overall climate change vulnerability throughout most of their range, with only the Snake River Plain ecoregion scored as high. The moderate to high vulnerability is primarily due to the generally moderate scores for exposure, low scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity cold desert types that naturally occupy extensive dry flats, flat plains, gently sloping alluvial fans, hillslopes and ridges (low topoclimate variability). Additionally, these shrublands are highly susceptible to invasive plants. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 54. Climate change adaptation strategies relative to vulnerability scores for Great Basin Xeric Mixed Sagebrush Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Baker and Kennedy 1985, Barbour and Major 1988, Barbour et al. 2007a, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Blackburn and Tueller 1970, Chambers et al. 2013, Chappell et al. 1997, Clifford et al. 2008, Comer et al. 2003*, Fryer 2009, Hansen and Hoffman 1988, Hironaka et al. 1983, Howard 1999, LANDFIRE 2007a, Rosentreter and Belnap 2003, Sawyer et al. 2009, Shiflet 1994, Steinberg 2002a, Tirmenstein 1999c, USDA-APHIS 2003, USDA-APHIS 2010, West 1983a, Wright et al. 1979, Young and Palmquist 1992, Zamora and Tueller 1973

CES304.777 Inter-Mountain Basins Big Sagebrush Shrubland

Figure 55. Photo of Inter-Mountain Basins Big Sagebrush Shrubland. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs throughout much of the interior western U.S., typically in broad basins between mountain ranges, plains and foothills between 800 and 2500 m elevation. Soils are typically deep, well-drained and non-saline. These shrublands are dominated by *Artemisia tridentata ssp. tridentata* (not as common in Wyoming or Montana but possibly on stabilized part of Killpecker Dunes in Wyoming) and/or *Artemisia tridentata ssp. wyomingensis* (predominant in Wyoming and Montana). Scattered *Juniperus* spp., *Sarcobatus vermiculatus*, and *Atriplex* spp. may be present in some stands. *Ericameria nauseosa, Chrysothamnus viscidiflorus, Purshia tridentata* (not commonly in Montana or Wyoming), or *Symphoricarpos oreophilus* may codominate disturbed stands (e.g., in burned stands, these may become more predominant). Perennial herbaceous components typically contribute less than 25% vegetative cover. Common graminoid species can include *Achnatherum hymenoides*, *Bouteloua gracilis, Elymus lanceolatus, Festuca idahoensis* (not in Montana or Wyoming), *Hesperostipa comata, Leymus cinereus, Pleuraphis jamesii* (not present in northeastern portions of the range), *Pascopyrum smithii, Poa secunda*, or *Pseudoroegneria spicata* (not in Wyoming). Dunes in the Red Desert have areas of large basin big sage with very dense canopies. In Wyoming, this system is likely to only contain *Artemisia tridentata ssp. tridentata*.

Distribution: This system occurs throughout much of the interior western U.S., typically in broad basins between mountain ranges, plains and foothills. Its core distribution is in the Great Basin, but it extends north into the Columbia Basin and west into the foothills of the Sierra Nevada and Cascades, and east into the Colorado Plateau, Wyoming Basins and central and eastern Montana, although much of the sagebrush in this region is more steppe in physiognomy.

Nations: US

States/Provinces: CA, CO, ID, MT, NV, OR, UT, WA, WY

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Klamath Mountains, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, High Plains, Southwestern Tablelands, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, California Coastal Sage, Chaparral, and Oak Woodlands, Southern and Baja California Pine-Oak Mountains, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: NatureServe Western Ecology Team

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These shrublands are dominated by *Artemisia tridentata ssp. tridentata* (not as common in Wyoming or Montana but possibly on the stabilized part of Killpecker Dunes in Wyoming) and/or *Artemisia tridentata ssp. wyomingensis* (predominant in Wyoming and Montana). Scattered *Juniperus* spp., *Sarcobatus vermiculatus*, and *Atriplex* spp. may be present in some stands. *Ericameria nauseosa, Chrysothamnus viscidiflorus, Purshia tridentata* (not commonly in Montana or Wyoming), or *Symphoricarpos oreophilus* may codominate disturbed stands (e.g., in burned stands, these may become more predominant). Perennial herbaceous components typically contribute less than 25% vegetative cover. Common graminoid species can include *Achnatherum hymenoides, Bouteloua gracilis, Elymus lanceolatus, Festuca idahoensis* (not in Montana or Wyoming), *Hesperostipa comata, Leymus cinereus, Pleuraphis jamesii* (not present in northeastern portions of the range), *Pascopyrum smithii, Poa secunda*, or *Pseudoroegneria spicata* (not in Wyoming). Some semi-natural communities are included that often originate on abandoned agricultural land or on other disturbed sites. In these locations, *Bromus tectorum* or other annual bromes and invasive weeds can be abundant. Most *Artemisia tridentata ssp. wyomingensis* communities in Wyoming are placed in Inter-Mountain Basins Big Sagebrush Steppe (CES304.778); the shrubland system is more restricted in environmental setting than the steppe. Dunes in the Red Desert have areas of large basin big sagebrush with very dense canopies. In Wyoming, this system is likely to only contain *Artemisia tridentata ssp. tridentata*. The vegetation description is based on several references, including Brown (1982a), West (1983a), Barbour and Billings (1988), Knight (1994), Shiflet (1994), Holland and Keil (1995), Reid et al. (1999), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Great Basin crust diversity is based on Rosentreter and Belnap (2003). Late-successional sagebrush lichen diversity is based on Belnap et al. (2001). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp.,

Oscillatoria agardhii, Phormidium spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites). Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin then warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp. Late-successional sagebrush lichen (5): *Acarospora schleicheri, Massalongia carnosa, Fuscopannaria cyanolepra (= Pannaria cyanolepra), Trapeliopsis wallrothii*, and *Texosporium sancti-jacobi*.

Biotic Pollination; Species Diversity: Medium
Although the dominant shrubs in this system (*Artemisia tridentata ssp. tridentata* and/or *Artemisia tridentata ssp. wyomingensis*) are self- or wind-pollinated, most forbs and shrubs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Howard 1999, Tirmenstein 1999c). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds important other species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially for red tubular flowers).

Nitrogen Fixation; Species Diversity: Medium
Big sagebrush shrublands occur in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea*, and *Psoralidium*), many Poaceae (*Bouteloua gracilis, Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana*, and *Pseudoroegneria spicata*), some Rosaceae (*Purshia tridentata*), and a few Brassicaceae can fix nitrogen in this system. Cyanobacteria (especially *Nostoc* and *Scytonema*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Pseudoroegneria spicata, Achnatherum hymenoides, Elymus lanceolatus, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Pascopyrum smithii, and *Poa secunda*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this big sagebrush shrubland type.

Environment: This ecological system occurs throughout much of the interior western U.S., typically in broad basins between mountain ranges, plains and foothills between 1500 and 2500 m elevation.

Climate: The climate where this system occurs is semi-arid with annual precipitation ranging from 18-40 cm and high inter-annual variation. Much of the precipitation falls as snow, and growing-season drought is characteristic. Temperatures are continental with large annual and diurnal variation. In drier regions, these shrublands are usually associated with perennial or ephemeral stream drainages with water tables less than 3 m from the soil surface.

Physiography/landform: Sites supporting this system include flat to steeply sloping uplands on alluvial fans and terraces, toeslopes, lower and middle slopes, draws, badlands, and deep, well-drained alluvial bottomlands foothills and basins and plains (Barker and McKell 1983).

Soil/substrates/hydrology: In drier regions, these shrublands are usually associated with perennial or ephemeral stream drainages with water tables less than 3 m from the soil surface. Substrates are typically deep, well-drained and non-saline, fine- to medium-textured alluvial soils with some source of subirrigation during the summer season, but moderately deep upland soils with ample moisture storage also support these shrublands. Some stands occur on deep, sandy soils, or soils that are highly calcareous (Hironaka et al. 1983). Although this system may grade into sites with alkaline soils at the edge of internally drained basins, *Artemisia tridentata* is a non-halophyte and requires low salinity for optimum growth. The importance of perennial bunch grasses, the most typical herbaceous associates, is favored with greater spring and summer rain, which increases northward and eastward.

The environmental description is based on several references, including Brown (1982a), Hironaka et al. (1983), West (1983a), Barbour and Billings (1988), Knight (1994), Shiflet (1994), Holland and Keil (1995), Reid et al. (1999), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Key Processes and Interactions: Complex ecological interactions of fire regimes and climate patterns result in equally complex patterns of species structure and composition in *Artemisia tridentata* stands. Prolonged drought on the more xeric sites may result in lower shrub cover. Flooding may also cause plant mortality if the soil remains saturated for an extended period of time. The Aroga moth is capable of defoliating large acreages (i.e., >1000 acres, but usually 10-100 acres). Heavy grazing by wildlife can remove the fine fuels that support mixed-severity fires and result in woody fuel buildup that leads to severe, stand-replacement fires (LANDFIRE 2007a, BpS 1210800).

Big sagebrush reproduces from seed only, so stands are inhibited by fire as *Artemisia tridentata* does not sprout after burning (Howard 1999, Tirmenstein 1999c). Increasing fire frequency can eliminate the shrubs from the stands (Daubenmire 1970, Tirmenstein 1999c). With a change in fire frequency, species composition will be altered as well (West 1983a). With a high fire frequency (every 2-5 years), perennial grasses and shrubs are eliminated and non-native annual grasses dominate (Whisenant 1990, D'Antonio and Vitousek 1992). At fire-return intervals of 10-30 years, short-lived resprouting shrubs such as *Chrysothamnus* or *Tetradymia* spp. dominate. At fire-return intervals of 30-70 years, a mixture of perennial bunch grasses and non-sprouting shrubs is maintained (Johnson 2000b). Finally, in the complete absence of fire, deep-rooted shrubs such as *Artemisia tridentata* become dominant. At higher-elevation sites with absence of fire (>100 years), *Pinus monophylla* and *Juniperus osteosperma* trees may invade and eventually dominate sites (Tirmenstein 1999c).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square mile. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total and two classes (classes D & E) that model conversion to forest systems (LANDFIRE 2007a, BpS 1210800). These are summarized as:

A) Early Development 1 - All Structures (15% of type in this stage): Early development is dominated by grasses and forbs with scattered shrubs representing <10% upper canopy cover. Post-replacement disturbance; grass-dominated with scattered shrubs. Fuel loading discontinuous. Surface fire occurs every 200 years on average but has no effect on succession. Succession to class B after 20 years.

B) Mid Development 1 Open (shrub-dominated - 50% of type in this stage): Shrub cover 11-50%. Shrubs and herbaceous vegetation can be codominant, fine fuels bridge the woody fuels, but fuel discontinuities are possible. Replacement fire accounts for 80% of fire activity (mean FRI of 125 years), whereas mixed-severity fire occurs every 500 years on average (20% of fire activity) and maintains vegetation in class B. Succession to class C after 40 years.

C) Mid Development 1 Closed (shrub-dominated - 25% of type in this stage): Shrubs dominate the landscape; fuel loading is primarily woody vegetation. Shrub density sufficient in old stands to carry the fire without fine fuels. Establishment of pinyon and juniper seedlings and saplings widely scattered. Replacement fire (mean FRI of 100 years) and rare flood events (return interval of 333 years) cause a transition to class A. Prolonged drought (mean return interval of 100 years) and insect/disease (every 75 years on average) cause a transition to class B. Succession to class D after 40 years.

D) Late Development 1 Open (5% of type in this stage): Shrubs may still represent the dominant lifeform with pinyon and juniper saplings common (1-15% upper canopy cover). Pinyon-juniper encroachment where disturbance has not occurred for at least 100 years (tree species cover <15%). Saplings and young trees are the dominant lifeform. Sagebrush cover (<25%) and herbaceous cover decreasing compared to class C. Replacement fire occurs every 125 years on average. Insect/disease (every 75 years) and prolonged drought (every 100 years) thin both trees and shrubs, causing a transition to class C. Succession to class E after 50 years.

E) Late Development 1 Closed (5% of type in this stage): Shrubland encroached with mature pinyon and/or juniper (cover 16-90%) where disturbance does not occur for at least 50 years in class D. Shrub cover <10% and graminoids scattered. Replacement fire occurs every 125 years on average. Prolonged drought thins trees, causing a transition to class B.

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has come from agriculture (wheat farming and non-native hay production) where soils are deeper and water sources are available. Rangeland management such as sagebrush reduction treatments (frequent burning, herbicide spraying, and mechanical techniques such as plowing or mowing, and planting *Agropyron cristatum*) also convert large areas (Wambolt and Payne 1986, Beck et al. 2012). Substantial area has been lost due to invasive non-native species such as *Bromus tectorum, Centaurea solstitialis, Hypericum perforatum, Poa pratensis, Taeniatherum caput-medusae*, and *Ventenata dubia* (Young and Evans 1971, 1973, Mack 1981b, D'Antonio and Vitousek 1992, Chambers et al. 2007a, D'Antonio et al. 2009, Chambers et al. 2013, Miller et al. 2014). These invasive species increase post-disturbance, including long-term excessive grazing by livestock, or direct soil disturbance from severe trampling by livestock, ORVs and roads. Altered fire regimes such as repeated, high-frequency fires have eliminated shrubs and created extensive grasslands dominated by non-native invasive annual grass *Bromus tectorum* and other non-native annual species (Pellant 1990, 1996).

Additionally, in some places fire suppression has allowed succession and conversion to woodlands (Tirmenstein 1999c, LANDFIRE 2007a, WNHP 2011).

The primary land uses that alter the natural processes of this system are associated with livestock management practices, annual exotic plant species, fire regime alteration, direct soil surface disturbance, and landscape fragmentation (WNHP 2011). Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus tectorum* and other exotic annual bromes. If soil moisture is sufficient and sagebrush seeds are available, grazing can result in increased shrub density depending on the amount of cheatgrass in the understory. There are strong links between foliose lichens and ecosystem health. Severe trampling breaks lichens into fragments too small to re-establish and eventually leads to foliose lichen elimination (Rosentreter and Eldridge 2002).

Fire further stresses livestock-altered vegetation by increasing exposure of bare ground and consequently increases exotic annuals and decreases perennial bunchgrass and sagebrush abundance. Presettlement stand-replacing fire frequency was 40-60 years, with smaller fires every 20-25 years (Wright et al. 1979). Repeated burning every few years or burning in summer will reduce the cover of perennial grasses and allow invasive forbs and cheatgrass to increase. Following a fire, sagebrush must re-establish itself from seed, and recovery is slow (Bunting et al. 1987). Fire favors shrubs such as *Ericameria nauseosa* that can resprout after fire (Tirmenstein 1999b). Fine fuel adjacency from exotic annual grasses, such as *Bromus tectorum, Taeniatherum caput-medusae, Bromus madritensis*, and *Schismus* spp., currently represents the most important fuelbed component in the system and can substantially increase the fire frequency. Locally in areas with a high fire frequency (every 2-5 years) or high-severity fire, perennial grasses and shrubs may be eliminated and non-native annual grasses will dominate (Pellant 1990, 1996).

Fire suppression, even in the absence of livestock grazing impacts, can increase shrub density that in turn reduces bunchgrass cover or results in increased grass litter and fire fuel. Both conditions increase the probability of fire and vegetation responses that increase annual grass abundance following fire (Davies et al. 2009). Fire suppression can lead to pinyon-juniper encroachment with subsequent loss of shrub and herbaceous understory where adjacent to pinyon-juniper woodlands (LANDFIRE 2007a).

Any soil and bunchgrass layer disturbances, such as vehicle tracks or chaining shrubs, will increase the probability of alteration of vegetation structure and composition, and response to fire as discussed above. Loss of shrub density and degradation of the bunchgrass layer's native diversity has been found to decrease the presence of obligate shrub-steppe birds (Vander Haegen et al. 2000). Fragmentation of shrub-steppe by agriculture increases cover of annual grasses, total annual/biennial forbs, and bare ground, and decreases cover of perennial forbs and biological soil crusts, and reduces populations of obligate insects (Quinn 2004), obligate birds and small mammals (Vander Haegen et al. 2000, 2001).

Human development has impacted many locations throughout the type distribution. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations and energy development facilities can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 55** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e.

from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 56, left**) and sensitivity (**Figure 56, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

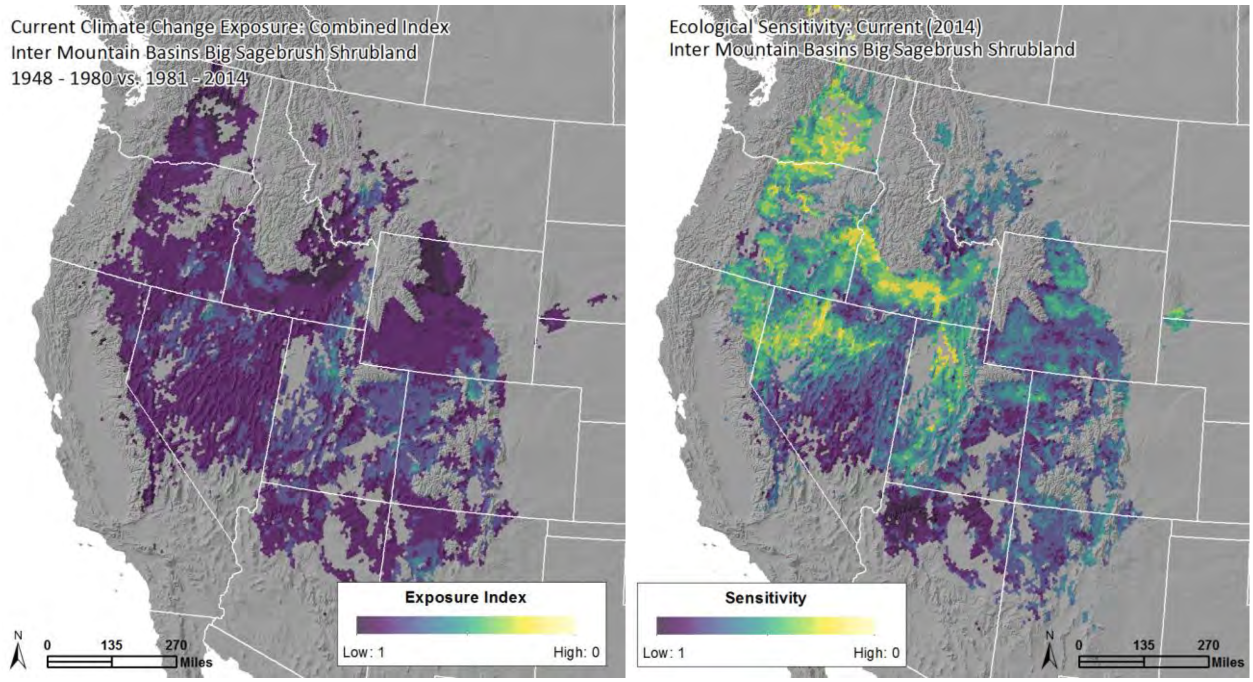

Figure 56. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Big Sagebrush Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 55. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Big Sagebrush Shrubland by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Central Basin & Range	Northern Basin & Range	Wyoming Basin	Colorado Plateaus	Arizona-New Mexico Plateau	Snake River Plain	Columbia Plateau	Southern Rockies	Middle Rockies	Blue Moun-tains	Eastern Cascades Slopes & Foothills	Wasatch & Uinta Moun-tains	North-western Great Plains	Arizona-New Mexico Moun-tains	Columbia Moun-tains-Northern Rockies	Mojave Basin & Range	Sierra Nevada	Thompson-Okanagan Plateau	Idaho Batho-lith	North Cas-cades
	Sq miles within ecoregion	27,204	17,774	17,606	9,805	8,470	7,635	6,994	2,901	2,365	2,071	2,019	1,227	1,132	732	393	193	177	82	67	55
Contributions to Relative Vulnerability by Factor																					
Vulnerability from **Exposure (2014)**		**Mod** 0.59	**Mod** 0.61	**Mod** 0.60	**Mod** 0.56	**Mod** 0.60	**Mod** 0.62	**Mod** 0.63	**Mod** 0.56	**Mod** 0.63	**Mod** 0.64	**Mod** 0.62	**Mod** 0.56	**Mod** 0.63	**Mod** 0.59	**Mod** 0.64	**Mod** 0.62	**Mod** 0.64	**Mod** 0.64	**Mod** 0.64	**Mod** 0.66
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.66	0.67	0.73	0.60	0.74	0.32	0.23	0.65	0.46	0.38	0.62	0.43	0.50	0.80	0.24	0.85	0.70	0.21	0.45	0.29
	Fire Regime Departure	0.42	0.52	0.46	0.66	0.66	0.22	0.30	0.46	0.63	0.38	0.39	0.44	0.55	0.61	0.54	0.70	0.61	Null	0.32	0.45
	Invasive Annual Grasses	0.75	0.45	0.90	0.90	0.98	0.62	0.59	1.00	1.00	0.50	0.46	0.99	0.67	1.00	0.89	0.77	0.62	1.00	0.70	0.80
	Sensitivity Average	**0.61**	**0.55**	**0.69**	**0.72**	**0.79**	**0.39**	**0.38**	**0.70**	**0.69**	**0.42**	**0.49**	**0.62**	**0.57**	**0.80**	**0.56**	**0.77**	**0.64**	**0.61**	**0.49**	**0.51**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.24	0.19	0.22	0.27	0.22	0.12	0.11	0.31	0.24	0.21	0.14	0.33	0.19	0.22	0.19	0.43	0.38	0.18	0.32	0.24
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.37**	**0.35**	**0.36**	**0.38**	**0.36**	**0.31**	**0.30**	**0.41**	**0.37**	**0.36**	**0.32**	**0.41**	**0.34**	**0.36**	**0.34**	**0.47**	**0.44**	**0.34**	**0.41**	**0.37**
Vulnerability from Measures of **Overall Resilience**		**High** 0.49	**High** 0.45	**Mod** 0.53	**Mod** 0.55	**Mod** 0.58	**High** 0.35	**High** 0.34	**Mod** 0.55	**Mod** 0.53	**High** 0.39	**High** 0.40	**Mod** 0.52	**High** 0.46	**Mod** 0.58	**High** 0.45	**Mod** 0.62	**Mod** 0.54	**High** 0.47	**High** 0.45	**High** 0.44
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**High**	**High**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of these widespread sagebrush shrublands exposure as of 2014 is moderate, with little variation across ecoregions. An emerging pattern of changing climate appears as increases of 0.5° to 0.7°C for Annual Mean Temperature and similar increases (up to 0.77°C) for Mean Temperature of the Warmest Quarter across most of the ecoregions where this system occurs. Only the Snake River Plain, Idaho Batholith, Northern Basin and Range, and Columbia Mountain/Northern Rockies do not have this pattern, showing less increases in temperature over smaller areas. The Mean Diurnal Range is decreasing in the Central Basin and Range ecoregion, for some 13% of the type's distribution, which equates to approximately 3021 km^2. This variable is the difference between the monthly mean maximum temperature and the monthly mean minimum temperature, suggesting the difference between day-time maximums and night-time minimums is decreasing.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced or possibly eliminated, effectively eliminating sagebrush recruitment.

Warming climate with more frequent droughts weakens big sagebrush shrubs and eliminates recruitment. Additionally, warmer/drier fuels may result in more frequent fires that could increase rate of loss of mature stands through conversion of these shrublands to annual grasslands that are adapted to frequent fire (Chambers et al. 2013).

Many stands of this shrubland occur in basins surrounded by ranges so it may be possible for species from this system to transition into foothill zones as suitable climate is diminished at lower elevations. Big sagebrush individuals frequently live 40-50 years with maximum ages of 100-150 years and so may be able to survive as relicts for decades without regeneration (Howard 1999, Tirmenstein 1999c). However, there could be accelerated loss of big sagebrush because of more frequent and extended drought, or more frequent and larger fires as a result of hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change varies from low to high (lower numerical scores) across the range of this type. Sensitivity appears to be highest in the Columbia Plateau, Snake River Plain, Blue Mountains, East Cascades and Idaho batholith ecoregions, due to the combination of extensive agriculture and development fragmenting occurrences and concentrations of invasive annual grasses, which in turn alters fire regimes.

Landscape condition varies from moderate to very poor (very low numerical scores) throughout much of the range (**Table 55**), as the ecosystem occurs across extensive basins and areas where agriculture is a significant factor (e.g., Snake River Plain, Columbia Plateau and Blue Mountains). Infrastructure development in other regions is a factor; there are many small roads that fragment occurrences, and in the Wasatch Front region of Utah, development of urban, suburban and exurban areas is significant.

Risk of invasive plants is most pronounced in the Northern Basin and Range and Eastern Cascades Slopes & Foothills ecoregions (**Figure 56**); these ecoregions encompass vast areas of cheatgrass invasion. Elsewhere the risk of invasives grasses tends to be in moderate to low categories. Fire regime departure is moderate to high (indicated by lower scores), with the effects of grazing, fire suppression and fine-fuels introduction by invasive grasses interacting.

The interactions of the stressors of overgrazing, fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity of this widespread shrubland is low range wide. Topoclimatic variability is low or very low throughout its range, as these shrublands occur across generally flat landforms and topography such as alluvial fans and terraces, toeslopes, lower and middle slopes, draws, badlands, alluvial bottomlands, foothills, basins and plains. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high ‘velocity’ of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within three of the four identified functional species groups is moderate. Nitrogen-fixation, biotic pollination, and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the Fabaceae, Rosaceae, Brassicaceae and Poaceae families, along with cyanobacteria and cyanolichens. Insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

The fourth functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Intermountain Basins Big Sagebrush Shrublands score just into the moderate range of overall climate change vulnerability throughout much of their range; while scoring as high in the Snake River Plain and Columbia Plateau ecoregions. This is primarily due to the generally moderate scores for exposure, moderate to low scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity cold desert types that naturally occupy extensive flat plains and valley bottoms. Additionally, these shrublands are highly susceptible to invasive plants. Therefore, common effects of land use throughout the West, including surface disturbance from roads, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 56. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Big Sagebrush Shrubland

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barbour and Billings 1988, Barbour et al. 2007a, Barker 1983, Barnett and Crawford 1994, Beck et al. 2012, Bell et al. 2009, Belnap 2001, Belnap et al. 2001, Brown 1982a, Bunting et al. 1987, CNHP 2010, Chambers et al. 2007a, Chambers et al. 2013, Comer et al. 2003*, Crawford et al. 2004, D'Antonio and Vitousek 1992, D'Antonio et al. 2009, Daubenmire 1970, Davies et al. 2009, Drut et al. 1994, Ersch 2009, Evans and Belnap 1999, Fertig 1998, Gregg and Crawford 2009, Hironaka et al. 1983, Holland and Keil 1995, Howard 1999, Johnson 2000b, Knight 1994, LANDFIRE 2007a, Mack 1981b, Miller et al. 2014, Pellant 1990, Pellant 1996, Quinn 2004, Reid et al. 1999, Reveal 1989, Rosentreter and Belnap 2003, Rosentreter and Eldridge 2002, Sawyer et al. 2009, Shiflet 1994, Spahr et al. 1991, Tirmenstein 1999b, Tirmenstein 1999c, USDA-APHIS 2003, USDA-APHIS 2010, Vander Haegen et al. 2000, Vander Haegen et al. 2001, WNHP 2011, WNHP unpubl. data, Wambolt and Payne 1986, West 1983a, West and Young 2000, Whisenant 1990, Wright et al. 1979, Young and Evans 1971, Young and Evans 1973

CES304.778 Inter-Mountain Basins Big Sagebrush Steppe

Figure 57. Photo of Inter-Mountain Basins Big Sagebrush Steppe. Photo credit: Matt Lavin, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/plant_diversity

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This widespread matrix-forming ecological system occurs throughout much of the Columbia Plateau and northern Great Basin, east into the Wyoming Basins, central Montana, and north and east onto the western fringe of the Great Plains in South Dakota. It is found at slightly higher elevations farther south. Relative to other portions of the distribution, in central Montana this system occurs in areas with more summer rain than winter snow precipitation, more overall annual precipitation, and it occurs on glaciated landscapes. Across the entire distribution of this type, soils are typically deep and non-saline, often with a microphytic crust. This shrub-steppe is dominated by perennial grasses and forbs (>25% cover) with *Artemisia tridentata ssp. tridentata* (this is not at all important in Wyoming occurrences), *Artemisia tridentata ssp. xericensis, Artemisia tridentata ssp. wyomingensis, Artemisia tripartita ssp. tripartita* (Snake River valley in Wyoming), *Artemisia cana ssp. cana*, and/or *Purshia tridentata* dominating or codominating the open to moderately dense (10-40% cover) shrub layer. *Atriplex confertifolia, Chrysothamnus viscidiflorus, Ericameria nauseosa, Sarcobatus vermiculatus, Tetradymia* spp., or *Artemisia frigida* may be common especially in disturbed stands. In Montana and Wyoming, stands are more mesic, with more biomass contributed by grasses, have less shrub diversity than stands farther west, and 50 to 90% of the occurrences are dominated by *Artemisia tridentata ssp. wyomingensis* with *Pascopyrum smithii*. Associated graminoids can include *Achnatherum hymenoides, Calamagrostis montanensis, Elymus lanceolatus ssp. lanceolatus, Koeleria macrantha, Poa secunda, Pascopyrum* *smithii, Hesperostipa comata, Nassella viridula, Bouteloua gracilis*, and *Pseudoroegneria spicata*. Important rhizomatous species include *Carex filifolia* and *Carex duriuscula*, which are very common and important in the eastern distribution of this system in both Wyoming and Montana. *Festuca idahoensis* is uncommon in this system, although it does occur in areas of higher elevations/precipitation; *Festuca campestris* is also uncommon. In Wyoming, both *Nassella viridula* and *Pseudoroegneria spicata* rarely occur, with the latter typically found in eastern Wyoming on ridgetops and rocky slopes outside of this system. In Montana, there is an absence of *Festuca* spp., except *Vulpia octoflora*. Common forbs are *Phlox hoodii, Arenaria* spp., *Opuntia* spp., *Sphaeralcea coccinea, Dalea purpurea, Liatris punctata*, and *Astragalus* spp. Areas with deeper soils more commonly support *Artemisia tridentata ssp. tridentata* but have largely been converted for other land uses. The natural fire regime of this ecological system likely maintains a patchy distribution of shrubs, so the general aspect of the vegetation is a grassland. Shrubs may increase following heavy grazing and/or with fire suppression, particularly in moist portions of the northern Columbia Plateau where it forms a landscape mosaic pattern with shallow-soil scabland shrublands. Where fire frequency has allowed for shifts to a native grassland condition, maintained without significant shrub invasion over a 50- to 70-year interval, the area would be considered Columbia Basin Foothill and Canyon Dry Grassland (CES304.993). This ecological system is closely related to the warm-dry sagebrush in the resistance-resilience framework.

Distribution: This system occurs throughout much of the Columbia Plateau, the northern Great Basin, central and southeastern Montana, and Wyoming, and is found at slightly higher elevations farther south.

Nations: CA, US

States/Provinces: BC, CA, CO, ID, MT, NV, OR, UT, WA, WY

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, High Plains, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: G. Kittel, M.S. Reid, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This shrub-steppe is dominated by perennial grasses and forbs (>25% cover) with *Artemisia tridentata ssp. tridentata* (not at all important in Wyoming occurrences), *Artemisia tridentata ssp. xericensis, Artemisia tridentata ssp. wyomingensis, Artemisia tripartita ssp. tripartita* (Snake River valley in Wyoming), *Artemisia cana ssp. cana*, and/or *Purshia tridentata* dominating or codominating the open to moderately dense (10-40% cover) shrub layer. *Atriplex confertifolia, Chrysothamnus viscidiflorus, Ericameria nauseosa, Sarcobatus vermiculatus, Tetradymia* spp., or *Artemisia frigida* may be common, especially in disturbed stands. In Montana and Wyoming, stands are more mesic, with more biomass of grass, have less shrub diversity than stands farther west, and 50 to 90% of the occurrences are dominated by *Artemisia tridentata ssp. wyomingensis* with *Pascopyrum smithii*. In addition, *Bromus arvensis (= Bromus japonicus)* and *Bromus tectorum* are indicators of disturbance, and *Bromus tectorum* is typically not as abundant as in the Intermountain West, possibly due to a colder climate. Associated graminoids can include *Achnatherum hymenoides, Calamagrostis montanensis, Elymus lanceolatus ssp. lanceolatus, Koeleria macrantha, Poa secunda, Pascopyrum smithii, Hesperostipa comata, Nassella viridula, Bouteloua gracilis*, and *Pseudoroegneria spicata*. Important rhizomatous species include *Carex filifolia* and *Carex duriuscula*, which are very common and important in the eastern distribution of this system in both Wyoming and Montana. *Festuca idahoensis* is uncommon in this system, although it does occur in areas of higher elevations/precipitation; *Festuca campestris* is also uncommon. In Wyoming, both *Nassella viridula* and *Pseudoroegneria spicata* rarely occur, with the latter typically found in eastern Wyoming on ridgetops and rocky slopes outside of this system. In Montana, there is an absence of *Festuca* spp., except *Vulpia octoflora*. Common forbs are *Phlox hoodii, Arenaria* spp., *Opuntia* spp., *Sphaeralcea coccinea, Dalea purpurea, Liatris punctata*, and *Astragalus* spp. Areas with deeper soils more commonly support *Artemisia tridentata ssp. tridentata* but have largely been converted for other land uses. The natural fire regime of this ecological system likely maintains a patchy distribution of shrubs, so the general aspect of the vegetation is a grassland. Shrubs may increase following heavy grazing and/or with fire suppression, particularly in moist portions of the northern Columbia Plateau where it forms a landscape mosaic pattern with shallow-soil scabland shrublands. Where fire frequency has allowed for shifts to a native grassland condition, maintained without significant shrub invasion over a 50- to 70-year interval, the area would be considered Columbia Basin Foothill and Canyon Dry Grassland (CES304.993). The floristic description is based on several references, including Daubenmire (1970), Mueggler and Stewart (1980), Brown (1982a), Hironaka et al. (1983), West (1983c), Barbour and Billings (1988), Knight (1994), Holland and Keil (1995), Howard (1999), Tirmenstein (1999c), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Soil crust is not as important in sites with high vascular cover and lower cover of bare ground in relatively mesic sites for this sagebrush shrubland and steppe (Belnap et al. 2001). Great Basin crust diversity is based on Rosentreter and Belnap (2003). Late-successional sagebrush lichen diversity is based on Belnap et al. (2001). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus, *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin then warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common liverworts (3) include *Athalamia hyalina* and *Riccia* spp. Late successional sagebrush lichen (5): *Acarospora schleicheri, Massalongia carnosa, Fuscopannaria cyanolepra (= Pannaria cyanolepra), Trapeliopsis wallrothii*, and *Texosporium sancti-jacobi*.

Biotic Pollination; Species Diversity: Medium
Although the dominant shrubs in this system (*Artemisia tridentata ssp. tridentata, Artemisia tridentata ssp. wyomingensis* and/or *Artemisia tripartita*) are self- or wind-pollinated, most forbs and shrubs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Howard 1999, Tirmenstein 1999c). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds and bats important other species. Insects: Bees (Apoidea), butterflies

and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds (especially for red tubular flowers).

Nitrogen Fixation; Species Diversity: Medium
Big sagebrush shrub steppe occurs in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea*, and *Psoralidium*), some Rosaceae (*Purshia tridentata*), many Poaceae (*Bouteloua gracilis, Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana*, and *Pseudoroegneria spicata*), and some Brassicaceae can fix nitrogen in this system. Cyanobacteria (especially *Nostoc* and *Scytonema*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Pseudoroegneria spicata, Achnatherum hymenoides, Elymus lanceolatus, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Pascopyrum smithii, and *Poa secunda*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. White-tailed prairie dog (*Cynomys leucurus*) is considered a keystone species of Inter-Mountain Basins Big Sagebrush Steppe (CES304.778) (Kotliar et al. 2006), in the area of the Wyoming Basin ecoregion where the range of the species overlaps with the system. Prairie dog colonies create habitat that benefits numerous other species with their burrowing and foraging activities which influence environmental heterogeneity, hydrology, nutrient cycling, biodiversity, landscape architecture, and plant succession in grassland habitats (Kotliar et al. 2006). They are also an important food source for many animals, including badgers, coyotes, eagles, hawks, and the critically endangered black-footed ferret (*Mustela nigripes*) (Hoagland 2006). The U.S. Fish and Wildlife Service estimated that about 160 million hectares (395 million acres) of potential habitat historically existed in the U.S., and about 20% was occupied at any one time (Gober 2000).

Environment: This widespread matrix-forming ecological system occurs throughout much of the Columbia Plateau and northern Great Basin, east into the Wyoming Basins, central Montana, and north and east onto the western fringe of the Great Plains in Montana and South Dakota. It is found at slightly higher elevations farther south.

Climate: Climate is semi-arid and continental with annual precipitation ranging from 18-40 cm and with high inter-annual variation. Precipitation amount and time vary depending on location, with stands in the western portion of its range receiving winter/spring precipitation and very little summer precipitation, whereas stands in the eastern portion of its range receive both winter and summer precipitation. Much of the precipitation falls as snow and growing-season drought is characteristic. Temperatures are continental with large annual and diurnal variation. In central Montana, this system differs slightly, with more summer rain than winter precipitation, more precipitation annually, and it occurs on glaciated landscapes.

Physiography/landform: Stands occur on stream terraces, point bars, valley floors, alluvial fans, floodplains, washes, gullies, stabilized dunes, mesic uplands, swales, and rocky slopes. Slopes are variable from gentle to very steep.

Soil/substrates/hydrology: Soils are typically deep and non-saline, often with a microphytic crust.

The environmental description is based on several references, including Daubenmire (1970), Mueggler and Stewart (1980), Brown (1982a), Hironaka et al. (1983), West (1983c), Barbour and Billings (1988), Knight (1994), Holland and Keil (1995), Howard (1999), Tirmenstein (1999c), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Key Processes and Interactions: The natural fire regime of this ecological system likely maintains a patchy distribution of shrubs, so the general aspect of the vegetation is a grassland. Shrubs may increase following heavy grazing and/or with fire suppression, particularly in moist portions of the northern Columbia Plateau where it forms a landscape mosaic pattern with shallow-soil scabland shrublands. Response to grazing can be variable depending on the type of grazer and the season in which grazing occurs. *Hesperostipa comata* can increase in abundance in response to either grazing or fire. In central and eastern Montana (and possibly elsewhere), complexes of prairie dog towns are common in this ecological system. Microphytic crust is very important in this ecological system.

Complex ecological interactions of fire regimes and climate patterns result in equally complex patterns of species structure and composition in *Artemisia tridentata* stands. Prolonged drought on the more xeric sites may reduce shrub cover. Flooding may also cause mortality if the soil remains saturated for an extended period of time. The Aroga moth is capable of defoliating large acreages (i.e., >1000 acres, but usually 10-100 acres). Heavy grazing by wildlife can remove the fine fuels that support mixed-severity fires and result in woody fuel buildup that leads to severe, stand-replacement fires (LANDFIRE 2007a, BpS 1210800).

Big sagebrush stands are inhibited by fire as *Artemisia tridentata* does not sprout after burning (Tirmenstein 1999c). Conversely, increasing fire frequency significantly will eliminate the shrubs from the stands (Daubenmire 1970, Tirmenstein 1999c). With a change in fire frequency, species composition will be altered as well (West 1983c). With a high fire frequency (every 2-5 years), perennial grasses and shrubs are eliminated and non-native annual grasses dominate. At fire-return intervals of 10-30 years, short-lived resprouting shrubs such as *Chrysothamnus* or *Tetradymia* spp. dominate. At fire-return intervals of 30-70 years, a mixture of perennial bunchgrasses and non-sprouting shrubs is maintained (Johnson 2000b). Finally, in the complete absence of fire, deep-rooted shrubs such as *Artemisia tridentata* become dominant. At higher-elevation sites with absence of fire (>100 years), *Pinus monophylla* and *Juniperus osteosperma* trees may invade and eventually dominate sites (Tirmenstein 1999c).

Insects are an important component of many shrub-steppe and grassland systems. Mormon crickets and grasshoppers are natural components of many rangeland systems (USDA-APHIS 2003, 2010). There are almost 400 species of grasshoppers that inhabit the western United States with 15-45 species occurring in a given rangeland system (USDA-APHIS 2003). Mormon crickets are also present in many western rangelands and, although flightless, are highly mobile and can migrate large distances consuming much of the forage while travelling in wide bands (USDA-APHIS 2010). Following a high population year for grasshoppers or Mormon crickets and under relatively warm dry spring environmental conditions that favor egg hatching and grasshopper and Mormon cricket survival, there may be large population outbreaks that can utilize 80% or more of the forage in areas as large as 2000 square miles. Conversely, relatively cool and wet spring weather can limit the potential for outbreaks. These outbreaks are naturally occurring cycles and, especially during drought, can denude an area of vegetation leaving it exposed to increased erosion rates from wind and water (USDA-APHIS 2003).

Climatic variability may have been as important a disturbance agent as fire in these areas. Prolonged drought may have helped to reduce the density and cover of sagebrush. The size of the area effected by the drought would vary from 100s-1000s of acres and may be related to soil type (LANDFIRE 2007a).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has four classes in total (LANDFIRE 2007a, BpS 0911250). These are summarized as:

A) Early Development 1 All Structures (15% of type in this stage): Herbaceous canopy cover is variable (0-50%). This class is dominated by forbs with varying presence of grasses. Post-fire cover and recovery rates vary greatly depending on fire severity and post-fire precipitation amounts and timing as well as pre-fire species composition. This stage lasts 9-15 years, depending on how quickly sagebrush is able to begin reoccupying the area. Replacement fire (MFRI= 100 years) resets.

B) Mid Development 1 Open (30% of type in this stage): Dominant lifeform is herbaceous (20-40% cover), shrub cover 0-10%. Scattered and usually small sagebrush are present, but perennial grasses and forbs continue to dominate. The general formation is that of a shrub savanna. Sagebrush cover is usually 1-5% in this stage. Stands are 15-35 years old. Succession to class C. Replacement fire (MFRI= 100 years) reset to class A. Surface fires (MFRI=1000 years) maintain in class B.

C) Late Development 1 Open (35% of type in this stage): Shrubs have canopy cover of 11-20%. Sagebrush is codominant with the perennial grasses and forbs. The general formation is that of a shrub-steppe. Stands are 35-70 years old; succession to class D. Replacement fire (MFRI=100 years) reset to class A. Mixed fire (MFRI= 50 years) opens the stand to class B. Surface fire (MFRI=1000 years) keeps in class C.

D) Late Development 1 Closed (20% of type in this stage): Shrubs have canopy cover of 21-30%. Sagebrush is dominant with relatively low cover of perennial grasses and forbs. Sagebrush cover can be variable, with the lowest productivity sites reaching only about 15% canopy cover with large areas of bare ground and rock in the interspaces. The general formation is that of a shrubland. Stands are greater than about 70 years old. Replacement fire (MFRI=85 years) reset to class A. Mixed fire (MFRI= 85 years) opens the stand to class B.

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from agriculture (wheat farming and non-native hay production) where soils are deeper. Rangeland management such as sagebrush reduction treatments (frequent burning, herbicide spraying, and mechanical techniques such as plowing or mowing, and planting *Agropyron cristatum*) also convert large areas (Wambolt and Payne 1986, Beck et al. 2012). Another major conversion type is due to invasive non-native species such as *Bromus tectorum, Centaurea solstitialis, Hypericum perforatum, Poa pratensis, Taeniatherum caput-medusae* and *Ventenata dubia* (Young and Evans 1971, 1973, Mack 1981b, Pellant 1990, 1996, D'Antonio and Vitousek 1992, Chambers et al. 2007a, 2013, D'Antonio et al. 2009). These invasive species increase post-disturbance, including long-term excessive grazing by livestock, or direct soil disturbance from severe trampling by livestock, ORVs and roads. Altered fire regimes, such as repeated, high-frequency fires have eliminated shrubs and created extensive grasslands dominated by non-native invasive annual grass *Bromus tectorum* and other non-native annual species. Additionally, in some places fire suppression has allowed succession and conversion to woodlands (Tirmenstein 1999c, LANDFIRE 2007a, WNHP 2011).

The primary land uses that alter the natural processes of this system are associated with livestock management practices, invasive annual plant species, fire regime alteration, direct soil surface disturbance, and fragmentation. Excessive grazing stresses the system through soil disturbance, diminishing or eliminating the biological soil crust, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and annual grasses, particularly *Bromus tectorum* and other exotic annual bromes. If soil moisture is sufficient and sagebrush seeds are available, grazing can result in increased shrub density. There are strong links between foliose lichens and ecosystem health. Severe trampling breaks lichens into fragments too small to re-establish and eventually leads to foliose lichen elimination (Rosentreter and Eldridge 2002). Domestic livestock grazing is a widespread disturbance factor in sagebrush systems and can affect ecosystem condition. Inappropriate livestock grazing, in terms of stocking rate or season of use, can alter species composition, ecosystem function and structure (Dyksterhuis 1949, as cited by Veblen et al. 2011).

Fire further stresses livestock-altered vegetation by increasing exposure of bare ground and consequently increases exotic annuals and decreases perennial bunchgrass and sagebrush abundance. Fire suppression, even in the absence of livestock grazing impacts, can increase shrub density that in turn reduces bunchgrass cover or results in increased grass litter and fire fuel. Both conditions increase the probability of fire and vegetation responses that increase annual grass abundance following fire (Davies et al. 2009).

Any soil and bunchgrass layer disturbances, such as vehicle tracks or chaining shrubs, will increase the probability of alteration of vegetation structure and composition, and response to fire as discussed above. Loss of shrub density and degradation of the bunchgrass layer's native diversity decreases obligate shrub-steppe birds (Vander Haegen et al. 2000).

Fragmentation of shrub-steppe by agriculture increases cover of annual grasses, total annual/biennial forbs, and bare ground, and decreases cover of perennial forbs and biological soil crusts and reduces obligate insects (Quinn 2004) and obligate birds and small mammals (Vander Haegen et al. 2001). Fine fuel adjacency from alien annual grasses, such as *Bromus tectorum*, currently represents the most important fuelbed component in the system and can substantially increase the fire frequency. With a high fire frequency (every 2-5 years), perennial grasses and shrubs are eliminated and non-native annual grasses dominate. At fire-return intervals of 10-30 years, short-lived resprouting shrubs such as *Chrysothamnus* or *Tetradymia* spp. dominate. This expansion of juniper trees into *Artemisia tridentata*-dominated ecosystems has many effects on the ecology of the site, including reduction of understory cover and species, increased fuel load as trees grow and expand, resulting eventually in large, high-severity fires with high tree and shrub mortality (Miller et al. 2011, 2014). These severely burned areas are highly susceptible to invasion by annual grasses, often resulting in conversion to *Bromus tectorum*-dominated stands (Chambers et al. 2007a, Condon et al. 2011). Conversion of *Artemisia tridentata* ecosystems to invasive non-native annual grasses causes habitat degradation, fragmentation and loss for several species, including sage-grouse (*Centrocercus* spp.) which is now at risk for federal listing (Knick et al. 2003).

An assessment was conducted by Veblen et al. (2011) to evaluate rangewide impacts of livestock grazing across the sagebrush distribution. Most information on range condition is at the local scale and not consistently collected for regional or rangewide assessment; however, the study was able to compile and utilize available data. Using Land Health Standards (LHS) data and sagebrush vegetation characteristics, the study compared LHS across a subset of allotments within the sagebrush biome. Results showed 798 allotments (70%) that met and 333 allotments that did not meet LHS. Livestock grazing was identified as the reason for unmet standards for 132 (approximately 15%) of the 333 allotments that did not meet standards. Therefore, across the sagebrush distribution, a relatively small percentage of allotments are being significantly impacted by livestock grazing.

When grasshopper and Mormon cricket populations reach outbreak levels, they cause significant economic losses for ranchers and livestock producers, especially when accompanied by a drought (USDA-APHIS 2003, 2010). Both rangeland forage and cultivated crops can be consumed by grasshoppers. The U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) is the Federal agency responsible for controlling economic infestations of grasshoppers on western rangelands with a cooperative suppression program. They work with federal land managing agencies to conduct grasshopper suppression. The goal of APHIS's grasshopper program is not to eradicate them but to reduce outbreak populations to less economically damaging levels (USDA-APHIS 2003). This APHIS effort dampens the natural ecological outbreak cycles of grasshoppers and Mormon crickets but does not eradicate the species.

Human development has impacted many locations throughout the type distribution. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 57** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 58, left**) and sensitivity (**Figure 58, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

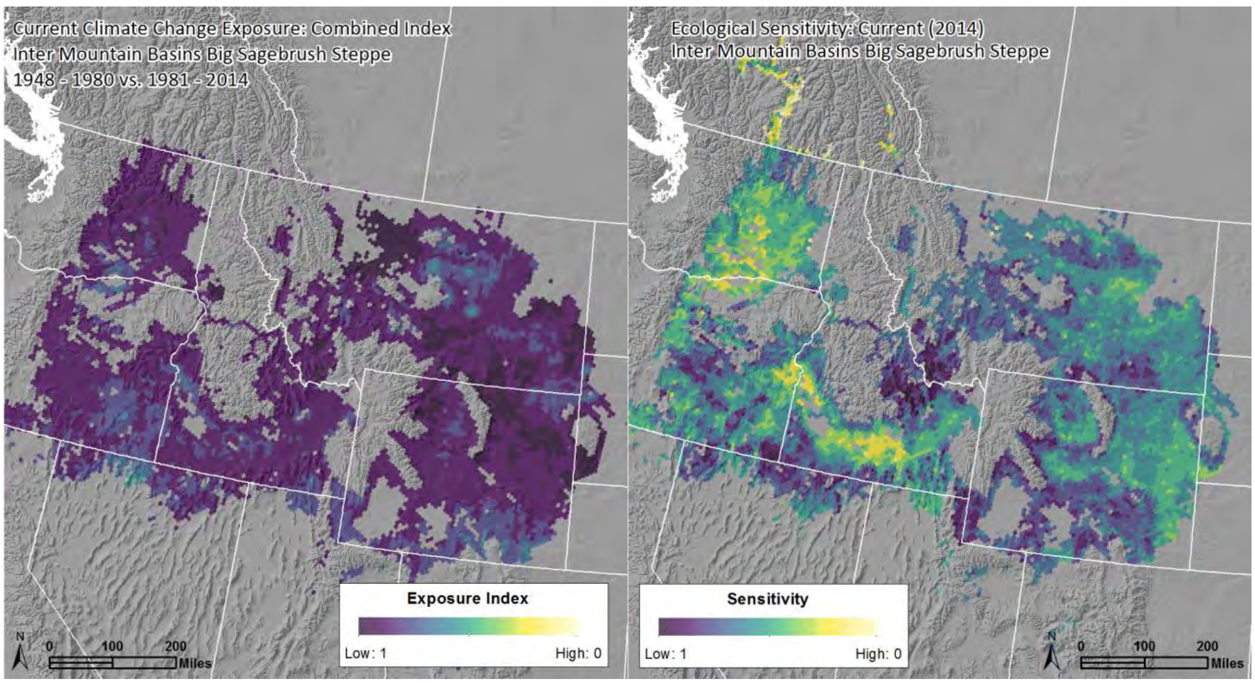

Figure 58. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Big Sagebrush Steppe. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 57. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Big Sagebrush Steppe by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	North-western Great Plains	Wyo-ming Basin	Northern Basin & Range	Columbia Plateau	Snake River Plain	Middle Rockies	Blue Moun-tains	North-western Glaciated Plains	Eastern Cascades Slopes & Foothills	Central Basin & Range	Southern Rockies	Columbia Mountains-Northern Rockies	Thomp son-Okana-gan Plateau	High Plains	Idaho Batho-lith	North Cas-cades	Wasatch & Uinta Moun-tains	Colorado Plateaus	Arizona-New Mexico Moun-tains	Cana-dian Rockies
	Sq miles within ecoregion	17,178	14,195	12,405	7,896	4,871	4,140	3,333	2,140	1,100	751	610	356	340	336	303	218	68	54	40	25
Contributions to Relative Vulnerability by Factor																					
Vulnerability from **Exposure (2014)**		**Mod** 0.63	**Mod** 0.61	**Mod** 0.59	**Mod** 0.63	**Mod** 0.61	**Mod** 0.63	**Mod** 0.62	**Mod** 0.65	**Mod** 0.59	**Mod** 0.57	**Mod** 0.59	**Mod** 0.64	**Mod** 0.67	**Mod** 0.62	**Mod** 0.61	**Mod** 0.64	**Mod** 0.57	**Mod** 0.53	**Mod** 0.59	**Mod** 0.64
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.71	0.72	0.67	0.26	0.40	0.49	0.54	0.43	0.47	0.56	0.70	0.34	0.29	0.47	0.53	0.32	0.51	0.43	0.55	0.44
	Fire Regime Departure	0.42	0.53	0.72	0.44	0.44	0.74	0.57	0.49	0.39	0.50	0.47	0.78	Null	0.54	0.60	0.43	0.71	0.46	0.21	0.44
	Invasive Annual Grasses	0.63	0.79	0.56	0.65	0.66	0.98	0.77	0.95	0.80	0.69	0.79	0.87	1.00	0.40	0.75	0.89	1.00	0.98	0.99	1.00
	Sensitivity Average	**0.59**	**0.68**	**0.65**	**0.45**	**0.50**	**0.74**	**0.63**	**0.62**	**0.55**	**0.58**	**0.65**	**0.67**	**0.65**	**0.47**	**0.63**	**0.55**	**0.74**	**0.63**	**0.58**	**0.63**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.18	0.24	0.21	0.14	0.14	0.30	0.28	0.12	0.22	0.22	0.30	0.23	0.24	0.22	0.43	0.33	0.31	0.22	0.17	0.20
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	0.88	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.34**	**0.54**	**0.35**	**0.32**	**0.32**	**0.40**	**0.39**	**0.31**	**0.36**	**0.36**	**0.40**	**0.36**	**0.37**	**0.36**	**0.47**	**0.41**	**0.40**	**0.36**	**0.33**	**0.35**
Vulnerability from Measures of **Overall Resilience**		**High** 0.47	**Mod** 0.61	**Mod** 0.50	**High** 0.39	**High** 0.41	**Mod** 0.57	**Mod** 0.51	**High** 0.47	**High** 0.46	**High** 0.47	**Mod** 0.53	**Mod** 0.52	**Mod** 0.51	**High** 0.41	**Mod** 0.55	**High** 0.48	**Mod** 0.57	**High** 0.49	**High** 0.46	**High** 0.49

Climate Change Vulnerability Index	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of this widespread sagebrush steppe system, exposure as of 2014 is moderate, but does show slight variation across ecoregions. An emerging pattern of changing climate appears as increases of 0.5° to 0.8°C for Annual Mean Temperature in all but four ecoregions where it occurs, ranging from 24% to 93% of its distribution in each ecoregion. However, over 1°C of increase is seen in the Northwest Glaciated Plains for 45% of its distribution. There are similar increases (up to 0.82°C) for Mean Temperature of the Warmest Quarter in five of the ecoregions where this system occurs. In three ecoregions (Columbia Plateau, Columbia Mountains, and North Cascades) the Mean Diurnal Range has decreased by 0.4°C for 15% of its distribution in the Columbia Plateau, where it is very common, and 72% in the North Cascades, where it is peripheral to the ecoregion.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced or possibly eliminated, effectively eliminating sagebrush recruitment.

Many stands of this shrubland occur in basins surrounded by ranges so it may be possible for species from this system to transition into foothill zone as suitable climate is diminished at lower elevations. Big sagebrush individuals are long-lived; frequently live 40-50 years with maximum ages of 100-150 years and so may be able to survive as relicts for decades without regeneration (Howard 1999, Tirmenstein 1999c). However, there could be accelerated loss of big sagebrush because of more frequent and extended drought, or more frequent and larger fires as a result of hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be moderate, with some areas that are high (lower numerical scores) across the range of this type. Sensitivity scores are particularly low (equating to high sensitivity) in the Columbia Plateau, Snake River Plain, and High Plains, ecoregions, due to the combination of extensive agriculture and development fragmenting occurrences and concentrations of invasive annual grasses, which in turn alters fire regimes.

Landscape condition varies from moderate to poor (**Table 57**), as the ecosystem occurs across extensive basins and areas where agriculture is a significant factor (e.g., Snake River Plain, Columbia Plateau, Columbia Mountains-Northern Rockies, North Cascades and Thompson-Okanogan Plateau). Infrastructure development is a factor in all its range. There are many small roads that fragment occurrences, and development of urban, suburban and exurban areas is significant.

Risk of invasive plants scored low in many ecoregions, but more pronounced in the Northwestern Great Plains, Northern Basin and Range, Columbia Plateau, Snake River Plain, North Cascades and High Plains ecoregions (**Figure 58**); these ecoregions encompass vast areas of cheatgrass invasion. Fire regime departure is moderate to high (indicated by lower scores), with the effects of fire suppression, grazing and fine-fuels introduction by invasive grasses interacting.

The interactions of the stressors of fragmentation by development, overgrazing, fire suppression, and invasive annual grass invasion have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity of this widespread sagebrush steppe system is low range wide. Topoclimatic variability is low or very low, as these shrublands occur across generally flat landforms and topography such as stream terraces, point bars, valley floors, alluvial fans, floodplains, washes, gullies, stabilized dunes, mesic uplands, swales, and rocky slopes. For the same increment of climate change, individual species must disperse longer distances more quickly to keep pace with change as compared with species in more topoclimatically heterogeneous landscapes. Therefore, the relatively high 'velocity' of change could result in loss of more previously characteristic species and introduction of novel species composition.

Diversity within three of the four identified functional species groups is moderate. Nitrogen-fixation, biotic pollination, and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae, Rosaceae*, *Brassicaceae* and *Poaceae* families, along with cyanobacteria and cyanolichens. Insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

The fourth functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

White-tailed prairie dog (*Cynomys leucurus*) was identified as playing a keystone role in this steppe ecological system. This species is not as wide-ranging as black-tailed prairie dog and overlaps in range with this ecological system only in the Wyoming Basin ecoregion. Due to its role as a keystone species, it's vulnerability to the recent change in climate was evaluated using the NatureServe Climate Change Vulnerability Index tool. It was found to be Less Vulnerable across the portion of its range that coincides with this system, suggesting it has been able to adapt to recent changes in climate conditions.

Vulnerability Summary for 1981-2014 Timeframe: Intermountain Basins Big Sagebrush Steppe scores into the high range of overall climate change vulnerability throughout its range, except in the Wyoming Basin and Middle Rockies ecoregions where it scores moderate vulnerability. The high vulnerability is primarily due to the generally moderate scores for exposure, adaptive capacity scores that tend towards low, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for low-diversity cold desert types that naturally occupy extensive flat plains and valley bottoms. For a given increment of climate change, individual species would need to disperse longer distances per year as compared with those that occur in more rugged landscapes that naturally support higher microclimate diversity. Additionally, these shrublands are highly susceptible to invasive plants throughout much of their range. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and wildfire-induced expansion of invasive plant species, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 58. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Big Sagebrush Steppe

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and viable prairie dog colonies; maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression or introduction of invasive plants as fine fuels. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Barbour and Billings 1988, Barbour et al. 2007a, Barnett and Crawford 1994, Beck et al. 2012, Bell et al. 2009, Belnap 2001, Belnap et al. 2001, Brown 1982a, CNHP 2010, Chambers et al. 2007a, Chambers et al. 2013, Comer et al. 2003*, Condon et al. 2011, Crawford et al. 2004, D'Antonio and Vitousek 1992, D'Antonio et al. 2009, Daubenmire 1970, Davies et al. 2009, Drut et al. 1994, Ecosystems Working Group 1998, Ersch 2009, Evans and Belnap 1999, Gober 2000, Gregg and Crawford 2009, Hironaka et al. 1983, Hoagland 2006, Holland and Keil 1995, Howard 1999, Johnson 2000b, Knick et al. 2003, Knight 1994, Kotliar et al. 2006, LANDFIRE 2007a, Mack 1981b, Miller et al. 2011, Miller et al. 2014, Mueggler and Stewart 1980, Pellant 1990, Pellant 1996, Quinn 2004, Rosentreter and Belnap 2003, Rosentreter and Eldridge 2002, Sawyer et al. 2009, Shiflet 1994, Tirmenstein 1999c, USDA-APHIS 2003, USDA-APHIS 2010, Vander Haegen et al. 2000, Vander Haegen et al. 2001, Veblen et al. 2011, WNHP 2011, WNHP unpubl. data, Wambolt and Payne 1986, West 1983c, West and Young 2000, Young and Evans 1971, Young and Evans 1973

CES304.785 Inter-Mountain Basins Montane Sagebrush Steppe

Figure 59. Photo of Inter-Mountain Basins Montane Sagebrush Steppe. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system includes sagebrush communities occurring at foothills (in Wyoming) to montane and subalpine elevations across the western U.S. from 1000 m in eastern Oregon and Washington to over 3000 m in the Southern Rockies. In Montana, it occurs on isolated mountains in the north-central portion of the state and possibly along the Boulder River south of Absarokee and at higher elevations. In British Columbia, it occurs between 450 and 1650 m in the southern Fraser Plateau and the Thompson and Okanagan basins. Climate is cool, semi-arid to subhumid. This system primarily occurs on deep-soiled to stony flats, ridges, nearly flat ridgetops, and mountain slopes. In general, this system is found on fine-textured soils, some source of subsurface moisture or more mesic sites, zones of higher precipitation, and areas of snow accumulation. Across its range, this is a compositionally diverse system. It is composed primarily of *Artemisia tridentata ssp. vaseyana, Artemisia cana ssp. viscidula*, and related taxa such as *Artemisia tridentata ssp. spiciformis*. *Purshia tridentata* may codominate or even dominate some stands. *Artemisia arbuscula ssp. arbuscula*-dominated shrublands commonly occur within this system on rocky or windblown sites. Other common shrubs include *Symphoricarpos* spp., *Amelanchier* spp., *Ericameria nauseosa*, *Peraphyllum ramosissimum*, *Ribes cereum*, and *Chrysothamnus viscidiflorus*. *Artemisia tridentata ssp. wyomingensis* may be present to codominant if the stand is clearly montane as indicated by montane indicator species such as *Festuca idahoensis*, *Leucopoa kingii*, or

Danthonia intermedia. Most stands have an abundant perennial herbaceous layer (over 25% cover, in many cases over 50% cover), but this system also includes *Artemisia tridentata ssp. vaseyana* shrublands. Common graminoids include *Danthonia intermedia, Festuca arizonica, Festuca idahoensis, Hesperostipa comata, Poa fendleriana, Elymus trachycaulus, Bromus carinatus, Poa secunda, Deschampsia cespitosa, Calamagrostis rubescens*, and *Pseudoroegneria spicata*. Species of *Achnatherum* are common, including *Achnatherum nelsonii ssp. dorei, Achnatherum nelsonii ssp. nelsonii, Achnatherum hymenoides*, and others. In many areas, wildfires can maintain an open herbaceous-rich steppe condition, although at most sites, shrub cover can be unusually high for a steppe system (>40%), with the moisture providing equally high grass and forb cover. This ecological system is closely related to the cool-moist sagebrush in the resistance-resilience framework.

Distribution: This system is found at montane and subalpine elevations across the western U.S. from 1000 m in eastern Oregon and Washington to over 3000 m in the Southern Rockies. In British Columbia, it occurs in the southern Fraser Plateau and the Thompson and Okanagan basins. This system occurs in mapzone 20 on the Rocky Mountain island ranges and on the western edge with mapzone 19.

Nations: CA, US

States/Provinces: AZ?, BC, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Klamath Mountains, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, High Plains, Southwestern Tablelands, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, California Coastal Sage, Chaparral, and Oak Woodlands, Southern California/Northern Baja Coast, Southern and Baja California Pine-Oak Mountains, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: R. Crawford, M.S. Reid and K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Across its range of distribution, this is a compositionally diverse system. It is composed primarily of *Artemisia tridentata ssp. vaseyana, Artemisia cana ssp. viscidula*, and related taxa such as *Artemisia tridentata ssp. spiciformis (= Artemisia spiciformis)*. *Purshia tridentata* may codominate or even dominate some stands. *Artemisia arbuscula ssp. arbuscula*-dominated shrublands commonly occur within this system on rocky or windblown sites. Other common shrubs include *Symphoricarpos* spp., *Amelanchier* spp., *Ericameria nauseosa, Peraphyllum ramosissimum, Ribes cereum*, and *Chrysothamnus viscidiflorus*. *Artemisia tridentata ssp. wyomingensis* may be present to codominant if the stand is clearly montane as indicated by montane indicator species such as *Festuca idahoensis, Leucopoa kingii*, or *Danthonia intermedia*. Most stands have an abundant perennial herbaceous layer (over 25% cover, in many cases over 50% cover), but this system also includes *Artemisia tridentata ssp. vaseyana* shrublands that generally have lower herbaceous cover and may have higher shrub cover. Common graminoids include *Achnatherum nelsonii ssp. dorei, Achnatherum nelsonii ssp. nelsonii, Achnatherum hymenoides, Bromus carinatus, Calamagrostis rubescens, Carex* spp., *Danthonia intermedia, Danthonia parryi, Deschampsia cespitosa, Elymus trachycaulus, Festuca arizonica, Festuca idahoensis, Festuca thurberi, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Pascopyrum smithii, Poa fendleriana, Poa secunda*, or *Pseudoroegneria spicata*. Forbs are often numerous and an important indicator of health. Forb species may include species of *Castilleja, Potentilla, Erigeron, Phlox, Astragalus, Geum, Lupinus*, and *Eriogonum*, as well as *Balsamorhiza sagittata, Achillea millefolium, Antennaria rosea, Eriogonum umbellatum, Fragaria virginiana, Artemisia ludoviciana,* *Hymenoxys hoopesii (= Helenium hoopesii)*, etc. In many areas, wildfires can maintain an open herbaceous-rich steppe condition, although at most sites, shrub cover can be unusually high for a steppe system (>40%), with the moisture providing equally high grass and forb cover. The vegetation description is based on several other references, including Daubenmire (1970), Young et al. (1977), Mueggler and Stewart (1980), Brown (1982a), Hironaka et al. (1983), West (1983c), Barbour and Billings (1988), Padgett et al. (1989), Knight (1994), Hansen et al. (1995), Holland and Keil (1995), Howard (1999), Johnson (2000b), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Functional Species Groups: Species play key functional roles in ecosystems, such as pollination, nitrogen fixation, substrate development, plant and animal dispersal, and others. Below are key functional roles for this type and groups of species that serve those roles across its distribution. The diversity of species playing the functional role is rated as High, Medium or Low.

Biological Soil Crust; Species Diversity: High
Soil crust is not as important in sites with high vascular cover and lower cover of bare ground in relatively mesic/higher elevation sites for this montane sagebrush shrubland and steppe (Belnap et al. 2001). Great Basin crust diversity is based on Rosentreter and Belnap (2003). Late-successional sagebrush lichen diversity is based on Belnap et al. (2001). Cyanobacteria (17): *Microcoleus vaginatus* is dominant, plus *Anabaena* spp., *Chroococcus minimus, Gloeothece palea, Lyngbya* spp., *Nostoc* spp., *Oscillatoria agardhii, Phormidium* spp., *Scytonema schmidtii*, and *Tolypothrix* spp. Lichens are similar to those in the Colorado Plateau in the southern Great Basin (21): *Collema tenax* and *Collema coccophorum* dominate sandy/silty sites. Other lichens include *Acarospora schleicheri, Buellia elegans, Caloplaca tominii, Catapyrenium squamulosum, Cladonia pyxidata, Diploschistes muscorum, Endocarpon pusillum, Fulgensia* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp., plus additional species (14) in the northern Great Basin: *Aspicilia desertorum, Candelariella terrigena, Leptochidium albociliatum, Leptogium lichenoides, Massalongia carnosa, Ochrolechia inaequatula, Physconia detersa, Psora* spp., *Psorotichia nigra*, and *Peltigera rufescens*. Algal diversity is higher in the Great Basin then warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Syntrichia ruralis*. Common Liverworts (3) include *Athalamia hyalina* and *Riccia* spp. Late-successional sagebrush lichens (5): *Acarospora schleicheri, Massalongia carnosa, Fuscopannaria cyanolepra (= Pannaria cyanolepra), Trapeliopsis wallrothii*, and *Texosporium sancti-jacobi*.

Biotic Pollination; Species Diversity: Medium
Although the dominant shrubs in this system (*Artemisia tridentata ssp. vaseyana* and/or *Artemisia tripartita*) are self- or wind-pollinated, most forbs and shrubs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Howard 1999, Tirmenstein 1999c). Pollinator loss will decrease seed production and recruitment of these plants, which are important components in the food web of this ecosystem. For example, forbs are important direct and indirect (via insects) food sources for sage-grouse (Barnett and Crawford 1994, Drut et al. 1994, Crawford et al. 2004, Ersch 2009, Gregg and Crawford 2009). Insects are the primary pollinators with birds and bats important other species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds.

Nitrogen Fixation; Species Diversity: Medium
Big sagebrush shrub steppe occurs in semi-arid climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. These semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Most species of Fabaceae (including species of *Astragalus, Dalea*, and *Psoralidium*), some Rosaceae (*Amelanchier utahensis, Peraphyllum ramosissimum, Purshia tridentata*), many Poaceae (*Bouteloua gracilis, Hesperostipa*

comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana, and *Pseudoroegneria spicata*), and some Brassicaceae can fix nitrogen in this system. Cyanobacteria (especially *Nostoc* and *Scytonema*) and cyanolichens fix large amounts of soil nitrogen and carbon and can be an important source of soil nitrogen in desert and semi-desert ecosystems (Evans and Belnap 1999, Belnap et al. 2001, Belnap 2001). Common heterocystic (special N-fixing type of cyanobacteria) genera found in soil crusts include *Anabaena, Nostoc*, and *Scytonema*. Common N-fixing soil lichens include *Nostoc*-containing species of *Collema*, and *Scytonema*-containing species of *Heppia* (Belnap 2001).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Achnatherum hymenoides, Achnatherum nelsonii, Bromus carinatus, Calamagrostis rubescens, Danthonia intermedia, Deschampsia cespitosa, Elymus lanceolatus, Elymus trachycaulus, Festuca arizonica, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Leucopoa kingii, Pascopyrum smithii, Poa fendleriana, Poa secunda, and *Pseudoroegneria spicata*.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this big sagebrush shrubland type.

Environment: This ecological system includes sagebrush communities occurring at foothills (in Wyoming) to montane and subalpine elevations across the western U.S. from 1000 m elevation in eastern Oregon and Washington to over 3000 m in the Southern Rockies. In Montana, it occurs in isolated mountains in the north-central portion of the state and possibly along the Boulder River south of Absarokee and at higher elevations. In British Columbia, it occurs between 450 and 1650 m in the southern Fraser Plateau and the Thompson and Okanagan basins.

Climate: Climate is cool, semi-arid to subhumid with yearly precipitation ranging from 25 to 90 cm/year. Much of this precipitation falls as snow. In general, this system occurs on fine-textured soils, some source of subsurface moisture or more mesic sites, zones of higher precipitation, and areas of snow accumulation.

Physiography/landform: This system primarily occurs on deep-soiled to stony flats, ridges, nearly flat ridgetops, and mountain slopes. Stands occur on all aspects, but the higher-elevation occurrences may be restricted to south- or west-facing slopes.

Soil/substrates/hydrology: Soils generally are moderately deep to deep, well-drained, and of loam, sandy loam, clay loam, or gravelly loam textural classes; soils often have a substantial volume of coarse fragments and are derived from a variety of parent materials.

The environmental description is based on several other references, including Daubenmire (1970), Young et al. (1977), Mueggler and Stewart (1980), Brown (1982a), Hironaka et al. (1983), West (1983c), Barbour and Billings (1988), Padgett et al. (1989), Knight (1994), Hansen et al. (1995), Holland and Keil (1995), Howard (1999), Johnson (2000b), West and Young (2000), Barbour et al. (2007a), and Sawyer et al. (2009).

Key Processes and Interactions: Complex ecological interactions of fire regimes and climate patterns result in equally complex patterns of species structure and composition in *Artemisia tridentata* stands (Johnson 2000b). Healthy stands often have a very productive herbaceous understory that is high quality forage for livestock.

Like other big sagebrush subspecies, *Artemisia tridentata ssp. vaseyana* stands are inhibited by fire as *Artemisia tridentata* does not sprout after being top-killed by fire and may take over 10 years to form stands with 20% or more cover (Johnson 2000b, Sawyer et al. 2009). Winward (1991) suggests *Artemisia tridentata ssp. vaseyana* shrublands have a natural fire regime of 10-30 years. Presettlement fires tended to be patchy, forming a mosaic of different age and density of shrubs because of different fire intensity across the landscape (Winward 1991, Tart 1996). Regeneration of mountain big sagebrush is from on-site or off-site seed and, depending on circumstances of the environment and seed source, *Artemisia tridentata* *ssp. vaseyana* seeds may sprout abundantly or very sparsely the following spring after burning (Johnson 2000b). Establishment after severe fires may proceed more slowly (Bunting et al. 1987, Johnson 2000b). Increasing fire frequency significantly will eliminate the shrubs from the stands (Daubenmire 1970, Johnson 2000b). Stand species composition will be altered with changes in fire frequency (West 1983c). With a high fire frequency (every 2-5 years), perennial grasses and shrubs are eliminated and non-native annual grasses dominate. At fire-return intervals of 10-30 years, short-lived resprouting shrubs such as *Chrysothamnus* or *Tetradymia* spp. dominate. At fire-return intervals of 30-70 years, a mixture of perennial bunch grasses and non-sprouting shrubs is maintained (Johnson 2000b). Finally, in the complete absence of fire, deep-rooted shrubs such as *Artemisia tridentata* become dominant. At higher-elevation sites with absence of fire (>100 years), trees such as *Pinus monophylla, Juniperus occidentalis*, and *Juniperus osteosperma* may invade and eventually dominant sites (Young et al. 1977, Bunting 1990, Johnson 2000b).

In addition, prolonged drought on the more xeric sites may reduce shrub cover. Flooding may also cause mortality if the soil remains saturated for an extended period of time. The Aroga moth is capable of defoliating large acreages (i.e., >1000 acres), but usually effected areas are relatively small (10-100 acres). Of the three big sagebrush subspecies and black sagebrush, *Artemisia tridentata ssp. vaseyana* was found to be the most palatable browse for elk (Wambolt 1995, 1996). These big game preference differences may make it more sensitive to effects of browsing. Heavy grazing in these mountain shrub-steppes may decrease fire frequency due to consumption of herbaceous forage (fine fuels), resulting in increased shrub density (woody fuel buildup) that leads to severe, stand-replacement fires (LANDFIRE 2007a, BpS 1211260).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total and two classes (classes D & E) that model conversion to forest systems (LANDFIRE 2007a, BpS 1211260). These are summarized as:

A) Early Development 1 Open (herbaceous-dominated - 20% of type in this stage): Herbaceous cover is variable but typically >50% (50-80%). Shrub cover is 0-5%. Replacement fire (mean fire return interval (FRI) of 80 years) setbacks succession by 12 years. Succession to class B after 12 years.

B) Mid Development 1 Open (shrub-dominated - 50% of type in this stage): Shrub cover 6-25%. Mountain big sagebrush cover up to 20%. Herbaceous cover is typically >50%. Initiation of conifer seedling establishment. Replacement fire mean FRI is 40 years. Succession to class C after 38 years.

C) Late Development 1 Closed (shrub-dominated - 15% of type in this stage): Shrubs are the dominant lifeform with canopy cover of 26-45+%. Herbaceous cover is typically <50%. Conifer (juniper, pinyon-juniper, ponderosa pine or white fir) cover <10%. Insects and disease every 75 years on average will thin the stand and cause a transition to class B. Replacement fire occurs every 50 years on average. In the absence of fire for 80 years, vegetation will transition to class D. Otherwise, succession keeps vegetation in class C.

D) Late Development 1 Open (conifer-dominated - 10% of type in this stage): Conifers are the upper lifeform (juniper, pinyon-juniper, ponderosa pine, limber pine or white fir). Conifer cover is 11-25%. Shrub cover generally less than mid-development classes but remains between 26-40%. Herbaceous cover <30%. The mean FRI of replacement fire is 50 years. Insects/diseases thin the sagebrush, but not the conifers, every 75 years on average, without causing a transition to other classes. Succession is from class C to class D after 50 years.

E) Late Development 2 Closed (conifer-dominated - 5% of type in this stage): Conifers are the dominant lifeform (juniper, pinyon-juniper, ponderosa pine, limber pine or white fir). Conifer cover ranges from 26-80% (pinyon-juniper 36-80% (Miller and Tausch 2001), juniper 26-40% (Miller and Rose 1999) and white fir 26-80%). Shrub cover 0-20%. Herbaceous cover <20%. The mean FRI for replacement fire is longer than in previous states (75 years). Conifers are susceptible to insects/diseases that cause diebacks (transition to class D) every 75 years on average (LANDFIRE 2007a). The woodland systems that this montane sagebrush system would succeed into vary by location.

ECOLOGICAL INTEGRITY

Change Agents: Conversion of *Artemisia tridentata* ecosystems to invasive, non-native grasses and forbs causes habitat degradation, fragmentation and loss for several species, including sage-grouse (*Centrocercus* spp.) which is now being considered for federal listing (Knick et al. 2003). Another potential means to ecological conversion of mountain sagebrush shrubland system is succession to conifer woodlands. With severe fire regime alteration and extended fire suppression, trees, especially junipers and pinyons, colonized these shrublands and grow to the eventual exclusion of the shade-intolerant sagebrush (LANDFIRE 2007a).

The primary land uses that alter the natural processes of this system are associated with domestic livestock grazing and introduction of exotic grasses. Excessive grazing stresses the system through soil disturbance, altering the composition of perennial species, and increasing the establishment of native disturbance-increasers and grasses, particularly *Poa pratensis*, a grazing-tolerant, exotic perennial grass. Excessive cattle grazing will decrease the abundance of native bunch grasses such as *Festuca idahoensis, Koeleria macrantha*, and *Pseudoroegneria spicata*, and increase the cover of grazing-tolerant grass species and forbs (Tart 1996). Overgrazing by sheep will also decrease some forbs, such as species of *Geranium, Ligusticum, Packera*, and *Potentilla*, and increase others, such as species of *Achillea, Antennaria, Arenaria*, and *Lupinus* (Tart 1996). In general, heavy grazing also favors shrubs that increase in density and cover and reduces the herbaceous layer (fine fuels) that allows fire to spread, which reduces fire frequency (Tart 1996).

Domestic livestock grazing is a widespread disturbance factor in sagebrush systems and can affect ecosystem condition (Veblen et al. 2011). Inappropriate livestock grazing, in terms of stocking rate or season of use, can alter species composition, ecosystem function and structure (Dyksterhuis 1949, as cited by Veblen et al. 2011). An assessment was conducted by Veblen et al. (2011) to evaluate rangewide impacts of livestock grazing across the sagebrush biome. Most information on range condition is at the local scale and not consistently collected for regional or rangewide assessment; however, the study was able to compile and utilize available data. Using LHS data and sagebrush vegetation characteristics, the study compared LHS across a subset of allotments within the sagebrush biome. Results showed 798 allotments (70%) that met and 333 allotments that did not meet LHS. Livestock grazing was identified as the reason for unmet standards for 132 (approximately 15%) of the 333 allotments that did not meet standards. Therefore, across the sagebrush biome, a relatively small percentage of allotments are being significantly impacted by livestock grazing.

Human development has impacted many locations throughout the type's distribution. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation is removed for building sites or more indirectly through natural fire regime alteration, and/or the introduction of invasive species. Mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species.

CLIMATE CHANGE VULNERABILITY

Climate Change Vulnerability Assessment: As described in the methods above, the results presented below are as of 2014, assessing climate change that has already occurred, and are not a forecast of future change over upcoming decades. The numeric scores and ratings for the components of the vulnerability assessment are provided in **Table 59** for this ecological system. The numeric scores can range from 0.01 to 1, with 0.01 indicating the most vulnerability, and 1 the least, for each metric. The lowest quartile (i.e. from 0 to 0.25) of index scores indicate Very High vulnerability to climate change effects within the assessment timeframe. Two maps are provided showing the spatial results for exposure (**Figure 60, left**) and sensitivity (**Figure 60, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

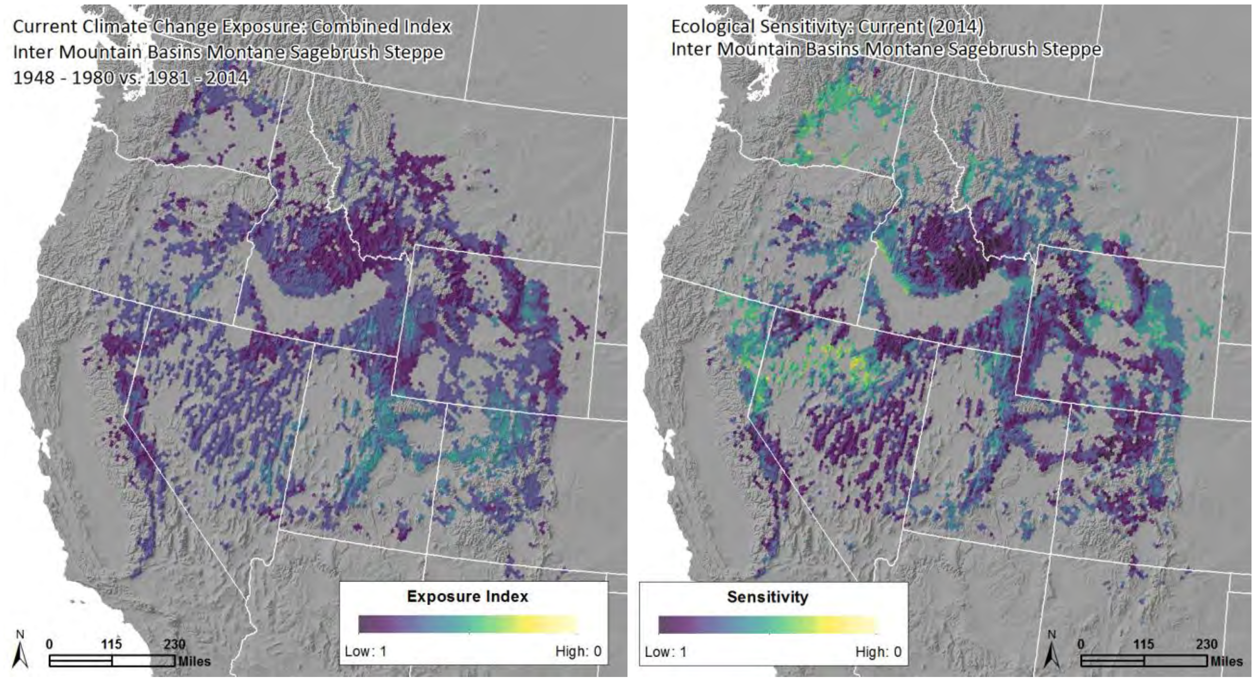

Figure 60. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Montane Sagebrush Steppe. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 59. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Montane Sagebrush Steppe by CEC ecoregion, for each metric and factor. The table is arrayed by CEC ecoregions in the columns and the factors and metrics in the rows, with the score for each factor/metric for each ecoregion in the cells. The ecoregions are ordered from most potential distribution (left) to the least (right). Ecoregions where the system has less than 19 miles² (50 km²) of potential extent are not scored. Scores can range from 0.01 to 1; a score closer to zero indicates greater contribution to vulnerability under each measure. A "null" in a cell indicates the metric was not scored for that particular ecoregion, e.g. no fire regime data are available for Mexico or Canada. Cell colors match the colors used in the maps above for each system; with yellow indicating greatest vulnerability or exposure, and dark purple the least.

	CEC Ecoregion	Middle Rockies	Central Basin & Range	Northern Basin & Range	Wyoming Basin	Southern Rockies	Idaho Batholith	Blue Moun-tains	Snake River Plain	Wasatch & Uinta Moun-tains	North-western Great Plains	Colorado Plateaus	Columbia Plateau	Eastern Cascades Slopes & Foothills	Sierra Nevada	Columbia Mountains-Northern Rockies	Mojave Basin & Range	North-western Glaciated Plains	North Cascades
	Sq miles within ecoregion	6,152	4,914	4,649	4,202	2,375	2,226	1,762	1,641	1,476	1,094	869	683	309	274	126	43	42	39
Contributions to Relative Vulnerability by Factor																			
Vulnerability from **Exposure (2014)**		**Mod** 0.57	**Mod** 0.54	**Mod** 0.55	**Mod** 0.55	**Mod** 0.51	**Mod** 0.55	**Mod** 0.55	**Mod** 0.55	**High** 0.49	**Mod** 0.55	**High** 0.48	**Mod** 0.55	**Mod** 0.54	**Mod** 0.57	**Mod** 0.55	**Mod** 0.54	**Mod** 0.60	**Mod** 0.55
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.71	0.82	0.78	0.74	0.74	0.69	0.62	0.55	0.62	0.62	0.69	0.19	0.74	0.64	0.25	0.82	0.53	0.40
	Fire Regime Departure	0.71	0.53	0.67	0.66	0.62	0.64	0.57	0.68	0.54	0.67	0.60	0.44	0.42	0.60	0.63	0.61	0.69	0.39
	Invasive Annual Grasses	0.99	0.89	0.88	0.97	0.97	0.91	0.90	0.82	1.00	0.66	0.98	0.86	0.64	0.85	0.97	0.83	1.00	0.83
	Sensitivity Average	**0.81**	**0.75**	**0.78**	**0.79**	**0.78**	**0.75**	**0.70**	**0.68**	**0.72**	**0.65**	**0.76**	**0.50**	**0.60**	**0.69**	**0.62**	**0.75**	**0.74**	**0.54**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.42	0.44	0.41	0.33	0.38	0.51	0.33	0.23	0.42	0.25	0.34	0.15	0.23	0.34	0.22	0.49	0.25	0.36
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.46**	**0.47**	**0.45**	**0.42**	**0.44**	**0.51**	**0.42**	**0.37**	**0.46**	**0.37**	**0.42**	**0.33**	**0.37**	**0.42**	**0.36**	**0.49**	**0.38**	**0.43**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.63	**Mod** 0.61	**Mod** 0.62	**Mod** 0.60	**Mod** 0.61	**Mod** 0.63	**Mod** 0.56	**Mod** 0.52	**Mod** 0.59	**Mod** 0.51	**Mod** 0.59	**High** 0.41	**High** 0.48	**Mod** 0.56	**High** 0.49	**Mod** 0.62	**Mod** 0.56	**High** 0.49
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**High**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of this widespread sagebrush steppe system, exposure as of 2014 is moderate, but does show some variation across ecoregions. The recent exposure has tipped into high in the Wasatch and Uintas, and Colorado Plateau ecoregions. In all but three of the 17 ecoregions, an emerging pattern of climate change appears as increases of 0.5° to 0.76°C for Annual Mean Temperature and similar increases (up to 0.79°C) for Mean Temperature of the Warmest Quarter in eight ecoregions. These increases are seen for somewhere between 28% and 96% of the system's distribution in any one ecoregion. In seven ecoregions, the Mean Diurnal Range has decreased by 0.5°C, suggesting that the difference between day-time maximums and night-time minimums is decreasing. This pattern is reflected across 10% to 78% of the system's distribution in any one ecoregion.

Climate Change Effects: Potential climate change effects would likely include a shift to plant species more common on hotter, drier sites, if climate change has the predicted effect of less available moisture with increasing mean temperature. Ecological consequences from such a climate shift would be similar to extended drought. Seedling establishment and survival would be reduced or possibly eliminated, effectively eliminating shrub recruitment. Warming climate with more frequent droughts can weaken big sagebrush individuals and eliminate recruitment.

Ecosystem Resilience: Sensitivity: Across the range of this very widespread sagebrush system, sensitivity to climate change tends to be low (higher scores) to moderate; with one ecoregion (Columbia Plateau) showing high sensitivity. The drivers of this sensitivity are primarily landscape condition and fire regime departure; risk of invasive grasses tends to be low in this higher elevation and more mesic shrubland type.

Landscape condition is particularly poor (low scores) in the Columbia Plateau, Columbia Mountains-Northern Rockies, and North Cascades ecoregions. The Columbia Plateau is an area of extensive agricultural activity that may have impacts on these shrublands. Elsewhere, including the 12 ecoregions with moderate landscape condition, infrastructure development is a factor; there are many small roads that fragment occurrences, and development of residential exurban areas is significant in some locations. Mining operations and transmission corridors are other impacts.

Risk of invasive grasses is low in all but one ecoregion, where it is moderate. This is to be expected as this system generally occurs at elevations above the zone of cheatgrass invasion and abundance, or on sites that are mesic and more resistant to cheatgrass invasion. However, this could change as increasing temperatures could enable higher elevation expansion of cheatgrass. Fire regime departure shows a different pattern, in that most ecoregions have moderate departure while three scored in the high range. Fire suppression can lead to invasion of conifers into these sagebrush communities, and livestock grazing (both sheep and cattle) reduces the cover of native bunchgrasses, which alters the fire regime over time.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these shrublands. Together, these result in an increased sensitivity of the system to the effects of changes in temperature or precipitation patterns in some of the ecoregions where it occurs.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low across the range of this widespread montane sagebrush system, being lowest in the Columbia Plateau ecoregion. Topoclimatic variability is low or very low throughout most of its range, but moderate in the Idaho Batholith ecoregion. These montane shrublands occur across moderate-relief landforms and topography, such as mountain slopes, nearly flat ridgetops, and ridges. Therefore, in some cases, they occur where local climates vary within short distances. Many options exist for species to move across these landscapes to adapt to changing climate conditions.

Diversity within three of the four identified functional species groups is moderate. Nitrogen-fixation, biotic pollination, and the diversity of cool-season perennial graminoids are the most limiting, with moderate within stand diversity for each of these groups. Nitrogen-fixing is provided by plants in the *Fabaceae, Rosaceae, Brassicaceae* and *Poaceae* families, along with cyanobacteria and cyanolichens. Insect taxa and some hummingbirds provide a critical function by pollinating the forbs that are important components of this system. Cool-season perennial graminoids are an important characteristic of this system, and variation in the amount and timing of precipitation influences the relative abundance of them. Cool-season plants use the most common C3 photosynthesis pathway to fix carbon, which is the most efficient under relatively moist conditions in winter and spring when temperatures are cool enough to avoid/reduce photo-respiration.

The fourth functional species group has high diversity; species of cyanobacteria, lichens, microfungi, algae, mosses and liverworts that contribute to substrate developing soils crusts appear to be naturally very diverse across the range of this type.

No keystone species were identified for this type, and therefore there is no contribution to vulnerability from this source.

Vulnerability Summary for 1981-2014 Timeframe: Intermountain Basins Montane Sagebrush Steppe scores into the moderate range of overall climate change vulnerability throughout its range, except in the Columbia Plateau ecoregion where it scores with high vulnerability. The moderate vulnerability is primarily due to the moderate scores for exposure, the moderate to low adaptive capacity scores, and variable contributions from sensitivity measures. In addition to low to moderate scores for topoclimate variability, these shrublands have moderate diversity within key functional species groups, such as nitrogen fixing species or biotic pollination and moderate to low fire regime departure that is manifested by juniper and pinyon invasion with fire suppression. Therefore, common effects of land use throughout the West, including surface disturbance from roads, grazing effects, and altered fire regime, have direct and substantial impact, increasing inherent vulnerability of this type.

Climate Change Adaptation: Adaptation to climate change in the management of this type could vary, depending on the relative degree of vulnerability and its contributing factors. These will vary across the range of the type; below some of the major kinds of strategies that might be considered for this type are characterized.

Table 60. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Montane Sagebrush Steppe

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Low	**Manage for persistence**, with actions focused on preventing impacts by non-climate stressors. Limit surface disturbance from new infrastructure, fire breaks, ORVs, and concentrated livestock use. Protect undisturbed soil crusts and maintain natural wildfire regimes. Limit fragmentation of contiguous occurrences especially when surrounded by other natural vegetation types.
Moderate	**Emphasize restoration to enhance resilience.** Restore native bunchgrass and forb diversity, considering trends in soil moisture regime, and evaluate needs for restoring species providing other functional roles (cool season grasses, nitrogen fixers, etc.). Localize models for wildfire regimes and restore regimes where they have been severely altered from prior wildfire suppression. Monitor for invasive plant expansion and effects of climate stress, including shrub regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Monitor for invasive expansion and effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Update and modify models for wildfire regimes suitable to forecasted future conditions.
Very High	**Plan for transformation to novel conditions.** Identify zones of likely invasion from exotics and from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for maintaining all identified functional species groups. Monitor for effects of climate stress, including shrub regeneration and loss/gain of neighboring species. Create new models for wildfire regime suitable to forecasted future conditions. Consider needs for "assisted migration" of most vulnerable species.

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