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

FORESTS & WOODLANDS

FINAL REPORT

Final Report for

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SUBMITTED TO

Department of the Interior
Bureau of Land Management

SUBMITTED BY

NatureServe
4600 North Fairfax Dr., 7th Floor
Arlington, VA 22203

COVER PHOTO

TITLE PHOTO

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- *Forests and Woodlands*

CO-PRINCIPAL INVESTIGATORS

Patrick Comer & Healy Hamilton, PhD

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Technical Report Contents

This report contains the conceptual models and resilience and vulnerability assessment results for a selection of forest and woodland ecological systems 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-four forest and woodland 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 mi^2 (mapped potential distribution)	Total mi^2 (mapped current distribution)	% of U.S. range on BLM lands
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%

System Name	Total mi^2 (mapped potential distribution)	Total mi^2 (mapped current distribution)	% of U.S. range on BLM lands
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%
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%
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			
Sonoran Paloverde-Mixed Cacti Desert Scrub	50,774	37,033	35.6%
Chihuahuan Creosotebush Desert Scrub	35,704	44,764	20.3%

System Name	Total mi^2 (mapped potential distribution)	Total mi^2 (mapped current distribution)	% of U.S. range on BLM lands
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%

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, mapped at 90m pixel resolution, or upscaled to 800m pixel resolution, are used, 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.

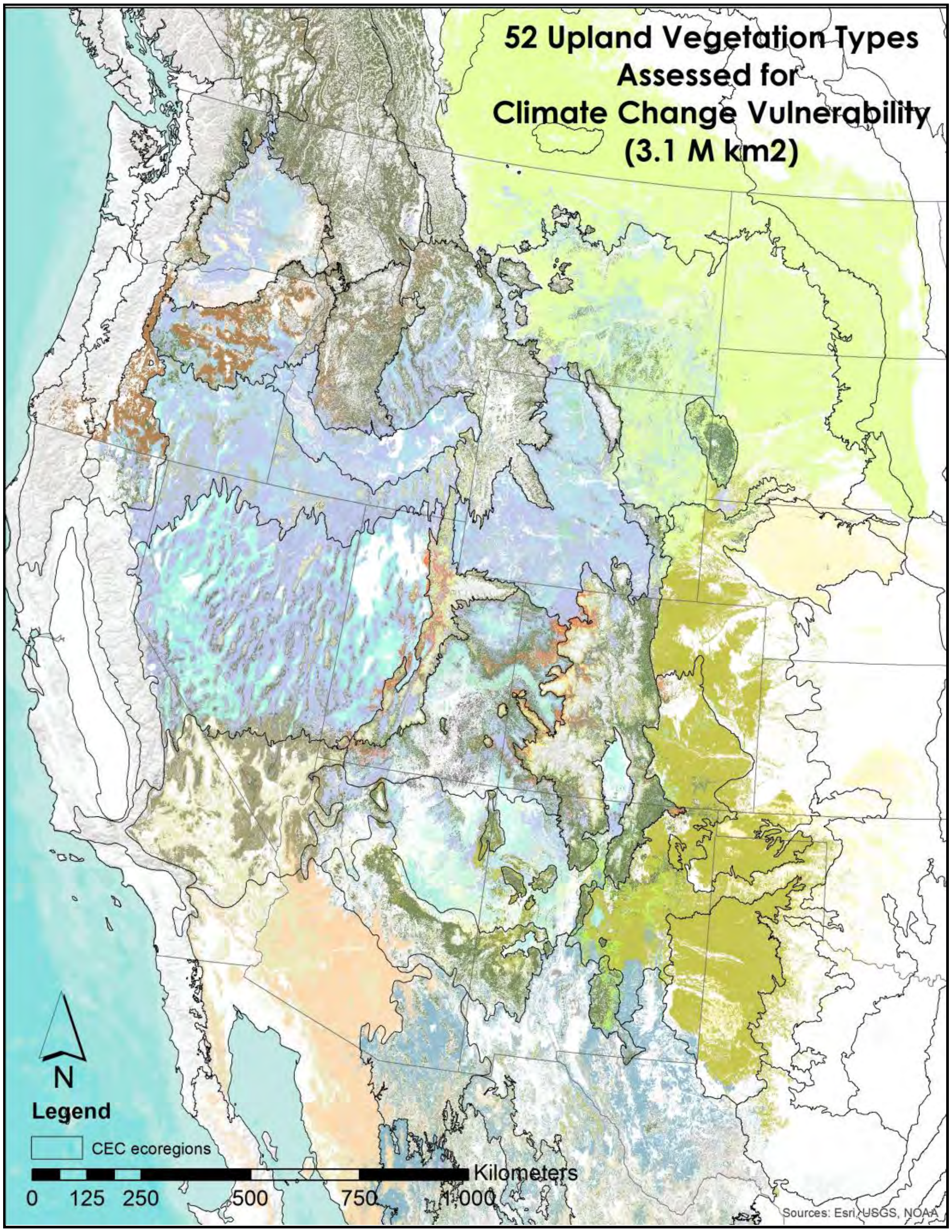

Figure 1. Mapped distributions of 52 ecological systems in western North America, with boundaries of the CEC ecoregions used for reporting on vulnerability (twenty-four forest and woodland ecosystem types are included in this report).

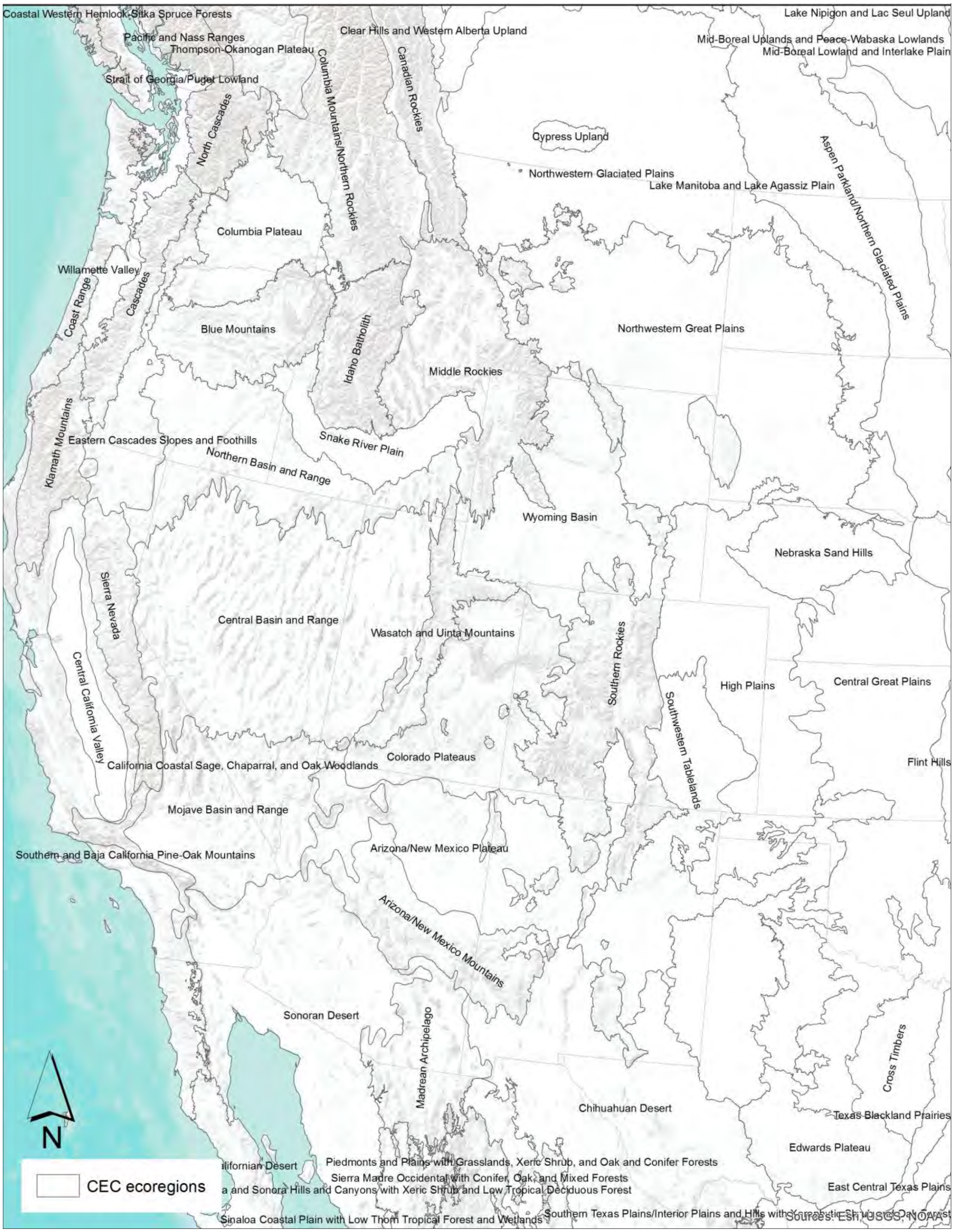

Figure 2. Boundaries and names of the western Commission on Environmental Cooperation (CEC) ecoregions.

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 it 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 timeframe to the baseline, hence measuring climate change vulnerability over the past 30 years.***

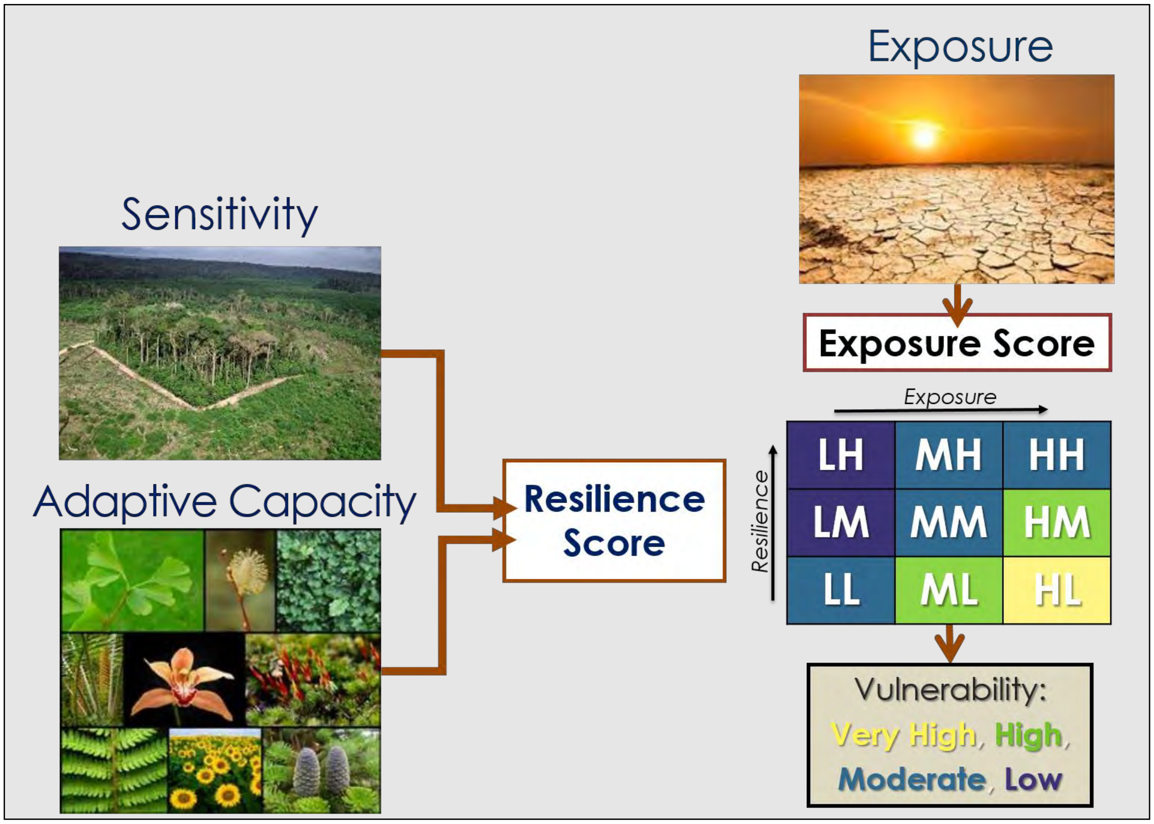

Figure 3. Schematic diagram of the analytical process for the Habitat Climate Change Vulnerability Index. In the matrix for obtaining the final vulnerability index (lower right), low resilience and high exposure result in Very High climate change vulnerability. High or moderate resilience and low exposure 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 (**Figure 2**) provide an appropriate and consistent spatial 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.

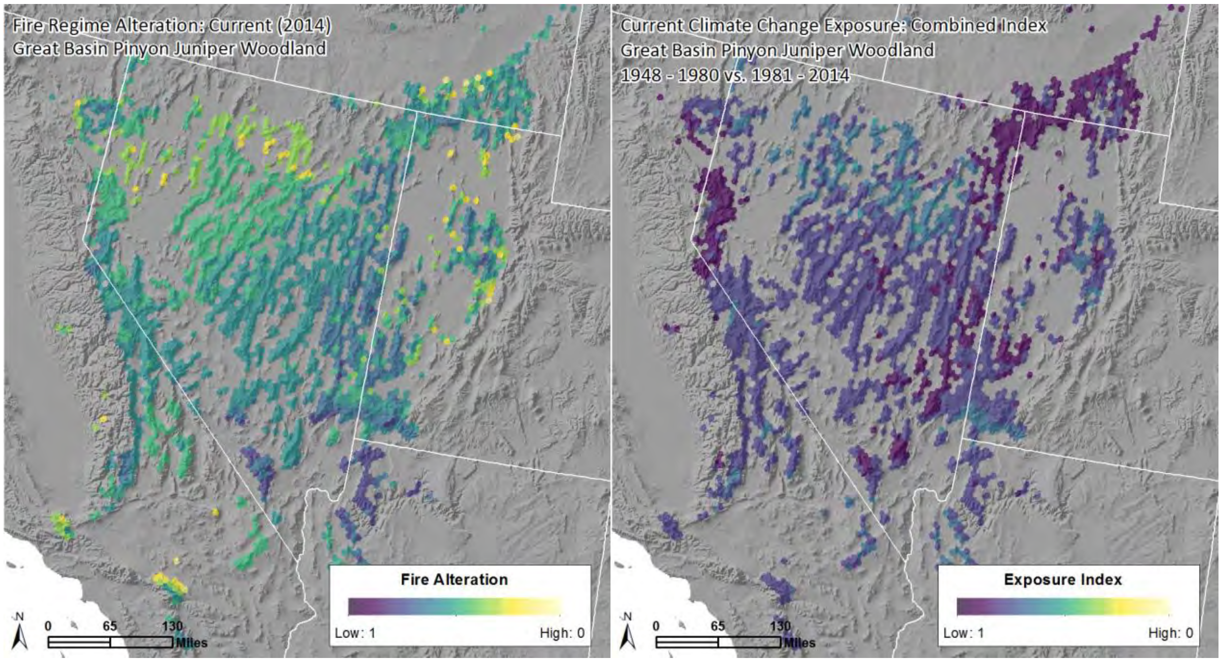

Figure 4. Examples of HCCVI components reported within 100 km^2 hexagons. In all of the maps, the color ramp is the same, with the dark purple representing the least vulnerability or exposure, best ecological condition, or least fragmentation or departure. The greens to yellows represent increasing vulnerability,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

Sensitivity includes measures of ecological condition or integrity. With decreasing integrity, ecosystem responses to climate change stress are increasingly compromised. Measures for sensitivity used here for these upland vegetation types include landscape condition (based on land use intensity), invasive grass risk, and fire regime alteration (using LANDFIRE Fire Regime Condition Class).

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
$\geq$0.75	Low vulnerability
0.50 to 0.75	Moderate vulnerability
0.25 to 0.50	High vulnerability
$\leq$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
		0.86	0.42	exposure expressed on a 0.0 to 1.0 scale
Sensitivity	Landscape Condition	0.68	0.73	
	Fire Regime Departure	0.42	0.52	
	Invasive grasses	0.81	0.36	not scored for all forests & woodlands
	Forest Insect and Disease	0.95	0.85	not scored for pinyon-juniper woodlands
	Sensitivity Average	0.72	0.62	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	not scored for any forests or woodlands
	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
		0.73	0.68	average of sensitivity and adaptive capacity
Climate Change Vulnerability Index		0.80	0.55	average of resilience and exposure
		Low	Mod	Vulnerability expressed as a 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 0.6º C for Mean Annual Temperature and 0.7º 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 (historic) 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.
Forest Insect and Disease	Forest insect and disease impacts on western US forests and woodlands are becoming pronounced, especially with increasing frequency of relatively mild winters (Kurz et al. 2008). With increasing rates of overwintering survival of both native and introduced insects, as well as compounded effects of drought (Breshears et al. 2005) there is increasing potential for	The National Insect and Disease Risk Map was used, and defines forest areas where, "*the expectation that, without remediation, at least 25% of standing live basal area greater than one inches in diameter will die over a 15-year timeframe (2013-2027) due to insects and diseases*" (Krist et al. 2012). The resultant 240 m pixel resolution

Dataset	Justification and Definition	Data Source/Citations
	substantial disruption in forest stand structure, composition, and interacting effects with other natural disturbance processes (Allen et al. 2010). This measure applied only to forest and woodland types where forest insects and diseases have substantial impact.	map represents insect and disease risk along a 0.0-1.0 ramp depicting low to high severity of predicted biomass loss (e.g., 0.05 = 5%, 0.25 = 25%, 0.35 = 35%, etc.). These index values were flipped in order to reflect our "1.0 = most favorable" to "0.0 = least favorable" index values. These per pixel scores were then summarized to average values per vegetation type per 100 km^2 hexagon.
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.
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.

Dataset	Justification and Definition	Data Source/Citations
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).
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.

Dataset	Justification and Definition	Data Source/Citations
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 (Hansen 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

1.B.1.Nd. Madrean-Balconian Forest & Woodland

M010. Madrean Lowland Evergreen Woodland

CES305.797 Madrean Pinyon-Juniper Woodland

Figure 5. Photo of Madrean Pinyon-Juniper Woodland. 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 system occurs on foothills, mountains and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, Trans-Pecos Texas, southern New Mexico and Arizona, generally south of the Mogollon Rim. Substrates are variable, but soils are generally dry and rocky. The presence of *Pinus cembroides, Pinus discolor*, or other Madrean trees and shrubs is diagnostic of this woodland system. *Juniperus coahuilensis, Juniperus deppeana, Juniperus pinchotii, Juniperus monosperma*, and/or *Pinus edulis* may be present to dominant. Madrean oaks such as *Quercus arizonica, Quercus emoryi, Quercus grisea*, or *Quercus mohriana* may be codominant. *Pinus ponderosa* is absent or sparse. If present, understory layers are variable and may be dominated by shrubs or graminoids.

Distribution: This system occurs in the Sierra Madre Occidentale and Sierra Madre Orientale of Mexico, Trans-Pecos Texas, southern New Mexico and Arizona, generally south of the Mogollon Rim. It occurs on the west side of the Sacramento Mountains but may transition into Southern Rocky Mountain Pinyon-Juniper Woodland (CES306.835) or Southern Rocky Mountain Juniper Woodland and Savanna (CES306.834) on the eastern side.

Nations: MX, US

States/Provinces: AZ, NM, TX

CEC Ecoregions: Southwestern Tablelands, Edwards Plateau, Arizona/New Mexico Plateau, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, Southern California/Northern Baja Coast, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: P. Comer

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Vegetation is characterized by an open to moderately dense tree canopy dominated by pinyon and juniper trees 2-5 m tall. The presence of pinyons *Pinus cembroides, Pinus discolor, Pinus remota*, or *Pinus edulis* with Madrean elements in the understory is diagnostic of this ecosystem. *Juniperus coahuilensis, Juniperus deppeana*, and *Juniperus pinchotii* are character species that are often present to dominant. *Pinus edulis* and *Juniperus monosperma* may be the dominants in the northern distribution in combination with Madrean shrub and/or graminoid elements. *Pinus ponderosa* is absent or scattered. Understory layers are variable, ranging from sparse to dense grass or shrub layers. If Madrean oak trees such as *Quercus arizonica, Quercus emoryi*, or *Quercus grisea* are present, then they do not dominate the tree canopy. Common shrub species may include chaparral, desert scrub or lower montane shrubs such as *Arctostaphylos pungens, Canotia holacantha, Ceanothus greggii, Cercocarpus montanus, Mimosa dysocarpa, Quercus turbinella*, or *Rhus trilobata*. Perennial grasses such as *Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Muhlenbergia emersleyi, Muhlenbergia pauciflora, Piptochaetium fimbriatum*, or *Piptochaetium pringlei* are present in many stands and may form an herbaceous layer. The vegetation description is based on several references, including Brown (1982a), Gottfried (1992), Dick-Peddie (1993), Muldavin et al. (2000b), and Gori and Bate (2007).

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
There is no specific species data for this Madrean woodland system, but diversity is assumed to be similar to the Colorado Plateau. There is a significant number of shared species with the Chihuahuan Desert (Rosentreter and Belnap 2003). Cover of soil crust is less in areas with shading from vascular plants. Biological crust diversity is based on Colorado Plateau crust diversity from Rosentreter and Belnap (2003) and assumed to be similar to the Madrean region. 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* spp., *Phormidium* spp., *Plectonema radiosum, Schizothrix calcicola*, and *Tolypothrix tenuis*). 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. Additional common desert lichen species include *Agrestia hispida (= Aspicilia hispida)* and *Peltula richardsii*. Algal diversity is fairly high, but biomass is low in the Colorado Plateau, but higher than warm desert regions with over 40 species. 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
Pinyon-juniper woodlands occur in semi-arid climates typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These

semi-arid woodlands typically have low to moderate herbaceous cover and low to moderate diversity. Most species of Fabaceae (including species of *Astragalus, Calliandra, Dalea, Lotus, Mimosa, Prosopis, Psoralidium, Psorothamnus*, and *Sophora*), Rhamnaceae (*Ceanothus greggii*), Rosaceae (*Cercocarpus, Purshia*) and many Poaceae (e.g., *Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Muhlenbergia emersleyi, Muhlenbergia pauciflora, Piptochaetium fimbriatum*, and *Piptochaetium pringlei*), and some Brassicaceae may fix nitrogen in 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). Diversity of nitrogen-fixing species is moderate to high rangewide, but within stand diversity is typically medium.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwings (*Bombycilla garrulus*), cedar waxwings (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkeys (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), Mexican jay (*Aphelocoma wollweberi*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Tirmenstein 1999i). The primary dispersers of pinyon seeds are scrub jays (*Aphelocoma californica*), pinyon jays (*Gymnorhinus cyanocephalus*), Steller's jays (*Cyanocitta stelleri*) and Clark's nutcrackers (*Nucifraga columbiana*) (Balda and Bateman 1971, Vander Wall and Balda 1977, Ligon 1978, Pavek 1994b, Gottfried et al. 1995). Mammals: Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Neotamias minimus (= Tamias minimus)*), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Panamint kangaroo rat (*Dipodomys panamintinus*), woodrats (*Neotoma* spp.), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias*) spp.), cliff chipmunks (*Neotamias dorsalis*), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) are all known to eat singleleaf pinyon seeds and may inadvertently disperse seeds in caches or have viable seeds pass through their gut (Hollander and Vander Wall 2004).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this pinyon-juniper woodland type.

Environment: This woodland system is common in foothills, mountains and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, Trans-Pecos Texas, southern New Mexico and Arizona, generally south of the Mogollon Rim. Elevation generally ranges from 1300-2225 m with high-elevation stands restricted to warmer southern aspects.

Climate: Climate is semi-arid with drought not uncommon. Summers are hot and winters are mild with cold periods and occasional snows. The mean annual precipitation ranges from 40-50 cm with approximately two-thirds occurring during the Arizona monsoon season from July to September, often as high-intensity convective storms. May and June are typically dry. Stands typically occur on nearly level to steep, rocky slopes.

Physiography/landform: Stands occur on cool aspects of steep scarp slopes, in canyons (including alluvial terraces), on gently sloping alluvial fan piedmonts (bajadas), steeper colluvial slopes and ridges, as well as mesatops. Pinyon and juniper woodlands extend down to 760 m elevation in Trans-Pecos ranges. At the lowest elevation, encinal generally occupies the rockier substrates or is restricted to drainages within grasslands (Brown 1982a).

Soil/substrate/hydrology: Soils are variable, but are generally shallow, rocky, calcareous, but may include deeper clay loamy to gravelly loamy soils. Parent materials include andesite, rhyolite, limestone, basalt, colluvium and alluvium (Sullivan 1993c, Pavek 1994b, Tirmenstein 1999i, Hauser 2007b).

Key Processes and Interactions: Dynamics are complicated by the variation in physiognomy and diverse plant communities present in this system. The pinyon-juniper woodlands and savannas included in this system are represented by what Moir and Carleton (1987) classified as the High Sun Mild climate zone (summer precipitation and warm climate). Romme et al. (2003) developed a pinyon-juniper classification with three types based on canopy structure, understory composition, and historic fire regime. All three types, pinyon-juniper grass savanna, pinyon-juniper shrub woodland, and pinyon-juniper forest, are included in this system. For this model an ecologically similar type, pinyon-juniper grass open woodland (with tree canopy >10% cover), was added to the pinyon-juniper grass savanna making this the more widespread type (Landis and Bailey 2005, Gori and Bate 2007). The other types are the pinyon-juniper shrub woodland, represented by pinyon-juniper trees with an understory of shrubs such as *Quercus turbinella*, and the pinyon-juniper forest type that has a typically sparse understory and is restricted to dry, rocky areas where it is protected from fires (Romme et al. 2003).

Fire dynamics for these types under historical natural conditions (also called natural range of variability (NRV) for pre-1900 timeframe) are summarized below based on (Romme et al. 2003).

The fire regime for the pinyon-juniper grass savanna/pinyon-juniper grass open woodland includes frequent, low-severity surface fires that are carried by the herbaceous layer. The low density of trees (5-20% cover) and high perennial grass cover is maintained by this fire regime. Mean fire interval is estimated to be 12-43 years (Gori and Bate 2007).

The fire regime for the pinyon-juniper shrub woodland is described as moderately frequent, high-severity crown fires that are carried by the shrub and tree layers. After a stand-replacing fire the site begins at early-seral stage and returns to a moderately dense tree layer with a moderate to dense shrub layer. Succession happens relatively quickly if the shrub layer includes chaparral species that recover rapidly from fire by re-sprouting or from fire-scarified seeds in a seed bank. Mixed-severity fires may alter this pattern by creating a mosaic of pinyon-juniper states (early-, mid-, and late-seral). Mean fire interval is estimated to be 23-81 years (Gori and Bate 2007).

The fire regime for the pinyon-juniper forest type is characterized by very infrequent, very high-severity fires that are carried by tree crowns. The stand dynamics are stable with a multi-age tree canopy and with little change in shrub or herbaceous layers.

The historical fire season was probably similar to that of other Madrean woodlands and grasslands, occurring predominantly before the summer monsoon between April and June when vegetation is dry and ignition sources from dry lightning strikes are common (Swetnam and Betancourt 1990).

Other important ecological processes include climate, drought, insect infestations, pathogens, herbivory and seed dispersal by birds and small mammals.

Juniper berries and pinyon nut crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995, Tirmenstein 1999i). Large mammals, such as mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), eat leaves and seeds of both species and browse woodland grasses, forbs and shrubs, including *Artemisia tridentata, Cercocarpus montanus, Quercus gambelii*, and *Purshia stansburiana* (Short and McCulloch 1977). The most important dispersers of juniper and pinyon seeds are birds. Juniper seeds that pass through the digestive tract of birds and other herbivores germinate faster than uneaten seeds (Johnsen 1962, Tirmenstein 1999i). The primary dispersers of pinyon seeds, i.e., scrub jays (*Aphelocoma californica*), pinyon jays (*Gymnorhinus cyanocephalus*), Steller's jays (*Cyanocitta stelleri*) and Clark's nutcrackers (*Nucifraga columbiana*), cache hundreds of thousands of pinyon seeds during mast crop years, many of which are never recovered (Balda and Bateman 1971, Vander Wall and

Balda 1977, Ligon 1978, Pavek 1994b). This seed dispersal mechanism is a good example of a co-evolved, mutualistic, plant-vertebrate relationship (Vander Wall et al. 1981, Evans 1988, Lanner 1996) and would be at risk with loss of trees or dispersers. In addition, small mammals, such as cliff chipmunk (*Neotamias dorsalis*) and rock squirrel (*Otospermophilus variegatus*), compete with birds (Christensen and Whitham 1993).

There are many insects, pathogens, and plant parasites that attack pinyon and juniper trees (Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). For pinyon, there are at least seven insects, plus a fungus (black stain root disease (*Leptographium wageneri*), and pinyon dwarf mistletoe (*Arceuthobium divaricatum*). These insects are normally present in these woodland stands, and during drought-induced water stress outbreaks may cause local to regional mortality (Wilson and Tkacz 1992, Gottfried et al. 1995, Rogers 1995). Most insect-related pinyon mortality in the West is caused by pinyon ips beetle (*Ips confusus)* (Rogers 1993).

Most pinyon-juniper woodlands in the Southwest have high soil erosion potential. Several studies have measured present-day erosion rates in pinyon-juniper woodlands, highlighting the importance of herbaceous cover and biological soil crusts (Belnap et al. 2001) in minimizing precipitation runoff and soil loss in pinyon-juniper woodlands.

ECOLOGICAL INTEGRITY

Change Agents: The Madrean pinyon-juniper woodland ecological system has been impacted by human activities over the last century. Historical fire regimes were disrupted following the introduction of livestock (and the 1890s drought). Fire suppression has increased woody species, led to changes in woody species composition and led to an uncharacteristic fire regime in many stands (Barton 1999, Gori and Bate 2007, Muldavin et al. 2002b, Turner et al. 2003). Grazing passively suppresses fire by removing fine fuels needed to carry surface and mixed-severity fires that likely maintained the structure and composition of pinyon-juniper savannas and pinyon-juniper shrub woodlands historically. Active fire suppression was also practiced by the Federal government during the last 100 years (Swetnam and Baisan 1996a). As fire became less frequent, pinyon and juniper trees became denser and subsequent fires became more severe (Gori and Bate 2007).

These impacts altered stand dynamics differently depending on stand structure. Fire dynamics under current conditions are summarized below for the three major pinyon-juniper types (pinyon-juniper grass savanna/open woodland, pinyon-juniper shrub woodland, and pinyon-juniper forest) developed by Romme et al. (2003) using canopy structure, understory composition, and historical fire regime.

The fire regime for the pinyon-juniper grass savanna/ open woodland has a fire frequency that is significantly reduced and fire severity has greatly increased from pre-1900, from low-severity surface fires towards high-severity and stand-replacing crown fires. Tree density has increased and herbaceous biomass has decreased from historical conditions with active fire suppression and livestock grazing. Currently stands have some very old trees (>300 years) present but not numerous, but are typically dominated by many young trees (<150 years). This type may also occur on sites with more rock soil and less grasses. This type is outside Historical Range of Variation (HRV) for disturbance regime, structure and composition (Gori and Bate 2007).

The fire regime for the pinyon-juniper shrub woodland has a fire frequency that is reduced and fire severity is somewhat increased from pre-1900, from low to moderately frequent, high-severity stand-replacing fires and moderately frequent mixed-severity fires that likely maintain this type, toward less frequent, higher severity fires (Gori and Bate 2007). Tree density has increased and herbaceous biomass has decreased from historical conditions with active fire suppression and livestock grazing. Currently most stands have a variable mix of tree and shrubs with few or no very old trees (>300 years) present. With fire suppression, this type may be outside HRV for disturbance regime, and possibly for structure and composition as recent fires are likely more severe than historical fire in late 1800s (Romme et al. 2003).

The fire regime for the pinyon-juniper forest type still has infrequent, high-severity fires that are carried by tree crowns. The stand dynamics remain relatively stable with little change in density of tree or shrub and herbaceous layers. Currently stands have numerous very old trees (>300 years) present with a multi-aged structure. Active fire suppression and livestock grazing are thought to have had little impact on fire frequency and severity and the overstory structure and composition with this type remains within HRV for disturbance regime (Gori and Bate 2007).

Historic fuelwood cutting for mining and domestic use and fencepost cutting was common in stands of this system until the late 1800s, and is still common in Arizona, New Mexico and northern Mexico today (Bahre 1991, Bennett 1992). Although fuelwood harvesting had dramatic effects historically, its consequences were generally local and short-lived (Turner et al. 2003). More recently, chemical and mechanical treatments such as chaining and rotochopping have impacted age structure, tree density and cover of many pinyon-juniper woodlands with current demand for these products continuing to increase (Ffolliott et al. 1979, Gottfried 1987, Dick-Peddie 1993, Gottfried and Severson 1993).

Fragmentation from a variety of sources such as construction of roads and secondary homes has occurred in many areas of pinyon-juniper woodlands (Gori and Bate 2007). Additional roads from oil and gas exploration and development is important in some areas. The introduction of non-native species is a threat to this ecosystem and needs to be further investigated (Gori and Bate 2007). Non-native species invasion is an important issue in the Great Basin pinyon-juniper woodlands which has led to increased fire frequency and size in that type (Miller and Tausch 2001). In Mesa Verde National Park, invasive non-native species dominate pinyon-juniper woodland areas post-fire (Romme et al. 2003). Post-fire succession may be altered if invasive non-native species colonize and prevent native grasses and forbs from establishing (Floyd et al. 2006).

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.

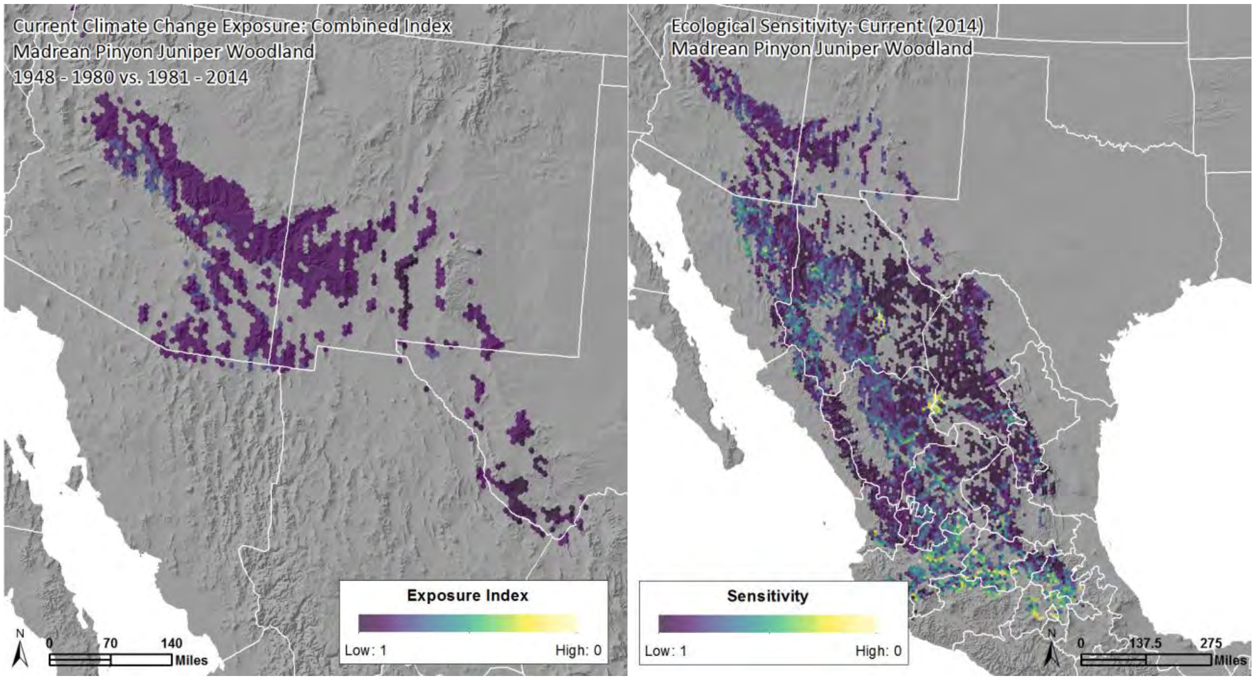

Figure 6. Climate exposure as of 2014 (left) and overall sensitivity (right) for Madrean Pinyon-Juniper Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity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

Table 5. Resilience, exposure and vulnerability scores for Madrean Pinyon-Juniper Woodland 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	Sierra Madre Occidental	Arizona-New Mexico Mountains	Piedmont & Plains (Mexico)	Madrean Archipelago	Hills & Interior Plains (Mexico)	Sierra Madre Oriental	Sinaloa & Sonora Hills & Canyons	Hills & Sierras (Mexico)	Interior Plains & Piedmonts (Mexico)	California Coastal Sage, Chaparral, & Oak	Sonoran Desert	Arizona-New Mexico Plateau
	Potential square miles within ecoregion	3,891	3,201	2,853	2,476	1,904	1,497	578	363	282	94	40	37	23
Contributions to Relative Vulnerability by Factor														
Vulnerability from **Exposure (2014)**		**Low** 0.87	**Low** 0.81	**Low** 0.85	**Low** 0.84	**Low** 0.82	**Low** 0.81	**Low** 0.88	**Low** 0.78	**Low** 0.81	**Low** 0.80	**Low** 0.76	**Low** 0.81	**Low** 0.84
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.90	0.79	0.93	0.77	0.85	0.60	0.82	0.81	0.61	0.46	0.77	0.95	0.94
	Fire Regime Departure	0.55	Null	0.59	Null	0.66	Null	Null	Null	Null	Null	0.96	0.58	0.60
	Invasive Annual Grasses	0.90	0.78	0.98	0.90	0.97	1.00	1.00	0.74	1.00	Null	0.48	0.98	1.00
	Sensitivity Average	**0.78**	**0.78**	**0.83**	**0.84**	**0.83**	**0.80**	**0.91**	**0.77**	**0.80**	**0.46**	**0.74**	**0.84**	**0.85**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.35	0.44	0.50	0.34	0.43	0.34	0.47	0.40	0.34	0.38	0.13	0.47	0.46
	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
	Keystone Species Vulnerability	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.42**	**0.47**	**0.50**	**0.42**	**0.46**	**0.42**	**0.49**	**0.45**	**0.42**	**0.44**	**0.32**	**0.49**	**0.48**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.60	**Mod** 0.63	**Mod** 0.67	**Mod** 0.63	**Mod** 0.65	**Mod** 0.61	**Mod** 0.70	**Mod** 0.61	**Mod** 0.61	**High** 0.45	**Mod** 0.53	**Mod** 0.66	**Mod** 0.66
Climate Change Vulnerability Index		**Mod**	**Mod**	**Low**	**Mod**	**Mod**	**Mod**	**Low**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Low**

Exposure Summary for 1981-2014 Timeframe: Overall exposure in the U.S., as of 2014, for this widespread woodland system is low. An emerging pattern of changing climate appears as increases of 0.54° to 0.7°C for Annual Mean Temperature throughout its distribution in all ecoregions. Similar increases in Mean Temperature of the Warmest Quarter are also seen in most ecoregions, but for smaller portions of its distribution in each (ranging from 18% to 50%). In the Arizona/New Mexico Mountains two other temperature variables show increases of 1.2°C for 12% of its distribution in the ecoregion: Minimum Temperature of the Coldest Month and Mean Temperature of the Coldest Quarter. These results suggest that in this ecoregion winter temperatures have increased over the past 30 years compared to the baseline years. In the Arizona/New Mexico Mountains, Chihuahuan Desert and Madrean Archipelago ecoregions, for some 10% to 15% of its distribution in each, Precipitation of the Driest Month shows increases of 1.3 to 1.9 mm, over the baseline average of 1.3 mm, a doubling of precipitation. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

Climate Change Effects: Climate change has affected the distribution of pinyon-juniper woodlands in the past. For example, after 500 BP, winter precipitation increased and caused a re-expansion of pinyon-juniper woodland that sharply increased after 1700 and again in the early 1900s (Davis and Turner 1986, Mehringer and Wigand 1990, as cited in Gori and Bate 2007).

Future climate is predicted to have less available moisture with increasing mean temperature. Ecological consequences from such a warming climatic shift would be similar to extended drought. With more frequent droughts pinyon trees may become more susceptible to lethal attacks by forest diseases and insects such as the pinyon ips beetles (*Ips confusus*). Longer, milder climate periods may increase the number of generations of ips beetles above the average of two and a half to three annually. Pinyons cannot repel pinyon ips beetles when weakened by drought and many will likely be killed, as occurred during the drought of 2002-2003 in the Southwest U.S. Loss of pinyons affects species dominance patterns, tree age structure, tree density, and canopy cover within pinyon-juniper woodlands and will shift dominance to juniper (Betancourt et al. 1993).

Additionally, warmer/drier fuels may result in more frequent fires that could increase the rate of loss of mature stands through conversion of these woodlands to annual grasslands or shrublands that are adapted to frequent fire.

With more drought, pinyon and juniper seed production and seedling establishment and survival would be likely reduced or possibly eliminated, effectively eliminating tree recruitment. Without recruitment, pinyon and juniper stands are essentially relicts of past climate conditions. Over time potential climate change effects could also include a shift to species more common on hotter, drier sites. This scenario would be expected to result in a contraction of Madrean pinyon-juniper woodland system and a possible limited migration to higher elevations in the future (Van Devender 1977, 1990, Betancourt et al. 1993, McAuliffe and Van Devender 1998).

Ecosystem Resilience: Sensitivity: Sensitivity to climate change is generally low (higher scores) across the range of this type with 12 of 13 ecoregions scored as low and two ecoregions scoring as moderate and high sensitivity (California Coastal Sage, Chaparral, & Oak and Interior Plains & Piedmonts [Mexico]) (**Table 5**).

Landscape condition is generally very good (little development) with 10 of 13 ecoregions scored as good, with moderate in 2 and poor in one. This ecosystem occurs across extensive and remote mountain ranges 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. The three ecoregions with moderate condition occur entirely in Mexico with areas of increased impacts from development.

Risk of invasive plants tends to be low overall with only the California Coastal Sage ecoregion having a more pronounced risk. Fire regime departure is moderate in 5 of the 6 ecoregions where it was scored. One of the 6 ecoregions has low departure, the California Coastal Sage. Seven ecoregions occur in Mexico, where no fire regime departure data are available. Although risk of annual grass invasion is generally low, the interactions of direct fire suppression and historic overgrazing by livestock, which removes the fine fuels that carry fire, have reduced fire frequency and altered the structure of these woodlands. This in turn makes them vulnerable to catastrophic crown fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these woodlands. 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 widespread ecological system. Topoclimatic variability is moderate to low, as these woodlands generally occur in mountainous topography, on landforms such as steep scarp slopes, in canyons (including alluvial terraces), on gently sloping alluvial fan piedmonts (bajadas), steeper colluvial slopes and ridges, as well as mesatops.

Diversity within each of the three identified functional species groups varies from moderate to high. Within individual stands, the most limiting functional role is that of nitrogen fixation, which is provided by a moderate number of species. This system has plant taxa in the *Fabaceae, Rhamnaceae, Rosaceae*, and *Poaceae* families of which a number are nitrogen-fixers. Cyanobacteria and cyanolichens in the soil crust also fix nitrogen. 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. Seed dispersal is provided by many bird and mammal species and appears to have high within-stand 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: These woodlands currently score in the moderate range of overall climate change vulnerability throughout most of their range; and low vulnerability in 3 ecoregions. This is primarily due to the low scores for exposure, the generally moderate scores for adaptive capacity and variable, but low to moderate contributions from overall resilience measures. Athough fire regime departure is scored for less than half of the ecoregions because this woodland system occurs largely in Mexico, where it is scored there is only moderate to low departure, it appears to be less of a factor. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Madrean Pinyon-Juniper Woodland

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Bahre 1991, Balda 1987, Balda and Bateman 1971, Barton 1999, Belnap 2001, Belnap et al. 2001, Bennett 1992, Betancourt et al. 1993, Breshears et al. 2005, Christensen and Whitham 1993, Comer et al. 2003*, Cully and Knight 1987, Davis and Turner 1986, Dick-Peddie 1993, Elliott 2012, Evans 1988, Eyre 1980, Ffolliott et al. 1979, Floyd et al. 2006, Gori and Bate 2007, Gottfried 1987, Gottfried 1992, Gottfried and Severson 1993, Gottfried et al. 1995, Hauser 2007b, Heil and Herring 1999, Hollander and Vander Wall 2004, Johnsen 1962, Landis and Bailey 2005, Lanner 1996, Ligon 1978, McAuliffe and Van Devender 1998, McCulloch 1969, Mehringer and Wigand 1990, Miller and Tausch 2001, Moir and Carleton 1987, Muldavin et al. 2002b, Pavek 1994b, Rogers 1993, Rogers 1995, Romme et al. 2003, Rosentreter and Belnap 2003, Salomonson 1978, Shiflet 1994, Short and McCulloch 1977, Short et al. 1977, Sivinski and Knight 1996, Sivinski and Lightfoot 1994, Sullivan 1993c, Swetnam and Baisan 1996a, Swetnam and Betancourt 1990, Tirmenstein 1999i, Turner et al. 2003, USFWS 1986, Van Devender 1977, Van Devender 1990, Vander Wall and Balda 1977, Vander Wall et al. 1981, Weber et al. 1999, Wilson and Tkacz 1992

1.B.2.Nb. Rocky Mountain Forest & Woodland

M501. Central Rocky Mountain Dry Lower Montane-Foothill Forest

CES306.959 Middle Rocky Mountain Montane Douglas-fir Forest and Woodland

Figure 7. Photo of Middle Rocky Mountain Montane Douglas-fir Forest and Woodland. Photo credit: Wikipedia.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs throughout the middle Rocky Mountains of central and southern Idaho (Lemhi, Beaverhead and Lost River ranges), south and east into the greater Yellowstone region, and south and east into the Wind River, Gros Ventre and Bighorn ranges of Wyoming. It extends north into Montana on the east side of the Continental Divide, north to about the McDonald Pass area, and into the Rocky Mountain Front region of Montana. This is a *Pseudotsuga menziesii*-dominated system without the maritime floristic composition; these are forests and woodlands occurring in the central Rockies where the southern monsoon influence is lessened and maritime climate regime is not important. This system includes extensive *Pseudotsuga menziesii* forests, occasionally with *Pinus flexilis* on calcareous substrates, and *Pinus contorta* at higher elevations. True firs, such as *Abies concolor, Abies grandis*, and *Abies lasiocarpa*, are absent in these occurrences, but *Picea engelmannii* can occur in some stands. Understory components include shrubs such as *Physocarpus malvaceus, Juniperus communis, Symphoricarpos oreophilus*, and *Mahonia repens*, and graminoids such as *Calamagrostis rubescens, Carex rossii*, and *Leucopoa kingii*. The fire regime is of mixed severity with moderate frequency. This system often occurs at the lower treeline immediately above valley grasslands, or sagebrush steppe and shrublands. Sometimes there may be a "bath-tub ring" of *Pinus ponderosa* at lower elevations or *Pinus flexilis* between the valley non-forested and the solid *Pseudotsuga menziesii* forest. In the Wyoming Basins, this system occurs as isolated stands of *Pseudotsuga menziesii*, with *Artemisia tridentata, Pseudoroegneria spicata, Leucopoa kingii*, and *Carex rossii*.

Distribution: This system occurs throughout the middle Rocky Mountains of central and southern Idaho (Lemhi, Beaverhead and Lost River ranges), south and east into the greater Yellowstone region, and south and east into the Wind River, Gros Ventre and Bighorn ranges of Wyoming. It extends north into Montana on the east side of the Continental Divide to the Rocky Mountain Front and includes all of the Beaverhead Mountains Section (M332E) (Bailey et al. 1994). It may also occur in scattered patches in southeastern Oregon.

Nations: US

States/Provinces: ID, MT, OR?, WY

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, Blue Mountains, Middle Rockies, Wasatch and Uinta Mountains, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, Northern Basin and Range, Wyoming Basin, Snake River Plain

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This is a *Pseudotsuga menziesii*-dominated system without the maritime floristic composition; it includes extensive *Pseudotsuga menziesii* forests, occasionally with *Pinus flexilis* on calcareous substrates and *Pinus contorta* at higher elevations. *Picea engelmannii* can occur in some stands; however, true firs, such as *Abies concolor, Abies grandis*, and *Abies lasiocarpa*, are absent. Understory components include shrubs such as *Artemisia tridentata, Physocarpus malvaceus, Juniperus communis, Symphoricarpos oreophilus*, and *Mahonia repens*, and graminoids such as *Calamagrostis rubescens, Carex rossii, Leucopoa kingii*, and *Pseudoroegneria spicata*. Sometimes there may be a "bath-tub ring" of *Pinus ponderosa* at lower elevations or *Pinus flexilis* between the valley non-forested and the solid *Pseudotsuga menziesii* forest.

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.

Forest Patch Disturbance; Species Diversity: Medium
Diversity: medium = 6-15 spp. Tree mortality caused by native insects and disease is an important ecological process that creates a diversity of habitats within forested landscapes that would otherwise have uniform stand structure. Although Douglas-fir (*Pseudotsuga menziesii*) is host to hundreds of fungi and insects, relatively few cause significant mortality in healthy mature trees, while many others weaken trees and make them vulnerable so that they can blow down and create forest gaps. These gaps allow more light to penetrate the tree canopy increasing production of shrubby and herbaceous understory, creating places for stand regeneration, and accelerating succession (Steinberg 2002e).

Insects: Bark beetles: Douglas-fir beetle (*Dendroctonus pseudotsugae*), pine engraver (*Ips pini*), and spruce beetle (*Dendroctonus rufipennis*) (spruce beetle), extended outbreaks of defoliators such as western spruce budworm (*Choristoneura occidentalis*).

Fungi: Root and butt rots such as *Phellinus* root rot (*Phellinus weirii*) and *Armillaria* root disease (*Armillaria ostoyae, Armillaria mellea*), red ring rot (*Phellinus pini*), velvet top fungus (*Haeolus* *schweinitzii*), and Quinine conk (*Fomitopsis officinialis*) (Burns and Honkala 1990a, Steinberg 2002e).

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 Graminoids; Species Diversity: Medium
Diversity: medium = 6-15 spp. This is not a major FSG except in grassy understory stands especially near lower treeline. Grasses include *Bromus porteri, Calamagrostis rubescens, Carex geyeri, Carex rossii, Elymus glaucus, Elymus lanceolatus, Elymus trachycaulus, Festuca campestris, Festuca idahoensis, Leucopoa kingii, Piptatheropsis micrantha, Poa fendleriana, Poa nervosa, 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 forest and woodland type.

Environment: These are forests and woodlands occurring in the Central Rockies where the southern monsoon influence is lessened and maritime climate regime is not important. These *Pseudotsuga menziesii* forests occur under a comparatively drier and more continental climate regime, and at higher elevations than in the Pacific Northwest. Elevations range from less than 1000 m in the central Rocky Mountains to over 2400 m in the Wyoming Rockies. Lower-elevation stands typically occupy protected northern exposures or mesic ravines and canyons, often on steep slopes. At higher elevations, these forests occur primarily on southerly aspects or ridgetops and plateaus.

Annual precipitation ranges from 50-100 cm with moderate snowfall and a greater proportion falling during the growing season. Monsoonal summer rains can contribute a significant proportion of the annual precipitation in the southern portion of the range.

Soils are highly variable and derived from diverse parent materials. *Pseudotsuga menziesii* forests are reported by most studies (Pfister et al. 1977, Steele et al. 1983, Mauk and Henderson 1984) to show no particular affinities to geologic substrates. Rock types can include extrusive volcanics in the Yellowstone region, and sedimentary rocks elsewhere in the Rockies. The soils are typically slightly acidic (pH 5.0-6.0), well-drained, and well-aerated. They can be derived from moderately deep colluvium or shallow-jointed bedrock and are usually gravelly or rocky.

Key Processes and Interactions: Successional relationships in this group are complex. *Pseudotsuga menziesii* is less shade-tolerant than some montane trees such as *Abies concolor* or *Picea engelmannii*, and seedlings compete poorly in deep shade. At drier locales, seedlings may be favored by moderate shading, such as by a canopy of *Pinus flexilis*, which helps to minimize drought stress. In some locations, much of these forests have been logged or burned during European settlement, and present-day stands are second-growth forests dating from fire, logging, or other stand-replacing disturbances (Mauk and Henderson 1984). *Pseudotsuga menziesii* forests were probably subject to a moderate-severity fire regime in presettlement times, with fire-return intervals of 30-100 years. Many of the important tree species in these forests are fire-adapted (*Populus tremuloides, Pinus contorta*) (Pfister et al. 1977). Some stands may have higher tree-stem density than historically, due largely to fire suppression (Steele et al. 1983).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2111660). These are summarized as:

A) (10% of type in this stage) Tree cover is 0-100%. Dominated by graminoids and seedling/sapling Douglas-fir and possibly lodgepole pine. Understory may be dominated by *Calamagrostis rubescens* and/or *Carex* spp. Shrub species such as *Symphoricarpos* spp. may be present. Succession occurs in approximately 40 years, and the class moves to a mid-open state. Replacement fire occurs every 500 years, and mixed fire occurs every 200 years. If this class experiences no fire in 20 years, it will move to class B, a mid-closed state. Wind/weather events occur infrequently (probability of 0.001), but the class is maintained in this state.

B) Mid Development 1 Closed (tree-dominated - 10% of type in this stage): Tree cover is 41-100%. Relatively dense pole and some medium Douglas-fir and possibly lodgepole pine. The understory is open and relatively depauperate. Understory may be dominated by *Calamagrostis rubescens* and/or *Carex* spp. This class persists for 80 years, then moves to a late-closed stage. Replacement fire occurs every 200 years, and mixed fire every 50 years, causing a transition to a mid-open stage. Insect/disease outbreaks occur with a probability of 0.005 and can move the class to a mid-open state. Also, wind/weather stress causes a change to a mid-open state with a probability of 0.001. Although reviewers recommended removing insects/disease from this class, it was decided by Region 1 insect experts that some insect damage is likely for the class B forest types. The insects to be concerned about at low levels are Douglas-fir pole beetle and western spruce budworm.

C) Mid Development 1 Open (tree-dominated - 10% of type in this stage): Tree cover is 21-40%. Open pole and medium Douglas-fir that may have lodgepole pine with patchy graminoid cover and dispersed shrubs such as *Symphoricarpos* spp. Understory may be dominated by *Calamagrostis rubescens* and/or *Carex* spp. Conifer heights range between 5-20 m but adjusted to eliminate class overlap. This class can persist for 60 years, then moves to a late-open stage. Replacement fire occurs every 200 years, and mixed fire every 40 years. Without fire for 58 years, this class can move to a mid-closed state. Insect/disease outbreaks and wind/weather events occur with a probability of .005, and maintain this class in a mid-open state.

D) Late Development 1 Open (conifer-dominated - 50% of type in this stage): Tree cover is 21-40%. Open canopy of medium to large Douglas-fir with a graminoid and shrub understory with highly variable understory cover. Lodgepole pine may be present. Understory may be dominated by *Symphoricarpos* spp., *Calamagrostis rubescens*, and/or *Carex* spp. Heights can exceed 25 m up to approximately 30 m. Replacement fire occurs every 500 years, and mixed fire every 50 years. Without fire for 45 years, this class can move to a late-closed state. Insect disturbance occurs every 10 years but does not move this class to another class. Wind/weather stress also occurs, with a probability of 0.008, but does not cause a transition to another class.

E) Late Development 1 Closed (conifer-dominated - 20% of type in this stage): Tree cover is 41-100%. Multi-storied Douglas-fir, sometimes with lodgepole pine present. Understory with variable cover often dominated by *Calamagrostis rubescens, Carex* spp., *Symphoricarpos* spp., and/or *Physocarpus malvaceus*. Heights can exceed 25 m up to approximately 30 m. Replacement fire occurs every 200 years, and mixed fire every 30 years, causing a transition back to a late-open state. Insect outbreaks occur frequently, probability of 0.01, and cause a transition to an open state. Wind/weather stress occurs with a probability of 0.005 and causes a transition to a late-open state.

Fire regime is predominantly mixed-severity (Fire Regime III) with a MFI of approximately 20-50 years (Houston 1973, Arno and Gruell 1983, Fischer and Clayton 1983, Littell 2002, Korb et al. in prep.). Mixed-severity fires are generally characterized as spatially heterogeneous (LANDFIRE 2007a, BpS 2111660). Fire regime in more northern stands is predominantly mixed with a MFI of approximately 35-50 years (Crane and Fischer 1986, Bradley et al. 1992) (LANDFIRE 2007a, BpS 1911660).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. Biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this forest and woodland system include altered fire regime, altered stand structure from fragmentation due to roads, logging, mining, or other human disturbances. These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed. Invasive exotic species can become abundant in disturbed areas and alter floristic composition. Direct and indirect effects of climate change may alter dynamics of indigenous insects such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) causing a buildup in population size (with less extreme winters) leading to large outbreaks that can cause high mortality in mature trees.

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.

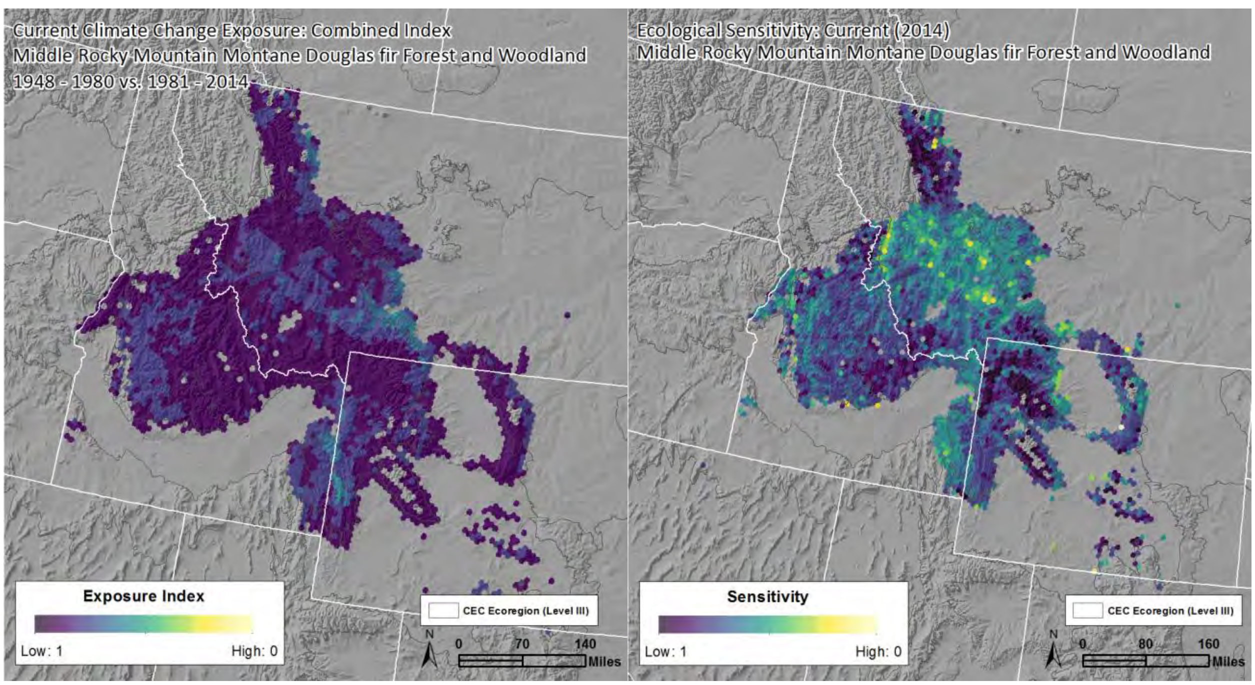

Figure 8. Climate exposure as of 2014 (left) and overall sensitivity (right) for Middle Rocky Mountain Montane Douglas-fir Forest and Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 7. Resilience, exposure and vulnerability scores for Middle Rocky Mountain Montane Douglas-fir Forest and Woodland 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	Idaho Batholith	Northwestern Great Plains	Wyoming Basin	Canadian Rockies	Columbia Mountains-Northern Rockies	Northern Basin & Range	Snake River Plain	Southern Rockies	Northwestern Glaciated Plains
	Potential square miles within ecoregion	7,118	1,913	312	246	170	138	54	38	33	27
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Low** 0.79	**Low** 0.81	**Low** 0.76	**Low** 0.83	**Low** 0.77	**Low** 0.84	**Mod** 0.75	**Low** 0.82	**Low** 0.80	**Low** 0.76
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.73	0.85	0.58	0.77	0.73	0.49	0.58	0.48	0.78	0.55
	Fire Regime Departure	0.55	0.55	0.55	0.51	0.82	0.61	0.51	0.63	0.63	0.74
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.85	0.90	0.94	0.92	0.82	0.74	0.89	0.93	0.98	0.98
	Sensitivity Average	**0.71**	**0.77**	**0.69**	**0.73**	**0.79**	**0.61**	**0.66**	**0.68**	**0.80**	**0.76**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.53	0.61	0.41	0.52	0.48	0.49	0.45	0.30	0.62	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
	Adaptive Capacity Average	**0.51**	**0.55**	**0.46**	**0.51**	**0.49**	**0.50**	**0.48**	**0.40**	**0.56**	**0.43**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.61	**Mod** 0.66	**Mod** 0.57	**Mod** 0.62	**Mod** 0.64	**Mod** 0.55	**Mod** 0.57	**Mod** 0.54	**Mod** 0.68	**Mod** 0.59
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this forest system is low. Climate exposure was low across nine of the ten ecoregions. In the remaining ecoregion (Northern Basin and Range), exposure was at the low end of moderate. Annual mean temperature has increased between 0.5° and 0.7°C across large portions (44-100%) of seven ecoregions. Other climate exposure effects were smaller in area or magnitude, but consistent with greater increases in winter relative to summer temperatures. For example, mean winter temperature increased by 1° to 2°C across small portions (<6%) of several ecoregions, while summer temperature increased by 0.6° to 0.7°C across the smallest ecoregion.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest and Middle Rocky Mountains regions 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). 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 tree recruitment. Without recruitment Douglas-fir stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken trees and may make them more susceptible to lethal attacks by forest diseases and insects. A warming climate with more frequent droughts may weaken Douglas-fir trees and may make them more susceptible to lethal attacks by forest diseases, such root and butt rot (*Armillaria mellea*) and red-brown butt rot (*Phaeolus schweinitzii*), and native Douglas-fir beetle (*Dendroctonus pseudotsugae*) and defoliators, Douglas-fir tussock moth (*Orgyia pseudotsugata*) and the western spruce budworm (*Choristoneura fumiferana*) (Burns and Honkala 1990a, Steinberg 2002).

Many stands of this woodland type occur in the montane zones of ranges so it may be possible for the species of this system to transition into upper montane and subalpine zones in taller mountain ranges as suitable climate is diminished at lower elevations. Interior Douglas-fir trees are long-lived and frequently live more than 400 years and so may be able to survive for centuries without regeneration (Burns and Honkala 1990a, Steinberg 2002). However, there could be accelerated loss of mature trees because of more frequent and extended drought resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Sensitivity to climate change is moderate to low across the range of this forest type, with moderate sensitivity in six ecoregions accounting for approximately 78% of the potential distribution.

Contributions to sensitivity from landscape condition ranged from low to the moderate end of high. These reflect modified conditions from logging and associated road networks, as well as urban, suburban and exurban development in lower elevation portions of the range.

Fire regime departure was moderate in all but one of ten ecoregions, and low in the remaining Canadian Rockies ecoregion. This reflects fire suppression practices across much of the region which have led to higher densities of *Pseudotsuga menziesii* and increased understory fuel loads. These lead to higher-intensity and stand-replacing fires.

Risk from insect and disease was scored as low in nine ecoregions and at the low end of moderate in the remaining ecoregion (Columbia Mountains-Northern Rockies). Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease.

The interactions of the stressors of fire suppression and landscape fragmentation have resulted in changes to the structure of these forests. Together, these result in an overall moderate sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Climate vulnerability from adaptive capacity is moderate to the moderate end of high across the range of this system. Four ecoregions scored in the moderate vulnerability range for adaptive capacity, and seven had high vulnerability. This low adaptive capacity is related to low topoclimatic variability, which was poor in seven ecoregions, and moderate in four. This reflects a low level of topoclimate variability associated with gentle slopes and valley floors in foothill and lower elevation portions of this system. There is potential for the species in this system to move upslope into areas of suitable climate and increased topographic variability. In terms of vulnerability related to functional species groups, the system scores moderate in terms of diversity of nitrogen fixers and for species that contribute to a diversity of successional stages through patch disturbance, suggesting increased vulnerability from loss of species in these groups. 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 forest type scores in the moderate range across all ecoregions. This is due to moderate contributions from sensitivity measures (landscape condition and fire regime departure), and moderate to low adaptive capacity associated with low topoclimate diversity. Many stands occur on middle or lower elevation slopes, so there may be potential for upslope migration of dominant species. Although insect and disease risk scored low for this system, these may be exacerbated by drought and severe fires across the range 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 Middle Rocky Mountain Montane Douglas-fir Forest and Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Amman 1977, Anderson 2003b, Arno and Gruell 1983, Bailey et al. 1994, Bell et al. 2009, Bradley et al. 1992b, Burns and Honkala 1990a, Comer et al. 2003*, Crane and Fischer 1986, Dale et al. 2001, Eyre 1980, Fischer and Bradley 1987, Graham and Jain 2005, Harvey 1994, Houston 1973, Korb et al. 2018, LANDFIRE 2007a, Littell 2002, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Mote et al. 2014, Pfister et al. 1977, Shafer et al. 2014, Steele et al. 1983, Steinberg 2002e, Stevens-Rumann et al. 2017, Westerling et al. 2006

CES306.805 Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest

Figure 9. Photo of Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest. Photo credit: Quantitative Ecology.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is composed of highly variable montane coniferous forests found in the interior Pacific Northwest, from southernmost interior British Columbia, eastern Washington, eastern Oregon, northern Idaho, western and north-central Montana, and south along the east slope of the Cascades in Washington and Oregon. In central Montana it occurs on mountain islands (the Snowy Mountains). This system is associated with a submesic climate regime with annual precipitation ranging from 50 to 100 cm, with a maximum in winter or late spring. Winter snowpacks typically melt off in early spring at lower elevations. Elevations range from 460 to 1920 m. Most occurrences of this system are dominated by a mix of *Pseudotsuga menziesii* and *Pinus ponderosa* (but there can be one without the other) and other typically seral species, including *Pinus contorta, Pinus monticola* (not in central Montana), and *Larix occidentalis* (not in central Montana). *Picea engelmannii* (or *Picea glauca* or their hybrid) becomes increasingly common towards the eastern edge of the range. The nature of this forest system is a matrix of large patches dominated or codominated by one or combinations of the above species; *Abies grandis* (a fire-sensitive, shade-tolerant species not occurring in central Montana) has increased on many sites once dominated by *Pseudotsuga menziesii* and *Pinus ponderosa*, which were formerly maintained by low-severity wildfire. Presettlement fire regimes may have been characterized by frequent, low-intensity surface fires that maintained relatively open stands of a mix of fire-resistant species. Under present conditions the fire regime is mixed severity and more variable, with stand-replacing fires more common, and the forests are more homogeneous. With vigorous fire suppression, longer fire-return intervals are now the rule, and multi-layered stands of *Pseudotsuga menziesii, Pinus ponderosa*, and/or *Abies grandis* provide fuel "ladders," making these forests more susceptible to high-intensity, stand-replacing fires. They are very productive forests which have been priorities for timber production. They rarely form either upper or lower timberline forests. Understories are dominated by graminoids, such as *Pseudoroegneria spicata, Calamagrostis rubescens, Carex geyeri*, and *Carex rossii*, that may be associated with a variety of shrubs, such as *Acer glabrum, Juniperus communis, Physocarpus malvaceus, Symphoricarpos albus, Spiraea betulifolia*, or *Vaccinium membranaceum* on mesic sites. *Abies concolor* and *Abies grandis x concolor* hybrids in central Idaho (the Salmon Mountains) are included here but have very restricted range in this area. *Abies concolor* and *Abies grandis* in the Blue Mountains of Oregon are probably hybrids of the two and mostly *Abies grandis*.

Distribution: This system is found in the interior Pacific Northwest, from southern interior British Columbia south and east into Oregon, Idaho (including north and central Idaho, down to the Boise Mountains), and western Montana, and south along the east slope of the Cascades in Washington and Oregon.

Nations: CA, US

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

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

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is generally dominated by a mix of *Pseudotsuga menziesii* and *Pinus ponderosa* (but there can be one without the other) and other typically seral species, including *Pinus contorta, Pinus monticola*, and *Larix occidentalis*. *Picea engelmannii* (or *Picea glauca* or their hybrid) becomes increasingly common towards the eastern edge of the range. *Abies grandis* (a fire-sensitive, shade-tolerant species not occurring in central Montana) has increased on many sites once dominated by *Pseudotsuga menziesii* and *Pinus ponderosa*. Understories are often dominated by graminoids, such as *Pseudoroegneria spicata, Calamagrostis rubescens, Carex geyeri*, and *Carex rossii*, which may be associated with a variety of shrubs, such as *Acer glabrum, Juniperus communis, Physocarpus malvaceus, Symphoricarpos albus, Spiraea betulifolia*, or *Vaccinium membranaceum* on mesic sites. *Abies concolor* and *Abies grandis x concolor* hybrids in central Idaho (the Salmon Mountains) are included here but have very restricted range in this area.

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.

Forest Patch Disturbance; Species Diversity: High
Diversity: high = >15 spp. Tree mortality caused by native insects and disease is an important ecological process that creates a diversity of habitats within forested landscapes that would otherwise have uniform stand structure. Although the dominant trees Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*), and less widespread grand fir (*Abies grandis*), Engelmann spruce (*Picea engelmannii*), or white spruce (*Picea glauca*) are host to hundreds of fungi and insects, relatively few of these cause significant mortality in healthy mature trees, while many others weaken trees and make them vulnerable so that they can blow down and create forest gaps. These gaps allow

more light to penetrate the tree canopy increasing production of shrubby and herbaceous understory, creating places for stand regeneration, and accelerating succession (Uchytil 1991g, Howard and Aleksoff 2000, Steinberg 2002e, Howard 2003b, 2003c).

Insects: Bark beetles: Douglas-fir beetle (*Dendroctonus pseudotsugae*), pine engraver (*Ips pini*), mountain pine beetle (*Dendroctonus ponderosae*), fir engraver beetle (*Scolytus ventralis*), western balsam bark beetle (*Dryocoetes confusus*)and spruce beetle (*Dendroctonus rufipennis*) (spruce beetle), extended outbreaks of defoliators such as western spruce budworm (*Choristoneura occidentalis*) (Burns and Honkala 1990a, Uchytil 1991g, Howard and Aleksoff 2000, Steinberg 2002e, Howard 2003b, 2003c).

Fungi: Root and butt rots such as *Phellinus* root rot (*Phellinus weirii*) and *Armillaria* root disease (*Armillaria ostoyae, Armillaria mellea*), Annosus (*Fomes annosus*), red ring rot (*Phellinus pini*), velvet top fungus (*Haeolus schweinitzii*), western red rot (*Dichomitus squalens*), Quinine conk (*Fomitopsis officinialis*), and comandra blister rust (*Cronartium comandrae*) (Burns and Honkala 1990a, Uchytil 1991g, Howard and Aleksoff 2000, Steinberg 2002e, Howard 2003b, 2003c).

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 Graminoids; Species Diversity: Medium
Diversity: medium = 6-15 spp. Understories are often dominated by graminoids, such as *Bromus vulgaris, Calamagrostis rubescens, Carex geyeri, Carex rossii, Festuca idahoensis, Festuca occidentalis*, 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 forest and woodland type.

Environment: This interior Pacific Northwest montane coniferous forest ecological system ranges from southernmost interior British Columbia, eastern Washington, and eastern Oregon across northern Idaho, western and north-central Montana extending east out on mountain islands (the Snowy Mountains) in the northwestern Great Plains and south along the east slope of the Cascades in Washington and Oregon. It has a submesic climate regime with annual precipitation ranging from 50 to 100 cm, with a maximum in winter or late spring. Winter snowpacks typically melt off in early spring at lower elevations. Stands are often dry in late summer when fire season begins. Elevations range from 460 to 1920 m. Substrates are variable, but it often occurs on shallow rocky soils.

Key Processes and Interactions: LANDFIRE developed several state-and-transition vegetation dynamics VDDT models for this system. Some mapzone teams created multiple models for different dominant trees. Below is a model with five classes from mountains of eastern Oregon (LANDFIRE 2007a, BpS 0910450). These are summarized as:

A) Early Development 1 All Structures (10% of type in this stage): Tree cover is 0-20%. Open stand of ponderosa pine and other tree seedlings mixed with grasses and shrubs. Early-seral dominant species include ceanothus, scouler willow, *Bromus*, some sedges and grasses. We use Comp/Maintenance to hold a portion of this class back in an extended shrub-dominated stage. Also, we use AltSucc. without TSD to allow a portion of this type to succeed to class B - mid-closed.

B) Mid Development 1 Closed (tree-dominated - 5% of type in this stage): Tree cover is 41-100%. Closed stands of 5-20 inches dbh early-seral tree species. Forests in this type rarely if ever exceed 80% canopy closure even in closed, dense conditions.

C) Mid Development 1 Open (tree-dominated - 30% of type in this stage): Tree cover is 11-40%. Open stands of 5-20 inches dbh early-seral tree species. Dominant understory plants include elk sedge, pinegrass, common snowberry, rose, mountain-mahogany (wetter), heartleaf arnica and lupines. This class has low probability of replacement fire due to discontinuous fuel in these open stands. A small portion of the class succeeds to class E - late-closed.

D) Late Development 1 Open (conifer-dominated - 45% of type in this stage): Tree cover is 11-40%. Open stands of 20+ inches dbh early-seral tree species. Dominant understory plants include elk sedge, pinegrass, common snowberry, rose, mountain-mahogany (wetter), heartleaf arnica and lupines.

E) Late Development 1 Closed (conifer-dominated - 10% of type in this stage): Tree cover is 41-100%. Closed stands of 20+ inches dbh early-seral tree tree species. Forests in this PNVG rarely if ever exceed 80% canopy closure even in closed, dense conditions. This class has relatively high probability of replacement fires, due to the dense understory, though it is less than the probability of replacement fire in the mid-closed.

Typical disturbance regimes under natural conditions include frequent, low-intensity underburns that maintain open stands of fire-resistant trees. Much more infrequent mixed-severity and stand-replacement wildfire occurred and tended to generate mosaics of older, larger trees and younger regeneration. Endemic bark beetles produced patch mortality. Rarer epidemic bark beetle outbreaks caused larger-scale overstory mortality and released understory trees. Defoliator outbreaks also caused fir mortality in some areas. Defoliation by spruce budworm is now more widespread than historically. Root diseases may play a significant role in later-seral forests in this environment (LANDFIRE 2007a, BpS 0910450).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. Biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this forest and woodland system include altered fire regime, altered stand structure from fragmentation due to roads, logging, mining, or other human disturbances. These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed. Invasive exotic species can become abundant in disturbed areas and alter floristic composition. Direct and indirect effects of climate change may alter dynamics of indigenous insects such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) or mountain pine beetle (*Dendroctonus ponderosae*) causing a buildup in population size (with less extreme winters) leading to large outbreaks that can cause high mortality in mature trees.

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.

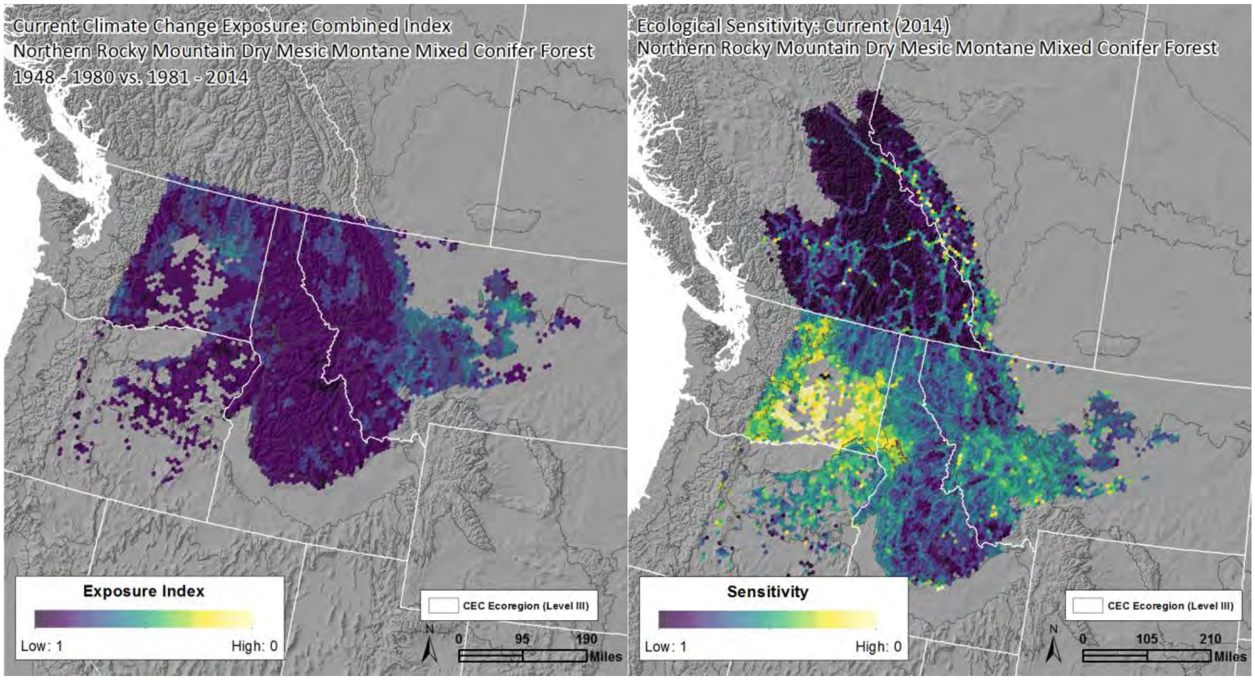

Figure 10. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 9. Resilience, exposure and vulnerability scores for Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest 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 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	Columbia Mountains-Northern Rockies	Thompson-Okanogan Plateau	Canadian Rockies	Idaho Batholith	Middle Rockies	North Cascades	Blue Mountains	Columbia Plateau	Eastern Cascades Slopes & Foothills	North-western Great Plains	Chilcotin Ranges & Fraser Plateau	Skeena-Omineca-Central Canadian Rocky Mountains	Pacific & Nass Ranges	Aspen Parkland-Northern Glaciated Plains	Clear Hills & Western Alberta Upland	North-western Glaciated Plains	Cascades	Northern Basin & Range
	Potential square miles within ecoregion	23,955	6,549	5,081	4,067	3,138	2,292	1,839	1,106	741	296	184	145	143	108	89	75	37	28
Contributions to Relative Vulnerability by Factor																			
Vulnerability from **Exposure (2014)**		Low 0.77	Mod 0.71	Mod 0.74	Low 0.85	Low 0.78	Low 0.79	Low 0.83	Low 0.79	Low 0.79	Mod 0.69	Mod 0.74	Low 0.77	Mod 0.69	Mod 0.70	Mod 0.72	Mod 0.71	Low 0.82	Low 0.88
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.70	0.79	0.77	0.76	0.68	0.55	0.63	0.27	0.27	0.61	0.92	0.90	0.94	0.50	0.79	0.65	0.72	0.78
	Fire Regime Departure	0.70	Null	0.64	0.61	0.54	0.31	0.37	0.47	0.53	0.56	Null	Null	Null	Null	Null	0.58	0.38	0.65
	Forest Insect & Disease	0.77	Null	0.78	0.79	0.84	0.89	0.76	0.94	0.83	0.94	Null	Null	Null	Null	Null	0.97	0.90	0.88
	Sensitivity Average	**0.72**	**0.79**	**0.73**	**0.72**	**0.69**	**0.58**	**0.59**	**0.56**	**0.54**	**0.71**	**0.92**	**0.90**	**0.94**	**0.50**	**0.79**	**0.73**	**0.67**	**0.77**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.37	0.35	0.35	0.54	0.48	0.46	0.41	0.24	0.29	0.37	0.25	0.28	0.47	0.25	0.23	0.35	0.46	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	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.44**	**0.43**	**0.43**	**0.52**	**0.49**	**0.48**	**0.46**	**0.37**	**0.40**	**0.43**	**0.38**	**0.39**	**0.49**	**0.38**	**0.37**	**0.42**	**0.48**	**0.39**
Vulnerability from Measures of **Overall Resilience**		Mod 0.58	Mod 0.61	Mod 0.58	Mod 0.62	Mod 0.59	Mod 0.53	Mod 0.52	High 0.47	High 0.47	Mod 0.57	Mod 0.65	Mod 0.64	Mod 0.71	High 0.44	Mod 0.58	Mod 0.58	Mod 0.57	Mod 0.58
Climate Change Vulnerability Index		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, the climate exposure as of 2014 for this widespread forest system is low to moderate. Across ten of 18 ecoregions climate exposure is low, and in the remaining eight ecoregions exposure is at the low end of moderate. Annual mean temperature has increased between 0.5° and 0.7°C across large portions (28-92%) of eight ecoregions. Exposure was generally greater in northern portions of the range extending into Canada. Other climate exposure effects were smaller in area or magnitude, but consistent with greater increases in winter and night-time temperatures. For example, mean winter temperature increased by 2°C across small portions (15%) of the Northwestern Glaciated Plains, and mean diurnal temperature range decreased by 0.3° to 0.4°C across small (<10%) portions of nine ecoregions.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest and Northern Rocky Mountains regions 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 el al. 2014). 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 tree recruitment. Without recruitment these mixed, Douglas-fir and ponderosa pine mixed stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) or mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact trees regionally (Schmid 1988, Burns and Honkala 1990a, Habeck 1992a, d, Howard 2003b, c, Steinberg 2002e).

Many stands of this ecological system woodland occur in montane of taller ranges, so it may be possible for the species of this system to move up into the upper montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* and *Pseudotsuga menziesii* frequently live more than 300-500 years and are known to live over 700 years, so they may be able to survive as relicts for centuries without regeneration (Habeck 1992a, d, Steinberg 2002e, Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from hotter, drier climate.

Ecosystem Resilience: Sensitivity: Sensitivity to climate change is moderate to low across the potential range of this forest type, with moderate sensitivity in 12 ecoregions accounting for approximately 85% of the potential distribution.

Contributions to sensitivity from landscape condition ranged from low to high, reflecting varied conditions across the wide range of this type. These reflect modified conditions from logging and associated road networks, as well as urban, suburban and exurban development in lower elevation portions of the range. This is particularly characteristic of conditions within the Colombia Plateau and Eastern Cascades ecoregions.

Fire regime departure was moderate to high, with greater departure occurring in the Pacific Northwest ecoregions. This reflects fire suppression practices across much of the region which have led to higher tree and understory densities and increases in *Abies grandis* and other fire-intolerant species relative to

Pseudotsuga menziesii and *Pinus ponderosa.* Increased fuel loads have led to the potential for higher-intensity and stand-replacing fires.

Risk from insect and disease was low across the range of the system. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can increase vulnerability to insects and disease.

The interactions of the stressors of fire suppression and landscape fragmentation have resulted in changes to the structure of these forests. Together, these result in an overall moderate sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Climate vulnerability from adaptive capacity is high across the range of the system, with 17 ecoregions scoring highly vulnerable. This low adaptive capacity is related to low topoclimatic variability characteristic of the gentle to moderate slopes characteristic of lower elevations for this type. There is potential for the species in this system to move upslope into areas of suitable climate and increased topographic variability. In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity of cool-season graminoids and high for species that can contribute to a range of successional stages through patch 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 forest type scores in the moderate range across all ecoregions. This is due to moderate contributions from sensitivity measures (landscape condition and fire regime departure), and moderate to low adaptive capacity associated with low topoclimate diversity. Many stands occur on lower elevation slopes, so there may be potential for upslope migration of dominant species. Although insect and disease risk scored low for this system, these may be exacerbated by drought and severe fires across the range.

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 Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Amman 1977, Anderson 2003b, Burns and Honkala 1990a, Comer et al. 2003*, Cooper et al. 1987, Crawford and Johnson 1985, Dale et al. 2001, Daubenmire and Daubenmire 1968, Eyre 1980, Graham and Jain 2005, Habeck 1992a, Habeck 1992d, Harvey 1994, Howard 2003b, Howard 2003c, Howard and Aleksoff 2000, LANDFIRE 2007a, Lillybridge et al. 1995, McKenzie et al. 2004, McKenzie et al. 2008, Mote et al. 2014, NCC 2002, Pfister et al. 1977, Schmid 1988, Shafer et al. 2014, Steele and Geier-Hayes 1995, Steele et al. 1981, Steen and Coupé 1997, Steinberg 2002e, Stevens-Rumann et al. 2017, Topik 1989, Topik et al. 1988, Uchytil 1991g, WNHP unpubl. data 2018, Westerling et al. 2006, Williams and Lillybridge 1983

CES306.030 Northern Rocky Mountain Ponderosa Pine Woodland and Savanna

Figure 11. Photo of Northern Rocky Mountain Ponderosa Pine Woodland and Savanna. Photo credit: Katja Schulz, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This inland Pacific Northwest ecological system occurs in the foothills of the northern Rocky Mountains in the Columbia Plateau region and west along the foothills of the Modoc Plateau and eastern Cascades into southern interior British Columbia. These woodlands and savannas occur at the lower treeline/ecotone between grasslands or shrublands and more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 500 m in British Columbia to 1600 m in the central Idaho mountains. Occurrences are found on all slopes and aspects; however, moderately steep to very steep slopes or ridgetops are most common. This ecological system generally occurs on glacial till, glacio-fluvial sand and gravel, dune, basaltic rubble, colluvium, to deep loess or volcanic ash-derived soils, with characteristic features of good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, rockiness, and periods of drought during the growing season. In the Oregon "pumice zone" this system occurs as matrix-forming, extensive woodlands on rolling pumice plateaus and other volcanic deposits. These woodlands in the eastern Cascades, Okanagan and northern Rockies regions receive winter and spring rains, and thus have a greater spring "green-up" than the drier woodlands in the central Rockies. *Pinus ponderosa* (primarily *var. ponderosa*) is the predominant conifer; *Pseudotsuga menziesii* may be present in the tree canopy but is usually absent.

In southern interior British Columbia, *Pseudotsuga menziesii* or *Pinus flexilis* may form woodlands or fire-maintained savannas with and without *Pinus ponderosa var. ponderosa* at the lower treeline transition into grassland or shrub-steppe. The understory can be shrubby, with *Artemisia tridentata, Arctostaphylos patula, Arctostaphylos uva-ursi, Cercocarpus ledifolius, Physocarpus malvaceus, Purshia tridentata, Symphoricarpos oreophilus* or *Symphoricarpos albus, Prunus virginiana, Amelanchier alnifolia*, and *Rosa* spp. common species. Understory vegetation in the true savanna occurrences is predominantly fire-resistant grasses and forbs that resprout following surface fires; shrubs, understory trees and downed logs are uncommon. These more open stands support grasses such as *Pseudoroegneria spicata, Hesperostipa* spp., *Achnatherum* spp., dry *Carex* species (*Carex inops*), *Festuca idahoensis*, or *Festuca campestris*. The more mesic portions of this system may include *Calamagrostis rubescens* or *Carex geyeri*, species more typical of Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest (CES306.805). Mixed fire regimes and surface fires of variable return intervals maintain these woodlands typically with a shrub-dominated or patchy shrub layer, depending on climate, degree of soil development, and understory density. This includes the northern race of Interior Ponderosa Pine old-growth (USFS Region 6, USFS Region 1). Historically, many of these woodlands and savannas lacked the shrub component resulting from 3- to 7-year fire-return intervals.

Distribution: This system is found in the Fraser River drainage of southern British Columbia south along the Cascades and northern Rocky Mountains of Washington, Oregon and California. In the northeastern part of its range, it extends across the northern Rocky Mountains west of the Continental Divide into northwestern Montana, south to the Snake River Plain in Idaho, and east into the foothills of western Montana.

Nations: CA, US

States/Provinces: BC, ID, MT, NV?, OR, WA, WY

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

Primary Concept Source: NatureServe Western Ecology Team

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pinus ponderosa* (primarily *var. ponderosa*) is the predominant conifer; *Pseudotsuga menziesii* may be present in the tree canopy but is usually absent. In southern interior British Columbia, *Pseudotsuga menziesii* or *Pinus flexilis* may form woodlands or fire-maintained savannas with and without *Pinus ponderosa var. ponderosa* at the lower treeline transition into grassland or shrub-steppe. The understory can be shrubby, with *Artemisia tridentata, Arctostaphylos patula, Arctostaphylos uva-ursi, Cercocarpus ledifolius, Physocarpus malvaceus, Purshia tridentata, Symphoricarpos oreophilus* or *Symphoricarpos albus, Prunus virginiana, Amelanchier alnifolia*, and *Rosa* spp. common species. Understory vegetation in the true savanna occurrences is predominantly fire-resistant grasses and forbs that resprout following surface fires; shrubs, understory trees and downed logs are uncommon. These more open stands support grasses such as *Pseudoroegneria spicata, Hesperostipa* spp., *Achnatherum* spp., dry *Carex* species (*Carex inops*), *Festuca idahoensis*, or *Festuca campestris*. The more mesic portions of this system may include *Calamagrostis rubescens* or *Carex geyeri*.

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.

Nitrogen Fixation; Species Diversity: Medium
Diversity: medium = 11-20 spp. These *Pinus ponderosa* woodlands occur in semi-arid to dry-mesic temperate climates, with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. Possible nitrogen-fixing plants include species of Fabaceae (including species of *Astragalus* and *Lupinus*); Polygonaceae (*Eriogonum*); Rhamnaceae (*Ceanothus*); Rosaceae (*Amelanchier, Cercocarpus, Potentilla, Purshia*); many species of Poaceae (including *Achnatherum occidentale, Bromus orcuttianus, Calamagrostis rubescens, Elymus glaucus, Festuca campestris, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus salinus, Poa fendleriana, Poa nervosa, Poa secunda*, and *Pseudoroegneria spicata*); and some Brassicaceae. Although grass diversity is moderate rangewide, it is generally low at stand level. Diversity of cyanobacteria and cyanolichens is low in savannas and temperate woodlands but may be higher in semi-arid woodland stands.

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 Graminoids; Species Diversity: High
Diversity: high = >15 spp. This is not a major FSG for this system except in true savanna stands. *Achnatherum occidentale, Bromus orcuttianus, Calamagrostis rubescens, Carex geyeri, Carex rossii, Carex inops, Elymus elymoides, Elymus glaucus, Festuca campestris, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus salinus, Poa fendleriana, Poa nervosa, 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 ponderosa pine woodland and savanna type.

Environment: This ecological system within the region occurs at the lower treeline/ecotone between grasslands or shrublands and more mesic coniferous forests typically in warm, dry, exposed sites at elevations ranging from 500-1600 m (1600-5248 feet). These woodlands receive winter and spring rains, and thus have a greater spring "green-up" than the drier ponderosa woodlands in the Colorado and New Mexico Rockies. In eastern Washington, precipitation varies from 36-76 cm (14-30 inches) with most occurring as snowfall (WNHP 2011). It can occur on all slopes and aspects; however, it commonly occurs on moderately steep to very steep slopes or ridgetops. This ecological system generally occurs on most geological substrates from weathered rock to glacial deposits to eolian deposits (e.g., glacial till, glacio-fluvial sand and gravel, dunes, basaltic rubble, colluvium, to deep loess or volcanic ash-derived soils) (WNHP 2011). Characteristic soil features include good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, and periods of drought during the growing season. Some occurrences may occur as edaphic climax communities on very skeletal, infertile and/or excessively drained soils, such as pumice, cinder or lava fields, and scree slopes. In the Oregon "pumice zone" this system occurs as matrix-forming, extensive woodlands on rolling pumice plateaus and other volcanic deposits. Surface textures are highly variable in this ecological system ranging from sand to loam and silt loam. Exposed rock and bare soil consistently occur to some degree in all the associations.

Key Processes and Interactions: Summer drought and frequent, low-severity fires create woodlands composed of widely spaced, large trees with small scattered clumps of dense, even-aged stands which regenerated in forest gaps or were protected from fire due to higher soil moisture or topographic protection. Closed-canopy or dense stands were also part of the historical range of stand variability but under natural disturbance regimes are a minor component of that landscape. Mixed fire regimes and surface fires of variable return intervals maintain these woodlands typically with a shrub-dominated or patchy shrub layer, depending on climate, degree of soil development, and understory density. Historically, many of these woodlands and savannas lacked the shrub component resulting from low-severity but high-frequency fires (2 - to 10-year fire-return intervals). Some sites, because of low productivity, naturally lacked a dense shrub understory. Mixed-severity fires had a return interval of 25-75 years while stand-replacing fire occurred at an interval of >100 years (Arno 1980, Fischer and Bradley 1987). The latter two intervals only occurred on 20-25% of stands within the landscape while surface fires were the dominant fire regime on over 75% of stands (Landfire 2007a). Presettlement fires were triggered by lightning strikes or deliberately set fires by Native Americans.

Pinus ponderosa is a drought-resistant, shade-intolerant conifer which usually occurs at lower treeline in the major ranges of the western United States. Establishment of ponderosa pine is erratic and believed to be linked to periods of adequate soil moisture and good seed crops as well as fire frequencies, which allow seedlings to reach sapling size.

Western pine beetle is another significant disturbance and especially affects larger trees. Bark beetle outbreaks are highly related to stand density. Denser stands in relation to site capacity will favor outbreaks, which will decrease as trees are thinned (Landfire 2007a). Mistletoe can cause tree mortality in young and small trees. Fires and insect outbreaks resulted in a landscape consisting of a mosaic of open forests of large trees (most abundant patch), small denser patches of trees, and openings (Franklin et al. 2008). White-headed woodpecker, pygmy nuthatch, and flammulated owl are indicators of healthy ponderosa pine woodlands. All these birds prefer mature trees in an open woodland setting (Jones 1998, Levad 1998 Winn 1998, as cited in Rondeau 2001).

LANDFIRE developed several state-and-transition vegetation dynamics VDDT models for this system across its range and dry or mesic conditions. This model is typical of much of the range and has five classes in total (LANDFIRE 2007a, BpS 1910530). These are summarized as:

A) Early Development 1 Open (5% of type in this stage): Fire-maintained grass/forb and/or seedlings and saplings. Seedling/sapling size class would be less than 5 inches in diameter. There would be no large patches (10-100 acres) of large or old-growth trees due to poor site conditions and abundance of rock outcroppings. However, dispersed large-diameter fire-remnant ponderosa pines and snag trees could be present. These large-diameter trees would have a density of less than one tree per acre. Grass species are the dominant lifeform in this class attaining maximum heights of 3 feet and patchy in distribution (25-75% cover).

B) Mid Development 1 Closed (tree-dominated - 10% of type in this stage): Tree cover is 41-60%. Closed ponderosa pine pole and medium-diameter stand; may have Douglas-fir as incidentals. Larger, old-growth trees may be present in this class, though the pole and medium-diameter class (5-21 inches) occurring between these large trees is most abundant and characteristic of this class. May see large-diameter snags, dead and downed trees present. High-density stunted pole stands are counted here; may see insect/disease here.

C) Mid Development 1 Open (tree-dominated - 20% of type in this stage): Tree cover is 0-40%. Open ponderosa pine pole and medium-diameter stand that may have Douglas-fir as incidentals. Larger, old-growth trees may be present in this class, the pole and medium-diameter (5-21 inches) trees are characteristic for this class. These patches have probably had recent fire or are drier so they retain a more open condition.

D) Late Development 1 Open (conifer-dominated - 55% of type in this stage): Tree cover is 0-40%. Fire-maintained open, park-like ponderosa pine; nearly any fire maintains; Douglas-fir may be seen as incidentals or in patches, but not a major component of the overstory. The overstory is characterized by large and very large ponderosa pine and isolated Douglas-fir. Understory is dominated by grasses and is relatively open. Seedlings are very infrequent, with <10% cover and usually occurring in patches.

E) Late Development 1 Close (conifer-dominated - 5% of type in this stage): Tree cover is 41-60%. High-density, multi-storied ponderosa pine stand; Douglas-fir regeneration on some sites. Thickets of various size classes distributed within the class and may be interspersed with large snags.

Frequent, non-lethal surface fires were the dominant disturbance factor, occurring every 3-30 years (Arno 1980, Arno and Petersen 1983, Fischer and Bradley 1987). Three-year fire-return intervals are likely very localized and associated with Native American burning. However, there is some disagreement as to the extent of Native burning. More median fire-return intervals were likely about 15 years. Mixed-severity fires likely occurred about every 50 years, again, depending on the vegetative state. Stand-replacement fires likely occurred in stands and small patches on the order of a few hundred acres every 300-700 years depending on the vegetative state. Some authors note that little information is available regarding the exact nature of stand-replacement fire severity in this BpS (LANDFIRE 2007a, BpS 1910530). Western pine beetle can attack large ponderosa pine in any canopy density (LANDFIRE 2007a, BpS 1910530).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from rural and urban development. Since European settlement, fire suppression, timber harvest, livestock grazing, introduced diseases, road building, development, and plantation establishments have all impacted natural disturbance regimes, forest structure, composition, landscape patch diversity, and tree regeneration (Franklin et al. 2008). Timber harvesting has focused on the large, older trees in mid- and late-seral forests thereby eliminating many old forest attributes from stands (Franklin et al. 2008). Overgrazing may have contributed to the contemporary dense stands by eliminating grasses in some areas thereby creating suitable spots for tree regeneration as well as reducing the abundance and distribution of flashy fuels that are important for carrying surface fires (Hessburg et al. 2005, Franklin et al. 2008). Road development has fragmented many forests creating firebreaks. With settlement and subsequent fire suppression, occurrences have become denser. Presently, many occurrences contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. These altered occurrence structures have affected fuel loads and alter fire regimes. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999). Longer fire-return intervals have resulted in many occurrences having dense subcanopies of overstocked and unhealthy young *Pinus ponderosa* (Reid et al. 1999). With vigorous fire suppression, longer fire-return intervals are now the rule, and multi-layered stands of *Pinus ponderosa* and/or *Pseudotsuga menziesii* provide fuel "ladders," making these forests more susceptible to high-intensity, stand-replacing fires. The resultant stands at all seral stages tend to lack snags, have high tree density, and are composed of smaller and more shade-tolerant trees (WNHP 2011). Mid-seral forest structure is currently 70% more abundant than in historical, native systems, and late-seral forests of shade-intolerant species are now essentially absent (WNHP 2011). Early-seral forest abundance is similar to that found historically but lacks snags and other legacy features.

In the Pacific Northwest, regionally downscaled climate models project increases in annual temperature of, on average, 3.2°F by the 2040s. Projected changes in annual precipitation, averaged over all models, are small (+1 to +2%), and some models project wetter autumns and winters and drier summers. Warmer temperatures will result in more winter precipitation falling as rain rather than snow throughout much of the Pacific Northwest, particularly in mid-elevation basins where average winter temperatures are near freezing. This change will result in: less winter snow accumulation, higher winter streamflows, earlier spring snowmelt, earlier peak spring streamflow and lower summer streamflows in rivers that depend on snowmelt (as do most rivers in the Pacific Northwest) (Littell et al. 2009). Potential climate change effects could include: reduction in freshwater inflows through the further reduction in summer flows (Littell et al. 2009); drop in groundwater table; increased fire frequency due to warmer temperatures resulting in drier fuels, the area burned by fire regionally is projected to double by the 2040s and triple by the 2080s (Littell et al. 2009); and additionally, likely warming may stress host trees so mountain pine beetle outbreaks are projected to increase in frequency and cause increased tree mortality.

The ways in which the climate in the region where this system reaches its eastern limit is likely to change, and the effects of those changes on the structure and function of this system are all hard to predict, and only broad generalizations can be made (Rice et al. 2012). Average annual temperature likely will increase by 1.7°C by 2050 and by 1.1° to 5.5°C by the end of this century. Annual precipitation may increase by 10%, with wetter winters and drier summers, but less certainty can be assigned to possible precipitation changes than temperature changes. Climate changes will also affect the ecological system indirectly, through bark beetle populations and other ecological agents. Changes in the extremes of temperature and precipitation likely will have a stronger effect than will changes in annual averages, and the patterns of these extremes are especially hard to predict. Climate changes almost certainly will disrupt the composition, structure, and function of this ecological system, in ways that can only be very generally anticipated.

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.

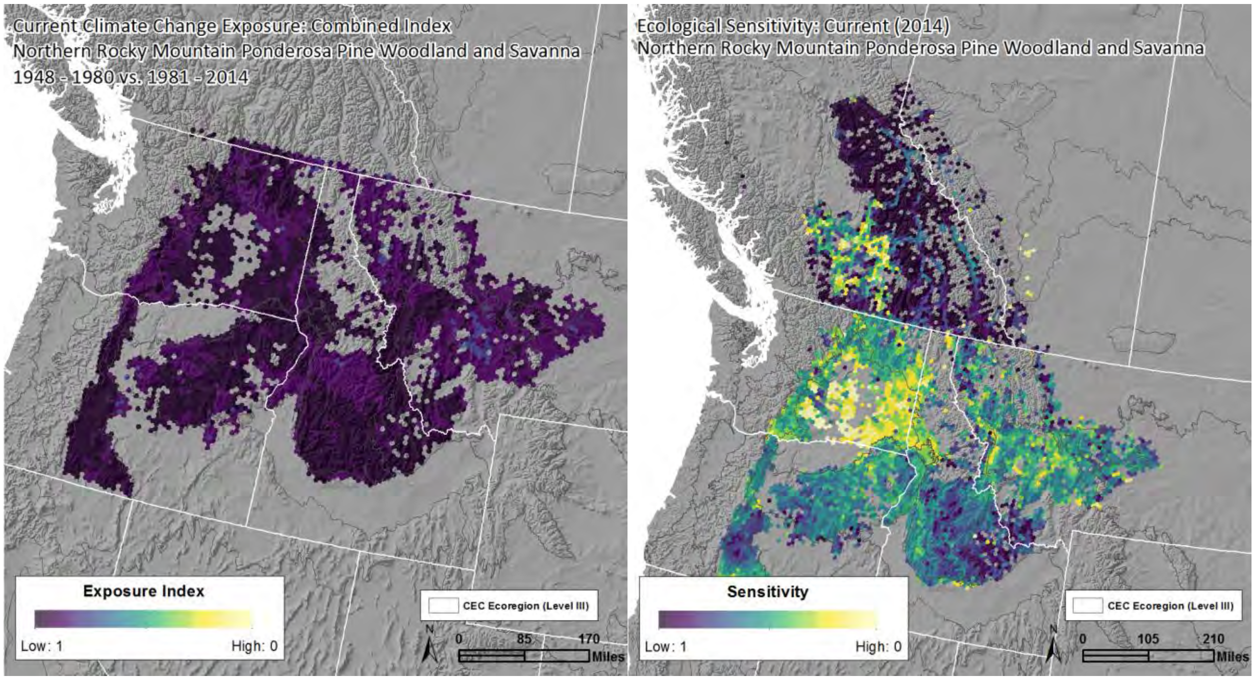

Figure 12. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northern Rocky Mountain Ponderosa Pine Woodland and Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively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

Table 11. Resilience, exposure and vulnerability scores for Northern Rocky Mountain Ponderosa Pine Woodland and Savanna 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 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	Blue Mountains	Eastern Cascades Slopes & Foothills	Idaho Batholith	Columbia Mountains-Northern Rockies	Thompson-Okanogan Plateau	Columbia Plateau	Middle Rockies	Cascades	North-western Great Plains	Canadian Rockies	North Cascades	North-western Glaciated Plains	Northern Basin & Range	Snake River Plain
	Potential square miles within ecoregion	7,074	6,138	2,089	1,237	968	808	794	341	188	163	160	45	25	20
Contributions to Relative Vulnerability by Factor															
Vulnerability from **Exposure (2014)**		Low 0.91	Low 0.92	Low 0.91	Low 0.89	Low 0.92	Low 0.91	Low 0.90	Low 0.93	Low 0.85	Low 0.83	Low 0.88	Low 0.84	Low 0.87	Low 0.89
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.66	0.60	0.65	0.45	0.39	0.22	0.51	0.62	0.53	0.60	0.33	0.30	0.71	0.51
	Fire Regime Departure	0.48	0.59	0.52	0.54	Null	0.51	0.48	0.57	0.56	0.64	0.71	0.62	0.54	0.56
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.79	0.76	0.88	0.92	Null	0.97	0.85	0.83	0.98	0.70	0.87	0.99	0.82	0.94
	Sensitivity Average	**0.64**	**0.65**	**0.68**	**0.64**	**0.39**	**0.57**	**0.61**	**0.68**	**0.69**	**0.65**	**0.64**	**0.64**	**0.69**	**0.67**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.35	0.25	0.53	0.24	0.27	0.20	0.43	0.31	0.33	0.20	0.34	0.22	0.24	0.38
	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
	Adaptive Capacity Average	**0.42**	**0.37**	**0.51**	**0.37**	**0.38**	**0.35**	**0.46**	**0.41**	**0.42**	**0.35**	**0.42**	**0.36**	**0.37**	**0.44**
Vulnerability from Measures of **Overall Resilience**		Mod 0.53	Mod 0.51	Mod 0.60	Mod 0.50	High 0.39	High 0.46	Mod 0.54	Mod 0.54	Mod 0.55	High 0.50	Mod 0.53	High 0.50	Mod 0.53	Mod 0.56
Climate Change Vulnerability Index		Mod	Mod	Low	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this woodland and savanna system is low across all ecoregions. Annual mean temperature has increased between 0.5° and 0.7°C across approximately 60% of its potential distribution. These changes were most pervasive in the Blue Mountains of the Pacific Northwest (71% affected) and the Middle Rockies (65% affected). Other climate exposure effects were smaller in area or magnitude, but consistent with greater increases in winter and night-time temperatures. For example, mean diurnal temperature range decreased by 0.4°C across 79% of the North Cascades, likely reflecting warmer night-time temperatures. In addition, mean temperature of the wettest quarter increased by over 1°C in small portions (6% or less) of all ecoregions.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest and Northern Rocky Mountains regions 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). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as *Ips* spp. by increasing the number of generations within a growing season or by allowing a population buildup over several years such as with mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact pine trees regionally (Schmid 1988, Burns and Honkala 1990a, Habeck 1992a, Howard 2003b, c).

Many stands of this ecological system woodland occur in the foothill zone of taller ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so it may be able to survive as relicts for centuries without regeneration (Habeck 1992a, Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across all 14 ecoregions within the potential range of this woodland and savanna type.

Contributions to sensitivity from landscape condition were moderate to high. Nine of the 14 ecoregions scored as moderately sensitive (comprising >80% of the range), four had high sensitivity, and one ecoregion (the Columbia Plateau) had very high sensitivity. Sensitivity in the Colombia Plateau reflects fragmentation from agricultural conversion and associated small roads. Moderate sensitivity across other ecoregions reflects fragmentation from road networks and a range of development types (e.g., suburban, energy development and transmission) in this lower elevation montane system.

Fire regime departure was moderate in 12 of the 14 ecoregions, and high in the Blue Mountains and Middle Rockies. This reflects fire suppression practices across much of the region which have led to higher densities of *Pinus ponderosa* and increased understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was generally low across 13 of the 14 ecoregions, and moderate in the Canadian Rockies. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease.

The interactions of the stressors of fire suppression and landscape fragmentation have resulted in changes to the structure of these woodlands. Together, these result in an overall moderate sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally low across the range of this system, with scores in the low range in 13 ecoregions, and scores in the lower range of moderate for the Idaho Batholith Ecoregion. This low adaptive capacity is related to low scores for topoclimatic variability. Scores were low in seven ecoregions and very low in six. These reflect a low level of topographic diversity associated with the lower slopes and plateaus characteristic of where this system occurs. Contributions to vulnerability from low adaptive capacity were greatest in the Colorado Plateau and Canadian Rockies regions. There is limited potential for the species in this system to move into areas of suitable climate nearby. In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity of nitrogen fixers and cool-season graminoids, suggesting increased vulnerability to potential loss of individual species from 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 woodland and savanna type scores in the moderate range for 13 ecoregions and low in the Idaho Batholith ecoregion. This is primarily due to moderate contributions from sensitivity measures (particularly fire regime departure), and low adaptive capacity scores associated with low topoclimate diversity. The system occurs in areas of low topoclimate variability and is also vulnerable to catastrophic fires from increased stand density and understory fuel loads. Many stands occur on lower elevation slopes, so there may be potential for upslope migration of dominant species. Although insect and disease risk were low for this system, these may be exacerbated by drought and severe fires across the range of this system. Overall vulnerability was greatest in the Columbia Plateau region, reflecting greater fragmentation and lower topoclimate diversity in this region.

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 Northern Rocky Mountain Ponderosa Pine Woodland and Savanna.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.

Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Arno 1980, Arno and Peterson 1983, Burns and Honkala 1990a, Camp et al. 1997, Comer et al. 2003*, Cooper et al. 1987, Dale et al. 2001, Daubenmire and Daubenmire 1968, Everett et al. 2000, Evers pers. comm., Eyre 1980, Fischer and Bradley 1987, Franklin and Dyrness 1973, Franklin et al. 2008, Habeck 1992a, Hessburg et al. 2005, Howard 2003b, Howard 2003c, Johansen and Latta 2003, LANDFIRE 2007a, Littell et al. 2009, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Mehl 1992, Meidinger and Pojar 1991, Mote et al. 2014, NCC 2002, Pfister et al. 1977, Reid et al. 1999, Rice et al. 2012a, Rondeau 2001, Schmid 1988, Shafer et al. 2014, Shiflet 1994, Stevens-Rumann et al. 2017, USFS 1993a, WNHP 2011, WNHP unpubl. data 2018, Westerling et al. 2006, Western Ecology Working Group n.d., Youngblood and Mauk 1985

CES303.650 Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna

Figure 13. Photo of Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This system occurs throughout the northwestern Great Plains along areas that border the Rocky Mountains. The expansion of this system within the central Great Plains may be due to fire suppression. These can be physiognomically variable, ranging from very sparse patches of trees on drier sites, to nearly closed-canopy forest stands on north slopes or in draws where available soil moisture is higher. This system occurs primarily on gentle to steep slopes along escarpments, buttes, canyons, rock outcrops or ravines and can grade into one of the surrounding prairie systems or the Great Plains canyon system. Soils typically range from well-drained loamy sands to sandy loams formed in colluvium, weathered sandstone, limestone, scoria or eolian sand. This system is primarily dominated by *Pinus ponderosa* but may include a sparse to relatively dense understory of *Juniperus scopulorum, Thuja*, or *Cercocarpus* with just a few scattered trees. Deciduous trees are an important component in some areas (western Dakotas, Black Hills) and are sometimes codominant with the pines, including *Fraxinus pennsylvanica, Betula papyrifera, Quercus macrocarpa, Ulmus americana, Acer negundo*, and *Populus tremuloides*. Along the Missouri Breaks in north-central Montana, woodlands dominated by *Pseudotsuga menziesii* are in similar ecological settings as *Pinus ponderosa* in the Great Plains and are included in this system. In the breaks where it occurs, *Pseudotsuga menziesii* has a very open canopy over grassy undergrowth, predominantly composed of *Pseudoroegneria spicata*, with little to no shrubs present. Important or common shrub species with ponderosa pine can include *Arctostaphylos uva-ursi, Mahonia repens, Yucca glauca, Symphoricarpos* spp., *Prunus virginiana, Juniperus communis, Juniperus horizontalis, Amelanchier alnifolia, Rhus trilobata*, and *Physocarpus monogynus*. The herbaceous understory can range from sparse to a dense layer with species typifying the surrounding prairie system, with mixedgrass species common, such as *Andropogon gerardii, Bouteloua curtipendula, Carex inops ssp. heliophila, Carex filifolia, Danthonia intermedia, Koeleria macrantha, Nassella viridula, Oryzopsis asperifolia, Pascopyrum smithii, Piptatheropsis micrantha*, and *Schizachyrium scoparium*. Timber cutting and other disturbances have degraded many examples of this system within the Great Plains. However, some good examples may occur along the Pine Ridge escarpment and Pine Ridge district of the Nebraska National Forest in Nebraska.

Distribution: This system is found in central and eastern Montana, the western Dakotas, eastern Wyoming (east of the Bighorns), the Black Hills, and south into the Sand Hills of Nebraska and northeastern Colorado (north of Pawnee National Grasslands to Cedar Point near Limon and south). In Montana, it occurs along the Missouri River breaks, around the Little Belts and Snowy mountains, in south-central Montana between the Bighorns and the Black Hills (along the Tongue and Powder rivers), and other areas of eastern Montana. In Wyoming, it is found around the Black Hills and Bear Lodge Mountains, and in isolated areas of eastern Wyoming on bluffs and rock outcrops, and along "breaks." Whether this system occurs in Kansas is uncertain.

Nations: US

States/Provinces: MT, ND, NE, SD, WY

CEC Ecoregions: Middle Rockies, Southern Rockies, Northwestern Glaciated Plains, Northwestern Great Plains, Nebraska Sand Hills, High Plains, Central Great Plains, Wyoming Basin

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is primarily dominated by *Pinus ponderosa* but may include a sparse to relatively dense understory of *Juniperus scopulorum, Thuja*, or *Cercocarpus* with just a few scattered trees. Deciduous trees are an important component in some areas (western Dakotas, Black Hills) and are sometimes codominant with the pines, including *Fraxinus pennsylvanica, Betula papyrifera, Quercus macrocarpa, Ulmus americana, Acer negundo*, and *Populus tremuloides*. Along the Missouri Breaks in north-central Montana, woodlands dominated by *Pseudotsuga menziesii* are in similar ecological settings as *Pinus ponderosa* in the Great Plains and are included in this system. In the breaks where it occurs, *Pseudotsuga menziesii* has a very open canopy over grassy undergrowth, predominantly composed of *Pseudoroegneria spicata*, with little to no shrubs present. Important or common shrub species with ponderosa pine can include *Arctostaphylos uva-ursi, Mahonia repens, Yucca glauca, Symphoricarpos* spp., *Prunus virginiana, Juniperus communis, Juniperus horizontalis, Amelanchier alnifolia, Rhus trilobata*, and *Physocarpus monogynus*. The herbaceous understory can range from sparse to a dense layer with species typifying the surrounding prairie system, with mixedgrass species common, such as *Andropogon gerardii, Bouteloua curtipendula, Carex inops ssp. heliophila, Carex filifolia, Danthonia intermedia, Koeleria macrantha, Nassella viridula, Oryzopsis asperifolia, Pascopyrum smithii, Piptatheropsis micrantha (= Piptatherum micranthum)*, and *Schizachyrium scoparium*.

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.

Nitrogen Fixation; Species Diversity: Medium
Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-desert ecosystems (Belnap 2001, Belnap et al. 2001), but are of minor importance in this system.

Diversity: medium = 11-20 spp. Ponderosa pine woodlands occur in semi-arid to dry-mesic climates, typically on rocky substrates with limited soil development and depth. Soil nutrients such as nitrogen are likely a significant constraint on plant growth in these sites. Possible nitrogen-fixing plants include species of Fabaceae (*Astragalus, Lupinus, Oxytropis, Thermopsis*, and *Vicia*); Polygonaceae (*Eriogonum*); some Brassicaceae; Rosaceae (*Amelanchier, Cercocarpus*); and many species of Poaceae. Grasses dominate the typically moderate to dense herbaceous layer (e.g., *Andropogon gerardii, Aristida purpurea, Bouteloua curtipendula, Bouteloua gracilis, Hesperostipa comata, Hesperostipa spartea, Muhlenbergia racemosa, Nassella viridula, Oryzopsis asperifolia, Pascopyrum smithii, Piptatheropsis micrantha, Pseudoroegneria spicata, Schizachne purpurascens, Schizachyrium scoparium*, and *Sporobolus heterolepis*).

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: Medium
Diversity: medium = 11-20 spp. This Great Plains ponderosa savanna and woodland system is adapted to a bimodal precipitation pattern with warm-season summer moisture in additional to cool-season winter precipitation. The understory is often dominated by a mixture of warm- and cool-season graminoids such as:

Cool-season graminoids: *Carex inops ssp. heliophila, Carex siccata, Hesperostipa comata, Hesperostipa spartea, Nassella viridula, Oryzopsis asperifolia, Pascopyrum smithii, Piptatheropsis micrantha, Pseudoroegneria spicata*, and *Schizachne purpurascens*.

Warm-season graminoids: *Andropogon gerardii, Aristida purpurea, Bouteloua curtipendula, Bouteloua gracilis, Muhlenbergia racemosa, Schizachyrium scoparium*, and *Sporobolus heterolepis*.

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 ponderosa pine woodland and savanna type.

Environment: The ponderosa pine system is found in a matrix of northwestern Great Plains grassland systems along escarpments and in foothills and mountains in the Black Hills. It is often surrounded by mixedgrass or tallgrass prairie, in places where available soil moisture is higher, or soils are more coarse and rocky. Some stands are found adjacent to major creek bottoms and the lower toeslope and footslope positions. In some cases, these woodlands or savannas may occur where fire suppression has allowed trees to become established (in areas where deciduous trees are more abundant) (Girard et al. 1987). These are typically not in the same setting as Rocky Mountain ponderosa pine, where ponderosa pine forms woodlands at lower treeline and grades into mixed montane conifer systems at higher elevations. These are physiognomically variable woodlands, ranging from very sparse patches of trees on drier, often rocky sites, to nearly closed-canopy forest stands on north slopes or in draws where available soil moisture is higher. This system occurs primarily on gentle to steep slopes along escarpments, buttes, canyons, rock outcrops or ravines and can grade into the Great Plains canyons the surrounding mixedgrass prairie systems (Hoffman and Alexander 1987). Soils typically range from well-drained loamy sands to loams formed in colluvium, weathered sandstone, limestone, calcareous shales, scoria or eolian sand (Hoffman and Alexander 1987, Hansen and Hoffman 1988).

Key Processes and Interactions: Marriot and Faber-Langendoen (2000) report different fire regimes for ponderosa pine communities in the Black Hills, with their "Dry Group" more typically having frequent surface fires and the "Mesic Group" having infrequent catastrophic fires (every 100-200 years). The Dry Group of associations includes lower elevation foothill savanna associations, and the mesic group somewhat higher elevation, north-slope, swale associations. K. Kindscher (pers. comm. 2007) believes that almost all the stands in Nebraska were there at the time of settlement and are not a result of pine expansion due to fire suppression; in addition, at least some have disappeared, such as the one in southern Nebraska (Franklin County). It is possible, however, that some areas of this system have expanded in size due to fire suppression, but this needs substantiation.

LANDFIRE developed several a state-and-transition vegetation dynamics VDDT models for this system for different map zones and savanna vs low elevation woodland stands. Shone in the grassland model for Map Zone 29 which has five classes in total (LANDFIRE 2007a, BpS 2911792). These are summarized as:

A) Early Development 1 All Structures (5% of type in this stage): This community is dominated by herbaceous and woody species, including the graminoids needlegrasses, western wheatgrass, bluebunch wheatgrass, sedges, Idaho fescue and little bluestem in moister areas, and various shrubs including skunkbush and snowberry. Ponderosa pine seedlings are scattered and found in small clumps. Little bluestem will also be an indicator species. Number of years in this class is variable depending on climatic patterns and fire disturbances. This class typically ends at 30 years in this model. Without fire for 25 years, this class can move to a mid-closed stage.

B) Mid Development 1 Closed (2% of type in this stage): Tree cover is 0-50%. Multi-story stand of small and medium trees with saplings and seedlings coming in as clumps. Understory is sparse. Some juniper might be present - could be an outlier. Grasses and shrubs are shaded out. This class lasts approximately 70 years, then moves to a late-closed stage. Low-severity surface fires occur every 15 years and move this stage to a mid-open stage. Replacement fires occur infrequently, approximately every 300 years. Insect/disease was modeled at approximately occurring every 50 years, not causing a transition.

C) Mid Development 1 Open (8% of type in this stage): Tree cover is 0-50%. Predominantly single-story stands with a few pockets of regeneration. Low shrubs such as snowberry and skunkbush and poison ivy are dominant as well as grasses and forbs. Graminoids could have up to 70-80% cover. Rocky Mountain juniper present in patches (Rocky Mountain juniper is not common on the Pine Ridge in Nebraska). *Carex* spp. and little bluestem will also be indicator species. This class lasts approximately 50 years then goes to a late-open stage. Without fire for 40 years, this could transition back to a mid-closed stage. Low-severity surface fires occur every 15 years, maintaining this class. Replacement fires occur very infrequently (modeled at 0.0015 probability).

D) Late Development 1 Open (80% of type in this stage): Tree cover is 0-50%. Predominantly single-story stands of large ponderosa pine with pockets of smaller size classes (replacement). Snowberry, skunkbush and patches of Rocky Mountain juniper. Understory is dominated by shrub species and grasses and poison ivy. Graminoids could have up to 70-80% cover. *Carex* spp. and little bluestem will also be indicator species. It is thought that class D, the late-open stage, should occupy approximately 80% of the historical landscape. Low-severity fires occur every 15 years and maintain this stage. Replacement fires occur very infrequently (0.0015 probability). If no fire occurs after 40 years, this class could transition to the late-closed stage. Insect/disease occurs every 50 years and maintains this stage.

E) Late Development 1 Closed (5% of type in this stage): Tree cover is 51-100%. This is a somewhat uniform late-development stage, multi-story stands of large, medium, small and seedling ponderosa pine. Shrubs and grasses are sparse. This type generally exceeds 70% canopy cover. dbh is less in this class than late-open. Low-severity surface fires occur every 15 years and cause a transition back to the late-open stage. Replacement fires occur every 300 years. Insect/disease occurs every 250 years, causing a transition back to the late-open stage. Drought can also occur - every 500 years, causing a transition to the late-open stage.

Generally, the fire regime is characterized by frequent fire-return interval of low-severity surface fire. The presence of abundant fire-scarred trees in multi-aged stands supports a prevailing historical model for ponderosa pine forests in which recurrent surface fires affected heterogeneous forest structure (Brown 2006). Mixed-severity fire occurs in closed-canopy conditions and stand-replacement fire is very infrequent (300+ years) (LANDFIRE 2007a, BpS 2911792). Low-severity fires are frequent and range from <10 years to more than 20 years (Fischer and Clayton 1983, Brown and Sieg 1999), but probably not more than 40 years at the high end (3-70 years range). The MFRI is approximately 12-15 years for low-severity fires (LANDFIRE 2007a, BpS 2911792).

There is considerable debate over the role of mixed-severity and surface fires in the historical range of variability in this and other ponderosa pine forests in the northern and central Rockies (Veblen et al. 2000, Baker and Ehle 2001, 2003, Barrett 2004a, b). However, Brown (2006) argues that surface fire was the dominant mode of fire disturbance and that the role of mixed-severity fires is overstated. For MZs 29 and 30, it was suggested that mixed fire be removed from this savanna model; reviewers agreed, and therefore mixed fire is not in this model (LANDFIRE 2007a, BpS 2911792).

Variation in precipitation and temperature interacting with fire, tip moths and ungulate grazing affects pine regeneration. Windthrow, storm damage and mountain pine beetles were minor disturbances in this type unless stands reach high densities. The interactions among drought, insects and disease are not well understood (LANDFIRE 2007a, BpS 2911792). *Pinus ponderosa - Juniperus scopulorum* savanna in the southern Black Hills has lots of rock exposure or sparsely grassed soils, which probably protected some of the juniper seed trees from being wiped out by fire (LANDFIRE 2007a, BpS 2911792).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: With settlement and a century of anthropogenic disturbance and fire suppression, stands now have a higher density of *Pinus ponderosa* trees, altering the fire regime and species composition. Presently, many stands contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. These altered structures have affected fuel loads and fire regimes. Presettlement fire regimes were primarily frequent (5- to 15-year return intervals), low-intensity ground fires triggered by lightning strikes or deliberately set by Native Americans, which maintained a savanna or open woodland structure. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999).

Conversion of this type has commonly come from urban and exurban development. Restoration to open woodland or savanna is difficult or impossible when adjacent to housing development. Common stressors and threats include fragmentation from housing and water developments, altered fire regime from fire suppression and indirectly from livestock grazing and fragmentation, and introduction of invasive non-native 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 14.** Climate change adaptation strategies relative to vulnerability scores for Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna. 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.

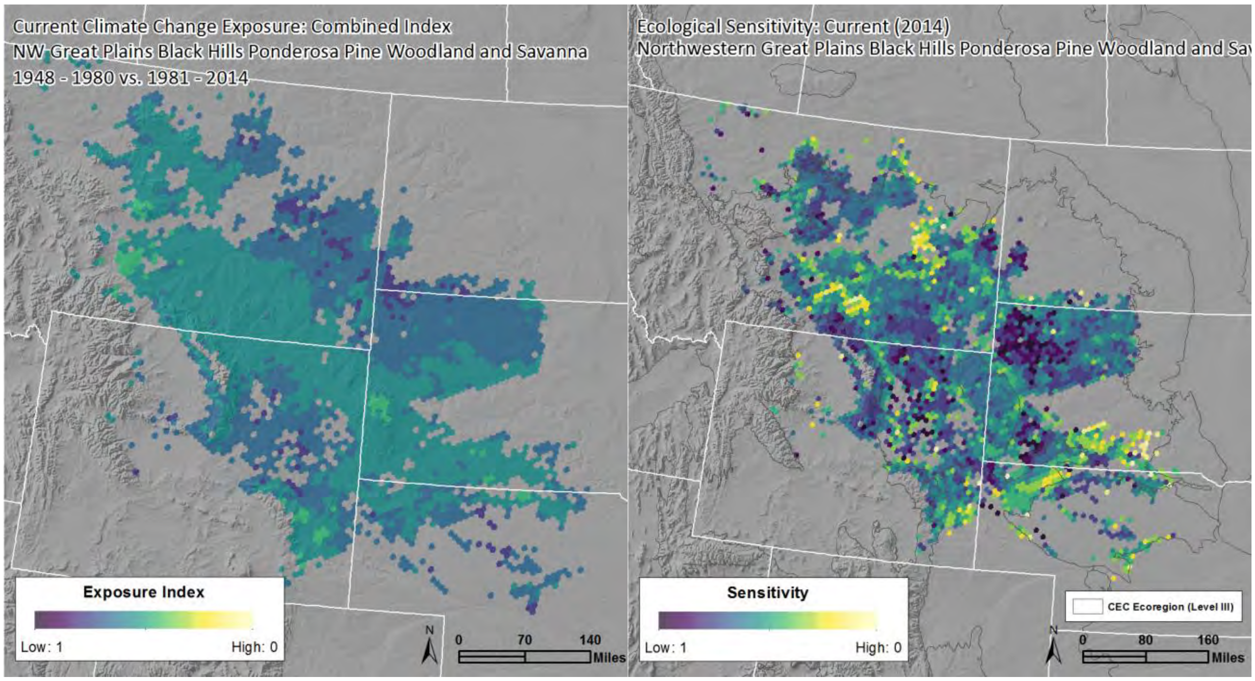

Figure 14. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 13. Resilience, exposure and vulnerability scores for Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna 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. 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 Great Plains	Middle Rockies	High Plains	Wyoming Basin	Northwestern Glaciated Plains	Nebraska Sand Hills	Southern Rockies
	Potential square miles within ecoregion	3,317	2,784	726	111	37	34	25
Contributions to Relative Vulnerability by Factor								
Vulnerability from **Exposure (2014)**		**Mod** 0.57	**Mod** 0.54	**Mod** 0.58	**Mod** 0.60	**Mod** 0.58	**Mod** 0.61	**Mod** 0.50
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.78	0.70	0.47	0.81	0.79	0.81	0.76
	Fire Regime Departure	0.52	0.52	0.58	0.59	0.53	0.51	0.51
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.98	0.66	0.95	0.95	0.99	0.99	0.96
	Sensitivity Average	**0.76**	**0.63**	**0.67**	**0.78**	**0.77**	**0.77**	**0.74**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.26	0.35	0.21	0.44	0.25	0.21	0.34
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.38**	**0.42**	**0.36**	**0.47**	**0.38**	**0.35**	**0.42**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.57	**Mod** 0.53	**Mod** 0.51	**Mod** 0.63	**Mod** 0.57	**Mod** 0.56	**Mod** 0.58
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this system is moderate across all seven ecoregions.

The annual mean temperature has increased by 0.5° to 0.8°C across substantial portions of five regions (22-82% of each region affected). The magnitude of the increase was greatest in the northern portion of the distribution, within the Northwestern Great Plain ecoregion, where an increase of 0.84°C in annual temperature is seen across 42% of this region.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Northwestern Great Plains region along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Shafer et al. 2014). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases. Longer, milder climate periods may increase the abundance of insect pests such as *Ips* spp. by increasing the number of generations within a growing season or by allowing a population buildup over several years such as with mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact pine trees regionally (Schmid 1988, Burns and Honkala 1990a, Howard 2003b, c).

Many stands of this ecological system woodland occur in foothill zone of taller ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so it may be able to survive as relicts for centuries without regeneration (Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change was moderate to low, with three of the seven ecoregions scoring low and four scoring in the moderate range for sensitivity. Sensitivity scores were driven largely by scores for fire regime departure.

Contributions to sensitivity from landscape condition were generally low; with the exception of two ecoregions. Landscape condition was high in the High Plains ecoregion and moderate in the Middle Rockies. Within these areas, landscape condition largely reflects fragmentation from agricultural conversion, with additional contributions from oil and gas development.

Fire regime departure was moderate in all ecoregions. This reflects fire suppression practices across much of the region which have led to higher densities of *Pinus ponderosa* and increased understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was low across six ecoregions and moderate in the Middle Rockies. Although currently estimated as low to moderate, sensitivity from this factor may increase with droughts and severe fires which can increase vulnerability to insects and disease.

Overall, landscape fragmentation has resulted in changes to the structure of these woodlands, 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 generally low across the range of this system, with scores in the low range in all seven ecoregions. This low adaptive capacity is related to low or very low topoclimatic variability. Scores were low for topoclimatic variability in five ecoregions and very low in two ecoregions (High Plains and Nebraska Sand Hills). Outside of the Black Hills and Big Horn ranges, these reflect a low level of topographic diversity associated with the gentle slopes and moderate-relief ravines and plateaus characteristic of where this system occurs. There is limited potential for the species in this system to disperse into areas of suitable climate nearby.

In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity of nitrogen fixers. Within individual stands, nitrogen fixation is provided by only a relatively few species and so their individual vulnerabilities to factors such as drought and human disturbance suggest increased overall vulnerability for the 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 CO_2 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 woodland and savanna type scores in the moderate range for all ecoregions. This is primarily due to moderate contributions from fire regime departure and low adaptive capacity scores associated with low topoclimate diversity. The system is also vulnerable to catastrophic fires from increased stand density and understory fuel loads. Although insect and disease risk were low for this system, these may be exacerbated by drought and severe fires.

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 Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.

Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Baker and Ehle 2001, Baker et al. 2003, Barrett 2004a, Barrett 2004b, Belnap 2001, Belnap et al. 2001, Bock and Bock 1984, Brown 2006, Brown and Sieg 1999, Burns and Honkala 1990a, Comer et al. 2003*, Dale et al. 2001, Eyre 1980, Fischer and Clayton 1983, Girard 1985, Girard et al. 1987, Girard et al. 1989, Graham and Jain 2005, Hansen and Hoffman 1988, Harvey 1994, Hoffman and Alexander 1987, Howard 2003b, Howard 2003c, LANDFIRE 2007a, Marriott and Faber-Langendoen 2000, McKenzie et al. 2004, McKenzie et al. 2008, Reid et al. 1999, Rolfsmeier and Steinauer 2010, Schmid 1988, Shafer et al. 2014, Stevens-Rumann et al. 2017, Thilenius 1972, Veblen et al. 2000, Westerling et al. 2006

CES306.955 Rocky Mountain Foothill Limber Pine-Juniper Woodland

Figure 15. Photo of Rocky Mountain Foothill Limber Pine-Juniper Woodland. Photo credit: Steven V. Cooper, Montana Natural Heritage Program.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in foothill and lower montane zones in the Rocky Mountains from northern Montana south to central Colorado and on escarpments across Wyoming extending out into the western Great Plains. Elevation ranges from 1000-2440 m. It occurs generally below continuous forests of *Pseudotsuga menziesii* or *Pinus ponderosa* and can occur in large stands well within the zone of continuous forests in the northeastern Rocky Mountains. It is restricted to shallow soils and fractured bedrock derived from a variety of parent material, including limestone, sandstone, dolomite, granite and colluvium. Soils have a high rock component (typically over 50% cover) and are coarse- to fine-textured, often gravelly and calcareous. Slopes are typically moderately steep to steep. At lower montane elevations, it is limited to the most xeric aspects on rock outcrops, and at lower elevations to the relatively mesic north aspects. Fire is infrequent and spotty because rocky substrates prevent a continuous vegetation canopy needed to spread. Vegetation is characterized by an open-tree canopy or patchy woodland that is dominated by *Pinus flexilis, Juniperus osteosperma*, or *Juniperus scopulorum*. *Pinus edulis* is not present. A sparse to moderately dense short-shrub layer, if present, may include a variety of shrubs, such as *Arctostaphylos uva-ursi, Artemisia nova, Artemisia tridentata, Cercocarpus ledifolius, Cercocarpus montanus, Dasiphora fruticosa ssp. floribunda, Ericameria nauseosa, Juniperus horizontalis, Purshia tridentata, Rhus trilobata, Rosa woodsii, Shepherdia canadensis* (important in

Montana stands), *Symphoricarpos albus*, or *Symphoricarpos oreophilus*. Herbaceous layers are generally sparse, but range to moderately dense, and are typically dominated by perennial graminoids such as *Bouteloua gracilis, Festuca idahoensis, Festuca campestris, Danthonia intermedia, Leucopoa kingii, Hesperostipa comata, Koeleria macrantha, Piptatheropsis micrantha, Poa secunda*, or *Pseudoroegneria spicata*. Within this ecological system, there may be small patches of grassland or shrubland composed of some of the above species.

Distribution: This system occurs in foothill and lower montane zones in the Rocky Mountains from northern Montana south to central Colorado and on escarpments across Wyoming, extending out into the western Great Plains. Elevation ranges from 1000-2400 m. This system may also occur in southeastern Idaho, though it would not be common there. It is also very likely to occur north into Canada along the Front Range of Alberta, in similar ecological settings.

Nations: CA?, US

States/Provinces: AB?, CO, MT, ND, SD, WY

CEC Ecoregions: Canadian Rockies, Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Northwestern Glaciated Plains, Northwestern Great Plains, High Plains, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Snake River Plain

Primary Concept Source: G. Jones and K.A. Schulz

Description Author: G. Jones, K.A. Schulz, G. Kittel

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Vegetation is characterized by an open-tree canopy or patchy woodland that is dominated by either *Pinus flexilis, Juniperus osteosperma*, or *Juniperus scopulorum*. *Pinus edulis* is not present. A sparse to moderately dense short-shrub layer, if present, may include a variety of shrubs, such as *Arctostaphylos uva-ursi, Artemisia nova, Artemisia tridentata, Cercocarpus ledifolius, Cercocarpus montanus, Dasiphora fruticosa ssp. floribunda, Ericameria nauseosa, Juniperus horizontalis, Purshia tridentata, Rhus trilobata, Rosa woodsii, Shepherdia canadensis* (important in Montana stands), *Symphoricarpos albus*, or *Symphoricarpos oreophilus*. Herbaceous layers are generally sparse, but range to moderately dense, and are typically dominated by perennial graminoids such as *Bouteloua gracilis, Festuca idahoensis, Festuca campestris, Danthonia intermedia, Leucopoa kingii, Hesperostipa comata, Koeleria macrantha, Piptatheropsis micrantha (= Piptatherum micranthum), Poa secunda*, 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.

Biological Soil Crust; Species Diversity: High
Biological soil crust diversity is based on Colorado Plateau crust diversity Rosentreter and Belnap (2003) that is thought to be similar because limber pine often occurs on calcareous substrates. 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* spp., *Phormidium* spp., *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* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp.). Algal diversity is fairly

high, but biomass is low in the Colorado Plateau, but higher than warm desert regions with over 40 species. 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
Limber pine and Utah juniper woodlands occur in semi-arid climates typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid woodlands typically have low to moderate herbaceous cover and diversity. In this system several species of Fabaceae (*Astragalus, Dalea, Lupinus*, and *Vicia*), Rosaceae (*Amelanchier, Cercocarpus, Dasiphora, Potentilla, Purshia*, and *Rosa*) and Poaceae (*Bouteloua, Festuca, Danthonia, Leucopoa, Hesperostipa, Koeleria, Piptatherum, Poa*, or *Pseudoroegneria*), and a few species of Brassicaceae may fix nitrogen. Rangewide nitrogen-fixing vascular species diversity is high, however, within stand nitrogen fixing species diversity is moderate to low. 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). Within stand species diversity of nitrogen fixers is typically moderate.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), Townsend's solitaire (*Myadestes townsendi*), chipping sparrow (*Spizella passerina*), blue jay (*Cyanocitta cristata*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Zlatnik 1999e, Scher 2002). The primary dispersers of limber pine seeds are Clark's nutcracker (*Nucifraga columbiana*) and pinyon jay (*Gymnorhinus cyanocephalus*) (Lanner and Vander Wall 1980, Lanner 1985, 1996). Other jays such as scrub jay (*Aphelocoma californica*) and Steller's jay (*Cyanocitta stelleri*) harvest and disperse limber pine seeds (Johnson 2001). Mammals: Several small mammals such as pocket mouse (*Perognathus* spp.), chipmunks (*Neotamias* spp.), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Kangaroo rats (*Dipodomys* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), and larger animals, including deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and bighorn sheep (*Ovis canadensis*), may consume and inadvertently disperse seeds in caches or have viable juniper and limber pine seeds pass through their gut.

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

Environment: This ecological system occurs in foothill and lower montane zones in the Rocky Mountains from northern Montana south to central Colorado and on exposed, windswept escarpments and other geographic breaks across Wyoming extending out into the northwestern Great Plains. Elevation typically ranges from 1000-2400 m. It occurs generally below continuous forests of *Pseudotsuga menziesii* or *Pinus ponderosa* but can occur in large stands well within the zone of continuous forests in the northeastern Rocky Mountains. In Wyoming, some limber pine stands are found up to 2440 m (8000 feet) elevation and are still included in this system.

Climate: This woodland system occurs in a semi-arid, cool-temperate climate. Annual precipitation patterns and amounts are variable but are typically below 500 mm annual precipitation with much occurring in winter as snow or spring rain.

Physiography/landform: Stands occur on moderately steep to steep slopes on all aspects but are most common on dry south- and west-facing slopes. At higher elevations, it is limited to the most xeric aspects on rock outcrops, and at lower elevations to the relatively mesic north aspects.

Soil/substrate/hydrology: It is restricted to shallow soils and fractured bedrock derived from a variety of parent material, including limestone and calcareous sandstone, but also dolomite, granite, gneiss, quartzite, rhyolite, schist, shale and colluvium. Some stands are on eroded substrates and resemble "badlands" while others may occur on lava flows. Soils are typically shallow and have a high rock component (skeletal) with typically over 50% cover of surface rock. They are often coarse-textured, such as gravelly, sandy loams or loams, but may include alkaline clays. Exposed soil is common, and many stands have over 50% cover of bare soil. Soil pH is typically neutral or slightly alkaline, but ranges from acidic to alkaline.

Key Processes and Interactions: The processes shaping the distribution and persistence of scarp woodlands is not well understood (CNHP 2010). The interaction of wind, fire, and topography is thought to have played a major role in the current pattern of occurrences. These woodlands are not physiologically limited to a particular substrate, but are generally found on larger, relatively high escarpments, and not on smaller or more gently sloping breaks. The abrupt topographic changes may act as natural firebreaks. In addition, the typically sparse vegetation of the breaks in comparison with the adjacent deeper soils does not allow grassland fires to carry into the woodland understory (CNHP 2010).

Although some of the conifers that are typically codominant in *Pinus flexilis* stands are late-successional species, they are not likely to displace *Pinus flexilis*. This is because most of these stands occur on harsh sites where *Pinus flexilis* is more competitive than most other conifer species. These stands are generally considered to be topographic or edaphic "climax" stands (Cooper 1975, Eyre 1980). Even in stands at lower elevations, such as prairie breaks, it is unlikely that other coniferous species will become dominant (Eyre 1980). Because *Pinus flexilis* occurs over a broad range of elevations, it can also be important as a post-fire seral species on drier sites in the Rocky Mountains (Cooper 1975, Peet 1988). Peet (1978a) reported apparent competitive displacement with *Pinus flexilis* in Colorado. He noted that *Pinus flexilis* may dominate xeric sites from low to high elevations, except where *Pinus aristata* or *Pinus albicaulis* occur. There, *Pinus flexilis* is largely restricted to lower elevation, rocky sites. Peet (1978a) also reported that *Pinus flexilis* occurs in the less xeric *Pinus contorta* and *Pinus ponderosa* habitats. However, the higher elevation *Pinus flexilis* stands would be included in Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland (CES306.819).

Birds and small mammals often eat and cache the large, wingless pine seeds. Most important is the Clark's nutcracker, which can transport the seeds long distances and cache them on exposed windswept sites (Lanner and Vander Wall 1980, Lanner 1985, 1996). This results in the regeneration of pines in clumps from forgotten caches (Woodmansee 1977, Eyre 1980, Steele et al. 1983).

Fire history information is lacking and has a wide range, making modeling difficult. As a whole, fire has occurred in this community in relation to fuel types adjacent to and within the woodland site. On shallow, rocky sites fire may have occurred less frequently. On deeper-soiled sites, the associated vegetation is more robust and would support a more frequent fire-return interval.

Given the uncertainty about the fire frequencies of this ecological system, it is predicted to vary from 30 to 80 years for mixed-severity fire and over 200 years for replacement fires (LANDFIRE 2007a). Fire is likely infrequent and spotty because rocky substrates prevent a continuous vegetation canopy that is needed for fire to spread.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has three classes in total (LANDFIRE 2007a, BpS 2010490). These classes are summarized as:

A) Early Development 1 All Structures (30% of type in this stage): Grass/forb/shrub/seedling - usually post-fire. Cover is 0-30%. Shrub height 0-1.0 m. The first 25 years dominated by shrub/herbaceous. Toward end of class increasing pine/juniper. When pine/juniper becomes dominant it has 10-20% cover. Height of pine/juniper reaching 15 m (48 feet). On shallow, rocky sites, seedlings tend to establish in protected areas, such as sheltered spaces in rocky outcrops. On these sites there is little grass or herb competition. On deeper-soiled sites, there is a significant herbaceous component and seedlings are established from bird seed caches and seed from limber pine and juniper that were not killed. This class lasts for 50 years or less. Replacement fire occurs every 250 years.

B) Mid Development 1 Open (30% of type in this stage): Tree cover is 21-40%. Tree height <10 m. Trees are established, but typically short and widely spaced. Grasses and herbs are sparse in shallow, rocky soils. On deeper-soil sites grasses and shrubs are prevalent. This class lasts until trees are approximately 100 years old, and then succeeds to Class C. Other indicator species might be *Cercocarpus montanus*. Replacement fire occurs every 200 years.

C) Late Development 1 Closed (40% of type in this stage). Tree cover is 41-60%. Tree height <10 m. Mature trees greater than 100 years old. On shallow, rocky sites trees dominate the site with sparse shrub-grass understory. On deeper-soil sites mature trees are codominant with shrub-grass understory with an increasing component of younger age class limber pine and juniper that will shade out shrubs and eventually leave a woodland site dominated by pine or pine-juniper overstory and grass understory. It is possible that limber pine might not occur in this stage in some areas. Replacement fire occurs every 200 years. Insect/disease occur with a probability of 0.0016 (every 625 years, or 0.16% of this class each year), returning the class to class A.

ECOLOGICAL INTEGRITY

Change Agents: Disturbance from firewood cutting, drought, and agricultural use may also influence the distribution and persistence of these woodlands (CNHP 2010).

Pinus flexilis is very susceptible to the non-native white pine blister rust (*Cronartium ribicola*) that infects and kills this tree (Hoff et al. 1980). There is long-term concern with the persistence of this species/system. Although the isolation of many stands on rocky outcrops and ranges has reduced that rate of spread, the only long-term solutions is propagating individuals that have high genetic resistance to blister rust (Steele et al. 1983, Burns and Honkala 1990a, Schmidt and McDonald 1990).

Other insect threats include epidemics of native mountain pine beetle (*Dendroctonus ponderosae*), which can attack and kill limber pine trees. The limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) is a common parasite of this tree, which can weaken but rarely kills it (Burns and Honkala 1990a).

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.

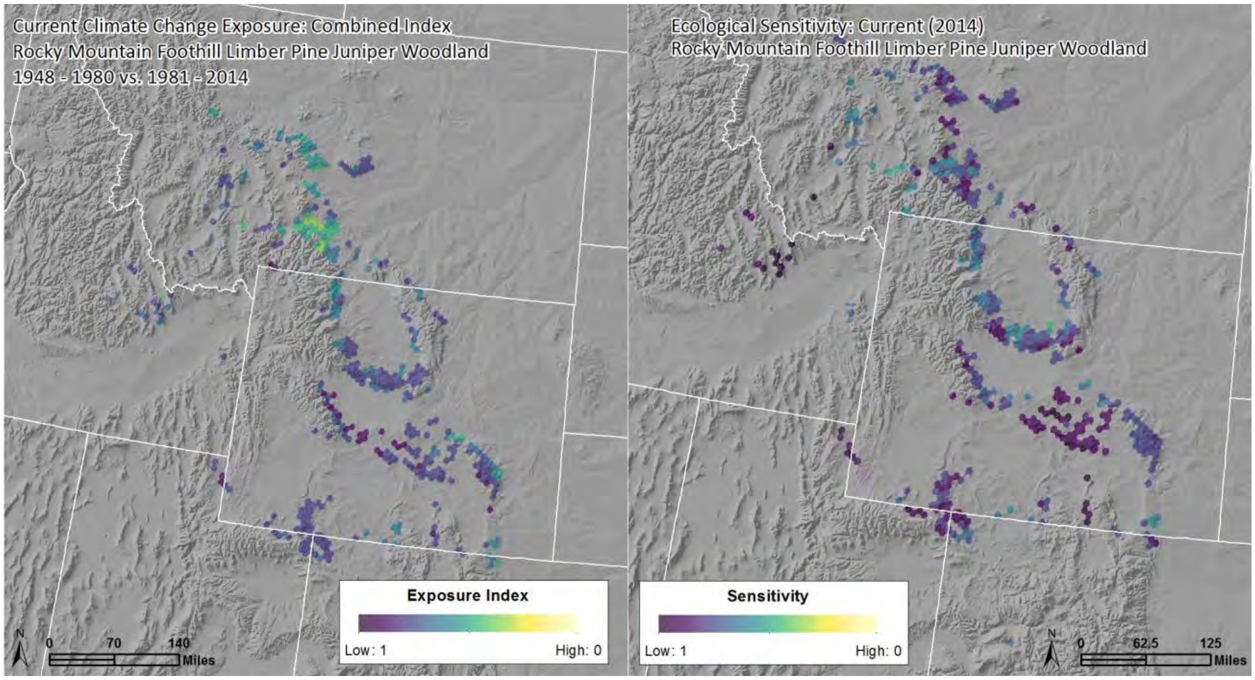

Figure 16. Climate exposure as of 2014 (left) and overall sensitivity (right) for Rocky Mountain Foothill Limber Pine-Juniper Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 15. Resilience, exposure and vulnerability scores for Rocky Mountain Foothill Limber Pine-Juniper Woodland 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	Middle Rockies	Northwestern Great Plains	Southern Rockies
	Potential square miles within ecoregion	303	143	122	74
Contributions to Relative Vulnerability by Factor					
Vulnerability from **Exposure (2014)**		**Mod** 0.75	**Mod** 0.66	**Mod** 0.52	**Mod** 0.71
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.77	0.75	0.66	0.82
	Fire Regime Departure	0.58	0.54	0.55	0.55
	Invasive Annual Grasses	0.94	1.00	1.00	0.96
	Sensitivity Average	**0.76**	**0.76**	**0.73**	**0.78**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.47	0.48	0.34	0.47
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null
	Adaptive Capacity Average	**0.49**	**0.49**	**0.42**	**0.49**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.62	**Mod** 0.63	**Mod** 0.58	**Mod** 0.63
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall for the distribution of these uncommon woodlands, exposure as of 2014 ranges from moderate in the Northwestern Great Plains and Middle Rockies ecoregions to somewhat limited in the Wyoming Basin and Southern Rockies ecoregions. An emerging pattern of changing climate appears as increases of 0.64° to 0.8°C for Annual Mean Temperature across more than 75% of its distribution in these four ecoregions. In addition, in the Middle Rockies ecoregion Mean Temperature of the Coldest Quarter has increased by 1.6°C across 25% of its distribution, and in the Northwestern Great Plains ecoregion Mean Temperature of the Driest Quarter has increased by 3.4°C across 16% of its distribution. In the Wyoming Basin and Southern Rockies ecoregions some 25% of its distribution shows increases of 0.7°C in Mean Temperature of the Warmest Quarter. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

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 tree recruitment. Without recruitment limber pine stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may weaken limber pine trees and may make them more susceptible to lethal attacks by forest diseases such root and butt rot (*Armillaria mellea*) and the red-brown butt rot (*Phaeolus schweinitzii*), and the more lethal non-native white pine blister rust (*Cronartium ribicola*) (Burns and Honkala 1990a).

Many stands of this woodland type occur in the foothill zones of taller mountain ranges so it may be possible for the species of this system to transition into lower montane zones as suitable climate is diminished at lower elevations. Limber pine and juniper trees are long-lived; *Juniperus osteosperma, Juniperus scopulorum*, and *Pinus flexilis* frequently live more than 300 years and so may be able to survive for centuries without regeneration (Burns and Honkala 1990a, Johnson 2001). However, there could be accelerated loss of mature trees because of more frequent and extended drought as a result of hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to the effects of climate change is low (higher scores) across the range of this type, with slightly lower scores (approaching moderate) in stands in the Northwestern Great Plains where landscape condition is moderate.

Landscape condition is very good (little development) (**Table 15**) in two ecoregions; however, in the Northwestern Great Plains the results show some impact from infrastructure with moderate landscape condition. This ecosystem occurs on remote hills, foothills and outcrops primarily in the Wyoming Basin, Middle Rockies, and Northwestern Great Plains ecoregions. This system does not occur on sites conducive to agriculture (but may be adjacent to dry-land farming), so these scores are likely a reflection of fragmentation due to many small roads, mining operations, some oil and gas development, transmission corridors, and areas of urban, suburban and exurban development.

The risk of invasive annual grasses is generally low across the range of this type; however, fire regime departure is moderate. Fire history information for this system is lacking and where it is available has a wide range of frequencies and severities, making interpretation of these results difficult. Direct fire suppression, grazing removal of fine fuels, and activities such as fire-wood cutting have probably combined to cause a shift in the structure of these woodlands. Cutting removes trees, especially older, larger individuals; loss of fine fuels and fire suppression reduce fire frequencies leading to stand-replacing fires when fire does occur. These interactions have altered the structural characteristics of these woodlands.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these woodlands. Together, these result in increased sensitivity of the system to the effects of changes in temperature or precipitation patterns

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low range wide for this somewhat uncommon woodland system. Topoclimatic variability is moderate, as these woodlands generally occur in the foothill and lower montane zones on exposed, windswept escarpments and other geographic breaks, and slopes are moderately steep to steep. Therefore, they occur where local climates vary somewhat within short distances. For example, in many instances, both north and south facing slopes as well as steep elevation gradients, can occur within short distances. Many options exist for species to move across these landscapes to adapt to changing climate conditions.

Diversity within each of the three identified functional species groups varies from moderate to high. Within individual stands, the most limiting functional role is that of nitrogen fixation, which is provided by a moderate number of species. This system has plant taxa in the *Fabaceae, Rosaceae,* and *Poaceae* families of which a number are nitrogen-fixers. Cyanobacteria and cyanolichens in the soil crust also fix nitrogen. 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. Seed dispersal is provided by many bird and mammal species and appears to have high within-stand 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: These woodlands score in the moderate range of overall climate change vulnerability throughout most of their range with high vulnerability in the Northwestern Great Plains where exposure is scored higher. The moderate vulnerability is primarily due to moderate scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are moderate for types such as this with moderate diversity within functional groups, moderate topoclimatic variability, and moderate fire regime departure. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, and long-term effects of fire regime alterations.

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 Rocky Mountain Foothill Limber Pine-Juniper Woodland.

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including low tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
	Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Belnap 2001, Belnap et al. 2001, Breshears et al. 2005, Burns and Honkala 1990a, Comer et al. 2003*, Eyre 1980, Hoff et al. 1980, Johnson 2001, LANDFIRE 2007a, Lanner 1985, Lanner 1996, Lanner and Vander Wall 1980, Peet 1978a, Peet 1988, Rosentreter and Belnap 2003, Scher 2002, Schmidt and McDonald 1990, Steele et al. 1983, Thilenius et al. 1995, Woodmansee 1977, Zlatnik 1999e

M020. Rocky Mountain Subalpine-High Montane Forest

CES304.776 Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland

Figure 17. Photo of Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs on montane slopes and plateaus in Utah, western Colorado, northern Arizona, eastern Nevada, southern Idaho, western Wyoming, and in north-central Montana in the Big Snowy Mountains. It also occurs in localized settings in the Klamath Mountains of California, as well as in the Sierra Nevada and adjacent Great Basin mountains (Inyo, White, Warner, and Modoc Plateau). Elevations range from 1700 to 2800 m. Occurrences are typically on gentle to steep slopes on any aspect but are often found on clay-rich soils in intermontane valleys. Soils are derived from alluvium, colluvium and residuum from a variety of parent materials but most typically occur on sedimentary rocks. The tree canopy is composed of a mix of deciduous and coniferous species, codominated by *Populus tremuloides* and conifers, including *Pseudotsuga menziesii, Abies concolor, Abies lasiocarpa, Abies magnifica, Picea engelmannii, Picea x albertiana, Picea pungens, Pinus contorta, Pinus flexilis, Pinus jeffreyi, Pinus contorta var. murrayana*, and *Pinus ponderosa*. As the stands age, cover of *Populus tremuloides* may be slowly reduced until the conifer species become dominant. Common shrubs include *Amelanchier alnifolia, Prunus virginiana, Acer grandidentatum, Symphoricarpos oreophilus, Juniperus communis, Paxistima myrsinites, Rosa woodsii, Spiraea betulifolia, Symphoricarpos albus*, or *Mahonia repens*. Herbaceous species include *Bromus carinatus, Calamagrostis rubescens, Carex geyeri, Elymus glaucus, Poa* spp., and *Achnatherum, Hesperostipa, Nassella*, and/or *Piptochaetium* spp. *Achillea millefolium, Arnica cordifolia*, Asteraceae spp., *Erigeron* spp., *Galium boreale, Geranium viscosissimum, Lathyrus* spp., *Lupinus argenteus, Mertensia arizonica, Mertensia lanceolata, Maianthemum stellatum, Osmorhiza berteroi*, and *Thalictrum fendleri*. Most occurrences at present represent a late-seral stage of aspen changing to a pure conifer occurrence. Nearly a hundred years of fire suppression and livestock grazing have converted much of the pure aspen occurrences to the present-day aspen-conifer forest and woodland ecological system. This is the typical meadow edge aspen-conifer setting in the Sierra Nevada where frequently, due to fire suppression, the conifers are replacing aspens.

Distribution: This system occurs on montane slopes and plateaus in Utah, eastern Nevada, southern Idaho, western and central Wyoming (in the Bighorn Mountains), and in north-central Montana in the Big Snowy Mountains. Elevations range from 1700 to 2800 m.

Nations: US

States/Provinces: AZ, CO, ID, MT, NV, UT, WY

CEC Ecoregions: Blue Mountains, Middle Rockies, Klamath Mountains, 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, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: NatureServe Western Ecology Team

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The open to moderately closed canopy is composed of a mix of deciduous and coniferous species, codominated by *Populus tremuloides* and conifers, including *Pseudotsuga menziesii, Abies concolor, Abies lasiocarpa, Picea engelmannii, Picea x albertiana (= Picea glauca x engelmannii), Picea pungens, Pinus contorta, Pinus flexilis*, and *Pinus ponderosa*. The sparse to moderately dense understory may be structurally complex and includes tall-shrub, short-shrub and herbaceous layers, or it may be simple with just an herbaceous layer or sparse. Because of the open growth form of *Populus tremuloides*, more light can penetrate the canopy than in a pure conifer occurrence. If present, the tall-shrub layer may be dominated by *Amelanchier alnifolia, Prunus virginiana*, or *Acer grandidentatum*, and short-shrub layer by *Symphoricarpos oreophilus, Juniperus communis*, or *Mahonia repens*. Other common shrubs include *Paxistima myrsinites, Rosa woodsii, Spiraea betulifolia, Symphoricarpos albus*, and in wet areas *Salix scouleriana*. Where the herbaceous layer is dense, it is often dominated by graminoids such as *Bromus carinatus, Calamagrostis rubescens, Carex geyeri, Elymus glaucus, Poa* spp., and species of *Achnatherum, Hesperostipa, Nassella*, and/or *Piptochaetium*. Sparse herbaceous layers are generally a more even mixture of forbs such as *Achillea millefolium, Arnica cordifolia, Eucephalus engelmannii (= Aster engelmannii), Erigeron speciosus, Fragaria vesca, Galium boreale, Geranium viscosissimum, Lathyrus* spp., *Lupinus argenteus, Mertensia arizonica, Mertensia lanceolata, Maianthemum stellatum, Osmorhiza berteroi (= Osmorhiza chilensis)*, and *Thalictrum fendleri*. Annuals are typically uncommon. The exotic species *Poa pratensis* and *Taraxacum officinale* are more common in livestock-impacted occurrences (Mueggler 1988). The vegetation description is based on several references, including DeByle and Winokur (1985), Mueggler (1988), Howard (1996), Reid et al. (1999), Bartos (2001), Comer et al. (2002), Tuhy et al. (2002), 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.

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 Graminoids; Species Diversity: High
Diversity: high = >15 spp. Aspen mixed conifer forests typically have an open to moderately herbaceous understory with significant perennial cool-season graminoid component. *Achnatherum hymenoides, Achnatherum lemmonii, Achnatherum lettermanii, Achnatherum occidentale, Bromus anomalus, Bromus carinatus, Bromus ciliatus, Bromus porteri, Calamagrostis rubescens, Carex geyeri, Carex rossii, Elymus glaucus, Elymus elymoides Elymus trachycaulus, Festuca arizonica, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Leymus cinereus, Poa fendleriana, Poa nervosa, 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.

Aspen (*Populus tremuloides*) functions as a keystone species in a pure aspen upland forest system by creating a relatively mesic environment under a closed forest canopy that allows enough light to penetrate to maintain a diverse and lush shrub and herbaceous understory that is distinctly different from adjacent conifer dominated stands. Aspen forests are important wildlife habitat, providing forage and cover for many species of insects, birds and mammals such as ruffed grouse, sharp-tailed grouse, snowshoe hare, deer, elk, bear, and other animals (DeByle 1985b). Aspen trees are habitat for many insects and fungi (leafminers, cankers), and up to 34 cavity nesting, mostly insectivorous birds (Scott et al. 1980).

Environment: This ecological system is found on montane slopes and high plateaus in Utah, western Colorado, northern Arizona, eastern Nevada, southern Idaho, and western Wyoming from 1700 to 2800 m elevation. Climate is temperate with cold winters. Mean annual precipitation is greater than 38 cm and typically greater than 50 cm. Although often drier, sites are similar to Rocky Mountain Aspen Forest and Woodland (CES306.813) with regards to environmental characteristics. Topography is variable, with sites ranging from level to steep slopes. Aspect varies according to the limiting factors. Occurrences at high elevations are restricted by cold temperatures and are found on warmer southern aspects. At lower elevations aspen is restricted by lack of moisture and is found on cooler north aspects and mesic microsites such as seeps and drainages. Soils are derived from alluvium, colluvium and residuum from a variety of parent materials and may include sedimentary, metamorphic or igneous rocks, but it appears to grow best on sedimentary rocks such as limestone and calcareous or neutral shales, or basalt (Mueggler 1988). Soil texture ranges from sandy loam to clay loam. This system represents a stable mixed aspen - conifer woodlands typically found on broad plateaus where periodic disturbance such as die-back from drought is thought to maintain the mixed deciduous-conifer composition. It is sometimes confused with the relatively short-lived, mid-seral stages of conifer-dominated forest and woodland systems such as Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland (CES306.828), Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland (CES306.830), or Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland (CES306.825). Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand (Mueggler 1988). Secondarily, its range is limited by the length of the growing season or low temperatures (Mueggler 1988). The environmental description is based on several other references, including DeByle and Winokur (1985), Mueggler (1988), Howard (1996), Reid et al. (1999), Bartos (2001), Comer et al. (2002), Tuhy et al. (2002), and Sawyer et al. (2009).

Key Processes and Interactions: *Populus tremuloides* is a fast-growing deciduous tree that reaches 20 m in height and forms clones that can be ancient, although the stems are relatively short-lived (up to 150 years in the western U.S.) (Howard 1996, Sawyer et al. 2009). It is thin-barked and stems are readily killed by fire, although the clone will usually resprout after burning or other disturbance (Howard 1996). It is a fire-adapted species that generally needs a large disturbance to establish and maintain dominance in a forest stand. Mixed aspen - conifer forests are generally seral and, in the absence of stand-replacing disturbance such as fire, will slowly convert to a conifer-dominated forest (Mueggler 1988). Although the young conifer trees in these occurrences are susceptible to fire, older individuals develop self-pruned lower branches and develop a thick corky bark that makes them resistant to surface fires. The natural fire-return interval is approximately 20 to 50 years for seral occurrences (Hardy and Arno 1996). Intervals that approach 100 years are typical of late-seral occurrences (Hardy and Arno 1996).

However, this system represents stable mixed aspen - conifer woodlands typically found on broad plateaus in the interior western U.S. where periodic disturbance such as die-back from drought or other disturbance is thought to maintain the mixed deciduous-conifer composition and not allow conifers to dominate and shade out the aspen (Tuhy et al. 2002). Sudden aspen decline (SAD) results in root mortality with subsequent effects on tree canopy and clone persistence. It appears to be triggered by severe drought (Worrall et al. 2010). This may have increasing impact on these forests. More research is needed to clarify the dynamics of this system as it is sometimes confused with the relatively short-lived, mid-seral stages of conifer-dominated forest and woodland systems such as Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland (CES306.828), Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland (CES306.830), or Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland (CES306.825).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 1810610). The model represents a fire maintained, seral mixed aspen - conifer types that succeeds to a conifer dominated types without mixed-severity fire (mean FRI of 20 years). The classes are summarized as:

A) Early Development 1 All Structures (14% of type in this stage): Grass/forb and aspen suckers <12 feet tall. Generally, this is expected to occur 1-3 years post-disturbance. Fire is absent. Succession to class B after 10 years.

B) Mid Development 1 Closed (tree-dominated - 40% of type in this stage): Tree cover is 41-100%. Aspen saplings over 12 feet tall dominate. Canopy cover is highly variable. Replacement fire occurs every 60 years on average. Mixed-severity fire (average FRI of 40 years) does not change the successional age of these stands, although this fire consumes litter and woody debris and may stimulate suckering. Succession to class C after 30 years.

C) Mid Development 1 Closed (tree-dominated - 35% of type in this stage): Tree cover is 41-100%. Aspen trees 5-16 inches dbh. Canopy cover is highly variable. Conifer seedlings and saplings may be present. Replacement fire occurs every 60 years on average. Mixed-severity fire (mean FRI of 40 years), while thinning some trees, promotes suckering and maintains vegetation in this class. Insect/diseases outbreaks occur every 200 years on average with 80% of times causing stand thinning (transition to class B) and 20% of times causing stand replacement (transition to class A). Conifer encroachment causes a succession to class D after 40 years.

D) Late Development 1 Open (tree-dominated - 10% of type in this stage): Tree cover is 0-40%. Aspen dominate, making up 80% of the overstory. Conifers which escape fire, or are the more fire-resistant species, are present in the understory and will likely cause the progressive suppression of aspen. Mixed-severity fire (20-year MFI) keeps this stand open, kills young conifers and maintains aspen (max FRI from Baker 1925). Replacement fire occurs every 60 years on average. In the absence of any fire for at least 100 years, the stand will become closed and dominated by conifers (transition to class E).

E) Late Development 1 Closed (conifer-dominated - 1% of type in this stage): Tree cover is 41-80%. Conifers dominate at 100+ years. Aspen over 16 inches dbh, uneven sizes of mixed conifer and main overstory is conifers. Greater than 50% conifer in the overstory. FRI for replacement fire is every 60 years. Mixed-severity fire (mean FRI of 20 years) causes a transition to class D. Insect/disease outbreaks will thin older conifers (transition to class D) every 300 years on average.

From (LANDFIRE 2007a, BpS 1810610): "This is a strongly fire-adapted community, more so than BpS 1011 (Rocky Mountains Aspen Woodland and Forest), with FRIs varying for mixed-severity fire with the encroachment of conifers. It is important to understand that aspen is considered a fire-proof vegetation type that does not burn during the normal lightning season, yet evidence of fire scars and historical studies show that native burning was the only source of fire that occurred mostly during the spring and fall. BpS 1061 has elements of Fire Regime Groups II, III and IV. Mean FRI for replacement fire is every 60 years on average in most development classes. Replacement fire is absent during early development (as for stable aspen, BpS 1011) and has a mean FRI of 100 years between 80 and 100 years in the open condition. The FRI of mixed-severity fire increases from 40 years in stands <100 years to 60 years in stands >100 years with conifer encroachment."

Under presettlement conditions, disease and insect mortality did not appear to have major effects; however, older aspen stands would be susceptible to outbreaks every 200 years on average. We assumed that 20% of outbreaks resulted in heavy insect/disease stand-replacing events (average return interval 1000 years), whereas 80% of outbreaks would thin older trees >40 years (average return interval 250 years). Older conifers (>100 years) would experience insect/disease outbreaks every 300 years on average (LANDFIRE 2007a, BpS 1810610).

ECOLOGICAL INTEGRITY

Change Agents: In the western U.S., *Populus tremuloides*-dominated and -codominated forests have been utilized primarily for livestock grazing. Stands typically have lush understories because the *Populus tremuloides* tree canopy allows significant light to pass through and sites tend to be relatively mesic (DeByle and Winokur 1985, Howard 1996). Heavy grazing by livestock can deplete or convert an understory dominated by shrubs and forbs to an understory dominated by grazing-tolerant grasses. Degraded stands were often seeded to grazing-tolerant introduced forage species such as *Bromus inermis, Dactylis glomerata, Phleum pratense*, and *Poa pratensis* (DeByle and Winokur 1985). Excessive browsing by livestock or wildlife can also significantly impact regeneration by suckers (DeByle and Winokur 1985, Howard 1996).

Logging, prescribed fire or some other stand-replacing disturbance will convert these conifer - *Populus tremuloides* mixed canopy stands to *Populus tremuloides*-dominated stands because disturbance will generally favor *Populus tremuloides* regeneration (DeByle and Winokur 1985, Howard 1996).

Human development has impacted many locations throughout its range. 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 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.

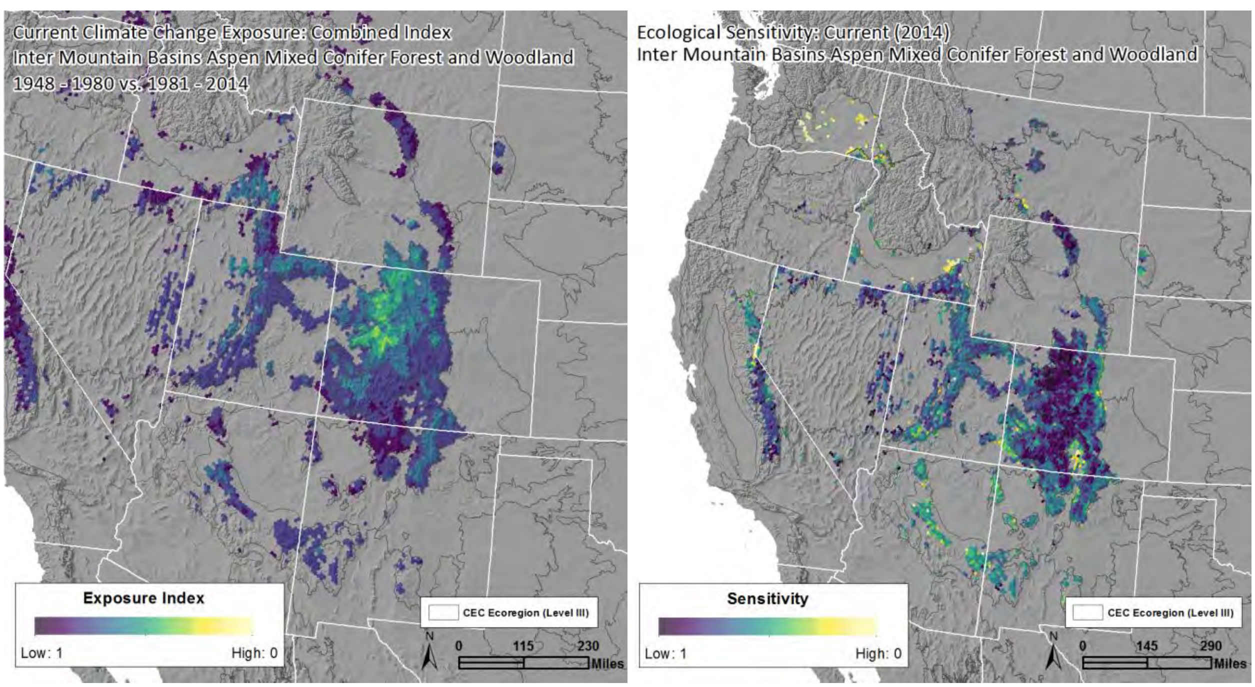

Figure 18. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively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

Table 17. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland 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	Southern Rockies	Wasatch & Uinta Mountains	Arizona-New Mexico Mountains	Northern Basin & Range	Colorado Plateaus	Central Basin & Range	Middle Rockies	Wyoming Basin	Sierra Nevada
	Potential square miles within ecoregion	7,127	2,321	362	316	270	205	115	30	28
Contributions to Relative Vulnerability by Factor										
Vulnerability from **Exposure (2014)**		Mod 0.68	Mod 0.72	Low 0.77	Mod 0.72	Mod 0.73	Mod 0.70	Low 0.80	Mod 0.70	Low 0.81
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.82	0.78	0.78	0.89	0.83	0.95	0.78	0.77	0.81
	Fire Regime Departure	0.75	0.49	0.22	0.54	0.53	0.40	0.64	0.62	0.51
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.82	0.84	0.81	0.90	0.87	0.92	0.84	0.85	0.80
	Sensitivity Average	**0.80**	**0.70**	**0.60**	**0.78**	**0.74**	**0.76**	**0.75**	**0.75**	**0.71**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.56	0.54	0.50	0.55	0.62	0.70	0.42	0.44	0.53
	Diversity within Functional Species Groups	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	Adaptive Capacity Average	**0.70**	**0.69**	**0.67**	**0.70**	**0.73**	**0.77**	**0.63**	**0.64**	**0.68**
Vulnerability from Measures of **Overall Resilience**		Mod 0.75	Mod 0.70	Mod 0.64	Mod 0.74	Mod 0.74	Low 0.77	Mod 0.69	Mod 0.69	Mod 0.70
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Low

Exposure Summary for 1981-2014 Timeframe: Overall, the climate exposure as of 2014 for this forest system is moderate across six of nine ecoregions, accounting for 95% of the potential distribution of the system. West-slope of the Southern Rockies and Uinta Mountains includes concentrated areas of moderate to high exposure. Exposure was low in the remaining Sierra Nevada, Middle Rockies and Arizona-New Mexico Mountains ecoregions. Annual mean temperature has increased between 0.5° and 0.7°C across most of the range. These changes were widespread in eight of the nine ecoregions (affecting 28-88% of the area of each).

This increase in annual temperature is reflected by increases in summer temperature of 0.6° to 0.7°C across more than 30% of five ecoregions. Greater increases in winter temperature, of 1° to 1.5°C, characterized 5-10% of the Middle Rockies, Wasatch and Uinta Mountains, and the Arizona-New Mexico Mountains ecoregions. Increases in precipitation of the driest month are seen across 1-10% of six ecoregions.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Average annual temperature is projected to continue to increase in western North America along with increasing number and severity of wildfires and insect outbreaks (Garfin et al. 2014, Mote et al. 2014, Shafer et al. 2014). Ecological consequences from such a climate shift would be similar to extended drought.

Aspen is a water-limited, drought-intolerant species (Niinemets and Valladares 2006), consequently drought can cause death or decline of aspen. The continued higher temperatures and increased moisture stress are predicted to affect aspen stands with increased mortality and decreased regeneration in general (Brandt et al. 2003b, Elliott and Baker 2004, Bartos 2008, Worrall et al. 2008a, Morelli and Carr 2011). In eastern Utah, decreased moisture availability is predicted to favor co-occurring conifer species over aspen, because aspen has a relatively higher water demand (Sexton et al. 2006). Indirect effects of a warming climate with more frequent droughts could weaken aspen and conifer trees and may make them more susceptible to lethal attacks by forest diseases and insects (Bethers et al. 2010).

Future climate changes may also increase the frequency of physical disturbances such as in fire because of increased temperatures and decreased precipitation (Westerling et al. 2006, Spracklen et al. 2009). More frequent fires would favor aspen regeneration through post-fire suckering (DeByle and Winokur 1985, Jones and DeByle 1985, Schier et al. 1985, Graham et al. 1990, Rogers 2002, Elliot and Baker 2004), which alone would be expected to increase seral aspen on the landscape. However, interactions between different ecological factors and variable extreme weather make the net effect of a warming climate difficult to predict. For example, other stressors such as heavy ungulate browsing on sprouts, may prevent aspen from establishing new trees (Romme et al. 2001) or changes in the abundance of insects and diseases on aspen.

However, this system represents stable mixed aspen - conifer woodlands maintained by periodic disturbance that prevents conifers from dominating and shading out the aspen, so increased fire frequency may result in conversion to Rocky Mountain Aspen Forest and Woodland (CES306.813). It is also possible that this disturbance-dependent, stable mixed aspen - conifer woodland and forest system could become more common over time if more frequent droughts limit conifer canopy closure.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate to low for this forest type. This moderate sensitivity was associated with moderate to very high contributions to sensitivity from fire regime departure, in contrast to low contributions from landscape condition and forest insect and disease risk.

Vulnerability from landscape condition is low across all ecoregions, reflecting limited development and fragmentation within the moderate to high elevation range of this type. Stands occur in areas not suited for agricultural conversion.

Fire regime departure is moderate across six ecoregions, but high within the Wasatch and Uinta Mountains and Central Basin and Range ecoregions, and very high in the Arizona-New Mexico Mountains. This reflects fire suppression practices across much of the range, which can lead to succession towards a mixed conifer forest state and the loss of aspen.

Risk from insect and disease was generally low across the range of the system. However, this low risk may be increased by stress from drought and fire.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity scored moderate across the range of this system, with scores in the moderate range for eight of nine ecoregions and with low vulnerability in the Central Basin and Range ecoregion. Adaptive capacity is moderate to low topoclimate variability. Low topoclimatic variability reflects the gentle slopes and plateaus where this woodland type often occurs. In terms of vulnerability related to functional groups, the system scores high in terms of cool-season graminoid diversity.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, these woodlands score in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure (fire suppression increasing the likelihood of conversion to mixed conifer forest types), and moderate adaptive capacity from low to moderate topoclimate variability. Although insect and disease risk were low for this system, these may be exacerbated by effects of recent drought and fire across the range 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 18. Climate change adaptation strategies relative to vulnerability scores for Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland.

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 and fire breaks. Maintain or restore natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Restore natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, and tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Adams 2010, Baker 1925, Bartos 2001, Bartos 2008, Bartos and Campbell 1998, Bell et al. 2009, Bethers et al. 2010, Bradley et al. 1992a, Brandt et al. 2003b, Comer et al. 2002, Comer et al. 2003*, Dale et al. 2001, DeByle 1985b, DeByle and Winokur 1985, DeVelice et al. 1986, Elliott and Baker 2004, Eyre 1980, Garfin et al. 2014, Graham et al. 1990, Hardy and Arno 1996, Henderson et al. 1977, Howard 1996a, Jones and DeByle 1985, LANDFIRE 2007a, Morelli and Carr 2011, Mote et al. 2014, Mueggler 1988, Niinemets and Valladares 2006, Reid et al. 1999, Rogers 2002, Romme et al. 2001, Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Schier et al. 1985, Scott et al. 1980, Sexton et al. 2006, Shafer et al. 2014, Shepperd 2008, Shiflet 1994, Spracklen et al. 2009, Tuhy et al. 2002, Westerling et al. 2006, Worrall et al. 2008a, Worrall et al. 2010, Youngblood and Mauk 1985, Youngblood and Mueggler 1981

CES306.807 Northern Rocky Mountain Subalpine Woodland and Parkland

Figure 19. Photo of Northern Rocky Mountain Subalpine Woodland and Parkland. Photo credit: Richard Droker, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system of the Northern Rockies, Cascade Range, and northeastern Olympic Mountains is typically a high-elevation mosaic of stunted tree clumps, open woodlands, and herb- or dwarf-shrub-dominated openings, occurring above closed forest ecosystems and below alpine communities. It includes open areas with clumps of *Pinus albicaulis*, as well as woodlands dominated by *Pinus albicaulis* or *Larix lyallii*. In the Cascade Range and northeastern Olympic Mountains, the tree clump pattern is one manifestation, but these are also woodlands with an open canopy, without a tree clump/opening patchiness to them; in fact, that is quite common with *Pinus albicaulis*. The climate is typically very cold in winter and dry in summer. In the Cascades and Olympic Mountains, the climate is more maritime in nature and wind is not as extreme. The upper and lower elevational limits, due to climatic variability and differing topography, vary considerably; in interior British Columbia, this system occurs between 1000 and 2100 m elevation, and in northwestern Montana, it occurs up to 2380 m. Landforms include ridgetops, mountain slopes, glacial trough walls and moraines, talus slopes, landslides and rockslides, and cirque headwalls and basins. Some sites have little snow accumulation because of high winds and sublimation. *Larix lyallii* stands generally occur at or near upper treeline on north-facing cirques or slopes where snowfields persist until June or July. In this harsh, often windswept environment, trees are often stunted and flagged from damage associated with wind and blowing snow and ice crystals, especially at the upper elevations of the type. The stands or patches often originate when *Picea engelmannii, Larix lyallii*, or *Pinus albicaulis* colonize a sheltered site such as the lee side of a rock. *Abies lasiocarpa* can then colonize in the shelter of the *Picea engelmannii* and may form a dense canopy by branch-layering. Major disturbances are windthrow and snow avalanches. Fire is known to occur infrequently in this system, at least where woodlands are present; lightning damage to individual trees is common, but sparse canopies and rocky terrain limit the spread of fire.

These high-elevation coniferous woodlands are dominated by *Pinus albicaulis, Abies lasiocarpa*, and/or *Larix lyallii*, with occasional *Picea engelmannii*. In the Cascades and Olympics, *Abies lasiocarpa* sometimes dominates the tree layer without *Pinus albicaulis*, though in this dry parkland *Tsuga mertensiana* and *Abies amabilis* are largely absent. The undergrowth is usually somewhat depauperate, but some stands support a near sward of heath plants, such as *Phyllodoce glanduliflora, Phyllodoce empetriformis, Empetrum nigrum, Cassiope mertensiana*, and *Kalmia polifolia*, and can include a slightly taller layer of *Ribes montigenum, Salix brachycarpa, Salix glauca, Salix planifolia, Vaccinium membranaceum, Vaccinium myrtillus*, or *Vaccinium scoparium* that may be present to codominant. The herbaceous layer is sparse under dense shrub canopies or may be dense where the shrub canopy is open or absent. *Vahlodea atropurpurea, Luzula glabrata var. hitchcockii*, and *Juncus parryi* are the most commonly associated graminoids.

In the mountains of northwestern and west-central Wyoming, where this upper-treeline system reaches the edge of its geographic range, the vegetation usually has the form of an open woodland, and only rarely as scattered groves of trees. At the highest elevations, *Pinus albicaulis* usually has a wind-stunted shrub form. On lower, more favorable sites, upright but wind-shaped *Pinus albicaulis* forms woodlands, sometimes with *Pinus contorta* as a codominant or even the dominant species. With decreased altitude, where this system merges into the subalpine forests, *Picea engelmannii* and *Abies lasiocarpa* become common tree species as well.

Distribution: This system occurs in the northern Rocky Mountains, west into the Cascade Range and northeastern Olympic Mountains, and east into the mountain "islands" of central Montana.

Nations: CA, US

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

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, Northern Basin and Range, Wyoming Basin, Central Basin and Range

Primary Concept Source: M.S. Reid

Description Author: C. Chappell, R. Crawford, G. Kittel, M.S. Reid, K.A. Schulz and G.P. Jones

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These high-elevation coniferous woodlands are dominated by *Pinus albicaulis, Abies lasiocarpa*, and/or *Larix lyallii*, with occasional *Picea engelmannii*. In the Cascades and Olympics, *Abies lasiocarpa* sometimes dominates the tree layer without *Pinus albicaulis*, though in this dry parkland *Tsuga mertensiana* and *Abies amabilis* are largely absent. The undergrowth is usually somewhat depauperate, but some stands support a near sward of heath plants, such as *Phyllodoce glanduliflora, Phyllodoce empetriformis, Empetrum nigrum, Cassiope mertensiana*, and *Kalmia polifolia*, and can include a slightly taller layer of *Ribes montigenum, Salix brachycarpa, Salix glauca, Salix planifolia, Vaccinium membranaceum, Vaccinium myrtillus*, or *Vaccinium scoparium* that may be present to codominant. The herbaceous layer is sparse under dense shrub canopies or may be dense where the shrub canopy is open or absent. *Vahlodea atropurpurea (= Deschampsia atropurpurea), Luzula glabrata var. hitchcockii*, and *Juncus parryi* are the most commonly associated graminoids.

In the mountains of northwestern and west-central Wyoming, where this upper-treeline system reaches the edge of its geographic range, the vegetation usually has the form of an open woodland, and only rarely as scattered groves of trees. At the highest elevations, *Pinus albicaulis* usually has a wind-stunted shrub form. On lower, more favorable sites, upright but wind-shaped *Pinus albicaulis* forms woodlands, sometimes with *Pinus contorta* as a codominant or even the dominant species. With decrease in altitude, where this system merges into the subalpine forests, *Picea engelmannii* and *Abies lasiocarpa* become common tree species as well.

Keystone Species:

Environment: This ecological system of the Northern Rockies, Cascade Range, and northeastern Olympic Mountains is typically a high-elevation mosaic of stunted tree clumps, open woodlands, and herb- or dwarf-shrub-dominated openings, occurring above closed forest ecosystems and below alpine communities. The upper and lower elevational limits, due to climatic variability and differing topography, vary considerably from 1000-3200 m depending on latitude. In interior British Columbia, this system occurs between 1000 and 2100 m elevation, and in northwestern Montana, it occurs up to 2380 m. In west-central Wyoming, this system occurs on various landforms over an elevational range from 2230 to 3200 m (Steele et al. 1983).

Climate: The climate is typically very cold in winter and dry in summer. Mean annual precipitation ranges from 60-180 cm, occurring mostly in the winter. Yearly snow accumulations are often over 3 m in the northern Cascades and 2-3 m in the Rockies. Some sites have little snow accumulation because of high winds and sublimation. In the Cascades and Olympic Mountains, the climate is more maritime in nature and wind is not as extreme.

Physiography/Landform: Landforms include ridgetops, mountain slopes, glacial trough walls and moraines, talus slopes, landslides and rockslides, and cirque headwalls and basins. Sites may be nearly level to steep sloping, on all aspects. Some stands occur at treeline in mesic, protected pockets away from the extremely harsh environmental conditions. It is not tied to particular aspects (Steele et al. 1983).

Soil/substrate/hydrology: Soils are generally lithic, well-to excessively drained, and coarse-textured such as shallow, gravelly sands or loams, but may include silt and clay loams. Soils are derived from colluvium, glacial till and residuum from a variety of volcanic, igneous, sedimentary and metamorphic geologic formations.

Key Processes and Interactions: *Pinus albicaulis* is a slow-growing, long-lived conifer that is common at higher elevations in the upper subalpine zone. It typically occurs in a mosaic of tree islands and meadows where it often colonizes sites and creates habitat for less hardy tree species. In lower subalpine forests, it is a seral species, establishing after a large disturbance such as stand-replacing fire or avalanche, or it is restricted to dry, rocky ridges where it competes well with shade-tolerant tree species. Without disturbance it will be overtopped in 100-120 years by faster growing, shade-tolerant species such as *Abies lasiocarpa, Picea engelmannii, Pseudotsuga menziesii*, and *Tsuga mertensiana*. Although crown fires and hot ground fires kill *Pinus albicaulis*, it tolerates low-intensity ground fires that will kill the shade-tolerant understory. Fire intervals range from 30-300 years.

In this harsh, often windswept environment, trees are often stunted and flagged from damage associated with wind and blowing snow and ice crystals, especially at the upper elevations of the type. The stands or patches often originate when *Picea engelmannii, Larix lyallii*, or *Pinus albicaulis* colonize a sheltered site such as the lee side of a rock. *Abies lasiocarpa* can then colonize in the shelter of the *Picea engelmannii* and may form a dense canopy by branch-layering. Major disturbances are windthrow and snow avalanches. Fire is known to occur infrequently in this system, at least where woodlands are present; lightning damage to individual trees is common, but sparse canopies and rocky terrain limit the spread of fire. *Larix lyallii* is a very slow-growing, long-lived tree, with individuals up to 1000 years in age. It is generally shade-intolerant; however, extreme environmental conditions limit potentially competing trees. In the Cascades and Olympic Mountains, the climate is more maritime in nature and wind is not as extreme, but summer drought is a more important process than in the related North Pacific Maritime Mesic Subalpine Parkland (CES204.837). In northwestern and west-central Wyoming, *Pinus albicaulis* is the initial colonizer, and trees of other species become established in the micro-sites that it creates (Callaway 1998, cited in Greater Yellowstone Coordinating Committee 2011). In the highest-elevation stands where *Pinus albicaulis* usually is the only tree present, vegetation dynamics are relatively simple: stands start out with rather dense overstories and sparse undergrowth and develop more open overstories and denser undergrowths over time. At lower elevations, *Pinus contorta* dominates some stands soon after fire, and the long-lived, more shade-tolerant *Pinus albicaulis* become dominant over time (Steele et al. 1983). As in the Pacific Northwest, fire has, in the past, been a minor process (compared to the subalpine forests at lower elevations): lightning starts many fires, but they rarely spread (Steele et al. 1983).

Birds and small mammals often eat and cache the large, wingless pine seeds and are responsible for the dispersal of this species. Most important is the Clark's nutcracker, which can transport the seeds long distances and cache them on exposed windswept and burned-over sites. This results in the regeneration of pines in clumps from forgotten caches (Eyre 1980, Burns and Honkala 1990a, Schmidt and McDonald 1990, Steel et al. 1983).

The mountain pine beetle (*Dendroctonus ponderosae*) has killed many mature trees in the past, during epidemics where populations of the beetles build up in lower elevation *Pinus contorta* stands, then move up into the *Pinus albicaulis* (Burns and Honkala 1990a, Schmidt and McDonald 1990, Steel et al. 1983).

ECOLOGICAL INTEGRITY

Change Agents: From WNHP (2011): The primary land uses that alter the natural processes of this system are associated with exotic species, direct soil surface disturbance, timber management, livestock practices, and fragmentation. The introduced pathogen white pine blister rust (*Cronartium ribicola*) increases *Pinus albicaulis* mortality in these woodlands (Kendall and Keane 2001) and changes fire regime, mountain pine beetle (*Dendroctonus ponderosae*) effects and successional relationships. Exotic species threatening this ecological system through invasion and potential replacement of native species include *Poa pratensis*. Excessive grazing stresses the system through soil disturbance and perennial layers to the establishment of native disturbance-increasers (*Lupinus* spp., *Juncus parryi, Achillea millefolium*) in similar Northern Rocky Mountain systems (Johnson 2004). Persistent grazing will further diminish native perennial cover, expose bare ground, and increase erosion and exotics (Johnson and Swanson 2005). Grazing effects are usually concentrated in less steep slopes, although grazing does create contour trail networks that can lead to addition slope failures. Cattle and heavy use by elk can reduce fescue cover and lead to erosion during summer storms (Johnson and Swanson 2005). Introduction of exotic ungulates can have noticeable impacts (e.g., mountain goats in the Olympic Mountains and domestic sheep grazing in the bunchgrass habitats east of the Cascades). Historical domestic sheep grazing may have occurred in these systems but its cumulative effects are unknown (Landfire 2007a). Locally, trampling and associated recreational impacts can affect sites for decades or longer (Lillybridge et al. 1995). Sites are naturally low in timber productivity and in stocking rates such that removal of trees can have very long-lasting influence on ecological processes (Lillybridge et al. 1995).

Conversion of this type has commonly come from conversion to invasive non-native species such as *Poa pratensis*, which increase post disturbance including long-term excessive grazing by livestock, or direct soil disturbance from timber management, heavy recreational use, severe trampling by livestock, and roads. However, conversion is not a major factor for this system.

Common stressors and threats include fragmentation from roads, altered fire regime from fire suppression, and indirectly from livestock grazing and fragmentation the introduction of invasive non-native species (WNHP 2011). The introduced pathogen white pine blister rust causes considerable *Pinus albicaulis* mortality in these woodlands and parklands (Kendall and Keane 2001). Mountain pine beetle epidemics also cause significant *Pinus albicaulis* mortality, especially during dry years. *Pinus albicaulis* are large-seeded trees and are dependent on animals for longer distance dispersal. Threats to these dispersers such as Clark's nutcracker are threats to the regeneration of these pines and the ecosystem.

In this system in Wyoming and eastern Idaho (Steele et al. 1983), livestock grazing likely is a minor threat because there is little forage. Grazers can, though, easily degrade forb-dominated undergrowths, but the vegetation where *Vaccinium scoparium* dominates (as it does in a high proportion of stands) appears to be less susceptible to grazing and, in fact, has been shown to withstand heavy grazing by deer and elk. In Wyoming, 59% of the area predicted to support whitebark pine is within designated national forest wilderness areas or national parts (WNDD 2013). In the Greater Yellowstone area of Wyoming, Montana, and Idaho, 62% of the whitebark pine is within national parks or wilderness areas (Macfarlane et al. 2009, Appendix A; these authors apparently neglected to include 2 wilderness areas in Wyoming, so that percentage likely is higher). Hence a large percentage of this ecological system apparently is in areas managed to minimize threats. Heavy recreational use can damage undergrowth vegetation and cause soil erosion so severe that it prevents restoration (Steele et al. 1983), but such impacts likely are limited to few stands because of the management status of the lands and because, even outside of protected areas, *Pinus albicaulis* woodlands are largely inaccessible to most people.

White pine blister rust is a very serious threat, as only 26% of the *Pinus albicaulis* trees in the Greater Yellowstone area show resistance (Greater Yellowstone Coordinating Committee 2011). Monitored plots show infection rates ranging from 0-84% of trees and averaging 20% (several studies cited in Greater Yellowstone Coordinating Committee 2011). Because of blister rust, restoration projects in eastern Idaho and western Montana have failed to produce significant regeneration of *Pinus albicaulis* (Keane and Parsons 2010, cited in Rice et al. 2012). Mountain pine beetle, too, is a major threat to this ecological system in the Greater Yellowstone area. Aerial surveys in 2009 revealed that 50% of *Pinus albicaulis* stands had suffered severe to complete mortality of pines, and 95% of forest stands containing *Pinus albicaulis* had measurable pine beetle activity (Macfarlane et al. 2009, cited in Rice et al. 2011). Several species of *Dendroctonus* have also killed great numbers of *Pinus contorta* and *Picea engelmannii*, other constituents of the vegetation in this ecological system in the area.

Potential climate change effects in the Pacific Northwest region are based on downscaled climate models projecting increases in annual temperature of, on average, 3.2°F by the 2040s. Increases in extreme high precipitation (falling as rain) in the western Cascades and reductions in snowpack are key projections from high-resolution regional climate models (Littell et al. 2009). Warmer temperatures will result in more winter precipitation falling as rain rather than snow throughout much of the Pacific Northwest, particularly in mid-elevation basins where average winter temperatures are near freezing. This change will result in less winter snow accumulation, higher winter streamflows, earlier spring snowmelt, earlier peak spring streamflow, and lower summer streamflows in rivers that depend on snowmelt (Littell et al. 2009). These potential changes in climate could include Increased fire frequency due to warmer temperatures resulting in drier fuels; the area burned by fire regionally is projected to double by the 2040s and triple by the 2080s (Littell et al. 2009). Additionally, likely climatic warming may stress host trees, so mountain pine beetle outbreaks are projected to increase in frequency and cause increased tree mortality. Finally, the amount of habitat with climate ranges required for these subalpine tree species, especially *Pinus albicaulis* which is susceptible to mountain pine beetle, will likely decline substantially by mid 21st century.

The ways in which the climate in the region where this system reaches its eastern limit is likely to change, and the effects of those changes on the structure and function of this system, are all hard to predict, and only broad generalizations can be made (Rice et al. 2012). Average annual temperature likely will increase by 1.7°C by 2050, and by 1.1° to 5.5°C by the end of this century. Annual precipitation may increase by 10%, with wetter winters and drier summers, but less certainty can be assigned to possible precipitation changes than temperature changes. The greatest direct impact of these changes on this ecological system likely would be that *Pinus albicaulis* retreats from the lower-elevation parts of its range and exists only at the highest elevations or disappears. Climate changes will also affect the ecological system indirectly, through changes in the fire regime (in general, more frequent and larger fires are likely), bark beetle populations, blister rust populations, and other ecological agents. Changes in the extremes of temperature and precipitation likely will have a stronger effect than will changes in annual averages, and the patterns of these extremes are especially hard to predict. Climate changes almost certainly will disrupt the composition, structure, and function of the parkland ecological system, in ways that can only be very generally anticipated.

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.

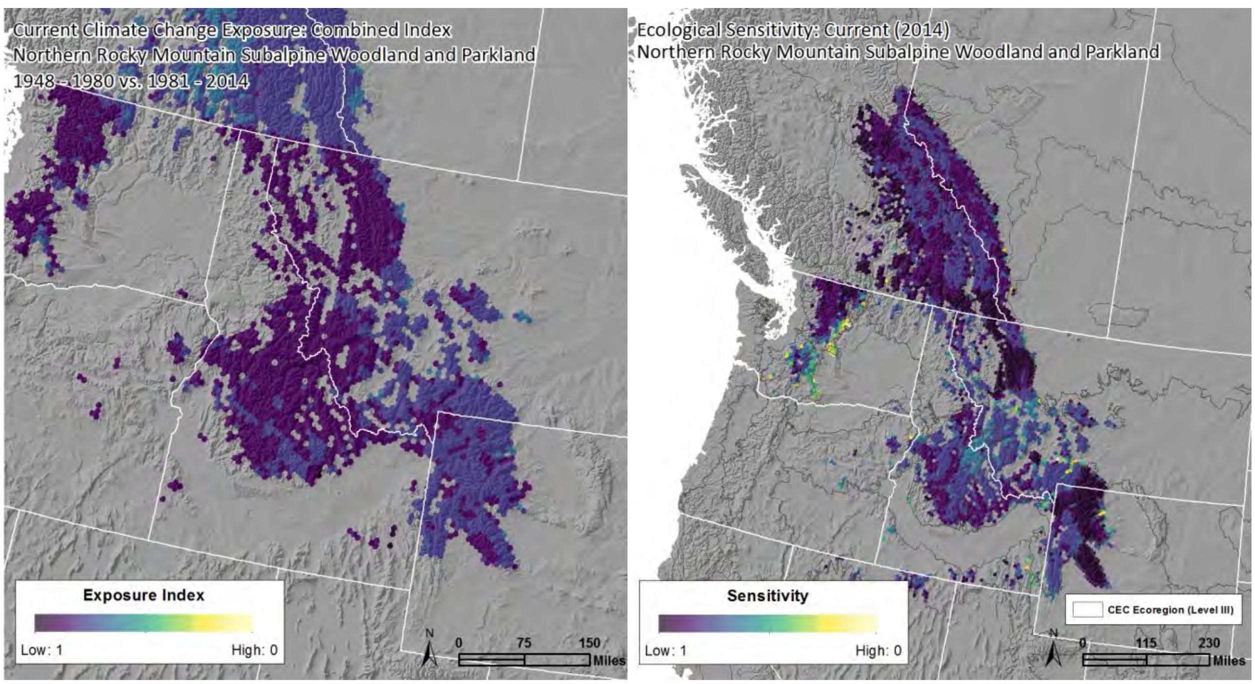

Figure 20. Climate exposure as of 2014 (left) and overall sensitivity (right) for Northern Rocky Mountain Subalpine Woodland and Parkland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 19. Resilience, exposure and vulnerability scores for Northern Rocky Mountain Subalpine Woodland and Parkland 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 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	Canadian Rockies	Columbia Mountains-Northern Rockies	Middle Rockies	Idaho Batholith	North Cascades	Blue Mountains	Thompson-Okanogan Plateau	Northern Basin & Range	Cascades
Potential square miles within ecoregion		11,456	6,233	4,326	2,156	532	80	61	54	21
Contributions to Relative Vulnerability by Factor										
Vulnerability from **Exposure (2014)**		Mod 0.75	Mod 0.74	Low 0.79	Low 0.83	Low 0.81	Low 0.81	Mod 0.70	Low 0.82	Low 0.82
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.85	0.83	0.97	0.97	0.91	0.97	0.85	0.90	0.83
	Fire Regime Departure	0.88	0.55	0.70	0.54	0.81	0.56	Null	0.55	0.55
	Forest Insect & Disease	0.85	0.79	0.80	0.88	0.89	0.81	Null	0.97	0.87
	Sensitivity Average	**0.86**	**0.72**	**0.83**	**0.80**	**0.87**	**0.78**	**0.85**	**0.81**	**0.75**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.71	0.72	0.62	0.63	0.63	0.64	0.51	0.67	0.55
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.60**	**0.61**	**0.56**	**0.56**	**0.56**	**0.57**	**0.50**	**0.58**	**0.52**
Vulnerability from Measures of **Overall Resilience**		Mod 0.73	Mod 0.67	Mod 0.69	Mod 0.68	Mod 0.72	Mod 0.68	Mod 0.68	Mod 0.69	Mod 0.64
Climate Change Vulnerability Index		Mod	Mod	Mod	Low	Low	Mod	Mod	Low	Mod

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this high elevation woodland and parkland system is low across six of the nine ecoregions, and at the low end of the moderate range in three ecoregions. Annual mean temperature has increased between 0.6° and 0.7°C across large portions (73-100%) of northern and western ecoregions (Blue Mountains, Middle Rockies, Canadian Rockies, Idaho Batholith, Columbia Mountains-Northern Rockies). Increases in annual temperature were reflected in increases of winter temperature by 1.7° and 1.42°C across >20% of the Canadian and Middle Rockies ecoregions. Other climate exposure effects were smaller in area or magnitude. However, consistent with greater increases in winter and night-time temperatures, mean diurnal temperature range decreased by 0.3°C across 67% of the North Cascades.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is low. Sensitivity was low cross seven ecoregions accounting for 75% of the potential range of this type, and at the low end of moderate in two ecoregions.

Contributions to sensitivity from landscape condition are low in all ecoregions. This reflects limited fragmentation from development and road networks across this distribution of this high-elevation montane parkland and woodland type.

Fire regime departure was moderate to low. Scores in seven ecoregions were moderate, reflecting general fire suppression practices across much of the region. Fires are historically infrequent in this subalpine system. Increased fire frequency from climate change and densification of adjacent mixed conifer systems may cause declines of *Pinus albicaulis,* one of the most common trees in this type.

General risk from insect and disease was generally low across all ecoregions. However, this does not account for species-specific effects of white pine blister rust on *Pinus albicaulis,* which have caused severe declines of this tree species.

Although this system currently has low sensitivity to climate change due to limited landscape fragmentation, continued fire regime departure interacting with increases in temperature and ongoing declines of *Pinus albicaulis* may result in increased sensitivity.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally moderate across the range of this system. This is associated with moderate scores for topoclimatic variability, and moderate scores for functional diversity across all ecoregions. These parklands and woodlands occur across a range of moderate- to high-elevation slopes, ridgetops and cirque basins. Therefore, they occur where local climates vary moderately within short distances, with limited potential for local dispersal across these landscapes to adapt to changing climate 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, these woodlands score in the moderate to low range of overall climate change vulnerability. This is primarily due to moderate adaptive capacity and moderate topoclimate variability. Although overall vulnerability for this system is moderate to low, insect and disease risk may be exacerbated by effects of increased temperature and disease-related declines of *Pinus albicaulis*, one of the common trees within this vegetation 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 20. Climate change adaptation strategies relative to vulnerability scores for Northern Rocky Mountain Subalpine Woodland and Parkland.

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including insect and disease outbreaks and low tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including including insect and disease outbreaks, tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including including insect and disease outbreaks, tree regeneration and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Arno 1970, Arno and Habeck 1972, Burns and Honkala 1990a, Callaway 1998, Comer et al. 2003*, Cooper et al. 1999, Ecosystems Working Group 1998, Eyre 1980, Greater Yellowstone Coordinating Committee 2011, Johnson 2004, Johnson and Swanson 2005, Keane and Parsons 2010, Kendall and Keane 2001, LANDFIRE 2007a, Lillybridge et al. 1995, Littell et al. 2009, Macfarlane et al. 2009, Meidinger and Pojar 1991, NCC 2002, Rice et al. 2012a, Steele et al. 1983, WNDD 2013, WNHP 2011, WNHP unpubl. data 2018, Williams and Lillybridge 1983, Williams and Smith 1990

CES306.813 Rocky Mountain Aspen Forest and Woodland

Figure 21. Photo of Rocky Mountain Aspen Forest and Woodland, mixed with gambel oak. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This widespread ecological system is more common in the southern and central Rocky Mountains but occurs in the montane and subalpine zones throughout much of the western U.S. and north into Canada. An eastern extension occurs along the Rocky Mountains foothill front and in mountain "islands" in Montana (Big Snowy and Highwood mountains), and the Black Hills of South Dakota. In California, this system is only found on the east side of the Sierra Nevada adjacent to the Great Basin. Large stands are found in the Inyo and White mountains, while small stands occur on the Modoc Plateau. In western Alberta, it occurs only in the Upper Foothills subregion, and north of there transitions to Western North American Boreal Mesic Birch-Aspen Forest (CES105.108). Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions, especially in the Canadian Rockies. Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand. Secondarily, it is limited by the length of the growing season or low temperatures. These are upland forests and woodlands dominated by *Populus tremuloides* without a significant conifer component (<25% relative tree cover). The understory structure may be complex with multiple shrub and herbaceous layers, or simple with just an herbaceous layer. The herbaceous layer may be dense or sparse, dominated by graminoids or forbs. In California, *Symphyotrichum spathulatum* is a common forb. Associated shrub species include *Symphoricarpos* spp., *Rubus parviflorus, Amelanchier alnifolia*, and *Arctostaphylos uva-ursi*.

Occurrences of this system originate and are maintained by stand-replacing disturbances such as avalanches, crown fire, insect outbreak, disease and windthrow, or clearcutting by man or beaver, within the matrix of conifer forests. It differs from Northwestern Great Plains Aspen Forest and Parkland (CES303.681), which is limited to plains environments. In Texas, this system occurs as small patches within the higher elevation conifer systems of the Guadalupe, Davis, and Chisos mountains. These patches are considered relictual remnants in this southwestern extension of this more commonly encountered type further north.

Distribution: This system is more common in the central and southern Rocky Mountains extending south to the Sacramento Mountains, however, it occurs in the montane and subalpine zones throughout much of the western U.S. and north into Canada, as well as west into California. Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions. Very small occurrences may be found in a few scattered locations of the Trans-Pecos of Texas.

Nations: CA, US

States/Provinces: AB, AZ, BC, CA, CO, ID, MT, NM, NV, OR, SD, 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, 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: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These are cold-deciduous, broad-leaved upland forests and woodlands dominated by *Populus tremuloides* without a significant conifer component (<25% relative tree cover). The tree canopy ranges from 5-20 m tall and may be open to closed. Conifers may be present but never codominant and include *Abies concolor, Abies lasiocarpa, Picea engelmannii, Picea pungens, Pinus ponderosa*, and *Pseudotsuga menziesii*. Because of the open growth form of *Populus tremuloides*, enough light can penetrate for lush understory development. Depending on available soil moisture and other factors such as disturbance, the understory structure may be complex with multiple shrub and herbaceous layers, or simple with just an herbaceous layer. The herbaceous layer may be dense or sparse, dominated by graminoids or forbs depending on available soil moisture and other factors such as disturbance. Associated shrub species include *Amelanchier alnifolia, Arctostaphylos uva-ursi, Artemisia tridentata, Juniperus communis, Prunus virginiana, Ribes montigenum, Robinia neomexicana, Rosa woodsii, Rubus parviflorus, Shepherdia canadensis, Symphoricarpos* spp., and the dwarf-shrubs *Mahonia repens* and *Vaccinium* spp. Numerous mesic forbs and graminoids may be present to dominant. Common graminoids may include *Bromus carinatus, Calamagrostis rubescens, Carex siccata (= Carex foenea), Carex geyeri, Carex rossii, Elymus glaucus, Elymus trachycaulus, Festuca thurberi, Hesperostipa comata*, and *Muhlenbergia montana*. Associated forbs may include *Achillea millefolium, Eucephalus engelmannii (= Aster engelmannii), Delphinium* spp., *Geranium viscosissimum, Heracleum sphondylium, Ligusticum filicinum, Lupinus argenteus, Osmorhiza berteroi (= Osmorhiza chilensis), Pteridium aquilinum, Rudbeckia occidentalis, Thalictrum fendleri, Valeriana occidentalis, Wyethia amplexicaulis*, and many others. Exotic grasses such as the perennials *Poa pratensis* and *Bromus inermis* and the annual *Bromus tectorum* are often common in occurrences disturbed by grazing. The over 60 associations included in this system document its heterogeneous nature. The vegetation description is based on several references, including Henderson et al. (1977), Eyre (1980), Hess and Wasser (1982), DeByle and Winokur (1985), Youngblood and Mauk (1985), DeVelice et al. (1986), Mueggler (1988), Powell (1988a), Knight (1994), Shiflet (1994), Reid et al. (1999), Neely et al. (2001), NCC (2002), Comer et al. (2002), Tuhy et al. (2002), Minnich (2007), and NatureServe Explorer (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.

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 Graminoids; Species Diversity: High
Diversity: high = >15 spp. Aspen forests typically have a relatively lush herbaceous understory with significant perennial cool-season graminoid component. *Achnatherum lettermanii, Achnatherum nelsonii, Achnatherum occidentale, Agrostis exarata, Bromus anomalus, Bromus carinatus, Bromus ciliatus, Bromus porteri, Calamagrostis canadensis, Calamagrostis rubescens, Carex geyeri, Carex hoodii, Carex rossii, Carex siccata, Carex sprengelii, Danthonia parryi, Deschampsia cespitosa, Elymus glaucus, Elymus lanceolatus, Elymus trachycaulus, Elymus virginicus, Festuca arizonica, Festuca idahoensis, Festuca thurberi, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus cinereus, Leymus salinus, Oryzopsis asperifolia, Poa fendleriana, Poa nemoralis ssp. interior, Poa nervosa*, and *Poa secunda*.

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.

Aspen (*Populus tremuloides*) functions as a keystone species in a pure aspen upland forest system by creating a relatively mesic environment under a closed forest canopy that allows enough light to penetrate to maintain a diverse and lush shrub and herbaceous understory that is distinctly different from adjacent conifer dominated stands. Aspen forests are important wildlife habitat, providing forage and cover for many species of insects, birds and mammals such as ruffed grouse, sharp-tailed grouse, snowshoe hare, deer, elk, bear, and other animals (DeByle 1985b). Aspen trees are habitat for many insect and fungi (leafminers, cankers), and up to 34 cavity nesting, mostly insectivorous birds (Scott et al. 1980).

Environment: This widespread montane and subalpine ecological system is more common in the central and southern Rocky Mountains extending south to the Sacramento Mountains of New Mexico, west into the high plateaus of the Colorado Plateau and ranges of the Great Basin into the eastern Sierra Nevada, and north into the Canadian Rockies. Eastern extensions occur along the Rocky Mountains foothill front and in mountain "islands" in Montana (Big Snowy and Highwood mountains), and the Black Hills of South Dakota. Very small occurrences may be found in a few scattered locations of the Trans-Pecos of Texas. Elevations generally range from 1525 to 3050 m (5000-10,000 feet), but occurrences can be found at lower elevations in some regions. Climate is temperate with a relatively long growing season, typically cold winters and deep snow. Mean annual precipitation is greater than 38 cm (15 inches) and typically greater than 51 cm (20 inches), except in semi-arid environments where occurrences are restricted to mesic microsites such as seeps or large snow drifts. Distribution of this ecological system is primarily limited by adequate soil moisture required to meet its high evapotranspiration demand (Mueggler 1988). Secondarily, its range is limited by the length of the growing season or low temperatures (Mueggler 1988). Topography is variable; sites range from level to steep slopes. Aspect varies according to the limiting factors. Occurrences at high elevations are restricted by cold temperatures and are found on warmer southern aspects. At lower elevations occurrences are restricted by lack of moisture and are found on cooler north aspects and mesic microsites. The soils are typically deep and well-developed, with rock often absent from the soil. Soil texture ranges from sandy loam to clay loam. Parent materials are variable and may include sedimentary, metamorphic or igneous rocks, but it appears to grow best on limestone, basalt, and calcareous or neutral shales (Mueggler 1988). In Texas, this system occurs on high mountain slopes, valleys and ridges at higher elevations on Permian limestone (Guadalupe Mountains) and igneous substrates (Davis and Chisos mountains). The environmental description is based on several other references, including Henderson et al. (1977), Bartos (1979), Bartos and Mueggler (1979), Eyre (1980), Hess and Wasser (1982), DeByle and Winokur (1985), Johnston and Hendzel (1985), Youngblood and Mauk (1985), DeVelice et al. (1986), Mueggler (1988), Powell (1988a), Knight (1994), Shiflet (1994), Bartos and Campbell (1998), Reid et al. (1999), Neely et al. (2001), Comer et al. (2002), Tuhy et al. (2002), Minnich (2007), and NatureServe Explorer (2009).

Key Processes and Interactions: Occurrences in this ecological system often originate, and are likely maintained by, stand-replacing disturbances such as crown fire, disease and windthrow, or clearcutting by man or beaver. The stems of these thin-barked, clonal trees are easily killed by surface fires, but they can quickly and vigorously resprout in densities of up to 30,000 stems per hectare (Knight 1994). As dbh increases beyond 15 cm, *Populus tremuloides* stems become increasingly resistant to fire mortality, and large stems may survive low-severity surface fire but usually show fire damage (Brown and DeByle 1987). The stems are relatively short-lived (100-150 years), and the stand will succeed to longer-lived conifer forest if undisturbed. Occurrences are favored by fire in the conifer zone (Mueggler 1988). With adequate disturbance a clone may live many centuries. Although *Populus tremuloides* produces abundant seeds, seedling survival is rare because the long moist conditions required to establish them are rare in the habitats that it occurs in. Superficial soil drying will kill seedlings (Knight 1994).

Although many diseases and insects attack *Populus tremuloides* (DeByle and Winokur 1985), under presettlement conditions, disease and insect mortality did not appear to have major effects; however, older aspen stands would be susceptible to outbreaks every 200 years on average (LANDFIRE 2007a, BpS:1210110). Sudden aspen decline (SAD) results in root mortality with subsequent effects on tree canopy and clone persistence. It appears to be triggered by severe drought (Worrall et al. 2010).

This system is also important habitat and browse for many species of wildlife, including various birds, beaver, snowshoe hare and large ungulates such as deer, elk and moose (DeByle and Winokur 1985). Concentrated use by elk can significantly impact stands (DeByle and Winokur 1985).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has three classes in total (LANDFIRE 2007a, BpS 2810110). These are summarized as:

A) Early Development 1 All Structures (5% of type in this stage): Aspen suckers less than 6 feet tall and abundant. Grasses and forbs resprout vigorously with high cover. Often densely vegetated.

B) Mid Development 1 Closed (pole-sized tree-dominated - 35% of type in this stage): Tree cover is 21-100%. Aspen over 6 feet tall dominate. Canopy cover highly variable, but usually dense. Understory also usually dense.

C) Late Development 1 Closed (tree-dominated - 60% of type in this stage): Tree cover is 21-100%. Aspen trees 9+ inches dbh. Canopy cover is highly variable, but usually dense. Understory dense. Lots of dead and downed material.

Fire, insects and disease. In absence of disturbance, may stay aspen. Fire will generally come from adjacent systems. Surface fire would generally affect the margins of stands as a result of fire on adjacent vegetation types. Mixed fire may occur, but is undocumented (LANDFIRE 2007a, BpS 2810110).

ECOLOGICAL INTEGRITY

Change Agents: In the western U.S., *Populus tremuloides* forests have been utilized primarily for livestock grazing and to a lesser extent harvested for wood products. Stands typically have lush understory because tree canopy allows significant light to pass through, and sites tend to be relatively mesic (DeByle and Winokur 1985, Howard 1996). Heavy grazing by livestock can deplete or convert an understory dominated by shrubs and forbs to an understory dominated by grazing-tolerant grasses. Degraded stands were often seeded to grazing-tolerant introduced forage species such as *Bromus inermis, Dactylis glomerata, Phleum pratense*, and *Poa pratensis* (DeByle and Winokur 1985). Excessive browsing by livestock or wildlife can also significantly impact regeneration by suckers (DeByle and Winokur 1985, Howard 1996).

Harvesting *Populus tremuloides* trees greatly stimulates regeneration by suckering. Stand structure is obviously affected depending on silviculture treatment (clearcut versus partial cut) and management objectives (DeByle and Winokur 1985). Prescribed burning can also regenerate stands (DeByle and Winokur 1985, Howard 1996). Introduced species can be brought in during logging operations and other management actions that disturbed soil.

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 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.

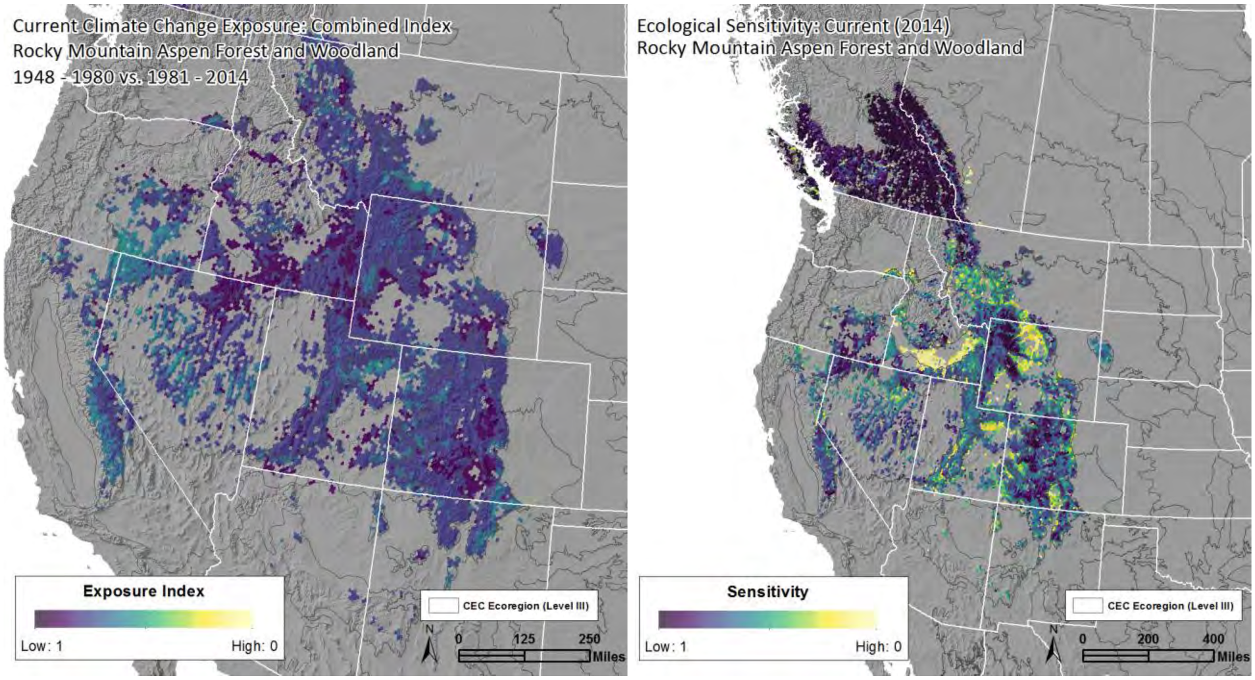

Figure 22. Climate exposure as of 2014 (left) and overall sensitivity (right) for Rocky Mountain Aspen Forest and Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure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

Table 21. Resilience, exposure and vulnerability scores for Rocky Mountain Aspen Forest and Woodland 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 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	Wasatch & Uinta Mountains	Middle Rockies	Northern Basin & Range	Central Basin & Range	Colorado Plateaus	Wyoming Basin	Sierra Nevada	Snake River Plain	Canadian Rockies	North-western Great Plains	Eastern Cascades Slopes & Foothills	Columbia Mountains-Northern Rockies	Blue Mountains
Potential square miles within ecoregion		3,062	1,691	1,640	1,302	531	399	242	113	94	77	59	43	25	23
Contributions to Relative Vulnerability by Factor															
Vulnerability from **Exposure (2014)**		Mod 0.75	Mod 0.73	Low 0.76	Low 0.75	Mod 0.72	Mod 0.72	Low 0.77	Mod 0.69	Low 0.79	Mod 0.74	Mod 0.68	Mod 0.68	Mod 0.74	Mod 0.71
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.82	0.75	0.71	0.81	0.90	0.74	0.68	0.93	0.45	0.69	0.48	0.87	0.83	0.74
	Fire Regime Departure	0.67	0.52	0.69	0.50	0.42	0.64	0.59	0.50	0.70	0.88	0.52	0.41	0.77	0.49
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.86	0.87	0.87	0.94	0.92	0.91	0.94	0.82	0.94	0.90	0.98	0.85	0.91	0.92
	Sensitivity Average	**0.78**	**0.71**	**0.76**	**0.75**	**0.75**	**0.76**	**0.74**	**0.75**	**0.70**	**0.82**	**0.66**	**0.71**	**0.84**	**0.71**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.49	0.51	0.46	0.46	0.62	0.52	0.37	0.60	0.27	0.34	0.28	0.37	0.44	0.36
	Diversity within Functional Species Groups	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	Adaptive Capacity Average	**0.66**	**0.68**	**0.65**	**0.65**	**0.73**	**0.68**	**0.60**	**0.72**	**0.55**	**0.59**	**0.56**	**0.61**	**0.64**	**0.60**
Vulnerability from Measures of **Overall Resilience**		Mod 0.72	Mod 0.69	Mod 0.70	Mod 0.70	Mod 0.74	Mod 0.72	Mod 0.67	Mod 0.73	Mod 0.63	Mod 0.71	Mod 0.61	Mod 0.66	Mod 0.74	Mod 0.66
Climate Change Vulnerability Index		Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Mod

Exposure Summary for 1981-2014 Timeframe: Overall, the climate exposure as of 2014 for this widespread forest system is moderate across ten of the 14 ecoregions, accounting for 65% of the potential distribution of the system. Exposure was low in four ecoregions. Annual mean temperature has increased between 0.5° and 0.7°C across most of the potential range. These changes were widespread in nine ecoregions (affecting >50% of the area of each).

Mean diurnal temperature range decreased by 0.3° to 0.5°C across portions of five ecoregions (10-70% of the area of each) suggesting that increases in night-time temperature are outpacing daytime increases.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). At the end of the Little Ice Age in the Sierra Nevada aspen extent appears to have increased after the cooler and wetter climate conditions (Shepperd et al. 2006), so the climate trends over the last several decades of increasing temperature and reduced moisture may explain some of the more recent decline in aspen extent. Across western North America, continued higher temperatures and increased moisture stress are predicted to affect aspen stands with increased mortality and decreased regeneration in general (Brandt et al. 2003b, Elliott and Baker 2004, Worrall et al. 2008a, b).

Aspen is a water-limited, drought-intolerant species (Niinemets and Valladares 2006), consequently drought can cause death or decline of aspen. In 2002, Sudden Aspen Decline (SAD), the rapid death of some or all mature aspen in a stand with little or no regeneration resulting from of a high percentage of root death, became evident in Utah and Arizona, and soon after in Colorado and elsewhere (Bartos 2008, Fairweather et al. 2008, Worrall et al. 2008a, b, Morelli and Carr 2011). Predisposing factors for SAD include open stands at lower elevations on exposed slope positions and southerly aspects, which are the site conditions that are especially sensitive to drought and may be an indicator of the response of aspen to warmer growing seasons in some parts of the West (Worrall et al. 2008a, b). Other contributing factors include secondary agents, insects and diseases which attack already weakened trees and may also be affected by climate change (Bethers et al. 2010).

Future climate changes may also increase the frequency of physical disturbances such as in fire because of increased temperatures and decreased precipitation (Westerling et al. 2006, Spracklen et al. 2009). More frequent fires would favor aspen regeneration through post-fire suckering (DeByle and Winokur 1985, Jones and DeByle 1985, Schier et al. 1985, Graham et al. 1990, Rogers 2002, Elliot and Baker 2004), which alone would be expected to increase seral aspen stands on the landscape. However, interactions between different ecological factors and variable extreme weather make the net effect of a warming climate difficult to predict. For example, other stressors, such as heavy ungulate browsing on sprouts, may prevent aspen from establishing new trees (Romme et al. 2001) or changes in the abundance of insects and diseases on aspen.

In addition, opportunities for natural aspen migration and reestablishment are limited in warming climate. Elliott and Baker (2004) found aspen seedling establishment may have occurred in cooler years with higher spring precipitation, whereas accelerated asexual reproduction (vegetative growth) increased in drier, warmer years at upper treeline in southwestern Colorado mountains. Climate change may have less effect on core aspen habitat in the montane and subalpine mountains and plateaus and more impact on areas where aspen occurs on marginal sites (lower elevation, warm aspects).

Because aspen is well-adapted to fire, increased fire frequency in western conifer forests from a warming climate should increase total area of serial aspen stands (DeByle and Winokur 1985).

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate to low for this forest type. Sensitivity was low for eight of the 14 ecoregions of this broadly distributed type, accounting for 77% of the potential distribution. Sensitivity was moderate in the remaining ecoregions. This low to moderate sensitivity was associated with varied landscape condition across the range and moderate to high contributions to sensitivity from fire regime departure. Risk from forest insect and disease was low to moderate.

Vulnerability from landscape condition was moderate to high in lower- and moderate-elevation areas where this type extends into valley floors associated with grazing, agricultural conversion and suburban or exurban development. Outside of these areas, stands occur in areas not suited for agricultural conversion, and landscape condition is associated with moderate to low fragmentation from road networks and timber extraction.

Fire regime departure was moderate across eight ecoregions, accounting for 92% of the potential distribution of this type. This reflects fire suppression practices across much of the range, leading to succession towards a mixed conifer forest state and the loss of aspen.

Risk from insect and disease was generally low across the range of the system. However, this low risk may be increased by interactions with drought (e.g., with sudden aspen death) and fire in the region (Worrel et al. 2010).

The stressors of landscape fragmentation and fire suppression within portions of the range have resulted in changes to the structure of these woodlands, which have increased the sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Vulnerability due to adaptive capacity is moderate across the range of this system, with scores in the moderate range in all ecoregions. Risk from adaptive capacity is related to moderate to low vulnerability from topoclimate variability. Low to moderate topoclimatic variability reflects the moderate slopes and plateaus characteristic of where this woodland type occurs. In terms of vulnerability related to functional groups, the system scores high in terms of graminoid diversity and the presence of aspen as a keystone species (which creates conditions favorable for its own persistence).

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, these woodlands score in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure (fire suppression increasing the likelihood of conversion to mixed conifer forest types), and moderate adaptive capacity from low to moderate topoclimate variability. Although insect and disease risk were low for this system, these may be exacerbated by effects of recent drought and fire across the range 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 22. Climate change adaptation strategies relative to vulnerability scores for Rocky Mountain Aspen Forest and Woodland.

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 and fire breaks. Maintain or restore natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.

Moderate	**Emphasize restoration to enhance resilience.** Restore natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, and tree regeneration.
High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including sudden aspen death, tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Adams 2010, Bartos 1979, Bartos 2008, Bartos and Campbell 1998, Bartos and Mueggler 1979, Bell et al. 2009, Bethers et al. 2010, Brandt et al. 2003b, Brown and DeByle 1987, Comer et al. 2002, Comer et al. 2003*, Dale et al. 2001, DeByle 1985b, DeByle and Winokur 1985, DeVelice et al. 1986, Downing and Pettapiece 2006, Elliott 2012, Elliott and Baker 2004, Eyre 1980, Fairweather et al. 2008, Graham et al. 1990, Henderson et al. 1977, Hess and Wasser 1982, Howard 1996a, Johnston and Hendzel 1985, Jones and DeByle 1985, Keammerer 1974a, Keammerer 1974b, Knight 1994, LANDFIRE 2007a, Minnich 2007b, Morelli and Carr 2011, Mueggler 1988, NCC 2002, Natural Regions Committee 2006, NatureServe Explorer 2011, Neely et al. 2001, Niinemets and Valladares 2006, Powell 1988a, Reid et al. 1999, Rogers 2002, Romme et al. 2001, Schier et al. 1985, Scott et al. 1980, Shepperd et al. 2006, Shiflet 1994, Spracklen et al. 2009, Tuhy et al. 2002, WNHP unpubl. data 2018, Westerling et al. 2006, Willoughby 2007, Worrall et al. 2008a, Worrall et al. 2008b, Worrall et al. 2010, Youngblood and Mauk 1985

CES306.820 Rocky Mountain Lodgepole Pine Forest

Figure 23. Photo of Rocky Mountain Lodgepole Pine Forest. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is widespread in upper montane to subalpine elevations of the Rocky Mountains, Intermountain West region, north into the Canadian Rockies and east into mountain "islands" of north-central Montana. These are subalpine forests where the dominance of *Pinus contorta* is related to fire history and topo-edaphic conditions. Following stand-replacing fires, *Pinus contorta* will rapidly colonize and develop into dense, even-aged stands. Most forests in this ecological system occur as early- to mid-successional forests which developed following fires. This system includes *Pinus contorta*-dominated stands that, while typically persistent for >100-year time frames, may succeed to spruce-fir; in the southern and central Rocky Mountains it is seral to Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland (CES306.828). More northern occurrences are seral to Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland (CES306.830). Soils supporting these forests are typically well-drained, gravelly, coarse-textured, acidic, and rarely formed from calcareous parent materials. These forests are dominated by *Pinus contorta* with shrub, grass, or barren understories. Sometimes there are intermingled mixed conifer/*Populus tremuloides* stands, with the latter occurring with inclusions of deeper, typically fine-textured soils. The shrub stratum may be conspicuous to absent; common species include *Arctostaphylos uva-ursi, Ceanothus velutinus, Linnaea borealis, Mahonia repens, Menziesia ferruginea* (in northern occurrences), *Purshia tridentata, Rhododendron albiflorum* (in northern occurrences), *Spiraea betulifolia, Spiraea douglasii, Shepherdia canadensis, Vaccinium cespitosum, Vaccinium scoparium, Vaccinium membranaceum, Symphoricarpos albus*, and *Ribes* spp. In southern interior British Columbia, this system is usually an open lodgepole pine forest found extensively between 500 and 1600 m elevation in the Columbia Range. In the Interior Cedar Hemlock and Interior Douglas-fir zones, *Tsuga heterophylla* or *Pseudotsuga menziesii* may be present. In Alberta, species composition indicates the transition to more boreal floristics, including such species as *Empetrum nigrum, Ledum groenlandicum, Leymus innovatus*, and more abundant lichens or mosses such as *Cladonia* spp., *Hylocomium splendens*, and *Pleurozium schreberi*.

Distribution: This system occurs at upper montane to subalpine elevations of the Rocky Mountains, Intermountain West region, north into the Canadian Rockies, and east onto mountain "islands" of north-central Montana. In Washington, this system occurs mostly on the east side of the Cascade Crest. In Oregon, this system only occurs in the Blue Mountains; all Oregon Cascades lodgepole pine forests are included in other systems.

Nations: CA, US

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

CEC Ecoregions: Columbia Mountains/Northern Rockies, Canadian Rockies, North Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Glaciated Plains, Northwestern Great Plains, Columbia Plateau, Northern Basin and Range, Wyoming Basin, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These forests are dominated by *Pinus contorta* with shrub, grass, or barren understories. Sometimes there are intermingled mixed conifer/*Populus tremuloides* stands, with the latter occurring with inclusions of deeper, typically fine-textured soils. The shrub stratum may be conspicuous to absent; common species include *Arctostaphylos uva-ursi, Ceanothus velutinus, Linnaea borealis, Mahonia repens, Menziesia ferruginea* (in northern occurrences), *Purshia tridentata, Rhododendron albiflorum* (in northern occurrences), *Spiraea betulifolia, Spiraea douglasii, Shepherdia canadensis, Vaccinium cespitosum, Vaccinium scoparium, Vaccinium membranaceum, Symphoricarpos albus*, and *Ribes* spp. In southern interior British Columbia, this system is usually an open lodgepole pine forest found extensively between 500 and 1600 m elevation in the Columbia Range. In the Interior Cedar Hemlock and Interior Douglas-fir zones, *Tsuga heterophylla* or *Pseudotsuga menziesii* may be present. In Alberta, species composition indicates the transition to more boreal floristics, including such species as *Empetrum nigrum, Ledum groenlandicum, Leymus innovatus*, and more abundant lichens or mosses such as *Cladonia* spp. (= *Cladina* spp.), *Hylocomium splendens*, and *Pleurozium schreberi*.

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.

Forest Patch Disturbance; Species Diversity: Medium
Diversity: medium = 6-15 spp. Tree mortality caused by native insects and disease is an important ecological process that creates a diversity of habitats within forested landscapes that would otherwise

have uniform stand structure. Although lodgepole pine (*Pinus contorta*) is host to hundreds of fungi and insects, relatively few of these cause significant mortality in healthy mature trees, while many others weaken trees and make them vulnerable so that they can blow down and create forest gaps. These gaps allow more light to penetrate the tree canopy increasing production of shrubby and herbaceous understory, creating places for stand regeneration, and accelerating succession (Amman 1977, Anderson 2003b).

Insects: Bark beetles: mountain pine beetle (*Dendroctonus ponderosae*), pine engraver (*Ips pini*), and Warren's collar weevil (*Hylobius warreni*), extended outbreaks of defoliators such as lodgepole terminal weevil (*Pissodes terminalis*) and lodgepole sawfly (*Neodiprion burkei*) (van der Kamp and Hawksworth 1985, Burns and Honkala 1990a, Anderson 2003b).

Fungi: Stem canker caused by *Atropellis piniphila*, comandra blister rust (*Cronartium comandrae*), western gall rust (*Peridermium harknessii*), root and butt rots such as *Phellinus* root rot (*Phellinus weirii*) and *Armillaria* root disease (*Armillaria ostoyae, Armillaria mellea*), red ring rot (*Phellinus pini*), velvet top fungus (*Haeolus schweinitzii*), and Quinine conk (*Fomitopsis officinialis*) (van der Kamp and Hawksworth 1985, Burns and Honkala 1990a, Anderson 2003b).

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.

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 forest type.

Environment: This system occurs in the upper montane to subalpine elevations of the Rocky Mountains, north into the Canadian Rockies and east into mountain "islands" of north-central Montana. Elevations range from just over 900 m in the northeastern Cascades to well over 3100 m in the Uinta Mountains in Utah and the southern Colorado Rockies. Temperature regimes are extreme throughout this region and frequent growing season frosts occur. Annual precipitation in these montane and subalpine habitats ranges from less than 40 cm to over 150 cm, usually with the majority falling as snow. Late-melting snowpacks provide the majority of growing-season moisture.

Soils are variable but are typically well-drained, gravelly, coarse-textured, acidic, rarely from calcareous parent materials with occasionally inclusions of deeper, typically fine-textured soils. Other stands occur on excessively well-drained pumice deposits, glacial till and alluvium on valley floors where there is cold-air accumulation, warm and droughty shallow soils over fractured quartzite bedrock, and shallow moisture-deficient soils with a significant component of volcanic ash.

Key Processes and Interactions: *Pinus contorta* is an aggressively colonizing, shade-intolerant conifer which usually occurs in lower subalpine forests in the major ranges of the western United States. Establishment is episodic and linked to stand-replacing disturbances, primarily fire. The incidence of serotinous cones varies within and between varieties of *Pinus contorta*, being most prevalent in Rocky Mountain populations. Closed, serotinous cones appear to be strongly favored by fire, and allow rapid colonization of fire-cleared substrates (Burns and Honkala 1990a). Hoffman and Alexander (1980, 1983) report that in stands where *Pinus contorta* exhibits a multi-aged population structure, with regeneration occurring, there is typically a higher proportion of trees bearing nonserotinous cones.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2810500). These are summarized as:

A) Early Development 1 All Structures (20% of type in this stage): Tree cover is 0-80%. Stand initiation: Grasses, forbs, low shrubs and lodgepole seedlings-saplings. This class does not last long; young lodgepole grows fast. If aspen is present, it grows faster and dominates lodgepole. Cover of trees (seedlings-saplings) varies widely.

B) Mid Development 1 Closed (20% of type in this stage): Tree cover is 51-100%. Stem exclusion (RMLANDS: Rocky Mountain Landscape Simulator): Moderate to dense pole-sized trees, sometimes very dense (dog-hair); longest time in this class without disturbance. Aspen usually not present.

C) Mid Development 1 Open (tree-dominated - 20% of type in this stage): Tree cover is 21-50%. Understory reinitiation: Variety of lodgepole size classes, some mature trees, often somewhat patchy. If aspen is present, lodgepole usually dominates it.

D) Late Development 1 Open (20% of type in this stage): Tree cover is 61-100%. Many mature lodgepole pine with closed canopy. Trees may vary in age, but consistent in size, diameters and heights.

E) Late Development 1 All Structures (10% of type in this stage): Tree cover is 31-60%. Many mature lodgepole pine, somewhat patchy, variety of lodgepole size classes, open canopies overall but patches of denser trees. Dead and downed woody materials increasing in volume, young trees infilling openings.

Before fire suppression began in the early 20th century, most fires were low-intensity, creeping, surface fires, whereas most fires today are high-intensity crown fires that occur during severe fire weather (dry and windy) (Lotan et al. 1985). The stand-replacing fire interval in lodgepole pine forests is about 215 years (LANDFIRE 2007a, BpS 2810500).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. Biological decomposition in lodgepole pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this forest system include altered fire regime, altered stand structure from fragmentation due to roads, logging, mining, or other human disturbances (CNHP 2010). These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed (CNHP 2010). Invasive exotic species can become abundant in disturbed areas and alter floristic composition. Direct and indirect effects of climate change may alter dynamics of indigenous insects such as mountain pine beetle (*Dendroctonus ponderosae*) and cause a buildup in population size with less extreme winters leading to large outbreaks the can cause high mortality in mature trees.

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 24, left**) and sensitivity (**Figure 24, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

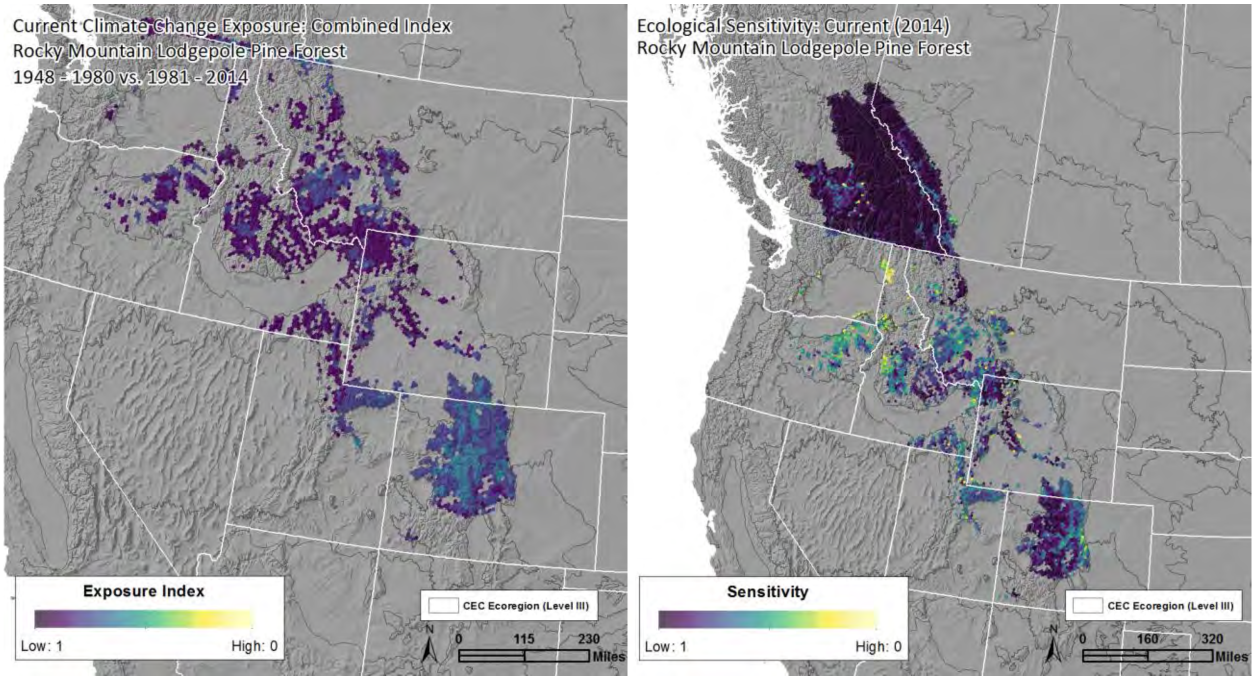

Figure 24. Climate exposure as of 2014 (left) and overall sensitivity (right) for Rocky Mountain Lodgepole Pine Forest. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow. *NOTE: modeling methods differed for type distributions outside of the USA. In this example, geophysical conditions on Canada could support lodgepole pine forests, but actual distributions differ due to natural disturbance processes, so patterns on the ground are more similar to those within the USA.*

Table 23. Resilience, exposure and vulnerability scores for Rocky Mountain Lodgepole Pine Forest 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 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	Columbia Mountains-Northern Rockies	Blue Mountains	Thompson-Okanogan Plateau	Middle Rockies	Canadian Rockies	Wasatch & Uinta Mountains	Eastern Cascades Slopes & Foothills	Idaho Batholith	Clear Hills & Western Alberta Upland	Wyom-ing Basin	Chilcotin Ranges & Fraser Plateau	Aspen Parkland-Northern Glaciated Plains	North Cascades
	Potential square miles within ecoregion	2,869	765	592	519	475	454	302	142	65	42	42	31	28	21
Contributions to Relative Vulnerability by Factor															
Vulnerability from **Exposure (2014)**		**Mod** 0.71	**Low** 0.85	**Low** 0.83	**Low** 0.82	**Low** 0.80	**Low** 0.84	**Mod** 0.73	**Low** 0.81	**Low** 0.80	**Low** 0.79	**Mod** 0.75	**Low** 0.84	**Low** 0.76	**Low** 0.83
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.77	0.91	0.73	0.85	0.79	0.80	0.73	0.30	0.72	0.81	0.83	0.90	0.47	0.93
	Fire Regime Departure	0.76	0.29	0.41	Null	0.58	0.91	0.51	0.61	0.59	Null	0.58	Null	Null	0.51
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.81	0.95	0.80	Null	0.77	0.86	0.66	0.89	0.87	Null	0.85	Null	Null	0.85
	Sensitivity Average	**0.78**	**0.71**	**0.64**	**0.85**	**0.72**	**0.85**	**0.63**	**0.60**	**0.73**	**0.81**	**0.76**	**0.90**	**0.47**	**0.76**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.52	0.44	0.37	0.29	0.35	0.34	0.43	0.33	0.33	0.19	0.50	0.19	0.20	0.45
	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
	Adaptive Capacity Average	**0.51**	**0.47**	**0.43**	**0.39**	**0.42**	**0.42**	**0.46**	**0.41**	**0.41**	**0.34**	**0.50**	**0.34**	**0.35**	**0.47**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.64	**Mod** 0.59	**Mod** 0.54	**Mod** 0.62	**Mod** 0.57	**Mod** 0.64	**Mod** 0.55	**Mod** 0.51	**Mod** 0.57	**Mod** 0.58	**Mod** 0.63	**Mod** 0.62	**High** 0.41	**Mod** 0.62
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the climate exposure as of 2014 for this broadly distributed forest system is low to moderate. Across 11 of the 14 ecoregions, accounting for 50% of the potential distribution of the system, exposure was low. Within the remaining three ecoregions, exposure was at the low end of moderate. Annual mean temperature has increased between 0.5° and 0.7°C across much of the range. These changes were substantial in eight ecoregions (affecting 25-91% of the area of each). Mean diurnal temperature range decreased by 0.3° to 0.4°C across portions of five ecoregions (4-10% of the area of each) suggesting that increases in night-time temperature are outpacing daytime increases. Precipitation of the driest quarter increased by 15-20% in small portions of the Southern Rockies and Wasatch and Uinta Mountains (10-15% of each region).

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest, Rocky Mountains, and Southwest regions along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014, Mote et al. 2014, Shafer et al. 2014). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as *Ips* spp. by increasing the number of generations within a growing season or by allowing a population buildup over several years such as with mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact pine trees regionally (Burns and Honkala 1990a, Anderson 2003b).

Many stands of this ecological system woodland occur in upper montane/subalpine zones of taller ranges so it may be possible for the species of this system to move up into the subalpine zone while suitable climate is diminished at lower elevations. *Pinus contorta* has an average lifespan of 150 to 200 years and is known to live over 400 years, so it may be able to survive as relicts for centuries without regeneration (Anderson 2003b). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate to low for this forest type. Sensitivity was low for seven of the 14 ecoregions of this broadly distributed type, accounting for 63% of the potential distribution. Sensitivity was moderate or at the moderate end of high in the remaining ecoregions. This low to moderate sensitivity was associated with varied landscape condition across the range and moderate to high contributions to sensitivity from fire regime departure.

Vulnerability from landscape condition was low to moderate across much of the range. However, in two ecoregions (Eastern Cascades and Northwestern Glaciated Plains) where this type extends to lower and moderate elevations, landscape condition vulnerability was high, reflecting fragmentation from road networks and suburban and exurban development. Outside of these areas, stands occur in areas not suited for agricultural conversion, and landscape condition is associated with moderate to low fragmentation from road networks and timber extraction.

Fire regime departure was variable across the region. Departure was low in the largest ecoregion (Southern Rockies), moderate across six regions, and very high in the Columbia Mountains-Northern

Rockies and the Blue Mountains ecoregions. These reflect fire suppression practices across much of the range, which have favored large homogenous stands of older lodgepole pine relative to heterogenous stands of different ages characteristic of smaller and more frequent fire regimes. Fire suppression can also favor succession to mixed conifer forest.

Risk from forest insect and disease was low across most ecoregions, with the exceptions of moderate risk in the Wasatch and Uinta Mountains. However, this generally low risk may be increased by interactions with drought and fire in the region.

The stressors of landscape fragmentation and fire suppression within portions of the range have resulted in changes to the structure of these woodlands, which have increased the sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Vulnerability due to adaptive capacity is high across the range of this system, with scores in the highly vulnerable range in 12 ecoregions and at the high range of moderate in two ecoregions. Risk from low adaptive capacity is related to high vulnerability from low topoclimate variability. Low topoclimatic variability reflects its extensive distribution across moderate slopes within montane areas. In terms of vulnerability related to functional groups, the system scores moderate in terms of species associated with patch disturbances, suggesting increased vulnerability due to potential loss of individual species from factors such as drought and human disturbance.

Vulnerability Summary for 1981-2014 Timeframe: Assuming climate exposure as of 2014, these woodlands score in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure and low adaptive capacity from low to moderate topoclimate variability. Although insect and disease risk were low for this system, these may be exacerbated by effects of recent drought and fire across the range 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 24. Climate change adaptation strategies relative to vulnerability scores for Rocky Mountain Lodgepole Pine Forest.

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 and fire breaks. Maintain or restore natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Restore natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Alexander 1986, Alexander et al. 1987, Amman 1977, Anderson 1999a, Anderson 2003b, Arno et al. 1985, Banner et al. 1993, Barrows et al. 1977, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Dale et al. 2001, DeLong 1996, DeLong et al. 1993, Despain 1973a, Despain 1973b, Ecosystems Working Group 1998, Eyre 1980, Garfin et al. 2014, Harvey 1994, Hess and Alexander 1986, Hess and Wasser 1982, Hoffman and Alexander 1976, Hoffman and Alexander 1980, Hoffman and Alexander 1983, Johnson and Clausnitzer 1992, Johnston 1997, Kingery 1998, LANDFIRE 2007a, Lloyd et al. 1990, Lotan et al. 1985, MacKinnon et al. 1990, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Mehl 1992, Meidinger and Pojar 1991, Moir 1969a, Mote et al. 2014, NCC 2002, Nachlinger et al. 2001, Neely et al. 2001, Pfister et al. 1977, RMLANDS 2018, Romme et al. 1986, Shafer et al. 2014, Steele et al. 1981, Steele et al. 1983, Steen and Coupé 1997, Stevens-Rumann et al. 2017, WNHP unpubl. data 2018, Westerling et al. 2006, Whipple 1975, Williams and Smith 1990, van der Kamp and Hawksworth 1985

M022. Southern Rocky Mountain Lower Montane Forest

CES306.823 Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland

Figure 25. Photo of Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This is a highly variable ecological system of the montane zone of the Rocky Mountains. It occurs throughout the southern Rockies, north and west into Utah, Nevada, Wyoming and Idaho. These are mixed-conifer forests occurring on all aspects at elevations ranging from 1200 to 3300 m. Rainfall averages less than 75 cm per year (40-60 cm), with summer "monsoons" during the growing season contributing substantial moisture. The composition and structure of the overstory are dependent upon the temperature and moisture relationships of the site and the successional status of the occurrence. *Pseudotsuga menziesii* and *Abies concolor* are most frequent, but *Pinus ponderosa* may be present to codominant. *Pinus flexilis* is common in Nevada. *Pseudotsuga menziesii* forests occupy drier sites, and *Pinus ponderosa* is a common codominant. *Abies concolor*-dominated forests occupy cooler sites, such as upper slopes at higher elevations, canyon sideslopes, ridgetops, and north- and east-facing slopes which burn somewhat infrequently. *Picea pungens* is most often found in cool, moist locations, often occurring as smaller patches within a matrix of other associations. As many as seven conifers can be found growing in the same occurrence, and there are a number of cold-deciduous shrub and graminoid species common, including *Arctostaphylos uva-ursi, Mahonia repens, Paxistima myrsinites, Symphoricarpos oreophilus,* *Jamesia americana, Quercus gambelii*, and *Festuca arizonica*. This system was undoubtedly characterized by a mixed-severity fire regime in its "natural condition," characterized by a high degree of variability in lethality and return interval.

Distribution: This system occurs throughout the southern Rockies, north and west into Utah, Nevada, eastern Wyoming (very southern in the Laramie Range and possibly on Sheep Mountain) and Idaho. Although not common, it does occur in southeastern Oregon but does not extend farther west into the Cascades.

Nations: US

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

CEC Ecoregions: 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, Mojave Basin and Range, Sonoran Desert, Chihuahuan Desert, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This highly variable ecological system comprises mixed-conifer forests at montane elevations throughout the Intermountain West region. The four main alliances in this system are found on slightly different, but intermingled, biophysical environments: *Abies concolor* dominates at higher, colder locations; *Picea pungens* represents mesic conditions; and *Pseudotsuga menziesii* dominates intermediate zones. As many as seven conifers can be found growing in the same occurrence, with the successful reproduction of the diagnostic species determining the association type. Common conifers include *Pinus ponderosa, Pinus flexilis, Abies lasiocarpa var. lasiocarpa, Abies lasiocarpa var. arizonica, Juniperus scopulorum*, and *Picea engelmannii*. *Populus tremuloides* is often present as intermingled individuals in remnant aspen clones or in adjacent patches. The composition and structure of the overstory are dependent upon the temperature and moisture relationships of the site and the successional status of the occurrence (DeVelice et al. 1986, Muldavin et al. 1996).

Several cold-deciduous shrub and graminoid species are found in many occurrences (e.g., *Arctostaphylos uva-ursi, Mahonia repens, Paxistima myrsinites, Symphoricarpos oreophilus, Jamesia americana, Quercus gambelii*, and *Festuca arizonica*). Other important species include *Acer glabrum, Acer grandidentatum, Amelanchier alnifolia, Arctostaphylos patula, Holodiscus dumosus, Jamesia americana, Juniperus communis, Physocarpus monogynus, Quercus arizonica, Quercus rugosa, Quercus x pauciloba, Quercus hypoleucoides, Robinia neomexicana, Rubus parviflorus*, and *Vaccinium myrtillus*. Where soil moisture is favorable, the herbaceous layer may be quite diverse, including graminoids *Bromus ciliatus (= Bromus canadensis), Calamagrostis rubescens, Carex geyeri, Carex rossii, Carex siccata (= Carex foenea), Festuca occidentalis, Koeleria macrantha, Muhlenbergia montana, Muhlenbergia straminea (= Muhlenbergia virescens), Poa fendleriana, Pseudoroegneria spicata*, and forbs *Achillea millefolium, Arnica cordifolia, Erigeron eximius, Fragaria virginiana, Linnaea borealis, Luzula parviflora, Osmorhiza berteroi, Packera cardamine (= Senecio cardamine), Thalictrum occidentale, Thalictrum fendleri, Thermopsis rhombifolia, Viola adunca*, and species of many other genera, including *Lathyrus, Penstemon, Lupinus, Vicia, Arenaria, Galium*, and others.

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.

Forest Patch Disturbance; Species Diversity: Medium
Diversity: medium = 6-15 spp. Tree mortality caused by native insects and disease is an important ecological process that creates a diversity of habitats within forested landscapes that would otherwise have uniform stand structure. Although the dominant trees Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and limber pine (*Pinus flexilis*) (common in Nevada) are host to hundreds of fungi and insects, relatively few cause significant mortality in healthy mature trees, while many others weaken trees and make them vulnerable so that they can blow down and create forest gaps. These gaps allow more light to penetrate the tree canopy increasing production of shrubby and herbaceous understory, creating places for stand regeneration, and accelerating succession (Amman 1977, Anderson 2003b).

Insects: Bark beetles: Douglas-fir beetle (*Dendroctonus pseudotsugae*), pine engraver (*Ips pini*), mountain pine beetle (*Dendroctonus ponderosae*) and spruce beetle (*Dendroctonus rufipennis*), extended outbreaks of defoliators such as western spruce budworm (*Choristoneura occidentalis*) (Burns and Honkala 1990a, Johnson 2001, Steinberg 2002e, Howard 2003b, 2003c).

Fungi: Root and butt rots such as *Phellinus* root rot (*Phellinus weirii*) and *Armillaria* root disease (*Armillaria ostoyae, Armillaria mellea*), red ring rot (*Phellinus pini*), velvet top fungus (*Haeolus schweinitzii*), Quinine conk (*Fomitopsis officinialis*), and comandra blister rust (*Cronartium comandrae*) (Burns and Honkala 1990a, Johnson 2001, Steinberg 2002e, Howard 2003b, 2003c).

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.

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 forest and woodland type.

Environment: These are mixed-conifer forests occurring on all aspects at elevations ranging from 1200 to 3300 m. Landforms are variable and can include canyons, plateaus, draws, benches, hills, mesas, ravines, shoulders, sideslopes and toeslopes. Slopes can be gentle to extremely steep. Rainfall averages less than 75 cm per year (40-60 cm), with summer "monsoons" during the growing season contributing substantial moisture. Geologic substrates include volcanic andesite, rhyolite, rhyolitic tuffs, colluvium, shale gneiss, granite, sandstone and limestone. Soils are variable from cobbles, clay loam, silt loam, sandy loam, sand, and gravel.

Key Processes and Interactions: Forests in this ecological system represent the gamut of fire tolerance. Formerly, *Abies concolor* in the Utah High Plateaus were restricted to rather moist or less fire-prone areas by frequent surface fires. These areas experienced mixed fire severities, with patches of crowning in which all trees are killed, intermingled with patches of underburn in which larger *Abies concolor* survived (www.fs.fed.us/database/feis/). With fire suppression, *Abies concolor* has vigorously colonized many sites formerly occupied by open *Pinus ponderosa* woodlands. These invasions have dramatically changed the fuel load and potential behavior of fire in these forests. In particular, the potential for high-intensity crown fires on drier sites now codominated by *Pinus ponderosa* and *Abies concolor* has increased. Increased landscape connectivity, in terms of fuel loadings and crown closure, has also increased the potential size of crown fires.

Pseudotsuga menziesii forests are the only true "fire-tolerant" occurrences in this ecological system. *Pseudotsuga menziesii* forests were probably subject to a moderate-severity fire regime in presettlement times, with fire-return intervals of 30-100 years. Many of the important tree species in these forests are fire-adapted (*Populus tremuloides, Pinus ponderosa, Pinus contorta*) (Pfister et al. 1977), and fire-induced reproduction of *Pinus ponderosa* can result in its continued codominance in *Pseudotsuga menziesii* forests (Steele et al. 1981). Seeds of the shrub *Ceanothus velutinus* can remain dormant in forest occurrences for 200 years (Steele et al. 1981) and germinate abundantly after fire, competitively suppressing conifer seedlings. Successional relationships in this system are complex. *Pseudotsuga menziesii* is less shade-tolerant than many northern or montane trees such as *Tsuga heterophylla, Abies concolor, Picea engelmannii*, and seedlings compete poorly in deep shade. At drier locales, seedlings may be favored by moderate shading, such as by a canopy of *Pinus ponderosa*, which helps to minimize drought stress. In some locations, much of these forests have been logged or burned during European settlement, and present-day occurrences are second-growth forests dating from fire, logging, or other occurrence-replacing disturbances (Mauk and Henderson 1984, Chappell et al. 1997).

Picea pungens is a slow-growing, long-lived tree which regenerates from seed (Burns and Honkala 1990a). Seedlings are shallow-rooted and require perennially moist soils for establishment and optimal growth. *Picea pungens* is intermediate in shade tolerance, being somewhat more tolerant than *Pinus ponderosa* or *Pseudotsuga menziesii*, and less tolerant than *Abies lasiocarpa* or *Picea engelmannii*. It forms late-seral occurrences in the subhumid regions of the Utah High Plateaus. It is common for these forests to be heavily disturbed by grazing or fire.

In general, fire suppression has lead to the encroachment of more shade-tolerant, less fire-tolerant species (e.g., climax) into occurrences and an attendant increase in landscape homogeneity and connectivity (from a fuels perspective). This has increased the lethality and potential size of fires.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2810510). These are summarized as:

A) Early Development 1 All Structures (15% of type in this stage): Shrub cover is 0-80%. Succession after a lethal fire will depend on what vegetation was on site before. In a general conifer-dominated scenario, some ponderosa pines are likely to survive. Fire will be an opportunity for new ponderosa pine establishment. On site Gambel oak will resprout. White fir will also be regenerating. If aspen cover is 50-100% prior to disturbance, the stand would regenerate back to aspen.

B) Mid Development 1 Closed (tree-dominated - 15% of type in this stage): Tree cover is 51-80%. If aspen is dominant the stand will achieve a mid-closed stage. Conifers such as white fir and Douglas-fir could be regenerating with it. Any surviving conifers such as ponderosa pine would be canopy dominants. If aspen canopy cover is 50-100%.

C) Mid Development 1 Open (tree-dominated - 10% of type in this stage): Tree cover is 21-50%. Ponderosa pine is the canopy dominant with an understory dominated by white fir. Douglas-fir present and some of its regeneration is entering the canopy. If aspen were present, the stand would have undergone some self-thinning that would have opened up the canopy. The conifers in the stand create a more flammable litter bed with their needles so that patchy surface fire could carry. Any fire would further open the stand by thinning aspen and fir. Eventually the aspen stand would become very open sharing the canopy with ponderosa pine and Douglas-fir.

D) Late Development 1 Open (conifer-dominated - 50% of type in this stage): Tree cover is 21-50%. Ponderosa pine is the canopy dominant. Douglas-fir can also be a canopy dominant. Recurrent fire maintains white fir as an understory tree, but a rare white fir will join the other two species in the canopy. If aspen is present, its numbers are few. Low levels of suckering may keep it in the stand. Open aspen stands are not common in the warm/dry mixed conifer.

E) Late Development 1 Closed (tree-dominated - 10% of type in this stage): Tree cover is 51-80%. Aspen stand is mature to over-mature with a heavy understory of conifers, mainly white fir and some Douglas-fir.

This BpS has a fire regime very similar to ponderosa pine. Frequent low-intensity surface fire is the dominant mode of disturbance. Fire intervals range from 2-71 years with a mean of 15 years. Lethal fires can occur on a limited scale, but this is not the norm unless aspen is involved. These will be characterized as mixed fires because they most likely occur as a part of a more widespread surface fire. Bark beetles may impact this BpS in isolated areas at small scales (LANDFIRE 2007a, BpS 2810510).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. Biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this forest and woodland system include altered fire regime, altered stand structure from fragmentation due to roads, logging, mining, or other human disturbances (CNHP 2010). These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed (CNHP 2010). Invasive exotic species can become abundant in disturbed areas and alter floristic composition. Direct and indirect effects of climate change may alter dynamics of indigenous insects such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) or mountain pine beetle (*Dendroctonus ponderosae*) causing a buildup in population size (with less extreme winters) leading to large outbreaks that can cause high mortality in mature trees.

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 26, left**) and sensitivity (**Figure 26, right**). The maps for the other components of the vulnerability assessment are provided on DataBasin.

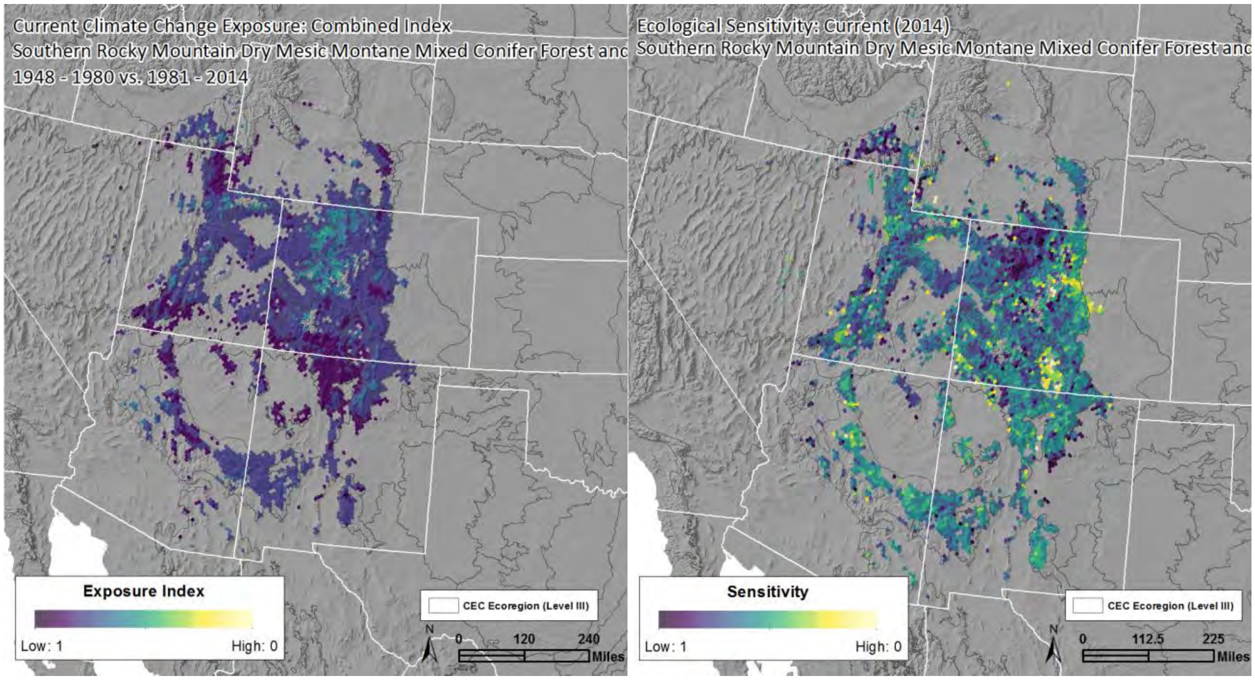

Figure 26. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, 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 Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland 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. 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	Colorado Plateaus	Wasatch & Uinta Mountains	Arizona-New Mexico Plateau
	Potential square miles within ecoregion	3,585	967	876	443	33
Contributions to Relative Vulnerability by Factor						
Vulnerability from **Exposure (2014)**		**Low** 0.76	**Low** 0.77	**Low** 0.75	**Low** 0.76	**Low** 0.80
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.78	0.87	0.83	0.78	0.76
	Fire Regime Departure	0.34	0.19	0.52	0.45	0.31
	Invasive Annual Grasses	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.82	0.81	0.88	0.87	0.89
	Sensitivity Average	**0.65**	**0.62**	**0.74**	**0.70**	**0.65**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.56	0.58	0.66	0.60	0.45
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.53**	**0.54**	**0.58**	**0.55**	**0.48**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.59	**Mod** 0.58	**Mod** 0.66	**Mod** 0.63	**Mod** 0.56
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall climate exposure as of 2014 for this widespread forest system was at the moderate end of low exposure for all ecoregions.

The annual mean temperature has increased over portions of all ecoregions by approximately 0.6°C. These changes were pervasive (96%) in the Arizona-New Mexico Mountains ecoregion and widespread (30-50%) in the remaining four ecoregions. This increase in annual temperature is reflected by increases in summer temperature of 0.6°C across 30-50% of all ecoregions. However, mean diurnal temperature range decreased by 0.3° to 0.5°C in portions of four ecoregions (1-20%), suggesting that minimum night-time temperature increases are outpacing day-time increases.

Increases in annual precipitation of the driest month characterize 13% of the Arizona-New Mexico Mountains ecoregion and increases in the precipitation of the driest quarter characterizes 11% of the Southern Rockies ecoregion. The effects of increased summer and fall precipitation are unclear but could help reduce effects of drought stress on trees during dry periods.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Southwest region along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). 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 tree recruitment. Without tree recruitment these woodland and forest stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) or mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact trees regionally (Burns and Honkala 1990a, Zouhar 2001a, Steinberg 2002e, Howard 2003b, c).

Many stands of this ecological system woodland occur in montane of taller ranges so it may be possible for the species of this system to move up into the upper montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* and *Pseudotsuga menziesii* frequently live more than 300-500 years and are known to live over 700 years, so they may be able to survive as relicts for centuries without regeneration (Zouhar 2001a, Steinberg 2002e, Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across all five ecoregions within the potential range of this forest type. Sensitivity is largely associated with fire regime departure for this type.

Contributions to sensitivity from landscape condition are low across all ecoregions, reflecting limited fragmentation from development or road networks within the range of this montane woodland. Fire regime departure was high or very high in four ecoregions and at the high end of moderate in the Colorado Plateau ecoregion. This reflects fire suppression practices across much of the region which have led to increased tree densities and understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was low across all ecoregions. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease.

Fire suppression has resulted in changes to the structure of these woodlands, which has increased the 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 system, with scores in the moderate range in four ecoregions, and scores in the lower range of moderate for the Arizona-New Mexico Plateau ecoregion. This moderate adaptive capacity is related to moderate scores for both topoclimatic variability and functional group diversity.

These woodlands are characterized by a moderate level of topoclimate variability associated with the varied slopes, plateaus, mesas and canyons of this generally mid-elevation forest type. Local climates vary somewhat within short distances, providing some options for species to move across these landscapes to adapt to changing climate conditions. In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity related to species associated with patch disturbances, providing for a range of successional stages within stands. 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 forest type scores in the moderate range of vulnerability within all ecoregions. This is primarily due to high contributions to sensitivity from fire regime departure combined with a moderate level of adaptive capacity. The system occurs in areas of moderate topoclimate variability and is vulnerable to catastrophic fires from increased stand density and understory fuel loads. Many stands occur on mid-elevation slopes, so there may be potential for upslope migration of dominant species. Although insect and disease risk were low for this system, these may be exacerbated by drought and severe fires across the range 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 26. Climate change adaptation strategies relative to vulnerability scores for Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.

Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Alexander et al. 1984b, Alexander et al. 1987, Amman 1977, Anderson 2003b, Boyce 1977, Bunin 1975c, Burns and Honkala 1990a, CNHP 2010, Chappell et al. 1997, Comer et al. 2002, Comer et al. 2003*, Dale et al. 2001, DeVelice et al. 1986, Eyre 1980, Fitzhugh et al. 1987, Garfin et al. 2014, Giese 1975, Graham and Jain 2005, Harvey 1994, Heinze et al. 1962, Hess 1981, Hess and Alexander 1986, Hess and Wasser 1982, Hoffman and Alexander 1980, Hoffman and Alexander 1983, Howard 2003b, Howard 2003c, Johnson 2001, Kaufmann et al. 2001, Komarkova et al. 1988b, LANDFIRE 2007a, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Mote et al. 2014, Muldavin et al. 1996, Nachlinger et al. 2001, Neely et al. 2001, Shafer et al. 2014, Steele et al. 1983, Steinberg 2002e, Stevens-Rumann et al. 2017, Tuhy et al. 2002, Westerling et al. 2006, Youngblood and Mauk 1985, Zouhar 2001a

CES306.825 Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland

Figure 27. Photo of Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland. Photo credit: U.S. Forest Service.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: These are mixed conifer forests of the Rocky Mountains west into the ranges of the Great Basin, occurring predominantly in cool ravines and on north-facing slopes. Elevations range from 1200 to 3300 m. Occurrences of this system are found on cooler and more mesic sites than Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (CES306.823). Such sites include lower and middle slopes of ravines, along stream terraces, moist, concave topographic positions and north- and east-facing slopes which burn somewhat infrequently. *Pseudotsuga menziesii* and *Abies concolor* are most common canopy dominants, but *Picea engelmannii, Picea pungens*, or *Pinus ponderosa* may be present. This system includes mixed conifer - *Populus tremuloides* stands. A number of cold-deciduous shrub species can occur, including *Acer glabrum, Acer grandidentatum, Alnus incana, Betula occidentalis, Cornus sericea, Jamesia americana, Physocarpus malvaceus, Robinia neomexicana, Vaccinium membranaceum*, and *Vaccinium myrtillus*. Herbaceous species include *Bromus ciliatus, Carex geyeri, Carex rossii, Carex siccata, Muhlenbergia straminea, Pseudoroegneria spicata, Erigeron eximius, Fragaria virginiana, Luzula parviflora, Osmorhiza berteroi, Packera cardamine, Thalictrum occidentale*, and *Thalictrum fendleri*. Naturally occurring fires are of variable return intervals and mostly light, erratic, and infrequent due to the cool, moist conditions.

Distribution: This system is found in the southern Rocky Mountains of Arizona and New Mexico north and west into the ranges of the Great Basin, Wyoming and southeastern Idaho, occurring predominantly in cool ravines and on north-facing slopes.

Nations: US

States/Provinces: AZ, CO, ID, NM, NV, OR?, UT, WY

CEC Ecoregions: 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, Mojave Basin and Range, Madrean Archipelago, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pseudotsuga menziesii* and *Abies concolor* are most common canopy dominants, but *Picea engelmannii, Picea pungens*, or *Pinus ponderosa* may be present. This system includes mixed conifer - *Populus tremuloides* stands. Several cold-deciduous shrub species can occur, including *Acer glabrum, Acer grandidentatum, Alnus incana, Betula occidentalis, Cornus sericea, Jamesia americana, Physocarpus malvaceus, Robinia neomexicana, Vaccinium membranaceum*, and *Vaccinium myrtillus*. Herbaceous species include *Bromus ciliatus, Carex geyeri, Carex rossii, Carex siccata, Muhlenbergia straminea (= Muhlenbergia virescens), Pseudoroegneria spicata, Erigeron eximius, Fragaria virginiana, Luzula parviflora, Osmorhiza berteroi, Packera cardamine, Thalictrum occidentale*, and *Thalictrum fendleri*.

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.

Forest Patch Disturbance; Species Diversity: Medium
Diversity: medium = 6-15 spp. Tree mortality caused by native insects and disease is an important ecological process that creates a diversity of habitats within forested landscapes that would otherwise have uniform stand structure. Although the dominant trees Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and blue spruce (*Picea pungens*) are host to hundreds of fungi and insects, relatively few cause significant mortality in healthy mature trees, while many others weaken trees and make them vulnerable so that they can blow down and create forest gaps. These gaps allow more light to penetrate the tree canopy increasing production of shrubby and herbaceous understory, creating places for stand regeneration, and accelerating succession (Amman 1977, Anderson 2003b).

Insects: Bark beetles: Douglas-fir beetle (*Dendroctonus pseudotsugae*), pine engraver (*Ips pini*), fir engraver beetle (*Scolytus ventralis*) and spruce beetle (*Dendroctonus rufipennis*) (spruce beetle), extended outbreaks of defoliators such as western spruce budworm (*Choristoneura occidentalis*) (Burns and Honkala 1990a, Pavek 1993d, Zouhar 2001a, Steinberg 2002e).

Fungi: Root and butt rots such as *Phellinus* root rot (*Phellinus weirii*) and *Armillaria* root disease (*Armillaria ostoyae, Armillaria mellea*), red ring rot (*Phellinus pini*), velvet top fungus (*Haeolus schweinitzii*), Yellow cap fungus (*Pholiota limonella*), Indian paint fungus (*Echindontium tinctorium*), and Quinine conk (*Fomitopsis officinialis*) (Burns and Honkala 1990a, Pavek 1993d, Zouhar 2001a, Steinberg 2002e).

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.

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 forest and woodland type.

Environment: This system includes conifer, mixed conifer, and some deciduous montane forests of the southern Rocky Mountains west into the ranges of the Great Basin. Stands occur predominantly in cool ravines and on north-facing slopes with elevations from 1200 to 3300 m. Occurrences of this system are found on cooler and more mesic sites than those in Southern Rocky Mountain White Fir - Douglas-fir Dry Forest Group (G226). Such sites include lower and middle slopes of ravines, along stream terraces, moist, concave topographic positions, and north- and east-facing slopes. Naturally occurring fires are of variable return intervals and mostly light, erratic, and infrequent due to the cool, moist conditions.

Key Processes and Interactions: Fire is the primary disturbance although insects can also play a major role especially in tree-gap dynamics. Fire frequencies are variable with a mixed-severity fire regime in the relatively cool/moist environments where this system occurs. In the absence of stand-replacing disturbance such as fire, this mesic mixed conifer and aspen forest system will slowly convert to forests dominated by more shade-tolerant trees such as *Picea pungens* and *Abies concolor*. However, these forests are linked to smaller, gap-forming disturbances, such as mixed-severity fire or windthrow facilitated by insect outbreaks and disease. These gaps allow regeneration of *Populus tremuloides* and other less shade-tolerant species such as *Pinus ponderosa* and *Pseudotsuga menziesii* and limits the abundances of *Abies concolor* (Mueggler and Campbell 1986, Mueggler 1988).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2810520). These are summarized as:

A) Early Development 1 All Structures (10% of type in this stage): Post-lethal fire vegetation will depend on what was on site before it burned. Aspen may or may not be present, depending on what was present prior to the fire or other replacement disturbance. The site will start as grass/forb/shrub; aspen may also be present. Fire will maintain or prolong this stage. Conifers may be present. Any surviving conifers will be seed source. This class may look like a pure aspen stand from above.

B) Mid Development 1 Closed (tree-dominated - 40% of type in this stage): Tree cover is 41-100%. If present, aspen will be over 10 feet tall and very dense. Seedling-medium-sized conifers can be found mixed with aspen, if present. Understory may include mountain snowberry, common juniper, wild rose, and many species of grasses and forbs.

C) Mid Development 1 Open (tree-dominated - 25% of type in this stage): Tree cover is 11-40%. If present, aspen will be over 10 feet tall and patchy. Seedling-medium-sized conifers can be found mixed with aspen, if present. Understory may include mountain snowberry, common juniper, wild rose, and many species of grasses and forbs. Canopy cover is low.

D) Late Development 1 Open (tree-dominated - 10% of type in this stage): Tree cover is 11-40%. Aspen will be rare and mid-level. Understory will be sparse.

E) Late Development 1 Closed (tree-dominated - 15% of type in this stage): Tree cover is 41-100%. Dense conifer stand. Blue spruce and subalpine fir can come in. Aspen present in small amounts. Lots of dead and downed material. Understory possibly depauperate.

Fire is the primary disturbance although insects can also play a major role. Fire frequencies are variable and the cool/moist conditions support a mixed fire regime. Mixed-severity fires occurred every 6-60 years. Lethal fires are usually at longer intervals, 100+ years (LANDFIRE 2007a, BpS 2810520).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. Biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Threats and stressors to this forest and woodland system include altered fire regime, altered stand structure from fragmentation due to roads, logging, mining, or other human disturbances (CNHP 2010). These disturbances can cause significant soil loss/erosion and negatively impact the water quality within the immediate watershed (CNHP 2010). Invasive exotic species can become abundant in disturbed areas and alter floristic composition. Direct and indirect effects of climate change may alter dynamics of indigenous insects such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) and spruce beetle (*Dendroctonus rufipennis*) (spruce beetle) causing a buildup in population size (with less extreme winters) leading to large outbreaks that can cause high mortality in mature trees.

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.

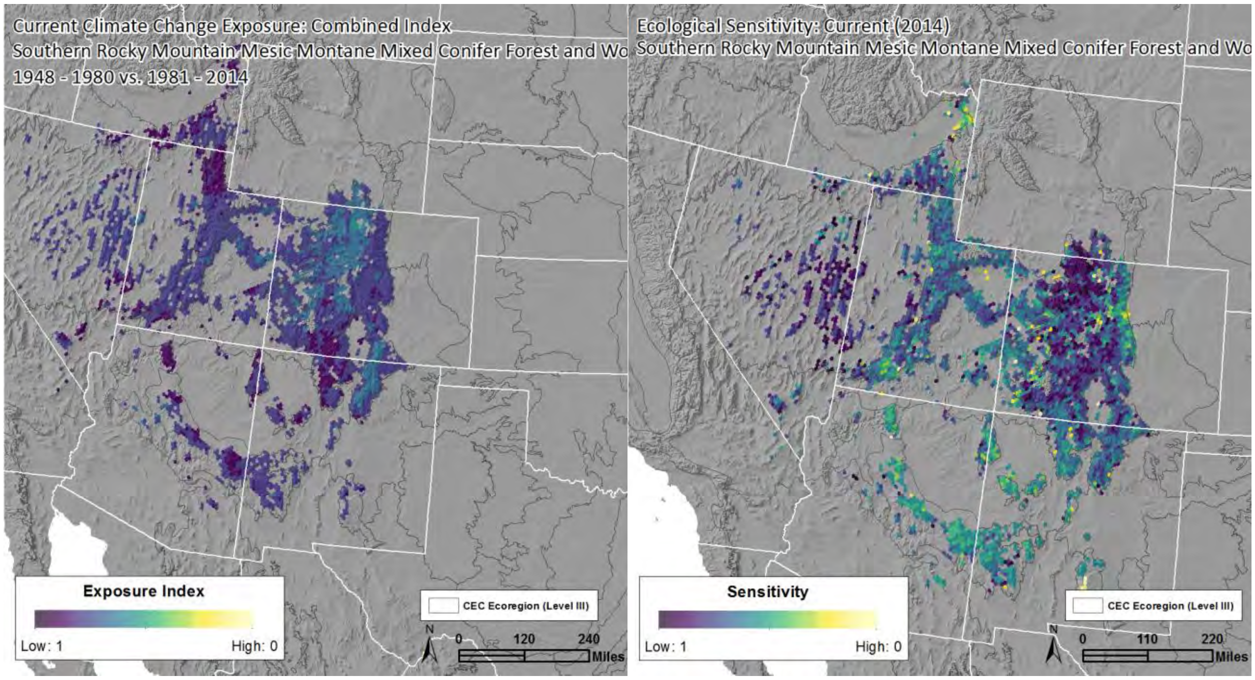

Figure 28. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 27. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland 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. 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	Wasatch & Uinta Mountains	Arizona-New Mexico Mountains	Central Basin & Range	Colorado Plateaus	Northern Basin & Range	Mojave Basin & Range	Madrean Archipelago
	Potential square miles within ecoregion	1,874	640	444	232	139	77	37	20
Contributions to Relative Vulnerability by Factor									
Vulnerability from **Exposure (2014)**		**Mod** 0.72	**Low** 0.78	**Low** 0.79	**Mod** 0.74	**Mod** 0.74	**Low** 0.79	**Low** 0.80	**Low** 0.79
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.82	0.81	0.85	0.97	0.86	0.91	0.72	0.87
	Fire Regime Departure	0.54	0.48	0.20	0.54	0.49	0.51	0.55	0.20
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.76	0.85	0.80	0.89	0.87	0.83	0.95	0.88
	Sensitivity Average	**0.71**	**0.71**	**0.62**	**0.80**	**0.74**	**0.75**	**0.74**	**0.65**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.60	0.63	0.59	0.72	0.70	0.56	0.72	0.71
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.55**	**0.57**	**0.55**	**0.61**	**0.60**	**0.53**	**0.61**	**0.61**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.63	**Mod** 0.64	**Mod** 0.58	**Mod** 0.70	**Mod** 0.67	**Mod** 0.64	**Mod** 0.67	**Mod** 0.63
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall climate exposure as of 2014 for this widespread forest system was low to moderate. In the Southern Rockies ecoregion comprising approximately half of the range, climate exposure was moderate. In the other seven ecoregions exposure was low or at the low end of moderate.

The annual mean temperature has increased over portions of all ecoregions by approximately 0.6°C. These changes were widespread (40-88%) in the southern portion of the range (Southern Rockies, Arizona-New Mexico Mountains, Central Basin and Range). This increase in annual temperature is reflected by increases in summer temperature of 0.5° to 0.7°C across portions of all eight regions, and was widespread in the Southern Rockies, Colorado Plateau, Mojave and Central Basin and Range, and Arizona-New Mexico Mountains (30-100% affected). However, mean diurnal temperature range decreased by 0.3° to 0.6°C in over 10% of the Colorado Plateau, Central Basin and Range, and Wasatch and Uinta Mountains ecoregions, suggesting that increases in minimum night-time minimum temperature increases are outpacing increases in day-time highs. Increases in annual precipitation of approximately 20% are found across 5-15% of the Southern Rockies and Central Basin and Range ecoregions.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Southwest region along with increasing number and severity of wildfires and insect outbreaks (Garfin et al. 2014). 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 tree recruitment. Without tree recruitment these woodland and forest stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) or mountain pine beetle (*Dendroctonus ponderosae*) causing outbreaks that could severely impact trees regionally (Burns and Honkala 1990a, Zouhar 2001a, Steinberg 2002e, Howard 2003b, c).

Many stands of this ecological system woodland occur in montane of taller ranges, so it may be possible for the species of this system to move up into the upper montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* and *Pseudotsuga menziesii* frequently live more than 300-500 years and are known to live over 700 years, so they may be able to survive as relicts for centuries without regeneration (Zouhar 2001a, Steinberg 2002e, Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across the potential range of this forest type. Sensitivity was moderate in seven of eight ecoregions, and low within the Central Basin and Range. Sensitivity is largely associated with fire regime departure for this type.

Contributions to sensitivity from landscape condition are low in ecoregions, reflecting relatively limited fragmentation from development or road networks within the range of this montane woodland. Fire regime departure was high or very high in four ecoregions and at the high end of moderate in the other four ecoregions. This reflects fire suppression practices across much of the region which have led to increased tree densities and understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was low across all ecoregions. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease.

Fire suppression has resulted in changes to the structure of these woodlands, which has increased the 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 system, with scores in the moderate range across all ecoregions. This moderate adaptive capacity is related to moderate scores for both topoclimatic variability and functional species group diversity.

These woodlands are characterized by a moderate level of topoclimate variability associated with the varied slopes, plateaus, mesas and canyons of this generally mid-elevation forest type. Local climates vary somewhat within short distances, providing some options for species to move across these landscapes to adapt to changing climate conditions.

In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity related to species associated with patch disturbances, providing for a range of successional stages within stands. 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 forest type scores in the moderate range of vulnerability for all ecoregions. This is primarily due to moderate to high contributions to sensitivity from fire regime departure and a moderate level of adaptive capacity. The system occurs in areas of moderate topoclimate variability and is vulnerable to catastrophic fires from increased stand density and understory fuel loads. Many stands occur on mid-elevation slopes, so there may be potential for upslope migration of dominant species. Although insect and disease risk were low for this system, these may be exacerbated by drought and severe fires across the range 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 28. Climate change adaptation strategies relative to vulnerability scores for Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Agree 1982, Alexander et al. 1984a, Alexander et al. 1984b, Alexander et al. 1987, Amman 1977, Anderson 1999a, Anderson 2003b, Boyce 1977, Bunin 1975c, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2002, Comer et al. 2003*, Cooper et al. 1987, Dale et al. 2001, DeVelice and Ludwig 1983c, DeVelice et al. 1986, Dieterich 1979, Eyre 1980, Fitzhugh et al. 1987, Fowells 1965, Garfin et al. 2014, Giese 1975, Graham and Jain 2005, Harvey 1994, Heinze et al. 1962, Hess 1981, Hess and Alexander 1986, Hess and Wasser 1982, Hoffman and Alexander 1980, Hoffman and Alexander 1983, Hopkins 1982, Howard 2003b, Howard 2003c, Komarkova et al. 1988b, LANDFIRE 2007a, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Moir and Ludwig 1979, Mueggler 1988, Mueggler and Campbell 1986, Nachlinger et al. 2001, Neely et al. 2001, Parson and DeBenedetti 1979, Pavek 1993d, Pfister 1972, Steinberg 2002e, Stevens-Rumann et al. 2017, Tuhy et al. 2002, Westerling et al. 2006, Youngblood and Mauk 1985, Zouhar 2001a

CES306.649 Southern Rocky Mountain Ponderosa Pine Savanna

Figure 29. Photo of Southern Rocky Mountain Ponderosa Pine Savanna. Photo credit: Patrick Comer.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is found predominantly in the Colorado Plateau region, west into scattered locations in the Great Basin, and north along the eastern front of the southern Rocky Mountains into southeastern Wyoming. These savannas occur at the lower treeline/ecotone between grassland/or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 1900 m in central and northern Wyoming to 2800 m in the New Mexico mountains to well over 2700 m on the higher plateaus of the Southwest. It is found on rolling plains, plateaus, or dry slopes usually on more southerly aspects. This system is best described as a savanna that has widely spaced (<25% tree canopy cover) (>150 years old) *Pinus ponderosa* (primarily *var. scopulorum* and *var. brachyptera*) as the predominant conifer. It is maintained by a fire regime of frequent, low-intensity surface fires. A healthy occurrence often consists of open and park-like stands dominated by *Pinus ponderosa*. Understory vegetation in the true savanna occurrences is predominantly fire-resistant grasses and forbs that resprout following surface fires; shrubs, understory trees and downed logs are uncommon. Important and often dominant species include *Festuca arizonica, Koeleria macrantha, Muhlenbergia montana, Muhlenbergia straminea*, and *Pseudoroegneria spicata*. Other important grasses, such as *Andropogon gerardii, Bouteloua gracilis, Elymus elymoides, Festuca idahoensis, Piptatheropsis micrantha*, and *Schizachyrium scoparium*, dominate less frequently. A century of anthropogenic disturbance and fire suppression has resulted in a higher density of *Pinus ponderosa* trees, altering the fire regime and species composition. Presently, many stands contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. Northern Rocky Mountain Ponderosa Pine Woodland and Savanna (CES306.030) in the eastern Cascades, Okanogan, and Northern Rockies regions receives winter and spring rains, and thus has a greater spring "green-up" than the drier woodlands in the Central Rockies.

Distribution: This ecological system is found predominantly in the Colorado Plateau region, west into scattered locations of the Great Basin, and north along the eastern front of the Rocky Mountains of Colorado and Wyoming. Pine woodlands and savannas of the Black Hills and central Montana are now included in Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna (CES303.650), as are woodlands and savannas in Nebraska and northeastern Colorado.

Nations: US

States/Provinces: AZ, CO, NM, NV, 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, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system is best described as a savanna that has widely spaced (<25% tree canopy cover) (>150 years old) *Pinus ponderosa* (primarily *var. scopulorum* and *var. brachyptera*) as the predominant conifer. It is maintained by a fire regime of frequent, low-intensity surface fires. A healthy occurrence often consists of open and park-like stands dominated by *Pinus ponderosa*. Understory vegetation in the true savanna occurrences is predominantly fire-resistant grasses and forbs that resprout following surface fires; shrubs, understory trees and downed logs are uncommon. Important and often dominant species include *Festuca arizonica, Koeleria macrantha, Muhlenbergia montana, Muhlenbergia straminea (= Muhlenbergia virescens)*, and *Pseudoroegneria spicata*. Other important grasses, such as *Andropogon gerardii, Bouteloua gracilis, Elymus elymoides, Festuca idahoensis, Piptatheropsis micrantha (= Piptatherum micranthum)*, and *Schizachyrium scoparium*, dominate less frequently. A century of anthropogenic disturbance and fire suppression has resulted in a higher density of *Pinus ponderosa* trees, altering the fire regime and species composition.

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.

Nitrogen Fixation; Species Diversity: Medium
*Although rangewide grass cover and grass species diversity is high in savanna systems, local diversity is low to moderate in these dry temperate savannas.

Diversity: medium = 11-20 spp. Ponderosa pine woodlands occur in semi-arid to dry-continental climates, typically on rocky substrates with limited soil development and depth. Soil nutrients such as nitrogen are a significant constraint on plant growth in many of these sites. Possible nitrogen-fixing plants include species of Fabaceae (including of *Astragalus, Lupinus*, and *Oxytropis*); Polygonaceae (*Eriogonum*); Rhamnaceae (*Ceanothus*); Rosaceae (*Amelanchier, Cercocarpus, Potentilla, Purshia*); many species of Poaceae. Moderately diverse grasses dominate the herbaceous layer (e.g., *Achnatherum scribneri, Andropogon gerardii, Blepharoneuron tricholepis, Bouteloua curtipendula, Bouteloua gracilis, Danthonia parryi, Elymus elymoides, Festuca arizonica, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Muhlenbergia montana, Nassella viridula,* *Pascopyrum smithii, Piptatherum* spp., *Poa fendleriana, Pseudoroegneria spicata*) and some Brassicaceae species. Diversity of cyanobacteria and cyanolichens is low in savannas because of high cover of grasses.

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: Medium
Diversity: medium = 11-20 spp. Southern Rocky Mountain Ponderosa Pine Savanna 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 lobatum, Achnatherum scribneri, Bromus marginatus, Carex geophila, Carex inops ssp. heliophila, Carex rossii, Elymus elymoides, Elymus lanceolatus, Elymus trachycaulus, Danthonia parryi, Festuca arizonica, Festuca idahoensis, Hesperostipa comata, Koeleria macrantha, Nassella viridula, Pascopyrum smithii, Poa fendleriana, Piptochaetium fimbriatum, Piptochaetium pringlei*, and *Pseudoroegneria spicata*.

Warm-season graminoids: *Andropogon gerardii, Aristida purpurea, Blepharoneuron tricholepis, Bothriochloa barbinodis, Bouteloua curtipendula, Bouteloua gracilis*, Bouteloua hirsuta, *Koeleria macrantha, Muhlenbergia dubia, Muhlenbergia emersleyi, Muhlenbergia montana, Muhlenbergia straminea, Schizachyrium scoparium*, and *Sporobolus cryptandrus*.

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 ponderosa pine savanna type.

Environment: These savannas occur at the lower elevation ecotone between pinyon conifer woodlands, grassland/or shrubland and upper elevation, more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 1900 m in central and northern Wyoming to 2800 m in the New Mexico mountains to well over 2700 m on the higher plateaus of the Southwest. It is found on rolling plains, plateaus, or dry slopes usually on more southerly aspects; however, it can occur on all slopes and aspects. Stands occur on soils derived from igneous, metamorphic, and sedimentary material, including basalt, andesite, intrusive granitoids and porphyrites, and tuffs (Youngblood and Mauk 1985). Characteristic soil features include good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, and periods of drought during the growing season. Surface textures are highly variable in this ecological system ranging from sand to loam and silt loam. Exposed rock and bare soil consistently occur to some degree in all the associations. Annual precipitation is 25-60 cm (8-24 inches), mostly through winter storms and some monsoonal summer rains. Typically, a seasonal drought period occurs throughout this system distribution as well.

Key Processes and Interactions: *Pinus ponderosa* is a drought-resistant, typically open-grown conifer, which usually occurs at lower treeline in the major ranges of the western United States. Mature trees have thick bark that protects the cambium layer from fire. Historically, fires and drought were influential in maintaining open-canopy conditions in these woodlands. Low-intensity surface fire would burn through these stands every 5-15 year, killing young trees, but not the fire-resistant mature ponderosa pine trees or grass understory maintaining an open park-like stand (Harrington and Sackett 1992, Mehl 1992, Swetnam and Baisan 1996). Infrequent stand-replacement fire on the order of a few hundred years (300-500 years) is possible (LANDFIRE 2007a). Drought and other weather events (e.g., blowdown), parasites and disease may play a minor role, and have very long rotations (LANDFIRE 2007a). Impacts from insects such as mountain pine beetles (*Dendroctonus ponderosae*) may be significant during outbreaks, but infrequent in occurrence (LANDFIRE 2007a). Beetles attack less vigorously growing trees, e.g., old, crowded, diseased, damaged, or growing on poor sites) especially during droughts (Leatherman et al. 2013). Winter mortality of beetles is a significant factor; however, a severe freeze of at least -30 degrees F is necessary for at least five days during midwinter (Leatherman et al. 2013).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2811170). These are summarized as:

A) Early Development 1 All Structures (Shrub-dominated - 10% of type in this stage): Bunchgrass-dominated (0-49 years). Some ponderosa pine individuals also becoming established.

B) Mid Development 1 Closed (tree-dominated - 5% of type in this stage): Small and medium-sized ponderosa pine (50-149 years), still with high bunchgrass cover. Closed canopy defined as >50%.

C) Mid Development 1 Open (tree-dominated - 20% of type in this stage): Small and medium-sized ponderosa pine (50-149 years), with moderate bunchgrass cover. Open canopy defined as 10-49%.

D) Late Development 1 Open (conifer-dominated - 60% of type in this stage): Large and very large old-growth ponderosa pine, with medium to high cover of bunchgrasses. Old-growth attributes prominent, including downed wood, snags and diseased trees.

E) Late Development 1 Open (conifer-dominated - 5% of type in this stage): Large and very large old-growth ponderosa pine, with medium cover of bunchgrasses. Old-growth attributes prominent, including downed wood, snags and diseased trees.

Mean composite surface fire intervals have been found to be 5-15 years (Swetnam and Baisan 1996a). Infrequent stand-replacement fire on the order of a few hundred years possible (300-500 years?). Drought and other weather events (e.g., blowdown), parasites and disease may play a minor role, and have very long rotations. Insects may be a significant, but infrequent occurrence (LANDFIRE 2007a, BpS 2811170).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: With settlement and a century of anthropogenic disturbance and fire suppression, stands now have a higher density of *Pinus ponderosa* trees, altering the fire regime and species composition. Presently, many stands contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. These altered structures have affected fuel loads and fire regimes. Presettlement fire regimes were primarily frequent (5- to 15-year return intervals), low-intensity ground fires triggered by lightning strikes or deliberately set by Native Americans. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999).

Conversion of this type has commonly come from urban and exurban development especially along the Front Range, water developments and reservoirs. With long-term fire suppression, stands have converted through succession to Southern Rocky Mountain Ponderosa Pine Woodland (CES306.648) or Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (CES306.823). Restoration to savanna is difficult or impossible when adjacent to housing development.

Common stressors and threats include fragmentation from housing and water developments, altered fire regime from fire suppression and indirectly from livestock grazing and fragmentation, and introduction of invasive non-native species (CNHP 2010b). Potential climate change effects could include a change in the current extent of this ecosystem with tree mortality in lower elevation stands converting to Western Great Plains Foothill and Piedmont Grassland (CES303.817), 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 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.

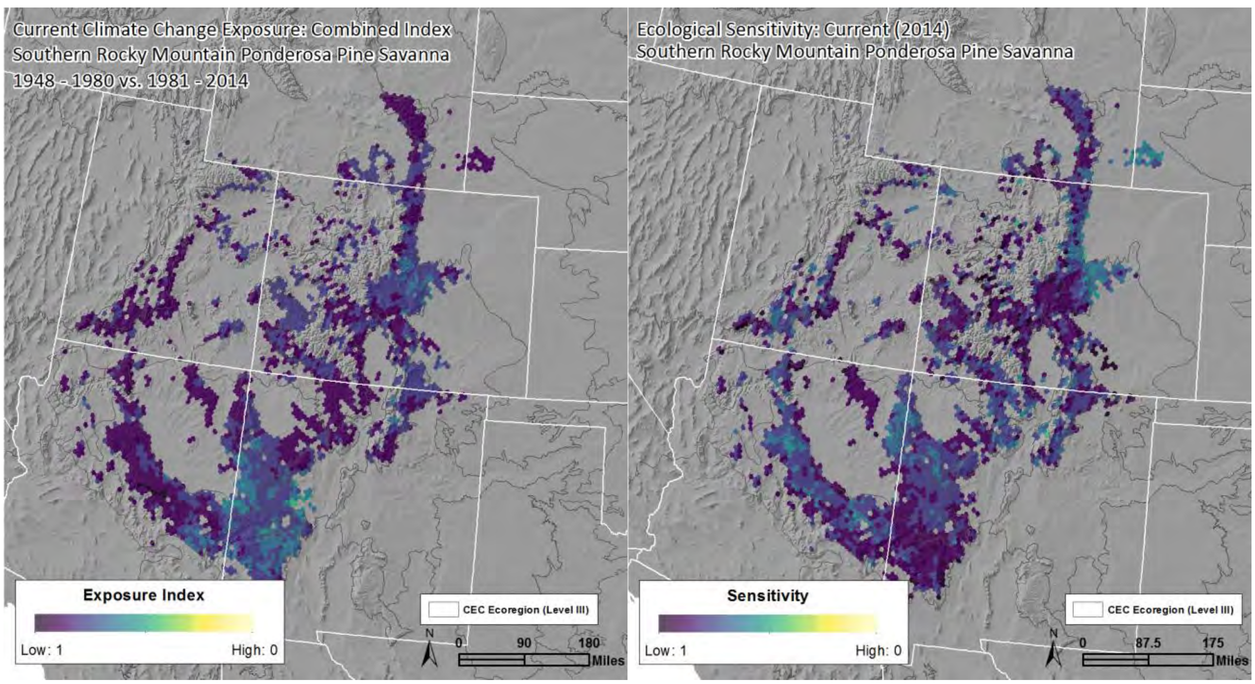

Figure 30. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Ponderosa Pine Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 29. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Ponderosa Pine Savanna 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 (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Arizona-New Mexico Mountains	Arizona-New Mexico Plateau	Southern Rockies	Wasatch & Uinta Mountains	Colorado Plateaus
	Potential square miles within ecoregion	2,762	1,562	552	51	46
Contributions to Relative Vulnerability by Factor						
Vulnerability from **Exposure (2014)**		**Low** 0.76	**Low** 0.76	**Low** 0.78	**Low** 0.81	**Low** 0.80
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.79	0.78	0.67	0.49	0.70
	Fire Regime Departure	0.36	0.28	0.67	0.49	0.54
	Invasive Annual Grasses	1.00	1.00	1.00	1.00	1.00
	Forest Insect & Disease	0.91	0.90	0.93	0.97	0.94
	Sensitivity Average	**0.77**	**0.74**	**0.82**	**0.74**	**0.79**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.31	0.28	0.36	0.31	0.33
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50
	Adaptive Capacity Average	**0.41**	**0.39**	**0.43**	**0.41**	**0.42**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.59	**Mod** 0.57	**Mod** 0.62	**Mod** 0.57	**Mod** 0.61
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this savanna system is low across all five ecoregions where this system occurs. The annual mean temperature has increased by 0.6°C across large portions of all regions. This increase was pervasive in all ecoregions (>80% of each region) except the Southern Rockies where 28% of the region was affected. Annual mean temperature increases were reflected by increases in summer temperatures of 0.6°C affecting all five ecoregions.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Southwest region along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as mountain pine beetle (*Dendroctonus ponderosae*) by increasing the number of generations within a growing season or by allowing a population buildup over several years causing outbreaks that could severely impact trees regionally (Burns and Honkala 1990a, Howard 2003b, c).

Many stands of this ecological system woodland occur in montane zone of taller ranges, so it may be possible for the species of this system to move up into the upper montane and lower subalpine zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so stands may be able to survive as relicts for centuries without regeneration (Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is low to the lower range of moderate across all five ecoregions within the range of this savanna type.

Contributions to sensitivity from landscape condition were low or moderate in all ecoregions except the Wasatch and Uinta Mountains, which scored in the highly vulnerable range. Greater sensitivity in this region likely reflects fragmentation from roads and development and a history of grazing in this region. Moderate sensitivity across other ecoregions reflects fragmentation from road networks and development such as along the eastern front of the Rocky Mountains in Colorado.

Fire regime departure was high in the two largest ecoregions (Mountains and Plateaus of Arizona and New Mexico), and moderate or near moderate in the remaining three regions. This reflects fire suppression practices across much of the region leading to higher densities of *Pinus ponderosa* and increased understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was generally low across all ecoregions. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease. Risk from invasive grasses was low across all five ecoregions.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally low across the range of this system, with scores in the low range in all five ecoregions. 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 lower slopes and plateaus characteristic of where this system occurs. There is potential for the species in this system to move upslope into areas of suitable climate and increased topographic variability. In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity of nitrogen fixers 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 savanna system scores in the moderate range of overall climate change vulnerability. This is primarily due to strong contributions from fire regime departure and low adaptive capacity associated with low topoclimate variability. Many stands occur on moderate-elevation slopes, so there may be potential for upslope migration of ponderosa pine. Although insect and disease risks were low for this system, these may be exacerbated by effects of recent severe droughts across the range 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 30. Climate change adaptation strategies relative to vulnerability scores for Southern Rocky Mountain Ponderosa Pine Savanna.

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 and fire breaks. Maintain or restore natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Restore natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Dale et al. 2001, Eyre 1980, Garfin et al. 2014, Graham and Jain 2005, Harrington and Sackett 1992, Harvey 1994, Howard 2003b, Howard 2003c, Johansen and Latta 2003, LANDFIRE 2007a, Leatherman et al. 2013, McKenzie et al. 2004, McKenzie et al. 2008, Mehl 1992, Reid et al. 1999, Smith 2006, Stevens-Rumann et al. 2017, Swetnam and Baisan 1996a, TNC 2013, Youngblood and Mauk 1985

CES306.648 Southern Rocky Mountain Ponderosa Pine Woodland

Figure 31. Photo of Southern Rocky Mountain Ponderosa Pine Woodland. Photo credit: U.S. Forest Service.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This very widespread ecological system is most common throughout the cordillera of the Rocky Mountains, from the Greater Yellowstone region south. It is also found in the Colorado Plateau region, west into scattered locations of the Great Basin. Its easternmost extent in Wyoming is in the Bighorn Mountains. These woodlands occur at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests typically in warm, dry, exposed sites. Elevations range from less than 1900 m in northern Wyoming to 2800 m in the New Mexico mountains. Occurrences are found on all slopes and aspects; however, moderately steep to very steep slopes or ridgetops are most common. This ecological system generally occurs on soils derived from igneous, metamorphic, and sedimentary material, with characteristic features of good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, rockiness, and periods of drought during the growing season. Northern Rocky Mountain Ponderosa Pine Woodland and Savanna (CES306.030) in the eastern Cascades, Okanogan, and Northern Rockies regions receives winter and spring rains, and thus has a greater spring "green-up" than the drier woodlands in the Central Rockies. *Pinus ponderosa* (primarily *var. scopulorum* and *var. brachyptera*) is the predominant conifer; *Pseudotsuga menziesii, Pinus edulis, Pinus contorta, Populus tremuloides*, and *Juniperus* spp. may be present in the tree canopy. The understory is usually shrubby, with *Artemisia nova, Artemisia tridentata, Arctostaphylos patula, Arctostaphylos uva-ursi, Cercocarpus montanus, Purshia stansburiana, Purshia tridentata, Quercus gambelii, Symphoricarpos* spp., *Prunus virginiana, Amelanchier alnifolia* (less so in Montana), and *Rosa* spp. common species. *Pseudoroegneria spicata, Pascopyrum smithii*, and species of *Hesperostipa, Achnatherum, Festuca, Muhlenbergia*, and *Bouteloua* are some of the common grasses. Mixed fire regimes and surface fires of variable return intervals maintain these woodlands, depending on climate, degree of soil development, and understory density.

Distribution: This system is found throughout the southern Rocky Mountains and extends into northern Utah and western Wyoming, in the Uinta and Wasatch ranges, and south into New Mexico. It also occurs in northern Arizona on the Mogollon Rim, north on the high plateaus and ranges in the Colorado Plateau region and scattered locations of the Great Basin.

Nations: US

States/Provinces: AZ, CO, ID?, NM, NV, UT, WY

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

Primary Concept Source: M.S. Reid

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pinus ponderosa* (primarily *var. scopulorum* and *var. brachyptera*) is the predominant conifer; *Pseudotsuga menziesii, Pinus edulis, Pinus contorta, Populus tremuloides*, and *Juniperus* spp. may be present in the tree canopy. The understory is usually shrubby, with *Artemisia nova, Artemisia tridentata, Arctostaphylos patula, Arctostaphylos uva-ursi, Cercocarpus montanus, Purshia stansburiana, Purshia tridentata, Quercus gambelii, Symphoricarpos* spp., *Prunus virginiana, Amelanchier alnifolia* (less so in Montana), and *Rosa* spp. common species. *Pseudoroegneria spicata, Pascopyrum smithii*, and species of *Hesperostipa, Achnatherum, Festuca, Muhlenbergia*, and *Bouteloua* are some of the common grasses.

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.

Nitrogen Fixation; Species Diversity: Medium
*Although rangewide grass diversity is high, locally diversity is low to moderate in these dry temperate woodlands.

Diversity: medium = 11-20 spp. Ponderosa pine woodlands occur in semi-arid to dry temperate, continental climates, typically on rocky substrates with limited soil development and depth. Soil nutrients such as nitrogen are a significant constraint on plant growth in many of these sites. Possible nitrogen-fixing plants include species of Fabaceae (including species of *Astragalus, Lupinus*, and *Oxytropis*); Polygonaceae (*Eriogonum*); Rhamnaceae (*Ceanothus*); Rosaceae (*Amelanchier, Cercocarpus, Potentilla, Purshia*); many species of Poaceae (including *Achnatherum hymenoides, Blepharoneuron tricholepis, Bouteloua curtipendula, Bouteloua gracilis, Bromus anomalus, Bromus porteri, Danthonia spicata, Elymus albicans, Elymus elymoides, Festuca arizonica, Festuca idahoensis, Festuca thurberi, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus salinus, Muhlenbergia longiligula, Muhlenbergia montana, Muhlenbergia straminea, Pascopyrum smithii, Piptatheropsis micrantha, Poa fendleriana, Poa secunda, Pseudoroegneria spicata*, and *Schizachyrium scoparium*); and some Brassicaceae species. Diversity of cyanobacteria and cyanolichens is low in savannas and temperate woodlands but may be higher in semi-arid woodland stands.

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: Medium
Diversity: medium = 11-20 spp. Southern Rocky Mountain Ponderosa Pine Woodland is adapted to a bimodal precipitation pattern with both summer, warm season and cool-season winter precipitation. Although this system has high graminoid diversity rangewide, locally stands have a low to moderately diverse mixture of warm and cool-season graminoids such as:

Cool-season graminoids: *Achnatherum hymenoides, Bromus anomalus, Bromus porteri, Carex geophila, Carex geyeri, Carex inops ssp. heliophila, Carex rossii, Carex siccata, Danthonia spicata, Elymus albicans, Elymus elymoides, Festuca arizonica, Festuca idahoensis, Festuca thurberi, Hesperostipa comata, Koeleria macrantha, Leucopoa kingii, Leymus salinus, Pascopyrum smithii, Piptatheropsis micrantha, Poa fendleriana, Poa secunda* and *Pseudoroegneria spicata*.

Warm-season graminoids: *Andropogon gerardii, Andropogon hallii, Blepharoneuron tricholepis, Bouteloua curtipendula, Bouteloua gracilis, Muhlenbergia longiligula, Muhlenbergia montana, Muhlenbergia straminea, Schizachyrium scoparium*, and *Sporobolus cryptandrus*.

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 ponderosa pine woodland type.

Environment: This ecological system within the region occurs in the southern Rocky Mountains at the lower treeline/ecotone between grassland or shrubland and more mesic coniferous forests. Stands are typically found in warm, dry, exposed sites at elevations ranging from 1980-2800 m (6500-9200 feet).

Climate: Climate is temperate with cold winter and warm summers. Precipitation generally contributes 25-60 cm annually to this system, mostly through winter snow and some monsoonal summer rains. Typically, a seasonal drought period occurs throughout this system as well.

Physiography/Landform: Stands can occur on all slopes and aspects; however, it commonly occurs on moderately steep to very steep slopes or ridgetops in foothills and lower montane slopes.

Soil/substrate/hydrology: Soils are variable. This ecological system generally occurs on soils derived from igneous, metamorphic, and sedimentary material, including basalt, basaltic, andesitic flows, intrusive granitoids and porphyrites, and tuffs (Youngblood and Mauk 1985). Characteristic soil features include good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, and periods of drought during the growing season. Some occurrences may occur as edaphic climax communities on very skeletal, infertile, and/or excessively drained soils, such as pumice, cinder or lava fields, and scree slopes. Surface textures are highly variable in this ecological system ranging from sand to loam and silt loam. Exposed rock and bare soil consistently occur to some degree in all the associations. *Pinus ponderosa / Arctostaphylos patula* represents the extreme with typically a high percentage of rock and bare soil present.

Fire plays an important role in maintaining the characteristics of these open-canopy woodlands. However, soil infertility and drought may contribute significantly in some areas as well.

Key Processes and Interactions: *Pinus ponderosa* is a drought-resistant, shade-intolerant conifer which usually occurs at lower treeline in the major ranges of the western United States. Historically, surface fires and drought were influential in maintaining open-canopy conditions in these woodlands. With settlement and subsequent fire suppression, occurrences have become denser. Presently, many occurrences contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or

Abies spp., as well as younger cohorts of *Pinus ponderosa*. These altered structures have affected fuel loads and alter fire regimes. Presettlement fire regimes were primarily frequent (5- to 15-year return intervals), low-intensity surface fires triggered by lightning strikes or deliberately set fires by Native Americans. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999).

Establishment is erratic and believed to be linked to periods of adequate soil moisture and good seed crops, as well as fire frequencies, which allow seedlings to reach sapling size. Longer fire-return intervals have resulted in many occurrences having dense subcanopies of overstocked and unhealthy young *Pinus ponderosa* (Reid et al. 1999). Mehl (1992) states the following: "Where fire has been present, occurrences will be climax and contain groups of large, old trees with little understory vegetation or down woody material and few occurring dead trees. The age difference of the groups of trees would be large. Where fire is less frequent, there will also be smaller size trees in the understory giving the occurrence some structure with various canopy layers. Dead, down material will be present in varying amounts along with some occurring dead trees. In both cases the large old trees will have irregular open, large branched crowns. The bark will be lighter in color, almost yellow, thick and some will like have basal fire scars."

Grace's warbler, pygmy nuthatch, and flammulated owl are indicators of a healthy ponderosa pine woodland. All of these birds prefer mature trees in an open woodland setting (Winn 1998, Jones 1998, Levad 1998 as cited in Rondeau 2001).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2810540). These are summarized as:

A) Early Development 1 All Structures (pole-sized tree-dominated - 10% of type in this stage): Openings with up to 10% cover by overstory dominated by ponderosa pine and sometimes Douglas-fir. Some openings may persist.

B) Mid Development 1 Closed (tree-dominated - 10% of type in this stage): Greater than 50% canopy cover in the northern Front Range (above c. 6500 feet) and >30% canopy cover in the southern Front Range.

C) Mid Development 1 Open (tree-dominated - 25% of type in this stage): Greater than 50% canopy cover in the northern Front Range (above c. 6500 feet) and <30% canopy cover in the southern Front Range

D) Late Development 1 Open (tree-dominated - 40% of type in this stage): Less than 50% canopy cover in the northern Front Range (above c. 6500 feet) and <30% canopy cover in the southern Front Range.

E) Late Development 1 Closed (tree-dominated - 15% of type in this stage): Less than 50% canopy cover in the northern Front Range (above c. 6500 feet) and <30% canopy cover in the southern Front Range.

Mixed-severity fire regime - typically an average fire frequency ranges from 40-100 years (5-100 ha) (Kaufmann et al. 2000, Veblen et al. 2000, Ehle and Baker 2003, Sherriff 2004). These fires range from low-severity to high-severity fires, and the forest structure was shaped by the pattern of fire at a landscape scale. Drought and other weather events (e.g., blowdown); insects such as mountain pine beetle, Douglas-fir beetle and western spruce budworm (Swetnam and Lynch 1993, Negron 1998, 2004); and pathogens such as dwarf mistletoe (Hawksworth 1961) also play important roles in this type.

Replacement-fire rotation uncertain, and this affects the amount of forest in each class. Cheesman Lake - fire rotation (all fires 75 years) and stand-replacement (460 years) estimation (LANDFIRE 2007a, BpS 2810540).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: With settlement and a century of anthropogenic disturbance and fire suppression, stands now have a higher density of *Pinus ponderosa* trees, altering the fire regime and species composition. Presently, many stands contain understories of more shade-tolerant species, such as *Pseudotsuga menziesii* and/or *Abies* spp., as well as younger cohorts of *Pinus ponderosa*. These altered structures have affected fuel loads and fire regimes. Presettlement fire regimes were primarily frequent (5- to 15-year return intervals), low-intensity ground fires triggered by lightning strikes or deliberately set by Native Americans. With fire suppression and increased fuel loads, fire regimes are now less frequent and often become intense crown fires, which can kill mature *Pinus ponderosa* (Reid et al. 1999).

Conversion of this type has commonly come from urban and exurban development, especially along the Front Range, water developments and reservoirs. With long-term fire suppression, stands have converted through succession to Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (CES306.823). Restoration to open woodland is difficult or impossible when adjacent to housing development. Common stressors and threats include fragmentation from housing and water developments, altered fire regime from fire suppression and indirectly from livestock grazing and fragmentation, and introduction of invasive non-native species (CNHP 2010).

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.

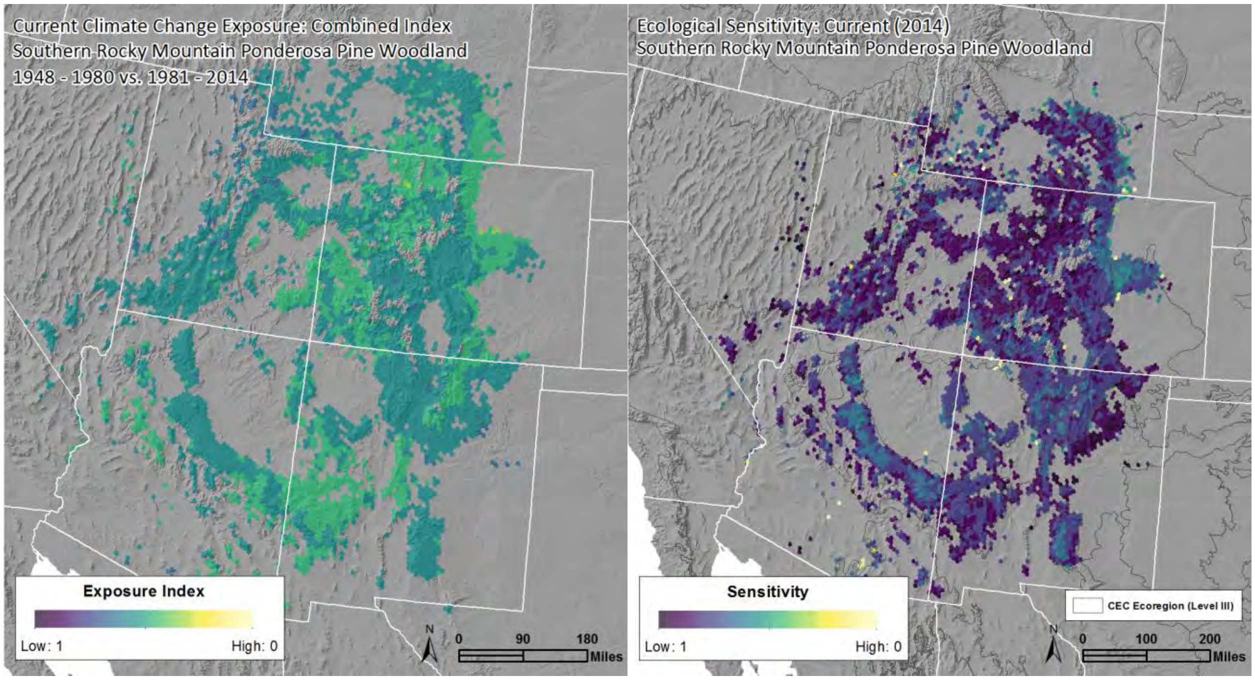

Figure 32. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Ponderosa Pine Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 31. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Ponderosa Pine Woodland 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 (scores closer to 0) indicating greatest vulnerability and dark purple (scores closer to 1) the least.

	CEC Ecoregion	Arizona-New Mexico Mountains	Southern Rockies	Colorado Plateaus	Arizona-New Mexico Plateau	Wasatch & Uinta Mountains	South-western Tablelands	High Plains	Mojave Basin & Range	Madrean Archipelago	Central Basin & Range	Wyoming Basin
	Potential square miles within ecoregion	7,342	5,162	916	542	484	333	80	48	43	25	24
Contributions to Relative Vulnerability by Factor												
Vulnerability from **Exposure (2014)**		**Mod** 0.51	**Mod** 0.51	**Mod** 0.51	**Mod** 0.52	**Mod** 0.53	**Mod** 0.51	**High** 0.47	**Mod** 0.54	**High** 0.49	**Mod** 0.54	**Mod** 0.53
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.77	0.73	0.71	0.76	0.61	0.48	0.38	0.75	0.86	0.81	0.69
	Fire Regime Departure	0.23	0.41	0.55	0.27	0.50	0.37	0.41	0.54	0.27	0.49	0.51
	Invasive Annual Grasses	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Forest Insect & Disease	0.86	0.86	0.93	0.86	0.95	0.89	0.98	0.92	0.95	0.99	0.99
	Sensitivity Average	**0.72**	**0.75**	**0.80**	**0.72**	**0.76**	**0.68**	**0.69**	**0.80**	**0.77**	**0.82**	**0.79**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.38	0.42	0.40	0.33	0.43	0.31	0.30	0.65	0.55	0.38	0.33
	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**	**0.46**	**0.45**	**0.42**	**0.47**	**0.40**	**0.40**	**0.58**	**0.52**	**0.44**	**0.42**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.58	**Mod** 0.60	**Mod** 0.62	**Mod** 0.57	**Mod** 0.62	**Mod** 0.54	**Mod** 0.55	**Mod** 0.69	**Mod** 0.65	**Mod** 0.63	**Mod** 0.61
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall exposure as of 2014 for this widespread woodland system was moderate to high. In nine of the 11 ecoregions across its range scores for exposure were near the high end of moderate. In the remaining two ecoregions scores were at the moderate end of high exposure.

The annual mean temperature has increased by 0.6°C across large portions of eight of the ten regions (40-99%). This increase in annual temperature is reflected by increases in summer temperature of 0.5° to 0.7°C across large portions of these same eight regions (25-96%).

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Southwest region along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Garfin et al. 2014). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as such as mountain pine beetle (*Dendroctonus ponderosae*) by increasing the number of generations within a growing season or by allowing a population buildup over several years causing outbreaks that could severely impact trees regionally (Burns and Honkala 1990a, Howard 2003b, c).

Many stands of this ecological system woodland occur in montane zone of taller ranges, so it may be possible for the species of this system to move up into the upper montane and lower subalpine zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so stands may be able to survive as relicts for centuries without regeneration (Howard 2003b, c). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is low (seven ecoregions) to the lower range of moderate (four ecoregions) across the range of this woodland type.

Contributions to sensitivity from landscape condition were variable across ecoregions, ranging from very high to low. This reflects a range of conditions from highly fragmented and degraded in portions of the eastern front of the Rocky Mountains with suburban development (Southwestern Tablelands and High Plains) and higher-elevation montane areas with few road networks such as in the Arizona-New Mexico Mountains ecoregions.

Fire regime departure was generally high (seven ecoregions), with one ecoregion having very high departure (Arizona-New Mexico Mountains), and scores in the high range of moderate in three ecoregions. This reflects fire suppression practices across much of the region leading to higher densities of *Pinus ponderosa* and increased understory fuel loads. These increase vulnerability to catastrophic stand-replacing fires.

Risk from insect and disease was generally low across all ecoregions. Although currently estimated as low, sensitivity from this factor may increase with droughts and severe fires which can affect vulnerability to insects and disease. Risk from invasive grasses was low across all ecoregions.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is generally low across the range of this system, with scores in the low range in nine ecoregions, and at the low end of moderate in the remaining two ecoregions. This low adaptive capacity is related to low or moderate topoclimatic variability across all ecoregions. These reflect a low level of topoclimatic diversity associated with the moderate slopes and plateaus characteristic of where this system occurs. There is potential for the species in this system to move upslope into areas of suitable climate and increased topographic variability. In terms of vulnerability related to functional groups, the system scores moderate in terms of diversity of nitrogen fixers 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 woodland system scores in the moderate range of overall climate change vulnerability. This is primarily due to strong contributions from fire regime departure and low adaptive capacity associated with low topoclimate variability. Many stands occur on moderate-elevation slopes, so there may be potential for upslope migration of ponderosa pine. Although insect and disease risks were low for this system, these may be exacerbated by effects of recent severe droughts across the range 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 32. Climate change adaptation strategies relative to vulnerability scores for Southern Rocky Mountain Ponderosa Pine Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Burns and Honkala 1990a, CNHP 2010, Comer et al. 2002, Comer et al. 2003*, Dale et al. 2001, DeVelice et al. 1986, Ehle and Baker 2003, Eyre 1980, Garfin et al. 2014, Graham and Jain 2005, Harvey 1994, Hawksworth 1961, Hess and Alexander 1986, Hoffman and Alexander 1976, Howard 2003b, Howard 2003c, Johansen and Latta 2003, Kaufmann et al. 2001, Komarkova et al. 1988b, LANDFIRE 2007a, Marriott and Faber-Langendoen 2000, Mauk and Henderson 1984, McKenzie et al. 2004, McKenzie et al. 2008, Mehl 1992, Muldavin et al. 1987, Muldavin et al. 1996, Nachlinger et al. 2001, Neely et al. 2001, Negron 1998, Negron and Popp 2004, Reid et al. 1999, Rondeau 2001, Sherriff 2004, Stevens-Rumann et al. 2017, Swetnam and Lynch 1993, Tuhy et al. 2002, Veblen et al. 2000, Westerling et al. 2006, Youngblood and Mauk 1985

1.B.2.Nc. Western North American Pinyon - Juniper Woodland & Scrub

M026. Intermountain Singleleaf Pinyon - Juniper Woodland

CES304.082 Columbia Plateau Western Juniper Woodland and Savanna

Figure 33. Photo of Columbia Plateau Western Juniper Woodland and Savanna. Photo credit: BLM Juniper Dunes Wilderness, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This woodland system is found along the northern and western margins of the Great Basin, from southwestern Idaho, along the eastern foothills of the Cascades, south to the Modoc Plateau of northeastern California. Elevations range from under 200 m along the Columbia River in central Washington to over 1500 m. Generally, soils are medium-textured, with abundant coarse fragments, and derived from volcanic parent materials. In central Oregon, the center of distribution, all aspects and slope positions occur. Where this system grades into relatively mesic forest or grassland habitats, these woodlands become restricted to rock outcrops or escarpments with excessively drained soils. The vegetation is characterized by an open stand of *Juniperus occidentalis* with an understory of open shrub-steppe (big sage, bitterbrush and/or rabbitbrush) with perennial bunchgrasses representing the dominant vegetation. *Pinus monophylla* is not present in this region, so *Juniperus occidentalis* is typically the only tree species, although *Pinus ponderosa* or *Pinus jeffreyi* may be present in some stands. *Cercocarpus ledifolius* may occasionally codominate. *Artemisia tridentata* is the most common shrub; others are

Purshia tridentata, Ericameria nauseosa, Chrysothamnus viscidiflorus, Ribes cereum, and *Tetradymia* spp. Graminoids include *Carex filifolia, Festuca idahoensis, Poa secunda*, and *Pseudoroegneria spicata*. These woodlands are generally restricted to rocky areas where fire frequency is low. Throughout much of its range, fire exclusion and removal of fine fuels by grazing livestock have reduced fire frequencies and allowed *Juniperus occidentalis* seedlings to colonize adjacent alluvial soils and expand into the sagebrush shrub-steppe and grasslands. *Juniperus occidentalis* savanna may occur on the drier edges of the woodland where trees are intermingling with or invading the surrounding grasslands and where local edaphic or climatic conditions favor grasslands over shrublands.

Distribution: This woodland and savanna system is found along the northern and western margins of the Great Basin, from southwestern Idaho, along the eastern foothills of the Cascades, south to the Modoc Plateau of northeastern California (Tirmenstein 1999h, Sawyer et al. 2009). It also occurs in scattered localities of northern Nevada and south-central Washington. This system is most abundant in central and south-central Oregon (Franklin and Dyrness 1973, Tirmenstein 1999h, Sawyer et al. 2009).

Nations: US

States/Provinces: CA, ID, NV, OR, WA

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Klamath Mountains, Columbia Plateau, Northern Basin and Range, Central Basin and Range, Snake River Plain

Primary Concept Source: M.S. Reid

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pinus monophylla* is not present in this region, so *Juniperus occidentalis* is the only tree species, although *Pinus ponderosa* or *Pinus jeffreyi* may be present in some stands. *Cercocarpus ledifolius* may occasionally codominate. *Artemisia tridentata* is the most common shrub; others are *Purshia tridentata, Ericameria nauseosa, Chrysothamnus viscidiflorus, Ribes cereum*, and *Tetradymia* spp. Graminoids include *Carex filifolia, Festuca idahoensis, Poa secunda*, 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.

Biological Soil Crust; Species Diversity: High
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
Western juniper woodlands occur in semi-arid climates typically on rocky substrates with limited soil depth and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid woodlands typically have low to moderate herbaceous cover and low diversity. Several species of Fabaceae (*Astragalus, Dalea, Lupinus*, and *Vicia*), Rosaceae (*Cercocarpus, Peraphyllum*, and *Purshia*), some species of Poaceae (e.g., *Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana*, and *Pseudoroegneria spicata*), and a few species of Brassicaceae may fix nitrogen in 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).

Perennial Cool-Season Graminoids; Species Diversity: Medium
Achnatherum hymenoides, Achnatherum thurberianum, Carex geyeri, Carex filifolia, Elymus lanceolatus, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Pascopyrum smithii, Poa secunda, and *Pseudoroegneria spicata*.

Seed Dispersal; Species Diversity: High
Birds: At least 12 bird species feed on western juniper fruits and are the primary juniper seed dispersers (Tirmenstein 1999h, Miller et al. 2005). Species include American robin (*Turdus migratorius*), cedar waxwings (*Bombycilla cedrorum*), Mountain bluebirds (*Sialia currucoides*), Steller's jay (*Cyanocitta stelleri*), Townsend's solitare (*Myadestes townsendi*), and western scrub jay (*Aphelocoma californica*) (Schupp et al. 1997, Chambers et al. 1999, Tirmenstein 1999h). Mammals also consume and disperse juniper seeds, including coyote (*Canis latrans*), cottontail rabbits (*Sylvilagus* spp.), and rodents such as deer mouse (*Peromyscus maniculatus*), yellow-pine chipmunk (*Neotamias amoenus (= Tamias amoenus)*), and golden-mantled ground squirrel (*Callospermophilus lateralis (= Spermophilus lateralis)*), which are known to cache seeds for later consumption (Vander Wall 1990, Miller et al. 2005).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this juniper-dominated woodland type.

Environment: This woodland system is found along the northern and western margins of the Great Basin, from southwestern Idaho, along the eastern foothills of the Cascades, south to the Modoc Plateau of northeastern California (Tirmenstein 1999h, Sawyer et al. 2009). Elevations range from under 200 m along the Columbia River in central Washington to over 1500 m. In northwestern California stands range from 700 to 2300 m elevation (Tirmenstein 1999h, Sawyer et al. 2009).

Climate: Throughout the range the climate is cool, semi-arid, continental with 200-360 mm of precipitation annually, with the majority falling in winter. The temperature regime is cool in summer, with a wide range in diurnal temperatures and night frosts occurring most of the year. Summer lightning storms and associated fire are common and are presumably important in structuring the vegetation. (Franklin and Dyrness 1973).

Physiography/landform: In central Oregon, the center of the woodland's range, stands are found on all aspects and slope positions. Where this type grades into relatively mesic forest or grassland habitats, the vegetation becomes restricted to rock outcrops or escarpments with excessively drained soils.

Soils/substrate/hydrology: Juniperus occidentalis stands occur on a wide variety of soil types. Generally, soils are well-drained, shallow and stony with rock outcrops common, but soils may be deeper. They are medium-textured, with abundant coarse fragments, and derived from volcanic parent materials such as basalt, andesite, rhyolite, pumice, volcanic ash, tuff, welded tuff, as well as colluvial, alluvial, or eolian material (Tirmenstein 1999h, LANDFIRE 2007a). Soils derived from pumice ash are the most common edaphic characteristic of this woodland (LANDFIRE 2007a). Origins of the pumice sands are Mount Mazama and Newberry Crater (Miller et al. 1999). In most other areas, it occurs on rimrock, shallow soil scablands and in other isolated pockets.

Key Processes and Interactions: *Juniperus occidentalis* is a long-lived tree that can exceed 3000 years in age in rocky, fire-protected areas such as along rimrock (Waigchler et al. 2001, Thorne et al. 2007). These fire sensitive trees do not sprout following fire and are typically killed by moderate to severe fires (Tirmenstein 1999h, Sawyer et al. 2009). Young junipers have thin bark and are readily killed by surface fires (Martin et al. 1978), whereas mature trees with thicker bark are described as "moderately resistant" (Fowells 1965). Reproductive age begins at about 20 years, peaks after 50 years and continues for many years (Miller and Rose 1995, Tirmenstein 1999h). Following stand-replacing fire, recovery time is relatively slow and depends on stand maturity, the size and season of burn, fire severity and juniper mortality, the persistence of the seeds in the seed bank, location of seed source, the presence of animal dispersers such as Clark's nutcrackers, competition from herbaceous species and shrubs, and the amount of post-fire precipitation (Burkhardt and Tisdale 1976, Tirmenstein 1999h). Large burns and long distances from seed sources slow recovery rates because seed dispersal is dependent on water and animals (Tirmenstein 1999h).

Juniperus occidentalis woodlands become "closed" at about 40% canopy cover when lateral tree roots fill interspaces between trees (Young et al. 1982, Thorne et al. 2007). At this stage cover of shrub and herbaceous layers begin to rapidly decline (Thorne et al. 2007).

Juniperus occidentalis savanna often occurs on the drier edges of the woodland where trees are intermingling with or invade the surrounding grasslands where local edaphic or climatic conditions favor grasslands over shrublands. Stands occur between the ponderosa zones and the sagebrush moisture zones and are expanding into big sagebrush steppe areas at a fairly rapid rate, creating extensive young stands, increasing the acreage of this type by more than five times (LANDFIRE 2007a, BpS 0910170). Western juniper woodlands and savannas experienced both large- and small-scale natural disturbances (LANDFIRE 2007a). Small-scale fires (less than 5 acres) and insects and disease kill single trees to small patches of trees throughout the stand on a frequent interval. Large-scale fires (>1000 acres) are less common, occurring once every 500 years or more (Miller et al. 1999). Drought can cause dieback and death of trees.

Areas where this system occurs contain some of the largest concentrations of ancient trees. Individuals may exceed 2000 years of age. These ancient western juniper woodlands provide important wildlife habitat. Cavities form in older trees and are important for many neotropical migrants. Western juniper cone-berries provide food for many animals, including elk, deer, coyotes, and small mammals such as mice, chipmunks, rabbits, squirrels, and woodrats; many such as coyotes serve as important dispersing agents of the junipers (Schupp et al. 1997, Tirmenstein 1999h). They are also used by wintering birds such as the American robin and Townsend solitaire (Burkhardt and Tisdale 1969, Eddleman 1984, Tirmenstein 1999h). This juniper is also an important food source for insects with 25 species of bark and wood boring beetles identified (Miller et al. 2005).

LANDFIRE developed a VDDT model for this system which has five classes (LANDFIRE 2007a, BpS 0910170):

A) Early Development (herbaceous-dominated with 0-60% cover - 2% of type in this stage): Herbaceous plants dominate this stage immediately following disturbance. Perennial bunchgrasses dominate the plant community. However, in the first few years following disturbance annual plants may dominate while perennial grasses and forbs recover. Succession to class B after 30 years. (Replacement and mixed fires).

B) Mid Development 1 Open (shrub-dominated with 0-30% cover - 5% of type in this stage): Shrubs dominate this stage. The composition of the shrub layer will be dependent on soil depth and climatic factors. Rabbitbrush will most likely be the dominant shrub following disturbance. However, big sagebrush, bitterbrush and wax current may also be found. Western juniper seedlings and saplings are present throughout the shrub layer. Western juniper has established below the canopy of the shrub layer. Shrub cover is approaching 20% on more productive sites but is most likely <15%. Herbaceous plants are being suppressed by the increase in woody plants. Succession to class C after 45 years. (Mixed and replacement fires).

C) Mid Development 2 Open (shrub/tree mix, tree cover 0-20% - 15% of type in this stage): Western juniper forms an even-aged woodland. Trees are characterized by regular conical shapes. Shrubs are being suppressed by the emerging woodland. Herbaceous vegetation is also being suppressed by the competition from woody plants. Succession to class E (late closed) after 45 years. (Mixed and replacement fires. Certain sites are edaphically constrained and thus transition to class D - late-open).

D) Late Development 2 Open (shrub/tree mix, tree cover 0-20% - 35% of type in this stage): Ancient western juniper savanna or open woodland composed of multiple structural layers. Some western juniper trees have dead portions in their canopies. Canopies are irregular in shape. Young trees can be found in open areas where recent small-scale disturbances occurred. Edaphic factors often maintain wide spacing between junipers. Understory grasses remain dominant and variable. (Maintains in class D. Many disturbances cause transitions to younger or more open conditions).

E) Late Development 1 Open (tree-dominated 20-40% cover - 43% of type in this stage): Ancient western juniper woodland composed of multiple structural layers. Some western juniper trees have dead portions in their canopies. Canopies are irregular in shape. Young trees can be found in open areas where recent small-scale disturbances occurred. Understory grasses are variable, based on slope, aspect and soil depth. (Maintains in class E. Many disturbances cause transitions to younger or more open conditions) (LANDFIRE 2007a).

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from catastrophic crown fires and "chaining" or mechanical removal of trees by land management agencies to convert woodlands to grasslands for livestock (Stevens 1999a, 199b, Stevens and Monsen 2004). Common stressors and threats include heavy grazing by livestock which removes the fine fuel layer that carries low-intensity fire. This results in an unnatural build-up of woody fuels, so when fires occur, they are large, high-intensity, severe fires that remove juniper from the system. If exotic species are present, post-crown fire and post-treatment outcomes may result in conversion to exotic species. Exotic annual grasses such as *Bromus tectorum* can replace the community creating an annual grassland which will be maintained by frequent fires (Mack 1981b, D'Antonio and Vitousek 1992, D'Antonio et al. 2009).

Some stands of this system contain ancient trees over 2000 years old. These ancient western juniper woodlands provide important wildlife habitat such as nesting cavities for neotropical migrants and berries for food (LANDFIRE 2007a). Uncharacteristic stand-replacing fire threatens these ancient stands.

Throughout much of the range of this system, *Juniperus occidentalis* populations are expanding into contiguous *Artemisia* shrub-steppe (Burkhardt and Tisdale 1976, Miller and Rose 1995, Bates et al. 2014). The reasons for this are not entirely clear, but *Juniperus occidentalis* has been documented to germinate and grow preferentially under the canopy of *Artemisia* and other shrubs (Everett 1986). Burkhardt and Tisdale (1969) noted that larger, older trees are often associated with rock outcrops, while younger trees are prevalent on adjacent alluvial soils. This pattern has also been observed in northeastern California (Barbour and Major 1988). This pattern has been interpreted to mean that *Juniperus occidentalis* is colonizing out from rocky refuges which offer shelter from fire, and that the recent expansion of *Juniperus occidentalis* woodlands can be linked to fire suppression (Bates et al. 2014). Active fire suppression and removal of fine fuels by grazing livestock have reduced fire frequency and allowed *Juniperus occidentalis* seedlings to colonize adjacent alluvial soils and expand into the shrub-steppe and grasslands (Tirmenstein 1999h, Bates et al. 2014).

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 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. Management actions such as chaining juniper stands creates a large food source of injured junipers for insects such as western juniper bark beetle (Miller et al. 2005). However, insect attacks usually do not result in the killing of live trees, unless combined with drought such as in the 1920s and 1930s when western junipers were killed by insects in central Oregon (Furniss and Carolin 1977).

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.

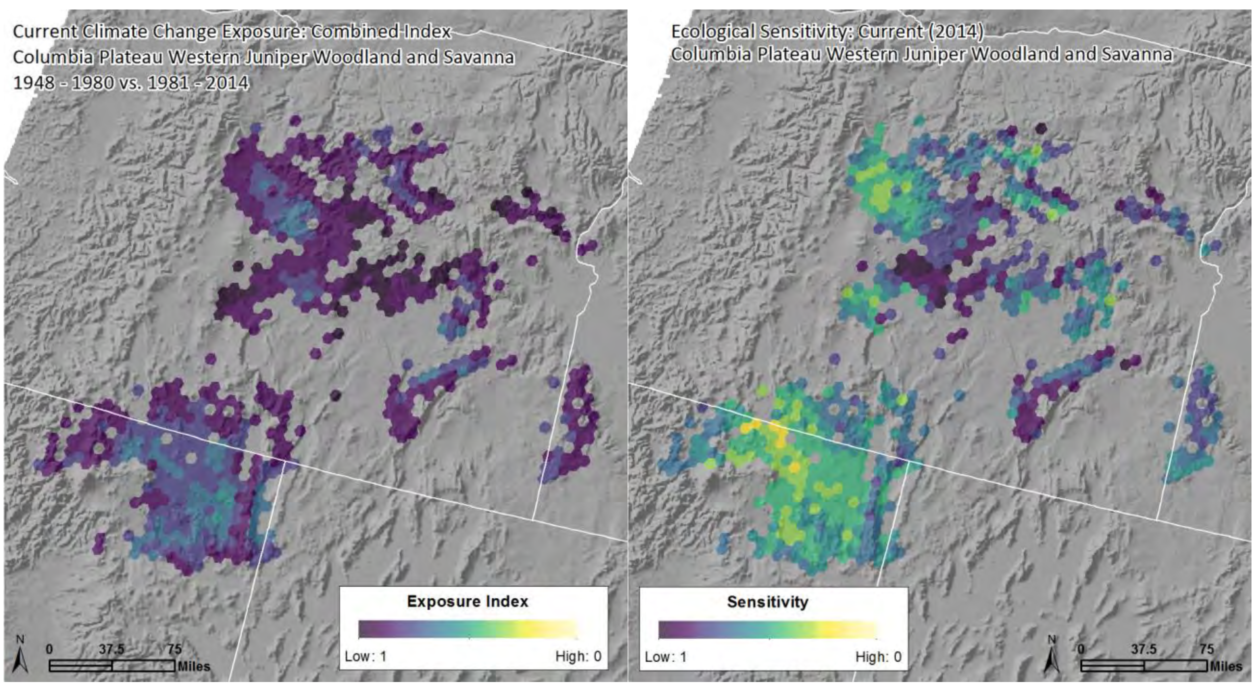

Figure 34. Climate exposure as of 2014 (left) and overall sensitivity (right) for Columbia Plateau Western Juniper Woodland and Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 33. Resilience, exposure and vulnerability scores for Columbia Plateau Western Juniper Woodland and Savanna 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	Eastern Cascades Slopes & Foothills	Blue Mountains	Northern Basin & Range	Klamath Mountains
	Potential square miles within ecoregion	1,212	1,157	643	22
Contributions to Relative Vulnerability by Factor					
Vulnerability from **Exposure (2014)**		**Mod** 0.75	**Low** 0.81	**Low** 0.82	**Low** 0.85
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.69	0.58	0.77	0.59
	Fire Regime Departure	0.32	0.51	0.76	0.35
	Invasive Annual Grasses	0.39	0.66	0.67	0.96
	Sensitivity Average	**0.47**	**0.58**	**0.73**	**0.63**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.22	0.25	0.24	0.35
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null
	Adaptive Capacity Average	**0.36**	**0.38**	**0.37**	**0.42**
Vulnerability from Measures of **Overall Resilience**		**High** 0.41	**High** 0.48	**Mod** 0.55	**Mod** 0.53
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, for the distribution of these woodlands, exposure as of 2014 is moderate. However, in all four ecoregions, an emerging pattern of changing climate appears as an increase of 0.5°C for Annual Mean Temperature. In the Blue Mountains and Northern Basin and Range ecoregions, where it is most common, this change is over 30% of its distribution in each; in the adjacent East Cascades Slopes ecoregion the change is seen in 64% of the distribution, while in the Klamath Mountains, where it occurs peripherally, 100% of its distribution shows this increase in temperature.

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 tree recruitment. Without recruitment these juniper stands are essentially relicts of past climate conditions.

Indirect effects of a warming climate with more frequent droughts could weaken juniper trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the number of generations of insect pests above the average of two and a half to three annually. Additionally, warmer/drier fuels may result in more frequent fires that could increase rates of loss of mature stands through conversion of these woodlands to annual grasslands or shrublands that are adapted to frequent fire (Thorne et al. 2007). Many stands of this ecological system woodland occur in foothill zone of taller mountain ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. *Juniperus occidentalis* frequently live more than 300 years and are known to live over 3000 years, so it may be able to survive as relicts for centuries without regeneration (Sawyer et al. 2009). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate for this system, except in the Northern Basin and Range ecoregion, where it is low (higher score). In 2 of the 4 ecoregions moderate sensitivity is a result of the interactions between landscape condition and fire regime departure. In the Eastern Cascades it appears to be driven by risk of invasive grasses and fire regime departure.

Landscape condition varies from moderate (some development) to very good (little development, higher scores) (**Table 33**). It is particularly poor in the Eastern Cascades and Northern Basin and Range ecoregions. In the Blue Mountains and Klamath Mountains, fragmentation has occurred due to many small roads through occurrences, and development of urban, suburban and exurban areas is significant in some areas.

Risk of invasive grasses seems to be low (higher scores) across most of this system's range, except in the Eastern Cascades in the Modoc Plateau region where risk is increased. Fire regime departure is also high in the Eastern Cascades, where it's likely that invasion by cheatgrass combined with fire suppression has altered the fire regime in this ecoregion. Moderately altered fire regime in the Blue and Klamath mountains may reflect fire suppression interacting with the effects of invasion of juniper into nearby sagebrush shrublands. Grazing has also altered the fire regime by removing grasses that act as fuels for frequent low-intensity fires, resulting in an unnatural build-up of woody fuels. In these situations, when fires occur, they are high-intensity and severe fires that remove juniper from the system.

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 woodlands. 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 range wide. Topoclimatic variability is generally low to moderate, as these savannas occur across low-relief landforms and topography, such as on lower mountain slopes, hills, plateaus, basins and flats often where juniper is expanding into semi-desert grasslands and steppe. 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 four identified functional species groups varies from moderate to high. 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 the high 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.

Seed dispersal is provided by many bird and mammal species and appears to have high within-stand diversity. Substrate developing soil crusts also have high within-stand diversity, and include many cyanobacteria, lichens and mosses.

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 woodland and savanna system scores in the moderate range of overall climate change vulnerability throughout its range. This moderate vulnerability is primarily due overall low scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are moderate for types such as this with moderate diversity within functional groups and with low topoclimatic variation. Sensitivity measures are low to high for fire regime departure and medium to high for landscape condition and invasive annual grasses. Additionally, these woodlands and savannas are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects - especially on soils - and long-term effects of fire regime alterations.

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 Columbia Plateau Western Juniper Woodland and Savanna

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
	fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Bates et al. 2014, Belnap 2001, Belnap et al. 2001, Burkhardt and Tisdale 1976, Chambers et al. 1999, Comer et al. 2003*, D'Antonio and Vitousek 1992, D'Antonio et al. 2009, Eddleman 1984, Everett 1986, Eyre 1980, Fowells 1965, Franklin and Dyrness 1973, Furniss and Carolin 2002, Kartesz 1988, LANDFIRE 2007a, Mack 1981b, Martin et al. 1978, Miller and Rose 1995, Miller et al. 1999, Miller et al. 2005, Romme et al. 2009, Rosentreter and Belnap 2003, Sawyer et al. 2009, Schupp et al. 1997, Shiflet 1994, Stevens 1999a, Stevens 1999b, Stevens and Monsen 2004, Thorne et al. 2007, Tirmenstein 1999h, Vander Wall 1990, WNHP unpubl. data, Waigchler et al. 2001, Young et al. 1982

CES304.773 Great Basin Pinyon-Juniper Woodland

Figure 35. Photo of Great Basin Pinyon-Juniper Woodland. Photo credit: Jeff Moser, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/facilitybikeclub

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs on dry mountain ranges of the Great Basin region and eastern foothills of the Sierra Nevada extending south in scattered locations throughout southern California. This woodland is typically found at lower elevations ranging from 1600-2800 m. These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus and ridges. Woodlands dominated by a mix of *Pinus monophylla* and *Juniperus osteosperma*, pure or nearly pure occurrences of *Pinus monophylla*, or woodlands dominated solely by *Juniperus osteosperma* comprise this system, but in some regions of southern California, *Juniperus osteosperma* is replaced by *Juniperus californica*. *Cercocarpus ledifolius* is a common associate. On the east slope of the Sierras in California, *Pinus jeffreyi* and *Juniperus grandis* may be components of these woodlands. Understory layers are variable. Associated species include shrubs such as *Arctostaphylos patula, Artemisia arbuscula, Artemisia nova, Artemisia tridentata, Cercocarpus ledifolius, Cercocarpus intricatus, Coleogyne ramosissima, Yucca brevifolia, Quercus gambelii, Quercus turbinella, Quercus john-tuckeri, Juniperus californica, Quercus chrysolepis*, and bunchgrasses *Hesperostipa comata, Festuca idahoensis, Pseudoroegneria spicata, Leymus cinereus*, and *Poa fendleriana*. This system occurs at lower elevations than Colorado Plateau Pinyon-Juniper Woodland (CES304.767) where sympatric.

Distribution: This system occurs on dry mountain ranges of the Great Basin region and eastern foothills of the Sierra Nevada, typically at lower elevations ranging from 1600-2800 m. It extends southwest in California to the northern Transverse Ranges (Ventura County) and San Jacinto Mountains (Riverside County).

Nations: US

States/Provinces: AZ, CA, ID, NV, UT

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Middle Rockies, Sierra Nevada, Wasatch and Uinta Mountains, Northern Basin and Range, Central Basin and Range, Colorado Plateaus, Arizona/New Mexico Plateau, Snake River Plain, Mojave Basin and Range, Sonoran Desert, California Coastal Sage, Chaparral, and Oak Woodlands, Southern and Baja California Pine-Oak Mountains, Arizona/New Mexico Mountains

Primary Concept Source: K.A. Schulz

Description Author: T. Keeler-Wolf, M.S. Reid, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: These woodlands are characterized by an open to moderately dense tree canopy typically composed of a mix of *Pinus monophylla* and *Juniperus osteosperma*, but either tree species may dominate to the exclusion of the other. In some regions of southern California, *Juniperus osteosperma* is replaced by *Juniperus californica*. *Cercocarpus ledifolius* is a common associate and may occur in tree or shrub form. On the east slope of the Sierra Nevada in California, *Pinus jeffreyi* and *Juniperus grandis (= Juniperus occidentalis var. australis)* may be components of these woodlands. Understory layers are variable, but shrubs such as *Artemisia tridentata* frequently form a moderately dense short-shrub layer. Other associated shrubs include *Arctostaphylos patula, Artemisia arbuscula, Artemisia nova, Cercocarpus intricatus, Coleogyne ramosissima, Quercus gambelii*, and *Quercus turbinella*. Bunch grasses such as *Poa fendleriana, Hesperostipa comata, Festuca idahoensis, Pseudoroegneria spicata, Leymus cinereus (= Elymus cinereus)*, and *Bouteloua gracilis* are commonly present and may form an herbaceous layer. In the southern extent, *Arctostaphylos patula, Ceanothus greggii, Garrya flavescens, Quercus john-tuckeri, Juniperus californica, Purshia stansburiana, Quercus chrysolepis, Yucca baccata*, and *Yucca brevifolia* are common.

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). 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 in 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: Low
Pinyon-juniper woodlands occur in semi-arid climates, typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid woodlands typically have low to moderate herbaceous cover and low diversity. Most species of Fabaceae (including species of concern: *Astragalus inyoensis, Astragalus convallarius*

var. margaretiae), many Poaceae (*Bouteloua gracilis, Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana, Pseudoroegneria spicata*), and species of Rhamnaceae (*Ceanothus greggii*), Rosaceae (*Amelanchier utahensis, Cercocarpus ledifolius, Cercocarpus intricatus, Prunus virginiana, Purshia stansburiana*), Elaeagnaceae (*Shepherdia rotundifolia*), and a few 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 is moderately high; within stand species diversity of nitrogen fixers is typically low.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), Mexican jay (*Aphelocoma wollweberi*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Scher 2002). The primary dispersers of pinyon seeds are scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). Mammals: Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Neotamias minimus (= Tamias minimus)*), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Panamint kangaroo rat (*Dipodomys panamintinus*), woodrats (*Neotoma* spp.), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*) squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), cliff chipmunk (*Neotamias dorsalis*), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) are all known to eat singleleaf pinyon seeds and may inadvertently disperse seeds in caches or have viable seeds pass through gut (Zouhar 2001b, Hollander and Vander Wall 2004).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this pinyon-juniper woodland type.

Environment: This system occurs on dry mountain ranges of the Great Basin region and eastern foothills of the Sierra Nevada extending south into the Mojave Desert ranges and southwest in to the northern Transverse Ranges and San Jacinto Mountains. Elevations range from 1000 to 2800 m. Upper elevation limits are determined by local climate and/or the presence of competing tree species. Stands generally occur on sites with shallow rocky soils or rock-dominated sites that are protected from frequent fire (rocky ridges, broken topography and mesatops).

Climate: Climate is temperate, continental, and semi-arid with cold winters. Precipitation ranges from 20 to 45 cm annually, mostly occurring during fall and winter months (Brown 1982a). Summers are typically dry and there is usually extreme variation in annual precipitation. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides.

Physiography/landform: These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, ridges, foothills, and upper alluvial fans.

Soil/substrates/hydrology: Soils supporting this system vary in texture, ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. Adjacent upland systems include Inter-Mountain Basins Montane Sagebrush Steppe (CES304.785), Inter-Mountain Basins Curl-leaf Mountain-mahogany

Woodland and Shrubland (CES304.772), Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland (CES304.776) above and at lower elevations, Great Basin Xeric Mixed Sagebrush Shrubland (CES304.774), Inter-Mountain Basins Big Sagebrush Shrubland (CES304.777), and Mojave Mid-Elevation Mixed Desert Scrub (CES302.742).

Key Processes and Interactions: *Pinus monophylla, Juniperus osteosperma*, and *Juniperus scopulorum* are slow-growing, long-lived trees (about 650 years for *Juniperus osteosperma*, 300 years for *Juniperus scopulorum*, and 800 years for *Pinus monophylla*, although older individuals are known) (Burns and Honkala 1990a, Zlatnik 1999e, Zouhar 2001b, Scher 2002, Sawyer et al. 2009). These trees are killed by severe fire because of thin bark and lack of self-pruning; however, mature trees can survive low-intensity fires (Zouhar 2001b, Sawyer et al. 2009). Although there is variation in fire frequency because of the diversity of site characteristics, stand-replacing fire was uncommon in this ecological system historically, with an average fire-return interval (FRI) of 100-1000 years occurring primarily during extreme fire behavior conditions and during long droughts (Zouhar 2001b) (LF BpS model 1210190). Mixed-severity fire (average FRI of 100-500 years) was characterized as a mosaic of replacement and surface fires distributed through stands in patches at a fine scale (<0.1 acre) (LF BpS model 1210190).

Fire rotation in the San Bernardino Mountains was determined to be 480 years (Wangler and Minnich 2006). These woodlands have a truncated long fire-return interval of 200+ years with surface to passive crown fires of medium size, low complexity, high intensity, and very high severity (Sawyer et al. 2009). After a stand-replacing fire, the site is usually colonized by herbaceous plants and shrubs. The shrubs act as nurse plants, with *Pinus monophylla* seedlings establishing 20-30 years post fire after shrub density increases, and then a tree canopy forms after 100-150 years (Minnich 2007). As tree canopy becomes denser there is a decline in shrub cover (Minnich 2007). Fires are associated with herbaceous fuel buildup following a wet period (Minnich 2007).

Other important ecological processes include drought, insect infestations, pathogens, herbivory, and seed dispersal by birds and mammals. Juniper berry and pinyon nut crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995). Large mammals, such as mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), eat leaves and seeds of both species and they browse woodland grasses, forbs and shrubs, including *Artemisia tridentata, Cercocarpus montanus, Quercus gambelii*, and *Purshia stansburiana* (Short and McCulloch 1977).

The principal dispersers of juniper and pinyon seeds are birds, although many mammals also feed on them. These animals consume juniper berries and excrete viable scarified juniper seeds over extensive areas, which germinate faster than uneaten seeds (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), turkey (*Meleagris gallopavo*), and five species of jays (Scher 2002). Pinyon seeds are a critically important food source for western scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). These birds are primary dispersers of pinyon seeds and during mast crop years cache hundreds of thousands of pinyon seeds, many of which are never recovered (Balda and Bateman 1971, Vander Wall and Balda 1977, Ligon 1978). Many mammals are also known to eat singleleaf pinyon seeds, including several species of mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias* spp.), deer, black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) (Christensen and Whitham 1993, Zouhar 2001b). Because singleleaf pinyon seeds are heavy and totally wingless, seed dispersal is dependent on vertebrate dispersers that store seeds in food caches, where unconsumed seeds may germinate. This seed dispersal mechanism is a good example of a co-evolved, mutualistic, plant-vertebrate relationship (Vander Wall et al. 1981, Evans 1988, Lanner 1996) and would be at risk with loss of trees or dispersers.

There are many insects, pathogens, and plant parasites that attack pinyon and juniper trees (Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). Juniper mistletoe (*Phoradendron juniperinum*) occurs on junipers and pinyon dwarf mistletoe (*Arceuthobium divaricatum*) occurs on pines. Both mistletoes reduce vigor and cause dieback but rarely cause mortality (Meeuwig and Bassett 1983). For pinyon, there are at least seven insects, and fungi such as blackstain root-rot (*Leptographium wageneri*), pinyon needle rust (*Coleosporium ribicola*), and pinyon blister rust (*Cronartium occidentale*) (Skelly and Christopherson 2003). The insects are normally present in these woodland stands, and during drought-induced water stress, outbreaks may cause local to regional mortality (Wilson and Tkacz 1992, Gottfried et al. 1995, Rogers 1995). Most insect-related pinyon mortality in the West is caused by pinyon Ips bark beetle (*Ips confusus*) (Rogers 1993). The current epidemic of ips beetles in many areas that has killed numerous pinyons has created high fuel loads that further threaten stands (Thorne et al. 2007).

LANDFIRE modelers predict severe weather (usually drought), insects and tree pathogens are coupled disturbances that thin trees to varying degrees and kill small patches every 250-500 years on average, with greater frequency in more closed stands (LF BpS model 1210190).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 1210190). These are summarized as:

A) Early Development 1 Open (herbaceous-dominated - 5% of type in this stage): Herbaceous cover is 0-15%. Shrub cover is 0%. Initial post-fire community dominated by annual grasses and forbs. Later stages of this class contain greater amounts of perennial grasses and forbs. Evidence of past fires (burnt stumps and charcoal) should be observed. Duration is 10 years with succession to class B, mid-development closed. Replacement fire occurs every 300 years on average.

B) Mid Development 1 Open (shrub-dominated - 5% of type in this stage): Shrub cover is 5-20%. Dominated by shrubs, perennial forbs and grasses. Tree seedlings starting to establish on favorable microsites. Total cover remains low due to shallow unproductive soil. Duration is 20 years with succession to class C unless infrequent replacement fire (FRI of 200 years) returns the vegetation to class A. It is important to note that replacement fire at this stage does not eliminate perennial grasses. Mixed-severity fire (average FRI of 200 years) thins the woody vegetation but does not change its succession age.

C) Mid Development 2 Open (shrub-dominated - 20% of type in this stage): Tree cover is 5-20%. Tree height <5 m. Shrub- and tree-dominated community with young juniper and pinyon seedlings becoming established. Duration is 70 years with succession to class D unless replacement fire (average FRI of 250 years) causes a transition to class A. It is important to note that replacement fire at this stage does not eliminate perennial grasses. Mixed-severity fire as in class B. Mortality from insects, pathogens, and drought occurs at a rotation of approximately 500 years and causes a transition to class B by killing older trees.

D) Late Development 1 Open (conifer-dominated - 35% of type in this stage): Tree cover is 5-40%. Tree height <10 m. Community dominated by young to mature juniper and pine of mixed age structure. Juniper and pinyon becoming competitive on site and beginning to affect understory composition. Duration 200 years with succession to class E unless replacement fire (average FRI of 1000 years) causes a transition to class A. Mixed-severity fire is less frequent than in previous states (500 years). Surface fire (mean FRI of 500 years) is infrequent and does not change successional dynamics. Tree pathogens and insects such as pinyon Ips become more important for woodland dynamics occurring at a rotation of 250 years, including both patch mortality (500-year rotation) and thinning of isolated individual trees (500-year rotation).

E) Late Development 2 Open (conifer-dominated - 35% of type in this stage): Tree cover is 5-50%. Tree height 5-25 m. Some sites dominated by widely spaced old juniper and pinyon, while elsewhere there are dense, old-growth stands with multiple layers. May have all-aged, multi-storied structure.

Occasional shrubs with few grasses and forbs and often much rock. Understory depauperate and high amounts of bare ground present. Grasses present on microsites with deeper soils (>50 cm [20 inches]) with restricting clay subsurface horizon. Potential maximum overstory replacement fire and mixed-severity fires are rare (average FRIs of 1000 and 500 years, respectively). Surface fire occurs when especially dry years follow wet years (500-year rotation) and will scar ancient trees. Tree pathogens and insects associated with drought conditions kill patches of trees (1000-year rotation), with succession to class C, and individual trees (1000-year rotation) with succession to class D. Duration 800+ years.

Most pinyon-juniper woodlands in the southwest have high soil erosion potential (Baker et al. 1995). Several studies have measured present-day erosion rates in pinyon-juniper woodlands, highlighting the importance of herbaceous cover and cryptogamic soil crusts (Baker et al. 1995, Belnap et al. 2001) in minimizing precipitation runoff and soil loss in pinyon-juniper woodlands.

ECOLOGICAL INTEGRITY

Change Agents: Threats to pinyon-juniper woodlands include invasion by introduced annual grasses, livestock grazing, development, and fire suppression. Before 1900, this system was mostly open woodland restricted to fire-safe areas on rocky ridges, etc., where the low cover of fine fuels reduced the spread of fires. Over the last 100 years fire regimes were altered because of fire suppression and grazing by livestock, which reduces the amount of fine fuels (grasses) that carry fire thus reducing fire frequency (Swetnam and Baisan 1996a). Currently, much of this system has a more closed canopy than historical conditions. Fire suppression has led to a buildup of woody fuels that in turn increases the likelihood of high-intensity, stand-replacing fires. Heavy grazing, in contrast to fire, removes the grass cover and tends to favor shrub and conifer species (Swetnam and Baisan 1996a).

These woodlands have been expanding into adjacent steppe grasslands and shrublands in many areas, reportedly in connection with livestock grazing and altered fire regimes (Blackburn and Tueller 1970, Tausch et al. 1981, Chambers 2001, Wangler and Minnich 2006, LANDFIRE 2007a, Weisberg et al. 2007). Historical fire suppression has resulted in denser tree canopies and a pinyon-juniper woodland expansion especially into big sagebrush shrublands (Wangler and Minnich 2006) and shrub-steppe and grassland (Blackburn and Tueller 1970). This may also 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).

Denser canopies in pinyon-juniper woodland can also increase fire severity, as well as increasing soil erosion because of reduction in ground cover with shading by tree canopy (Tausch and West 1988, Zouhar 2001b). Recently, significant losses in pinyon-juniper woodlands are a result of shortening of fire-return intervals (FRI) because of invasion by introduced *Bromus tectorum* and other annuals that provide fine fuels that carry fire (Thorne et al. 2007).

Currently, epidemics of the native pinyon ips beetle (*Ips confusus*) often occur during drought periods when mature trees are weakened and vulnerable to ips beetle attacks, which kill many pinyons in turn creating very high fuel loads throughout much of the system's range (Furniss and Carolin 2002, Thorne et al. 2007). In addition, many of these communities have been severely impacted by past range practices of chaining, tilling, and reseeding with exotic forage grasses. Although the dominant trees appear to regenerate after such disturbances, the effects on native understory species are poorly known (Thorne et al. 2007).

Human development has impacted some locations throughout the Great Basin. 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. Management actions such as chaining pinyon-juniper stands creates a large food source of injured pines for ips beetles to feed on that can quickly multiply creating epidemic outbreaks of beetles that attack and kill many healthy pinyons (Furniss and Carolin 2002). Drought stresses pinyon trees and makes them less able to survive Ips attacks (Furniss and Carolin 2002, Thorne et al. 2007).

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.

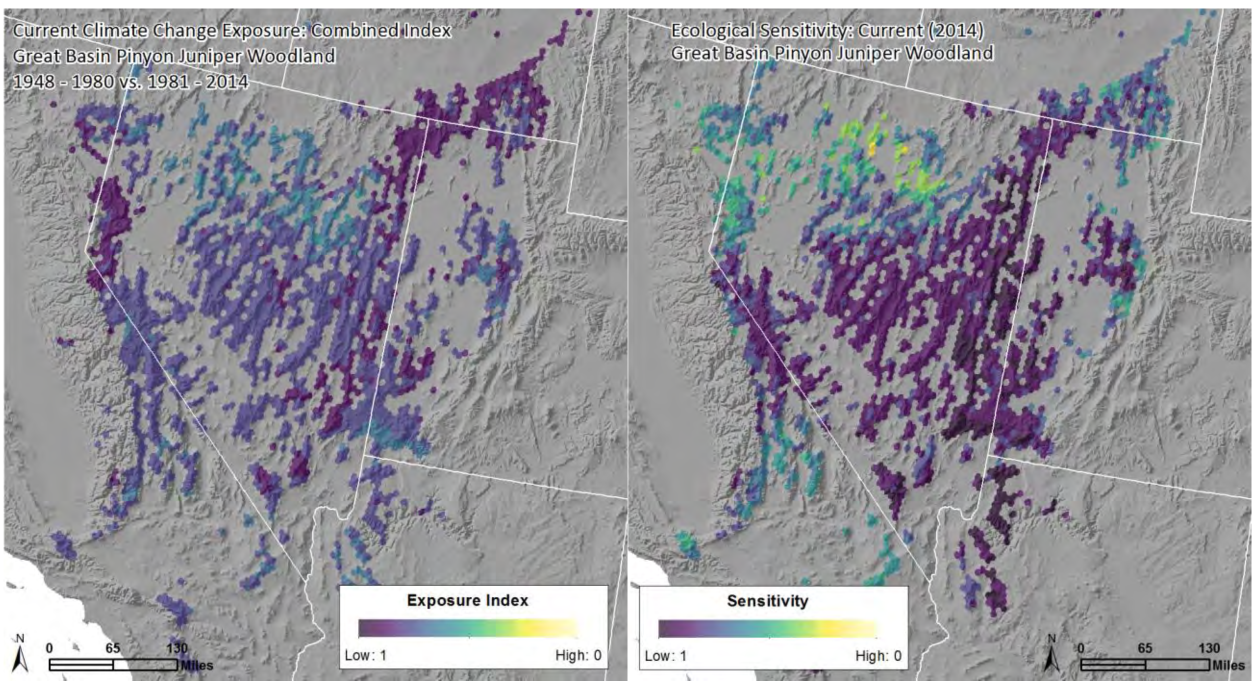

Figure 36. Climate exposure as of 2014 (left) and overall sensitivity (right) for Great Basin Pinyon-Juniper Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 35. Resilience, exposure and vulnerability scores for Great Basin Pinyon-Juniper Woodland 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	Mojave Basin & Range	Northern Basin & Range	Arizona-New Mexico Plateau	Southern & Baja California Pine-Oak Mountains	Sierra Nevada	Colorado Plateaus	Eastern Cascades Slopes & Foothills	Wasatch & Uinta Mountains
	Potential square miles within ecoregion	6,873	860	462	227	137	80	36	33	31
Contributions to Relative Vulnerability by Factor										
Vulnerability from **Exposure (2014)**		**Mod** 0.53	**Mod** 0.53	**Mod** 0.58	**Mod** 0.52	**Mod** 0.53	**Mod** 0.53	**High** 0.50	**Mod** 0.54	**High** 0.49
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.91	0.84	0.82	0.93	0.64	0.88	0.78	0.90	0.85
	Fire Regime Departure	0.59	0.63	0.56	0.79	0.46	0.66	0.72	0.59	0.83
	Invasive Annual Grasses	0.94	0.81	0.85	0.97	0.70	0.54	0.93	0.41	0.98
	Sensitivity Average	**0.81**	**0.76**	**0.74**	**0.90**	**0.60**	**0.69**	**0.81**	**0.63**	**0.89**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.56	0.59	0.47	0.49	0.50	0.58	0.54	0.39	0.51
	Diversity within Functional Species Groups	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
	Adaptive Capacity Average	**0.36**	**0.37**	**0.31**	**0.32**	**0.33**	**0.37**	**0.35**	**0.27**	**0.34**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.59	**Mod** 0.57	**Mod** 0.53	**Mod** 0.61	**High** 0.46	**Mod** 0.53	**Mod** 0.58	**High** 0.45	**Mod** 0.61
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**High**	**Mod**	**Mod**	**High**	**Mod**

Exposure Summary for 1981-2014 Timeframe: As of 2014, overall climate exposure is moderate, but does show some variation across ecoregions with scores tipping into the high range in the Colorado Plateau and Wasatch & Uninta Mounatains ecoregions. For the distribution of this woodland, an emerging pattern of changing climate appears as increases of 0.6°C for Annual Mean Temperature and 0.7°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. The Mean Diurnal Range is decreasing in the Central and Mojave Basin and Range ecoregions, for some 12% to 23% of the type's distribution in those ecoregions. 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. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

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 tree recruitment. Without recruitment, pinyon and juniper stands are essentially relicts of past climate conditions.

Warming climate with more frequent droughts also weakens pinyon trees and may make them more susceptible to lethal attacks by forest diseases and insects such as the pinyon ips beetles (*Ips confusus*). Pinyons cannot repel pinyon ips beetles when weakened by drought and many are killed. During the drought of 2002-2003, the population of ips beetles built up to epidemic levels that killed millions of pinyon trees in the southwestern U.S. (Thorne et al. 2007). Longer milder climate periods may increase the number of generations of ips beetles above the average of two and a half to three annually. Additionally, warmer/drier fuels may result in more frequent fires that could increase the rate of loss of mature stands through conversion of these woodlands to annual grasslands or shrublands that are adapted to frequent fire (Thorne et al. 2007).

Many stands of this woodland occur in foothill zones of taller mountain ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. Pinyon and juniper trees are long-lived; *Juniperus osteosperma, Juniperus scopulorum* and *Pinus monophylla* frequently live more than 300 years and so may be able to survive as relicts for centuries without regeneration (Burns and Honkala 1990a, Sawyer et al. 2009). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is low to moderate across the range of this type. Landscape condition tends to be very good (**Table 35**), as the ecosystem occurs across extensive and remote mountain ranges of the Great Basin. Infrastructure development is limited but tends to occur at lower elevations of its range. In particular in the Southern California-Baja Mountains ecoregion, which is the edge of distribution for these woodlands, extensive development has occurred with housing, roads and other infrastructure contributing to lower landscape condition.

Risk of invasive plants tends to be low and is currently concentrated at the lower elevation range of the type. In the Eastern Cascades and Sierra Nevada ecoregions invasives risk is moderate. The Central Basin and Range and Northern Basin and Range ecoregions encompass vast areas of cheatgrass invasion, especially concentrated in sagebrush vegetation adjacent to (and just downslope from) these pinyon-juniper woodlands. Fire regime departure is moderate to high (lower scores) in all but two ecoregions, with interacting effects of fire suppression and perhaps some locations with fine-fuels introduction by invasive grasses.

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 woodlands. 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 varies from low range wide. Topoclimatic variability is generally moderate, as these woodlands occur in rugged mountainous topography, and therefore they occur where local climates vary within short distances. For example, both north and south facing slopes as well as steep elevation gradients, can occur within short distances. Many options exist for species to move across these landscapes to adapt to changing climate conditions.

However, the adaptive capacity is more limited when considering the diversity within functional species groups, which varies from high to low among groups. While two of the three functional species groups have high diversity, nitrogen fixation has low diversity and is the most limiting in relation to adaptive capacity. 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 for the system. Conversely, seed dispersers and substrate developing soils crusts appear to be naturally diverse across the range of this type. Many species of birds and mammals disperse both juniper and pinyon seed. Soil crust taxa include many cyanobacteria, lichens and mosses.

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: These woodlands currently score in the moderate range of overall climate change vulnerability throughout most of their range. This is primarily due to moderate scores for exposure, moderate to low scores for adaptive capacity, and variable contributions from sensitivity measures. They score high in vulnerability along two ecoregions (Baja California Pine-Oak Mountains and Eastern Cascades Slopes & Foothills) that are marginal to the overall range. Inherent vulnerabilities are high for types such as this with low diversity within key functional species groups, such as nitrogen fixing species. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Great Basin Pinyon-Juniper Woodland

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Baker et al. 1995, Balda 1987, Balda and Bateman 1971, Belnap 2001, Belnap et al. 2001, Blackburn and Tueller 1970, Breshears et al. 2005, Brooks and Minnich 2006, Brown 1982a, Burns and Honkala 1990a, Chambers 2001, Christensen and Whitham 1993, Comer et al. 2003*, Evans 1988, Evans and Belnap 1999, Eyre 1980, Furniss and Carolin 2002, Gottfried et al. 1995, Hollander and Vander Wall 2004, Johnsen 1962, Keeler-Wolf and Thomas 2000, LANDFIRE 2007a, Lanner 1996, Ligon 1978, McCulloch 1969, Meeuwig and Bassett 1983, Minnich 2007b, Rogers 1993, Rogers 1995, Rosentreter and Belnap 2003, Salomonson 1978, Sawyer et al. 2009, Scher 2002, Shiflet 1994, Short and McCulloch 1977, Short et al. 1977, Skelly and Christopherson 2003, Swetnam and Baisan 1996a, Tausch and West 1988, Tausch et al. 1981, Thorne et al. 2007, Vander Wall and Balda 1977, Vander Wall et al. 1981, Wangler and Minnich 2006, Weber et al. 1999, Weisberg et al. 2007, Wilson and Tkacz 1992, Zlatnik 1999e, Zouhar 2001b

CES304.772 Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and Shrubland

Figure 37. Photo of Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and Shrubland. Photo credit: Las Pilitas Nursery.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in hills and mountain ranges of the Intermountain West basins from the eastern foothills of the Sierra Nevada northeast to the foothills of the Bighorn Mountains. It typically occurs from 600 m to over 2650 m in elevation on rocky outcrops or escarpments and forms small- to large-patch stands in forested areas. Most stands occur as shrublands on ridges and steep rimrock slopes, but they may be composed of small trees in steppe areas. Scattered junipers or pines may also occur. This system includes both woodlands and shrublands dominated by *Cercocarpus ledifolius*. *Artemisia tridentata ssp. vaseyana, Purshia tridentata*, with species of *Arctostaphylos, Ribes*, or *Symphoricarpos* are often present. Undergrowth is often very sparse and dominated by bunchgrasses, usually *Pseudoroegneria spicata* and *Festuca idahoensis*. *Cercocarpus ledifolius* is a slow-growing, drought-tolerant species that generally does not resprout after burning and needs the protection from fire that rocky sites provide.

Distribution: This system occurs in hills and mountain ranges of the Intermountain West basins from the eastern foothills of the Sierra Nevada northeast to the foothills of the Bighorn Mountains.

Nations: US

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

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Blue Mountains, Middle Rockies, Klamath Mountains, Sierra Nevada, Wasatch and Uinta Mountains, Southern Rockies, Idaho Batholith, Northwestern Great Plains, High Plains, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, Snake River Plain, Mojave Basin and Range

Primary Concept Source: K.A. Schulz

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system includes both short and tall shrublands and short woodlands dominated by *Cercocarpus ledifolius*. Some stands occur as scattered shrub communities in steppe or on rocky outcrops or steep escarpments within forests and woodlands, especially on upper slopes and ridges. The woodlands occur mostly in the eastern Sierra Nevada and ranges in the Great Basin. Common shrub associates are *Artemisia tridentata* and *Purshia tridentata*, with species of *Amelanchier, Arctostaphylos, Holodiscus, Prunus, Ribes*, and *Symphoricarpos* commonly present. Scattered trees may also be present, including *Pinus monophylla, Juniperus* spp., *Pinus ponderosa, Pinus flexilis, Pinus jeffreyi, Pseudotsuga menziesii*, or *Abies concolor*. Undergrowth is often very sparse and dominated by bunchgrasses, usually *Achnatherum hymenoides (= Oryzopsis hymenoides), Achnatherum occidentale (= Stipa occidentalis), Hesperostipa* spp., *Poa fendleriana, Poa secunda, Pseudoroegneria spicata*, and *Festuca idahoensis*, and at higher elevations *Calamagrostis rubescens* and *Festuca idahoensis*.

Cercocarpus ledifolius woodlands and shrublands are poorly distinguished in the literature, as most authors describe the species as having either a tall-shrub or small-tree growth form within a single association. Some associations may have shrub-dominated stands in one area and also have a woodland physiognomy in another. The woodland physiognomy appears to be more typical, based on available literature. Near the northern edge of its range in Montana and Idaho, *Cercocarpus ledifolius* is described as occurring primarily in the shrub form (Mueggler and Stewart 1980, Tisdale 1986). These northern variants are the only described stands which appear to be clearly distinct from the woodland alliance.

The woodland stands may be dominated by different varieties of *Cercocarpus ledifolius* than shrubland stands. In Wyoming, the Natural Heritage Program is proposing to recognize two *Cercocarpus ledifolius* alliances, based upon varieties of *Cercocarpus ledifolius*. The most widespread proposed alliance (in Wyoming) is dominated by *Cercocarpus ledifolius var. ledifolius*, which grows up to about 1.5 m tall. The other proposed alliance, dominated by *Cercocarpus ledifolius var. intercedens*, is found only along the western border of the state, and the growth form is as small trees 4-5 m tall. The two taxa are obviously different in Wyoming, in stature and leaf characteristics, and are easily separated (Reid et al. 1998). The shorter variety, *Cercocarpus ledifolius var. ledifolius*, is not reported from Nevada or California (USDA NRCS 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
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 shrubland and woodland (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 than warm desert regions with over 72 species. Common mosses (7) include *Bryum* spp., *Ceratodon purpureus, Funaria hygrometrica, Pterygoneurum ovatum*, and *Tortula 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 small tree/shrubs in this system are chiefly wind-pollinated (although some pollination by insects may occur), most forbs need to be pollinated by organisms such as bees to fertilize ova to produce viable seed (Gucker 2006c). 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 for certain species. Insects: Bees (Apoidea), butterflies and moths (Lepidoptera), wasps and ants (Hymenoptera), flies (Diptera) and beetles (Coleoptera). Vertebrates: hummingbirds.

Nitrogen Fixation; Species Diversity: Medium
*Although rangewide diversity is high, locally diversity is moderate in these Semi-arid shrublands and dry temperate woodlands.

Diversity: medium 11-20. *Cercocarpus ledifolius* woodlands and shrublands occur in semi-arid climates to dry temperate climates often on substrates where soil nutrients such as nitrogen are a significant constraint on plant growth. Locally, these semi-arid shrublands typically have low to moderate herbaceous cover and moderate diversity. Rangewide, possible nitrogen-fixing plant species are variable and include species of Fabaceae (including species of *Astragalus* and *Lupinus*); Rosaceae (*Amelanchier, Cercocarpus, Purshia*); and many Poaceae (*Achnatherum hymenoides, Achnatherum lemmonii, Calamagrostis rubescens, Elymus elymoides, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Leymus salinus, Poa secunda*, and *Pseudoroegneria spicata*), and some Brassicaceae. 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
More open stands may have a significant herbaceous layer dominated by cool-season graminoids such as: *Achnatherum hymenoides, Achnatherum lemmonii, Calamagrostis rubescens, Elymus elymoides, Festuca idahoensis, Hesperostipa comata, Leymus cinereus, Leymus salinus, 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 mountain-mahogany woodland and shrubland type.

Environment: This ecological system is widespread in semi-arid hills and mountain ranges of the intermountain western U.S. from the eastern foothills of the Sierra Nevada and Cascade Range east into the Rocky Mountains including the foothills of the Bighorn Mountains. It also occurs south into the Mojave Desert and the Grand Canyon in northern Arizona. Stands mostly occur below montane conifer forests and above desert scrub from 1500 to 3200 m in elevation, extending down to 600 m in the north (Gucker 2006c). Higher-elevation stands typically occur on warmer and drier southerly slopes. Annual precipitation averages 25-45 cm, with a significant proportion falling as winter snow. Sites typically have shallow to deep, well-drained, often rocky, nutrient-poor, sandy loam soils frequently derived primarily from carbonate sediments (limestone or dolomite) or on sandstones rich in calcium carbonate (Reid et al. 1999). Other rock types include quartz, gneiss, and basalt.

Key Processes and Interactions: *Cercocarpus ledifolius* is a slow-growing, drought-tolerant species which can inhabit very poor sites, such as cliffs, stony slopes, and outcrops. Stands are often small and clumped near ridgetops. These sites may also afford the species some protection from fire as the oldest individuals have been observed in these stands (Ross 1999). Succession in these stands is variable depending on site conditions and disturbance as *Cercocarpus ledifolius* is both a primary early-successional colonizer that rapidly invades bare mineral soils after disturbance and the dominant long-lived species in mid- and late-seral stands (Duncan 1975, Gruell et al. 1985). Shade tolerance is low so higher-elevation stands on sites where conifers can grow will eventually be overtopped by taller conifer trees forming woodlands with a *Cercocarpus ledifolius* subcanopy or shrub layer until replaced by more shade-tolerant shrubs such as *Physocarpus malvaceus* or *Acer glabrum* (Gruell et al. 1985, Steele and Geier-Hayes 1995).

Mature *Cercocarpus ledifolius* have thick bark and may survive "light" fires (Schultz 1987). However, more often they are killed by fire, and regeneration is by seedling establishment as sprouts following fire are rare and short-lived (Gruell et al. 1985, Gucker 2006c). Range expansion of this system in the last century has been attributed to decreased fire frequency (Gruell 1982, Gruell et al. 1994). From 1750 to the early 1900s, a mean fire-return interval was between 13 and 22 years, and stands were likely restricted to rocky sites where fuel levels were low. Since 1900 the fire-return interval has increased substantially because of fine fuel reductions with heavy livestock grazing, fire exclusion practices, and/or decreased human-caused fires (Arno and Wilson 1986). However, in the Petersen Mountains of western Nevada, the extent of curl-leaf mountain-mahogany has "decreased dramatically" from 1954 to 1997 as a result of increased fire incidence linked to increased cheatgrass dominance (Ross 1999).

Cercocarpus ledifolius is highly favored by native ungulates for winter range. Excessive browsing by deer and other wildlife has "high-lined" individual shrubs and reduced regeneration (West and Young 2000). Seeds are consumed by a variety of small mammals (Plummer et al. 1968). Mortality from bark damage (drilling) by red-breasted sapsuckers has been reported from Bald Mountain near the California-Nevada border (Ross 1999).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 1210620). These are summarized as:

A) Early Development 1 All Structures (10% of type in this stage): Curl-leaf mountain-mahogany rapidly invades bare mineral soils after fire. Litter and shading by woody plants inhibits establishment. Bunchgrasses and disturbance-tolerant forbs and resprouting shrubs, such as snowberry, may be present. Rabbitbrush and sagebrush seedlings are present. Vegetation composition will affect fire behavior, especially if chaparral species are present. Replacement fire (average FRI of 500 years), mixed-severity fire (average FRI of 100 years) and native herbivory of seedlings (2 out every 100) all affect this class. Replacement fire and native herbivory will reset the ecological clock to zero. Mixed-severity fire does not affect successional age. Succession to class C after 20 years.

B) Mid Development 1 Closed (10% of type in this stage): Young curl-leaf mountain-mahogany are common, although shrub diversity is very high. One out of every 1000 mountain-mahogany are taken by herbivores but this has no effect on model dynamics. Replacement fire (mean FRI of 150 years) causes a transition to class A. Mixed-severity fire can result in either maintenance (mean FRI of 80 years) in the class or a transition to class D (mean FRI of 200 years). Succession to class E after 90 years.

C) Mid Development 1 Open (15% of type in this stage): Curl-leaf mountain-mahogany may codominate with mature sagebrush, bitterbrush, snowberry and rabbitbrush. Few mountain-mahogany seedlings are present. Replacement fire (mean FRI is 150 years) will cause a transition to class A, whereas mixed-severity fire (mean FRI of 50 years) will thin this class but not cause a transition to another class. Native herbivory of seedlings and young saplings occurs at a rate of 1:100 seedlings but does not cause an ecological setback or transition. Succession to class B after 40 years.

D) Late Development 1 Open (20% of type in this stage): Moderate cover of mountain-mahogany. This class represents a combined Mid2-Open and Late1-Open cover and structure combination resulting from mixed-severity fire in class C (note: the combined class results in a slightly inflated representation in the landscape). Further, this class describes one of two late-successional endpoints for curl-leaf mountain-mahogany that is maintained by surface fire (mean FRI of 50 years). Evidence of infrequent fire scars on older trees and presence of open savanna-like woodlands with herbaceous-dominated understory are evidence for this condition. Other shrub species may be abundant, but decadent. In the absence of fire for 150 years (2-3 FRIs for mixed-severity and surface fires), the stand will become closed (transition to class E) and not support a herbaceous understory. Stand-replacement fire every 300 years on average will cause a transition to class A. Class D maintains itself with infrequent surface fire and trees reaching very old age.

E) Late Development 1 Closed (45% of type in this stage): High cover of large shrub or tree-like mountain-mahogany. Very few other shrubs are present and herb cover is low. Duff may be very deep. Scattered trees may occur in this class. This class describes one of two late-successional endpoints for curl-leaf mountain-mahogany. Replacement fire every 500 years on average is the only disturbance and causes a transition to class A. Class will become old-growth with trees reported to reach 1000+ years.

Curl-leaf mountain-mahogany is easily killed by fire and does not resprout (Marshall 1995b, Gucker 2006c). It is a primary early succession colonizer rapidly invading bare mineral soils after disturbance. Fires are not common in early-seral stages, when there is little fuel, except in chaparral. Replacement fires (mean FRI of 150-500 years) become more common in mid-seral stands, where herbs and smaller shrubs provide ladder fuels. By late succession, two classes and fire regimes are possible depending on the history of mixed-severity and surface fires. In the presence of surface fire (FRI of 50 years) and past mixed-severity fires in younger classes, the stand will adopt a savanna-like woodland structure with a grassy understory, spiny phlox and currant. Trees can become very old and will rarely show fire scars. In late, closed stands, the absence of herbs and small forbs makes replacement fires uncommon (FRI of 500 years), requiring extreme winds and drought. In such cases, thick duff provides fuel for more intense fires. Mixed-severity fires (mean FRI of 50-200 years) are present in all classes, except the late-closed one, and more frequent in the mid-development classes (LANDFIRE 2007a, BpS 1210620).

Ungulate herbivory: Heavy browsing by native medium-sized and large mammals reduces mountain-mahogany productivity and reproduction (Marshall 1995b, Gucker 2006c). This is an important disturbance in early- and mid-seral stages, when mountain-mahogany seedlings are becoming established. Browsing by small mammals has been documented (Marshall 1995b, Gucker 2006c), but is relatively unimportant and was incorporated as a minor component of native herbivory mortality.

Avian-caused mortality: In western Nevada, for ranges in close proximity to the Sierra Nevada, sapsucker's drilling of young curl-leaf mountain-mahogany has been observed to cause stand-replacement mortality (C. Ross, NV BLM, pers. comm. 2018). Windthrow and snow creep on steep slopes are also sources of mortality.

ECOLOGICAL INTEGRITY

Change Agents: *Cercocarpus ledifolius* browse may have limited livestock use including domestic goats, sheep, or cattle in spring, fall, and/or winter but rarely in the summer (Gucker 2006c). Stands often occur on steep rocky slopes, but open shrubland or open woodland stands with grassy understory could provide significant livestock forage.

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.

Curl-leaf mountain-mahogany seedlings appear to be sensitive to drought, frost, and competition from exotic vegetation, especially *Bromus tectorum* (Plummer et al. 1968, Shaw et al. 2004, Gucker 2006c). High seedling mortality can also result from heavy browsing by wildlife and mature shrubs can be heavily pruned and suppressed as well (Gucker 2006c).

Fire suppression and exclusion have facilitated an increase in abundance of this system in the Intermountain West (Gruell et al. 1994, Gucker 2006c). However, increased fire frequency and severity from excessive fine-fuel buildup due to cheatgrass invasion may negatively impact some stands.

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.

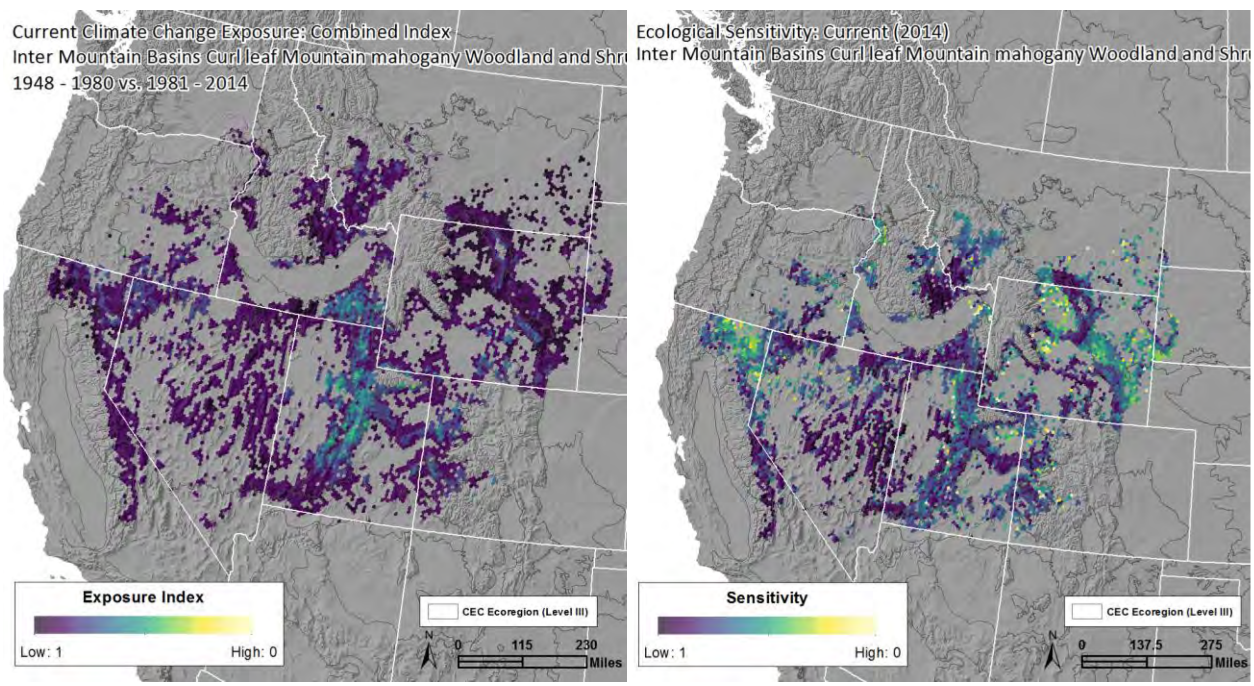

Figure 38. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and Shrubland. The results have been summarized and are

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 Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and 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. 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	Central Basin & Range	Wasatch & Uinta Mountains	Northern Basin & Range	Wyoming Basin	Middle Rockies	Colorado Plateaus	Northwestern Great Plains	Southern Rockies	Eastern Cascades Slopes & Foothills	Sierra Nevada	Blue Mountains
	Potential square miles within ecoregion	1,171	518	316	162	155	118	109	95	71	42	24
Contributions to Relative Vulnerability by Factor												
Vulnerability from **Exposure (2014)**		Low 0.85	Mod 0.71	Low 0.79	Low 0.85	Low 0.86	Low 0.82	Low 0.89	Low 0.85	Low 0.84	Low 0.87	Low 0.87
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.93	0.77	0.87	0.79	0.69	0.85	0.71	0.72	0.82	0.87	0.59
	Fire Regime Departure	0.67	0.52	0.60	0.63	0.73	0.51	0.65	0.58	0.33	0.63	0.53
	Invasive Annual Grasses	1.00	1.00	0.98	1.00	1.00	1.00	0.98	1.00	0.94	0.98	0.92
	Forest Insect & Disease	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
	Sensitivity Average	**0.86**	**0.76**	**0.82**	**0.81**	**0.81**	**0.79**	**0.78**	**0.77**	**0.70**	**0.83**	**0.68**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.63	0.56	0.47	0.42	0.48	0.60	0.29	0.38	0.37	0.64	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	**0.57**	**0.53**	**0.48**	**0.46**	**0.49**	**0.55**	**0.40**	**0.44**	**0.44**	**0.57**	**0.43**
Vulnerability from Measures of **Overall Resilience**		Mod 0.72	Mod 0.65	Mod 0.65	Mod 0.63	Mod 0.65	Mod 0.67	Mod 0.59	Mod 0.60	Mod 0.57	Mod 0.70	Mod 0.55
Climate Change Vulnerability Index		Low	Mod	Mod	Mod	Low	Mod	Mod	Mod	Mod	Low	Mod

Exposure Summary for 1981-2014 Timeframe: The exposure as of 2014 for this woodland and shrubland system is low across 10 of the 11 ecoregions, accounting for 82% of its potential range. Exposure was moderate in the remaining Wasatch and Uinta Mountains ecoregion.

Annual mean temperature has increased between 0.5° and 0.7°C across 10 ecoregions (37-90% of each region). Summer temperature increases of 0.5° to 0.7°C characterize >10% of the area of ecoregions in the central portion of the distribution of this system (Central Basin and Range, Wasatch and Uinta Mountains, and Colorado Plateau ecoregions). Increases in winter temperature were larger in magnitude but were found in less than 5% of the area within any ecoregion. Increased temperatures could exacerbate the effects of drought and reduce recruitment of dominant shrubs within this system.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the interior western U.S. along with increasing number and severity of wildfires and insect outbreaks (Garfin et al. 2014, Mote et al. 2014, Shafer et al 2014). 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 recruitment. Without recruitment curl-leaf mountain-mahogany are essentially relicts of past climate conditions. 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 because of 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 woodland occur in foothill zone of taller ranges so it may be possible for the species of this system to move up into the lower to mid-montane zone while suitable climate is diminished at lower elevations. *Cercocarpus ledifolius* tends to be shorter lived on less harsh sites with deeper soils that burn more frequently, whereas individuals often live more than 300 years on rocky, fire-protected sites (Ross 1999) and are known to live 600 years in relict sites, so it may be able to survive for centuries without regeneration (Dealy 1975). However, there could be accelerated loss of mature trees 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 was moderate to low, with nine ecoregions accounting for 97% of the potential distribution of this type having low sensitivity. The remaining two ecoregions scored moderate for sensitivity. Sensitivity scores were driven largely by fire regime departure.

Contributions to sensitivity from landscape condition were low to moderate, reflecting a combination of fragmentation from roads, urban and suburban development and energy development. These tend to be most severe in valley and foothill regions across the distribution of this type.

Fire regime departure was moderate across ten ecoregions, and high in the remaining Eastern Cascades, Slopes and Foothills ecoregion. This reflects fire suppression practices which have led to the expansion of this generally fire-intolerant type.

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 moderate across all ecoregions of this system. This moderate adaptive capacity is related to moderate (four ecoregions) to low scores (seven ecoregions) for topoclimate variability. These reflect a low level of topoclimate variability associated with lower elevation occurrences of this system extending into valley floors and gentle slopes, especially in the

Northwestern Great Plains. In terms of vulnerability related to functional groups, the system scores high for biological crusts. Species of lichens, algae and cyanobacteria that contribute to substrate developing soil crusts appear to be naturally very diverse across the range of this type. However, the system has moderate diversity in terms of pollinators and decomposers, suggesting increased vulnerability to loss of individual species within these groups. 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 woodland and shrubland system scores in the moderate to low range of overall climate change vulnerability. This is primarily due to moderate contributions to sensitivity from fire regime departure and low adaptive capacity associated with low topoclimate diversity. Although the system is characterized by high levels of fire regime departure, fire suppression has facilitated the spread of this system into areas where fire is thought to have previously excluded it. This altered distribution may interact with changes in climate to influence the sensitivity of this system to the effects of changes in temperature or precipitation patterns.

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 Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and 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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Arno and Wilson 1986, Baker 1983c, Baker and Kennedy 1985, Barbour and Major 1977, Barbour et al. 2007a, Barlow 1977, Barnett and Crawford 1994, Belnap 2001, Belnap et al. 2001, Brown 1982a, Comer et al. 2003*, Cooper et al. 1995, Crawford et al. 2004, Dale et al. 2001, Dealy 1975, Dealy 1978, Drut et al. 1994, Duncan 1975, Ersch 2009, Evans and Belnap 1999, Garfin et al. 2014, Gregg and Crawford 2009, Gruell 1982, Gruell et al. 1985, Gruell et al. 1994, Gucker 2006c, Knight 1994, Knight et al. 1987, LANDFIRE 2007a, Lewis 1975a, Lewis 1975b, Marshall 1995b, Maser et al. 1984, Minnich 2007b, Mote et al. 2014, Mueggler and Stewart 1980, NatureServe Explorer 2011, Phillips et al. 1964, Plummer et al. 1968, Reid et al. 1999, Rich 1980, Rosentreter and Belnap 2003, Ross 1999, Ross pers. comm., Sawyer and Keeler-Wolf 1995, Sawyer et al. 2009, Schultz 1987, Shafer et al. 2014, Shaw et al. 2004, Shiflet 1994, Steele and Geier-Hayes 1995, Stevens-Rumann et al. 2017, Tisdale 1986, USDA NRCS 2011, USFS 1994b, WNHP unpubl. data 2018, Wauer 1977, West and Young 2000

CES304.782 Inter-Mountain Basins Juniper Savanna

Figure 39. Photo of Inter-Mountain Basins Juniper Savanna. Photo credit: Range Types of North America.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occupies dry foothills and sandsheets of western Colorado, northwestern New Mexico, northern Arizona, Utah, and west into the Great Basin of Nevada and southern Idaho. It is typically found at lower elevations ranging from 1000-2300 m. This system is generally found at lower elevations and more xeric sites than Great Basin Pinyon-Juniper Woodland (CES304.773) or Colorado Plateau Pinyon-Juniper Woodland (CES304.767). These occurrences are found on lower mountain slopes, hills, plateaus, basins and flats often where juniper is expanding into semi-desert grasslands and steppe. The vegetation is typically open savanna, although there may be small-patch inclusions of juniper woodlands. This savanna is typically dominated by an open canopy of *Juniperus osteosperma* trees with high cover of perennial bunchgrasses and forbs, with *Bouteloua gracilis, Hesperostipa comata*, and *Pleuraphis jamesii* being most common. In the southern Colorado Plateau, *Juniperus monosperma* or juniper hybrids may dominate the tree layer. Pinyon trees are typically not present because sites are outside the ecological or geographic range of *Pinus edulis* and *Pinus monophylla*. It has been suggested that all *Juniperus osteosperma* stands in Wyoming be placed in Colorado Plateau Pinyon-Juniper Woodland (CES304.767). This savanna system does not occur in Wyoming. Extensive *Juniperus osteosperma* woodlands should be included in one of the pinyon-juniper woodland systems or Rocky Mountain Foothill Limber Pine-Juniper Woodland (CES306.995).

Distribution: This juniper savanna occurs from northwestern New Mexico, northern Arizona, western Colorado, Utah, west into the Great Basin of Nevada and southern Idaho. Where it occurs in California, it is found only in the far eastern edges of the state adjacent to other Great Basin systems.

Nations: US

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

CEC Ecoregions: Middle Rockies, Wasatch and Uinta Mountains, Southern Rockies, Northern Basin and Range, Wyoming Basin, Central Basin and Range, Colorado Plateaus, 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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: The vegetation is typically open savanna, although there may be small-patch inclusions of juniper woodlands. This savanna is typically dominated by an open canopy of *Juniperus osteosperma* trees with high cover of perennial bunchgrasses and forbs, with *Bouteloua gracilis, Hesperostipa comata*, and *Pleuraphis jamesii* being most common. In the southern Colorado Plateau, *Juniperus monosperma* or juniper hybrids may dominate the tree layer. Pinyon trees are typically not present because sites are outside the ecological or geographic range of *Pinus edulis* and *Pinus monophylla*.

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
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* spp., *Phormidium* spp., 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* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp.). Algal diversity is fairly high, but biomass is low in the Colorado Plateau. 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
Juniper savannas occur in semi-arid climates where soil nutrients such as nitrogen are likely a significant constraint on plant growth. Within this system several species of Fabaceae, including species of *Astragalus*, many Poaceae (e.g., *Andropogon hallii, Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Hesperostipa comata, Hesperostipa neomexicana, Leymus salinus, Pleuraphis jamesii*, and *Pseudoroegneria spicata*), species of Rosaceae (*Amelanchier utahensis* and *Cercocarpus montanus*), and some Brassicaceae fix nitrogen. 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).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
In the Colorado Plateau there is a bi-modal precipitation pattern that favors both cool- and warm-season graminoids. However, the predominant winter precipitation in the Great Basin limits understory to mostly cool-season species. Cool-season graminoids: *Achnatherum hymenoides, Elymus elymoides, Hesperostipa comata, Hesperostipa neomexicana, Leymus salinus*, and *Pseudoroegneria spicata*. Warm-season graminoids: *Andropogon hallii, Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Pleuraphis jamesii*, and *Pleuraphis mutica*.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), Townsend's solitaire (*Myadestes townsendi*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Scher 2002). Mammals: Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Neotamias minimus (= Tamias minimus)*), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Panamint kangaroo rat (*Dipodomys panamintinus*), woodrats (*Neotoma* spp.), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), cliff chipmunk (*Neotamias dorsalis*), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), deer (*Odocoileus* spp.), foxes (*Vulpes* spp.), and bighorn sheep (*Ovis canadensis*) are all known to eat juniper berries and may inadvertently disperse seeds in caches or have viable seeds pass through gut (Scher 2002).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this juniper-dominated savanna type.

Environment: This widespread ecological system occupies dry foothills and sandsheets of western Colorado, northwestern New Mexico, northern Arizona, Utah, and west into the Great Basin of Nevada and southern Idaho. It is typically found at lower elevations ranging from 1000-2300m, but may extend up to 2650 m.

Climate: Climate is cool, semi-arid, and continental. Summers are generally hot and dry. Winters are typically cold with occasional snow and there can be extended periods of freezing temperatures. Mean annual precipitation is 25-35 cm, but the seasonal distribution varies across the range of the system. Generally, winter precipitation in the form of westerly storms is maximal along the northwest edge of the range, and summer moisture increases to the east and south (monsoons). Annual precipitation on the Colorado Plateau has a bimodal distribution with moisture peaking in winter and summer.

Physiography/landform: Stands occur on lower to middle elevation mountain slopes and foothills of the many ranges and plateaus of the region.

Soil/substrate/hydrology: Substrates are typically moderately deep to deep, coarse- to fine-textured soils that readily support a variety of growth forms, including trees, grasses, and other herbaceous plants (Stuever and Hayden 1997a, Romme et al. 2009).

Key Processes and Interactions: *Juniperus osteosperma* is a relatively short (generally <10 m tall), shade-intolerant, drought-tolerant, slow-growing, long-lived tree (up to 650 years old) (Meeuwig and Bassett 1983, Zlatnik 1999e). *Juniperus osteosperma* is non-sprouting and may be killed by fire (Wright et al. 1979). Litter from juniper has an allelopathic effect on some grasses such as *Bouteloua gracilis, Festuca idahoensis*, and *Poa secunda* (Jameson 1970, Zlatnik 1999e).

Within a given region, the density of juniper trees, both historically and currently, is strongly related to topo-edaphic gradients. Less steep sites, especially those with finer-textured soils are where savannas, grasslands, and shrub-steppes have occurred in the past. Stands in this system occurred on these gentler slopes and historically may have been large and savanna-like with a very open upper canopy and high grass production. Juniper savanna is usually distributed across the landscape in patches that range from 10s to 100s of acres in size (LANDFIRE 2007a). In areas with very broken topography and/or mesa landforms, this type may have occurred in patches of several hundred acres (LANDFIRE 2007a). In Utah and Nevada pinyon and juniper landscape patches tended to be 10-100s of acres in size (LANDFIRE 2007a).

Key ecological processes are fire, climate fluctuations, grazing/herbivory, and insect/disease outbreaks. The effect of a fire on these stands is largely dependent on the tree height and density, fine-fuel load on the ground, weather conditions and season (Wright et al. 1979). Large trees generally survive unless the fire gets into the crown due to heavy fuel loads in the understory. In this system fire acts to open stands, kill young trees, increase diversity and productivity in understory species, and create a mosaic of stands of different sizes and ages across the landscape (Bradley et al. 1992).

Uncertainty exists about the fire frequencies of this ecological system, though it is predominantly Fire Regime Group III (fire frequency 30-100 years) (LANDFIRE 2007a); the fire regime is primarily determined by fire occurrence in the surrounding matrix vegetation (LANDFIRE 2007a). Lightning-ignited fires were common but typically did not affect more than a few individual trees. Replacement fires were uncommon to rare (average FRI of 100-500 years) and occurred primarily during extreme fire behavior conditions (LANDFIRE 2007a). Mixed-severity fire (average FRI of 100-500 years) was characterized as a mosaic of replacement and surface fires distributed through the patch at a fine scale (<0.1ac) (LANDFIRE 2007a). Surface fires could occur in stands where understory grass cover is high and provides adequate fuel. Surface fires were primarily responsible for producing fire scars on juniper trees and killing juniper seedlings and saplings (average FRI of 100 years).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2411150). The model was reviewed and references to pinyon were removed, then summarized as:

A) Early Development 1 Open (herbaceous-dominated - 5% of type in this stage): Initial post-fire community dominated by annual forbs. Later stages of this class contain greater amounts of perennial grasses and forbs. Duration 10 years with succession to class B, mid-development closed. Replacement fire occurs every 100 years on average. Infrequent mixed-severity fire (average FRI of 300 years) thins vegetation.

B) Mid Development 1 Open (herbaceous-dominated - 5% of type in this stage): Dominated by perennial forbs and grasses. Total cover remains low due to shallow, unproductive soil. Duration 20 years with succession to class C unless infrequent replacement fire (FRI of 100 years) returns the vegetation to A. It is important to note that replacement fire at this stage does not eliminate perennial grasses, thus, succession age in A after this type of fire would be older than zero and <10. Mixed-severity fire (average FRI of 100 years) thins the woody vegetation.

C) Mid Development 2 Open (15% of type in this stage): Shrub-dominated community with young juniper seedlings becoming established. Duration 70 years with succession to class D unless replacement fire (average FRI of 200 years) causes a transition to class A. It is important to note that replacement fire at this stage does not eliminate perennial grasses, thus, succession age in class A after this type of fire would be older than zero and <10. Mixed-severity fire as in class B.

D) Late Development 1 Open (tree-dominated - 35% of type in this stage): Community dominated by young juniper of mixed age structure. Juniper becoming competitive on site and beginning to affect understory composition. Duration 300 years with succession to class E unless replacement fire (average FRI of 500 years) causes a transition to class A. Mixed-severity fire is less frequent than in previous states

(200 years), whereas surface fire every 100 years on average becomes more important at this age in succession.

E) Late Development 2 Open (tree-dominated - 40% of type in this stage): Site dominated by widely spaced old juniper trees. Grasses (e.g., *Bouteloua gracilis, Hesperostipa comata*) present on microsites sites with deeper soils (>20 in) with restricting clay subsurface horizon. Replacement fire and mixed-severity fires are rare (average FRIs of 500 years). Surface fire every 100 years on average will scar ancient trees. Duration 600+ years.

Drought is an important ecological process which limits seedling recruitment and survival and causes mortality of mature trees (Romme et al. 2009). Other important ecological variables include insect infestations, pathogens, herbivory, and seed dispersal by birds and mammals. Juniper berries crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995). The most important dispersers of juniper seeds are birds although mammals also feed on them (Scher 2002). These animals consume juniper berries and excrete viable scarified juniper seeds, which germinate faster than uneaten seeds, over extensive areas (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwings (*Bombycilla garrulus*), but cedar waxwings (*Bombycilla cedrorum*), American robins (*Turdus migratorius*), turkeys (*Meleagris gallopavo*), and several species of jays are also dispersers (Scher 2002).

There are several insects, plant parasites and pathogens (*Cercospora sequoiae*, a blight, and *Gymnosporangium* spp., stem rusts) that attack juniper trees (Burns and Honkala 1990a, Rogers 1995). Two insects, western cedar borer (*Trachykele blondeli*) and juniper twig pruner (*Styloxus bicolor*), damage mature trees and can cause mortality (Rogers 1995). Juniper mistletoe (*Phoradendron juniperinum*) occurs on junipers where it reduces vigor and causes dieback, but rarely causes mortality (Meeuwig and Bassett 1983).

Biological soils crusts (BSC) are important for soil fertility, soil moisture, and soil stability in many semi-arid ecosystems and may be important on juniper savanna sites, especially on those with more exposed soil surface and less herbaceous and litter cover, and low disturbance (Belnap et al. 2001, Belnap and Lange 2003). Cyanobacteria (especially *Nostoc*) fix large amounts of soil nitrogen and carbon (Evans and Belnap 1999, Belnap 2001).

ECOLOGICAL INTEGRITY

Change Agents: Numerous threats influence juniper savannas, including warming climate, heavy livestock grazing, tree harvest, and insect-pathogen outbreaks (West 1999b). The altered fire regime (intensity and frequency) in this savanna system in the form of fire exclusion has also allowed for juniper infill in some stands as well as expansion of juniper trees into the surrounding grasslands (West 1999b, Romme et al. 2009). Heavy grazing by livestock reduces fine fuels and indirectly decreases fire frequency, favoring fire-sensitive woody species such as *Juniperus osteosperma*. This results in uncharacteristically high cover of trees that shade out the grassy understory as it transitions from savanna to woodland. Some people confuse these younger juniper woodlands with true woodlands dependent on naturally fire-protected features such as rock outcrops. Lacking understory to carry fire, these woodlands only burn under extreme fire conditions resulting in high-intensity, high-severity stand-replacing fires. With loss of perennial grass cover with tree shading, these stands may have difficulty re-establishing the native perennial grass-dominated juniper savanna. Additionally, these stands are vulnerable to invasion by non-native annual grasses such as *Bromus tectorum* that can increase fire frequency beyond the natural fire regime.

Many stands within this system have been impacted by past range practices of chaining, tilling, and reseeding with exotic forage grasses. Although the dominant trees appear to regenerate after such disturbances, the effects on understory species are poorly known.

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.

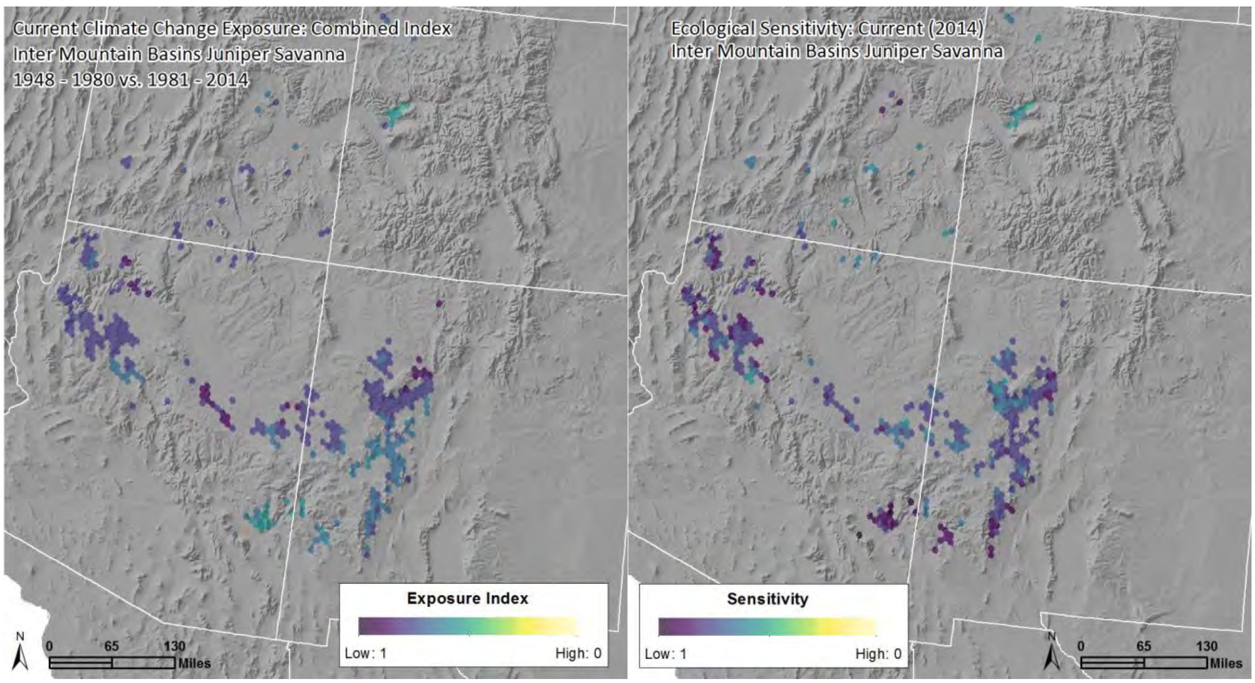

Figure 40. Climate exposure as of 2014 (left) and overall sensitivity (right) for Inter-Mountain Basins Juniper Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 39. Resilience, exposure and vulnerability scores for Inter-Mountain Basins Juniper Savanna 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	Arizona-New Mexico Plateau	Arizona-New Mexico Mountains	Colorado Plateaus
	Potential square miles within ecoregion	386	202	47
Contributions to Relative Vulnerability by Factor				
Vulnerability from **Exposure (2014)**		**Mod** 0.74	**Mod** 0.70	**Mod** 0.71
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.82	0.82	0.65
	Fire Regime Departure	0.35	0.46	0.36
	Invasive Annual Grasses	1.00	1.00	0.92
	Sensitivity Average	**0.72**	**0.76**	**0.64**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.26	0.32	0.37
	Diversity within Functional Species Groups	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null
	Adaptive Capacity Average	**0.38**	**0.41**	**0.43**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.55	**Mod** 0.58	**Mod** 0.54
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this uncommon savanna system is moderate. The Annual Mean Temperature has increased by 0.66°C in all ecoregions; in the Arizona/New Mexico Plateau and Arizona/New Mexico Mountains ecoregions, this increase is across >90% of its distribution; in the Colorado Plateaus for 70%. Similar increases are seen for the Mean Temperature of the Warmest Quarter (up to 0.79°C), ranging from 32% to 40% of its distribution. In the Arizona/New Mexico Plateau and Arizona/New Mexico Mountains ecoregions, Precipitation of the Coldest Quarter shows an increase of some 15 mm over the baseline average of 32 mm; in the Arizona/New Mexico Plateau ecoregion this increase is across 32% of its distribution, and only 10% in the Arizona/New Mexico Mountains.

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 tree recruitment. Without recruitment juniper stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may weaken juniper trees and may make them more susceptible to lethal attacks by forest diseases and insects. Additionally, warmer/drier fuels may result in more frequent fires that could increase rates of loss of mature trees.

Many stands of this woodland type occur in the foothill zones of taller ranges and plateaus so it may be possible for the species of this system to transition into lower montane zone as suitable climate is diminished at lower elevations. Juniper trees are long-lived; *Juniperus osteosperma* and *Juniperus scopulorum* frequently live more than 300 years and so may be able to survive as relicts for centuries without regeneration (Burns and Honkala 1990a). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires as a result of hotter, drier climate.

Ecosystem Resilience: Sensitivity: This uncommon juniper savanna system has sensitivity to climate change scoring as low (higher scores) in one ecoregions, and moderate in two others. In the Colorado Plateaus ecoregion (moderate sensitivity) it is the combination of moderate landscape condition (more development) and moderate fire regime departure that is reflected in the sensitivity score.

Landscape condition is high (less development, higher scores) in the Arizona-New Mexico Plateau and Arizona-New Mexico Mountains ecoregions, and moderate in the Colorado Plateau. However, even in the 2 ecoregions with good landscape condition, the scores indicate that development is a factor (scores of 0.82). 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 low, but this system is poorly mapped in the Great Basin, and hence was not assessed in the areas where cheatgrass has invaded many ecosystems. On the other hand, fire regime departure is moderate and approaching high in all three ecoregions. This is best explained as a reflection of fire suppression allowing for juniper becoming increasingly dense and shifting the stand structure from open scattered old trees to a younger, denser woodland. Higher cover of trees and grazing both reduce cover of the grasses which carry fire; hence these woodlands only burn under extreme fire conditions resulting in high-intensity, high-severity stand-replacing fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these savannas. 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 range wide for this uncommon system. Topoclimatic variability is generally low, as these savannas occur across generally low-relief landforms and topography, such as on lower mountain slopes, hills, plateaus, basins and flats often where juniper is expanding into semi-desert grasslands and steppe. 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 four identified functional species groups varies from moderate to high. Nitrogen-fixation and the diversity of the mix of cool-season and warm-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. A mix of cool-season and warm-season perennial 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.

Seed dispersal is provided by many bird and mammal species and appears to have high within-stand diversity. Substrate developing soil crusts also have high within stand diversity, and include many cyanobacteria, lichens and mosses.

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: These tree savannas score in the moderate range of overall climate change vulnerability throughout their range. This is primarily due to moderate scores for exposure, low scores for adaptive capacity, and moderate to high average scores for sensitivity measures. Inherent vulnerabilities are moderate to high for types such as this with moderate scores for fire regime departure and low to moderate topoclimate variability. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Juniper Savanna

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 and fire breaks.
Moderate	**Emphasize restoration to enhance resilience.** Restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.

Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Balda 1987, Bell et al. 2009, Belnap 2001, Belnap and Lange 2003, Belnap et al. 2001, Bradley et al. 1992a, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Evans and Belnap 1999, Eyre 1980, Gottfried et al. 1995, Jameson 1970, Johnsen 1962, LANDFIRE 2007a, McCulloch 1969, Meeuwig and Bassett 1983, Rogers 1995, Romme et al. 2003, Romme et al. 2009, Rosentreter and Belnap 2003, Salomonson 1978, Scher 2002, Shiflet 1994, Short et al. 1977, Stuever and Hayden 1997a, West 1999b, Wright et al. 1979, Zlatnik 1999e

M027. Southern Rocky Mountain-Colorado Plateau Two-needle Pinyon - Juniper Woodland

CES304.766 Colorado Plateau Pinyon-Juniper Shrubland

Figure 41. Photo of Colorado Plateau Pinyon-Juniper Shrubland. Photo credit: Jimmy Thomas, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system is characteristic of the rocky mesatops and slopes on the Colorado Plateau and western slope of Colorado, but these stunted tree shrublands may extend further upslope along the low-elevation margins of taller pinyon-juniper woodlands. Sites are drier than Colorado Plateau Pinyon-Juniper Woodland (CES304.767). Substrates are shallow/rocky and shaly soils at lower elevations (1200-2000 m). Sparse examples of the system grade into Colorado Plateau Mixed Bedrock Canyon and Tableland (CES304.765). The vegetation is dominated by dwarfed (usually <3 m tall) *Pinus edulis* and/or *Juniperus osteosperma* trees forming extensive tall shrublands in the region along low-elevation margins of pinyon-juniper woodlands. Other shrubs, if present, may include *Artemisia nova, Artemisia tridentata ssp. wyomingensis, Chrysothamnus viscidiflorus*, or *Coleogyne ramosissima*. Herbaceous layers are sparse to moderately dense and typically composed of xeric graminoids.

Distribution: This system occurs on rocky mesatops and slopes on the Colorado Plateau.

Nations: US

States/Provinces: AZ, CO, NM, UT

CEC Ecoregions: Wasatch and Uinta Mountains, Southern Rockies, Wyoming Basin, 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: The vegetation is dominated by dwarfed (usually <3 m tall) *Pinus edulis* and/or *Juniperus osteosperma* trees forming extensive tall shrublands in the region along low-elevation margins of pinyon-juniper woodlands. Other shrubs, if present, may include *Artemisia nova, Artemisia tridentata ssp. wyomingensis, Chrysothamnus viscidiflorus*, or *Coleogyne ramosissima*. Herbaceous layers are sparse to moderately dense and typically composed of xeric graminoids.

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
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* spp., *Phormidium* spp., *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* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp. Algal diversity is fairly high and biomass is low in the Colorado Plateau, but higher than warm desert regions with over 40 species. 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: Low
Pinyon-juniper shrublands occur in semi-arid climates typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid pinyon-juniper shrublands typically have low herbaceous cover and low diversity. Within this system several species of Fabaceae, Poaceae (e.g., *Bouteloua gracilis, Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana, Pseudoroegneria spicata)*, Rosaceae (*Amelanchier utahensis, Cercocarpus intricatus, Cercocarpus montanus, Coleogyne ramosissima, Purshia stansburiana, Purshia tridentata*), and some Brassicaceae can fix nitrogen; however, within stand species diversity is typically low. 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.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Scher 2002). The primary dispersers of pinyon seeds are scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). Mammals: Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Neotamias minimus (= Tamias minimus)*), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), woodrats (*Neotoma* spp.), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*), squirrels (*Sciurus* spp.), chipmunks (*Neotamias* spp.), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), deer (*Odocoileus* spp.), and bighorn sheep (*Ovis canadensis*) are all known to eat singleleaf pinyon seeds and may inadvertently disperse seeds (Anderson 2002).

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

Environment: This tree-dominated ecological system is characteristic of the dry, lower elevation sites in the rocky canyons of the Colorado Plateau and Western Slope of Colorado (1200-1600 m elevation), but these stunted-tree shrublands may extend further upslope to 2000 m on locally xeric sites (Stuever and Hayden 1997a).

Climate: Climate is semi-arid to arid with hot summers and cold winters. Based on data from Moab, Utah, average annual precipitation is approximately 25 cm. Precipitation mostly occurs as rain during monsoons (late July to October) and spring (March to May). June is the driest month.

Physiography/landform: Stands occur on the rocky mesatops, canyon rims, and dry slopes and ridges that are too dry for woodlands.

Soil/substrate/hydrology: Substrates are shallow/rocky and shaly soils at lower elevations. Sandstone is the most common parent material.

Key Processes and Interactions: *Pinus edulis* is extremely drought-tolerant and slow-growing (Little 1987). It is also non-sprouting and may be killed by fire (Wright et al. 1979, Wright and Bailey 1982a). This shrubland or stunted woodland (<3 m tall) is characteristic of the drier, hotter low-elevation sites (usually <1600 m), rock outcrops and sites with shallow soils that limit tree growth. The understory is typically sparser than Colorado Plateau Pinyon-Juniper Woodland (CES304.767) and this system is more affected by drought than fires; however, occurrences of this system will burn under extreme fire conditions. The effect of fire on a stand is largely dependent on tree height and density, fine-fuel load on the ground, weather conditions, and season (Dwyer and Pieper 1967, Wright et al. 1979, Wright and Bailey 1982a). Trees are more vulnerable in open stands where fires frequently occur in the spring, when the relative humidity is low, wind speeds are over 10-20 mph, and there are adequate fine fuels to carry fire (Wright et al. 1979, Wright and Bailey 1982a). Under other conditions, burns tend to be spotty with low tree mortality. Large trees are generally not killed unless fine fuels, such as tumbleweeds, have accumulated beneath the trees to provide ladder fuels for the fire to reach the crown (Jameson 1962). Closed-canopy stands burn infrequently because they typically do not have enough understory or wind to carry fire (Wright et al. 1979).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2311020). These are summarized as:

A) Early Development 1 Open (herbaceous-dominated - 5% of type in this stage): Initial post-fire community dominated by annual forbs. Later stages of this class contain greater amounts of perennial grasses and forbs. Duration 10 years with succession to class B, mid-development closed. Replacement fire occurs every 100 years on average. Infrequent mixed-severity fire (average FRI of 300 years) thins vegetation.

B) Mid Development 1 Open (shrub-dominated - 5% of type in this stage): Dominated by shrubs, perennial forbs and grasses. Total cover remains low due to shallow, unproductive soil. Duration 20 years with succession to class C unless infrequent replacement fire (FRI of 100 years) returns the vegetation to class A. It is important to note that replacement fire at this stage does not eliminate perennial grasses, thus, succession age in class A after this type of fire would be older than zero and <10. Mixed-severity fire (average FRI of 100 years) thins the woody vegetation but does not cause a transition to another class.

C) Mid Development 2 Open (shrub-dominated - 10% of type in this stage): Shrub-dominated community with young juniper and pinyon seedlings becoming established. Duration 70 years with succession to class D unless replacement fire (average FRI of 200 years) causes a transition to class A. It is important to note that replacement fire at this stage does not eliminate perennial grasses, thus, succession age in class A after this type of fire would be older than zero and <10. Mixed-severity fire as in class B.

D) Late Development 1 Open (conifer-dominated - 35% of type in this stage): Community dominated by young and stunted juniper and pinyon of mixed age structure. Juniper and pinyon becoming competitive on site and beginning to affect understory composition. Duration 300 years with succession to E unless replacement fire (average FRI of 500 years) causes a transition to A. Mixed-severity fire is less frequent than in previous states (200 years), whereas surface fire every 100 years on average becomes more important at this age in succession.

E) Late Development 2 Open (conifer-dominated - 45% of type in this stage): Site dominated by widely spaced old and stunted juniper and pinyon. Understory depauperate and high amounts of bare ground and rock present. Grasses present on microsites with deeper soils (>50 cm [20 inches]) with restricting clay subsurface horizon. Potential maximum overstory coverage is greater in those stands with pinyon as compared to those with only juniper. Replacement fire and mixed-severity fires are rare (average FRIs of 500 years). Surface fire every 100 years on average will scar ancient stunted trees. Duration 600 years+.

Other important ecological processes include drought, insect infestations, pathogens, herbivory and seed dispersal by birds and mammals. Juniper berries and pinyon nut crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995). The most important dispersers of juniper and pinyon seeds are birds, although many mammals also feed on them. These animals consume juniper berries and excrete viable scarified juniper seeds, which germinate faster than uneaten seeds, over extensive areas (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), but others include cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), turkey (*Meleagris gallopavo*), and several species of jays (Scher 2002). Pinyon seeds are a critically important food source for scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). These birds are the primary dispersers of pinyon seeds and, during mast crop years, cache hundreds of thousands of pinyon pine seeds, many of which are never recovered (Balda and Bateman 1971, Vander Wall and Balda 1977, Ligon 1978). Because pinyon seeds are heavy and totally wingless, seed dispersal is dependent on vertebrate dispersers that store seeds in food caches, where unconsumed seeds may germinate. This dispersal mechanism is a good example of a co-evolved, mutualistic, plant-vertebrate relationship (Vander-Wall et al. 1981, Evans 1988, Lanner 1996) and would be at risk with loss of trees or dispersers. Many mammals are also known to eat pinyon seeds, such as several species of mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias* spp.), and desert bighorn sheep (*Ovis canadensis nelsoni*) and, although less effective, they may inadvertently disperse seeds (Anderson 2002).

Although *Pinus edulis* is drought-tolerant, prolonged droughts will weaken trees and promote mortality by secondary agents. Periodic die-offs of pinyon pine caused by insects, such as the pinyon ips beetle (*Ips confusus*), or fungal agents, such as blackstain root-rot (*Leptographium wageneri*), tend to be correlated with droughts (Anhold 2005). These mortality events may be localized or widespread but can result in 50 to 90% mortality of *Pinus edulis* in affected areas (Harrington and Cobb 1988). There are many insects, pathogens, and plant parasites that attack pinyon and juniper trees (Meeuwig and Bassett 1983, Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). Juniper mistletoe (*Phoradendron juniperinum*) occurs on junipers and pinyon dwarf mistletoe (*Arceuthobium divaricatum*) occurs on pines. Both mistletoes reduce vigor and cause dieback but rarely cause mortality (Meeuwig and Bassett 1983). For pinyon and juniper, there are at least seven insects, and fungi such as black stain root-rot (*Leptographium wageneri*), and pinyon needle rust and pinyon blister rust (Skelly and Christopherson 2003). The insects are normally present in these woodland stands and during drought-induced water stress, outbreaks may cause local to regional mortality (Wilson and Tkacz 1992, Gottfried et al. 1995, Rogers 1995). Most insect-related pinyon mortality in the West is caused by pinyon ips bark beetle (*Ips confusus)* (Rogers 1993).

Most pinyon-juniper woodlands and shrublands in the Southwest have high soil erosion potential (Baker et al. 1995). Several studies have measured present-day erosion rates in pinyon-juniper woodlands, highlighting the importance of herbaceous cover and biological soil crusts in minimizing precipitation runoff and soil loss (Baker et al. 1995, Ladyman and Muldavin 1996, Belnap et al. 2001).

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from catastrophic crown fires and "chaining" or mechanical removal of trees by land management agencies to convert these wooded areas to grasslands for livestock (Stevens 1999, Tausch 1999a, Tausch and Hood 2007). Before 1900, this system was mostly open shrubland restricted to fire-safe areas on rocky ridges and outcrops where the low cover of fine fuels reduced the spread of fires. Over the last 100 years fire regimes were altered by fire suppression and grazing by livestock, which reduces the amount of fine fuels (grasses) that carry fire, thus reducing fire frequency (Pieper and Wittie 1990, Swetnam and Baisan 1996, Miller and Tausch 2001). Consequently, some stands of this system have a more closed canopy. Direct and indirect fire suppression has led to a buildup of woody fuels that increases the likelihood of high-intensity, stand-replacing fires. If exotic species are present, post-crown fire and post-treatment outcomes may result in conversion to exotic species.

In addition, energy exploration and development and mining operations can drastically impact natural vegetation. Road building and power transmission lines continue to fragment vegetation and provide vectors for invasive species. Invasion by introduced annual grass, such as *Bromus tectorum* and other annuals, provide fine fuels that carry fire (Tausch 1999a, Miller and Tausch 2001, Tausch and Hood 2007), although the sites where this system occurs may be too dry for cheatgrass to become abundant.

Management actions such as chaining pinyon-juniper stands creates a large food source of injured pines for native ips beetles (*Ips confusus*) to feed on that can quickly multiply, creating epidemic outbreaks of beetles that attack and kill many healthy pinyons (Furniss and Carolin 2002). Increasingly frequent drought stresses pinyons and makes them less able to survive ips attacks (Furniss and Carolin 2002).

Other 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. This system is popular for outdoor recreation (e.g., hiking, camping, mountain biking, and off-road vehicle recreation) in canyons and mesas in southern Utah. Recreationalists are vectors for invasive species and likely degrade these shrublands in other ways such as soil compaction, soil erosion, and damage to biological soil crusts (Schwinning et al. 2008).

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.

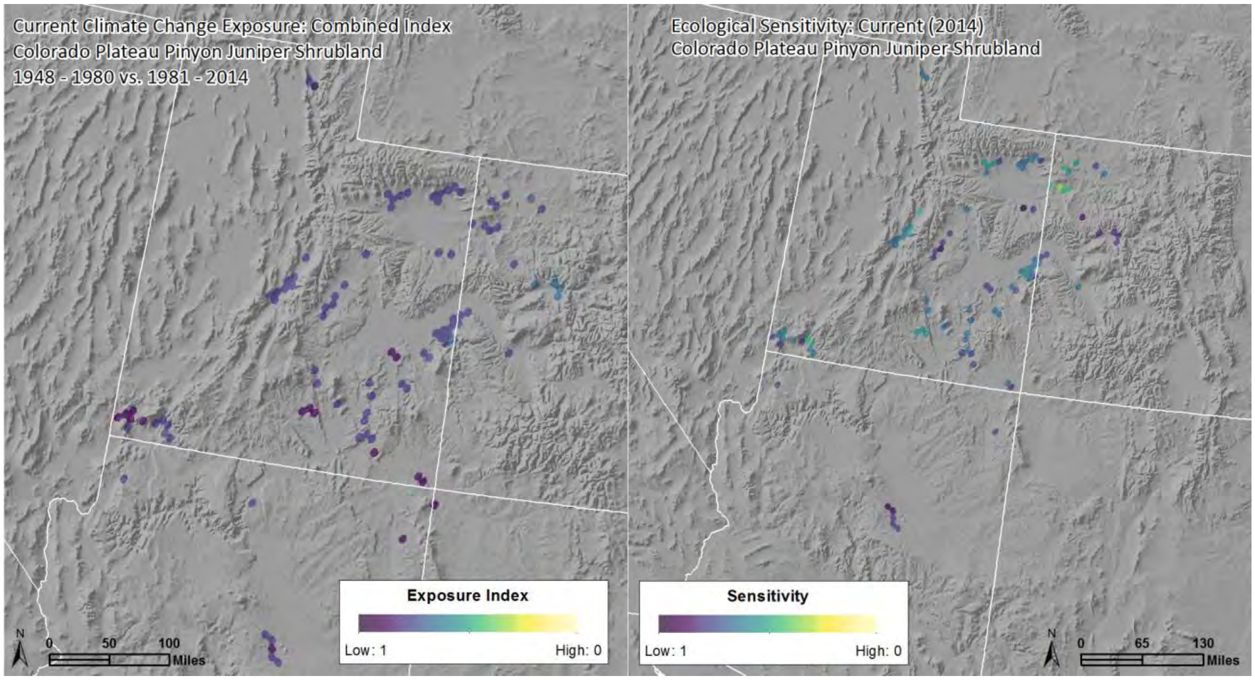

Figure 42. Climate exposure as of 2014 (left) and overall sensitivity (right) for Colorado Plateau Pinyon-Juniper Shrubland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 41. Resilience, exposure and vulnerability scores for Colorado Plateau Pinyon-Juniper 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	Colorado Plateaus
	Potential square miles within ecoregion	105
Contributions to Relative Vulnerability by Factor		
Vulnerability from **Exposure (2014)**		**Mod** 0.55
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.63
	Fire Regime Departure	0.45
	Invasive Annual Grasses	0.89
	Sensitivity Average	**0.66**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.32
	Diversity within Functional Species Groups	0.16
	Keystone Species Vulnerability	Null
	Adaptive Capacity Average	**0.24**
Vulnerability from Measures of **Overall Resilience**		**High** 0.45
Climate Change Vulnerability Index		**High**

Exposure Summary for 1981-2014 Timeframe: Rangewide for this uncommon system, exposure as of 2014 is somewhat limited. In the Colorado Plateaus ecoregion, where it is most abundant, an emerging pattern of changing climate is seen as increases in Annual Mean Temperature and Mean Temperature of the Warmest Quarter of 0.64°C, for about 40% of its distribution in the ecoregion. No other variables showed any marked change. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

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 tree recruitment. Without recruitment pinyon and juniper stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may weaken pinyon trees and may make them more susceptible to lethal attacks by forest diseases and insects such as the pinyon ips beetles (*Ips confusus*). Longer milder climate periods may increase the number of generations of ips beetles above the average of two and a half to three annually. Additionally, warmer/drier fuels may result in more frequent fires that could increase rates of loss of mature stands through conversion of these wooded stands to annual grasslands or shrublands that are adapted to frequent fire (Miller and Tausch 2001).

Pinyon and juniper trees are long-lived; *Juniperus osteosperma* and *Pinus edulis* frequently live more than 300 years and so may be able to survive as relicts for centuries without regeneration (Burns and Honkala 1990a). However, there could be accelerated loss of mature trees because of more frequent and extended drought growing in this marginal tree habitat as a result of hotter, drier climate.

Climate change has affected the distribution pinyon-juniper woodlands in the past and current climate change will likely shift the geographic and elevational distribution in the future (Van Devender 1977, 1990, Betancourt et al. 1993, McAuliffe and Van Devender 1998). For example, after 500 years BP, winter precipitation increased and caused a re-expansion of pinyon-juniper woodland that sharply increased after 1700 and again in the early 1900s (Davis and Turner 1986, Mehringer and Wigand 1990, as cited in Gori and Bate 2007). Shorter term variation in climate has important implications for this system. Regional droughts coupled with stress-induced insect outbreaks (pinyon ips beetle) have caused widespread mortality of pinyons (Breshears et al. 2005). This affects species dominance patterns, tree age structure, tree density, and canopy cover within pinyon-juniper woodlands and will shift dominance to juniper (Betancourt et al. 1993). Conversely, wet periods create conditions for tree recruitment and growth.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across the range of this type, which is restricted to the Colorado Plateaus ecoregion.

These dwarf-woodlands often occur on remote plateaus and in canyonlands away from infrastructure development; however, landscape condition is moderate (more development) (**Table 41**). 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 minor areas of urban, suburban and exurban development.

Risk of invasive plants in low overall and is currently concentrated in northwestern Colorado where there is oil and gas development. Fire regime departure is moderate across the range of this system. Although the risk of annual grass invasion is low, interactions of direct fire suppression and historic overgrazing by livestock, which removes the fine fuels that carry fire, have reduced fire frequency and altered the structure of this scrub making it vulnerable to catastrophic crown fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these scrublands. 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 for this uncommon ecological system is very low in the one ecoregion where it occurs. Both topoclimatic variability and diversity within functional species groups contribute to the very low adaptive capacity. Topoclimatic variability is low, as these dwarf-woodlands occur across landforms with generally little topographic relief, such as rocky mesa tops, canyon rims, and dry slopes 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.

While two of the three functional species groups have high diversity, nitrogen fixation has low diversity and is the most limiting in relation to adaptive capacity. 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 for the system. Conversely, seed dispersers and substrate developing soils crusts appear to be naturally diverse across the range of this type. Many species of birds and mammals disperse both juniper and pinyon seed. Soil crust taxa include many cyanobacteria, lichens and mosses.

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: These wooded shrublands score in the high range of overall climate change vulnerability. This is primarily due to their moderate scores for exposure, very low scores for adaptive capacity, and generally moderate contributions from sensitivity measures. Inherent vulnerabilities are high for types such as this with low diversity within key functional species groups, such as with nitrogen fixing species, and low topoclimate variability. Additionally, these shrublands are highly susceptible to effects of drought. They occur on lower elevation sites for pinyon and juniper and have increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Colorado Plateau Pinyon-Juniper 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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches.

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
	Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson 2002, Anhold 2005, Baker et al. 1995, Balda 1987, Balda and Bateman 1971, Belnap 2001, Belnap et al. 2001, Betancourt et al. 1993, Breshears et al. 2005, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Davis and Turner 1986, Dwyer and Pieper 1967, Evans 1988, Furniss and Carolin 2002, Gori and Bate 2007, Gottfried et al. 1995, Harrington and Cobb 1988, Jameson 1962, Johnsen 1962, LANDFIRE 2007a, Ladyman and Muldavin 1996, Lanner 1996, Ligon 1978, Little 1987, McAuliffe and Van Devender 1998, McCulloch 1969, Meeuwig and Bassett 1983, Mehringer and Wigand 1990, Miller and Tausch 2001, Pieper and Wittie 1990, Rogers 1993, Rogers 1995, Romme et al. 2009, Rosentreter and Belnap 2003, Salomonson 1978, Scher 2002, Schwinning et al. 2008, Shiflet 1994, Short et al. 1977, Skelly and Christopherson 2003, Stevens 1999a, Stuever and Hayden 1997a, Swetnam and Baisan 1996a, Tausch 1999, Tausch and Hood 2007, Van Devender 1977, Van Devender 1990, Vander Wall and Balda 1977, Vander Wall et al. 1981, Weber et al. 1999, Wright and Bailey 1982a, Wright et al. 1979

CES304.767 Colorado Plateau Pinyon-Juniper Woodland

Figure 43. Photo of Colorado Plateau Pinyon-Juniper Woodland. Photo credit: Bob Wick, BLM Dominguez-Escalante NCA, used under Creative Commons license CC BY 2.0, https://creativecommons.org/licenses/by/2.0

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occurs in dry mountains and foothills of the Colorado Plateau region including the Western Slope of Colorado to the Wasatch Range, south to the Mogollon Rim, and east into the northwestern corner of New Mexico. It is typically found at lower elevations ranging from 1500-2440 m. These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Soils supporting this system vary in texture, ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. *Pinus edulis* and/or *Juniperus osteosperma* dominate the tree canopy. In the southern portion of the Colorado Plateau in northern Arizona and northwestern New Mexico, *Juniperus monosperma* and hybrids of *Juniperus* spp. may dominate or codominate the tree canopy. *Juniperus scopulorum* may codominate or replace *Juniperus osteosperma* at higher elevations. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent. Associated species include *Arctostaphylos patula, Artemisia tridentata, Cercocarpus intricatus, Cercocarpus montanus, Coleogyne ramosissima, Purshia stansburiana, Purshia tridentata, Quercus gambelii, Bouteloua gracilis, Pleuraphis jamesii, Pseudoroegneria spicata, Poa secunda*, or *Poa fendleriana*. This system occurs at higher elevations than Great Basin Pinyon-Juniper Woodland (CES304.773) and Colorado Plateau shrubland systems where sympatric.

Distribution: This system occurs on dry mountains and foothills of the Colorado Plateau region from the Western Slope of Colorado to the Wasatch Range, south to the Mogollon Rim, and east into the northwestern corner of New Mexico. It is typically found at lower elevations, ranging from 1500-2440 m. In Wyoming, it would occur only in the southern portions of mapzone 22.

Nations: US

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

CEC Ecoregions: Wasatch and Uinta Mountains, Southern Rockies, 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: K.A. Schulz

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

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pinus edulis* and/or *Juniperus osteosperma* dominate the tree canopy. In the southern portion of the Colorado Plateau in northern Arizona and northwestern New Mexico, *Juniperus monosperma* and hybrids of *Juniperus* spp. may dominate or codominate the tree canopy. *Juniperus scopulorum* may codominate or replace *Juniperus osteosperma* at higher elevations. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent. Associated species include *Arctostaphylos patula, Artemisia tridentata, Cercocarpus intricatus, Cercocarpus montanus, Coleogyne ramosissima, Purshia stansburiana, Purshia tridentata, Quercus gambelii, Bouteloua gracilis, Pleuraphis jamesii, Pseudoroegneria spicata, Poa secunda*, or *Poa fendleriana*.

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
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* spp., *Phormidium* spp.,

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* spp., *Heppia lutosa, Leproloma membranaceum (= Lepraria membranacea), Physconia muscigena, Psora* spp., *Squamarina lentigera*, and *Toninia* spp. Algal diversity is fairly high, but biomass is low in the Colorado Plateau, but higher than warm desert regions with over 40 species. 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: Low
Pinyon-juniper woodlands occur in semi-arid climates typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. These semi-arid woodlands typically have low to moderate herbaceous cover and low diversity. Most species of Fabaceae (including species of concern: *Astragalus inyoensis, Astragalus convallarius var. margaretiae*), and many Poaceae (*Bouteloua gracilis, Hesperostipa comata, Festuca idahoensis, Leymus cinereus, Poa fendleriana, Pseudoroegneria spicata*), Rosaceae (*Amelanchier utahensis, Cercocarpus intricatus, Cercocarpus montanus, Coleogyne ramosissima, Purshia stansburiana, Purshia tridentata*), and some Brassicaceae can fix nitrogen in this system. However, within stand species diversity is typically low. 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 is moderate; however, within stand species diversity of nitrogen fixers is typically low.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), Mexican jay (*Aphelocoma wollweberi*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Scher 2002). The primary dispersers of pinyon seeds are scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). Mammals: Great Basin pocket mouse (*Perognathus parvus*), least chipmunk (*Neotamias minimus (= Tamias minimus)*), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Panamint kangaroo rat (*Dipodomys panamintinus*), woodrats (*Neotoma* spp.), white-tailed antelope ground squirrel (*Ammospermophilus leucurus*), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), cliff chipmunk (*Neotamias dorsalis*), rock squirrel (*Otospermophilus variegatus (= Spermophilus variegatus)*), deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) are all known to eat singleleaf pinyon seeds and may inadvertently disperse seeds in caches or have viable seeds pass through gut (Hollander and Vander Wall 2004).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this pinyon-juniper woodland type.

Environment: This ecological system occurs in dry mountains and foothills of the Colorado Plateau region, including the western slope of Colorado to the Wasatch Range, south to the Mogollon Rim, and east into the northwestern corner of New Mexico. It is typically found at lower elevations ranging from 1500-2440 m (Hess and Wasser 1982, Stuever and Hayden 1997a).

Climate: Climate is semi-arid. Annual precipitation is usually from 30-55 cm in the form of rain and snow. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides.

Physiography/landform: These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Stands occur on a variety of aspects and slopes. Slope may range from nearly level to steep (up to 80%).

Soil/substrates/hydrology: Soils supporting this system vary in depth and texture, ranging from shallow, stony, cobbly, gravelly sandy loams to often deeper clay loam or clay. Parent materials likewise vary widely from granite, basalt, limestone, and sandstone to mixed alluvium (Springfield 1976). Soil depths may range from shallow to deep.

Key Processes and Interactions: Key ecological processes are drought, fire, herbivory, and insect/disease outbreaks. Both *Pinus edulis* and *Juniperus osteosperma* are relatively short (generally <15 m tall), shade-intolerant, drought-tolerant, slow-growing, long-lived trees (especially *Juniperus osteosperma* can reach 650 years old) (Meeuwig and Bassett 1983, Little 1987, Zlatnik 1999e, Romme et al. 2003). Both tree species are also non-sprouting and may be killed by fire (Wright et al. 1979). The effect of a fire on these stands is largely dependent on the tree height and density, fine fuel load on the ground, weather conditions and season (Wright et al. 1979). Large trees generally survive unless the fire gets into the crown due to heavy fuel loads in the understory. In this system fire acts to open stands, increase diversity and productivity in understory species, and create a mosaic of stands of different sizes and ages across the landscape while maintaining the boundary between woodlands and adjacent shrublands or grasslands (Bradley et al. 1992).

As modeled by LANDFIRE (2007a), the fire regime is characterized by somewhat frequent mixed-severity mosaic fires (mean FRI of 150-200 years) with very infrequent replacement fires (mean FRI of 200-500 years) (Rondeau 2001). Surface fire occurs only in the earliest succession class every 200 years on average (LANDFIRE 2007a). There is frequent fire spread from adjacent types (LANDFIRE 007a). Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides. Weather-related stress thins trees every 145 years on average in more closed stands (LANDFIRE 2007a). Insects/disease has a similar effect, but with a greater frequency in closed stands (mean return interval of 100 years) than open ones (mean return interval of 1000 years) (LANDFIRE 2007a). Competition from grasses and older trees in late-open stands is also included as a disturbance that maintains stand openness (LANDFIRE 2007a).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2310160). These are summarized as:

A) Early Development 1 All Structures (10% of type in this stage): Grass/forb/shrub/seedling - usually post-fire. Cover is 0-30%. Shrub height 0.5 m. Both replacement fire and surface fire occur in this class (mean FRI of 200 years for both). The dominant succession path is to class C (mid, open) after 60 years, although the model allows for an alternate succession pathway to class B (mid, closed) 1/100 times to represent tree invasion.

B) Mid Development 1 Closed (20% of type in this stage): Tree cover is 40-70%. Tree height <5 m. Mid-development, dense (>40% cover) pinyon-juniper woodland; understory is sparse. Replacement fire occurs every 400 years on average. Three disturbances cause a transition to class C (mid, open): mixed-severity fire (mean FRI of 150 years), insects/disease (mean return interval of 100 years) and weather-related stress (mean return interval of 150 years). Succession to class E, late-closed, after 120 years.

C) Mid Development 1 Open (25% of type in this stage): Tree cover is 10-40%. Tree height <5 m. Mid-development, open (<40% cover) pinyon-juniper stand with mixed shrub/herbaceous community in understory. The mean FRI for replacement fire is 500 years. Mixed-severity fire (mean FRI of 200 years) and insects/disease (mean return interval of 1000 years) maintain stand structure. Primary succession pathway to class D, late-open, after 100 years, although an alternate succession pathway to class B 2/100 times is included to represent tree invasion;

D) Late Development 1 Open (35% of type in this stage): Tree cover is 10-40%. Tree height 5-10 m. Late-development, open juniper-pinyon stand with "savanna-like" appearance; mixed grass/shrub/herbaceous community. Replacement fire is infrequent (mean FRI of 500 years). Mixed-severity fire (mean FRI of 200 years), insects/disease (mean return interval of 1000 years) and competition (1/100 prob/year) maintain vegetation in class D, which is the primary succession endpoint. Alternate succession to class E, late-closed, occurs 1/200 times to represent tree invasion;

E) Late Development 2 Open (conifer-dominated - 35% of type in this stage): Tree cover is 40-70%. Tree height 5-10 m. Dense, old-growth stands with multiple layers. Late-development, closed pinyon-juniper forest. May have all-aged, multi-storied structure. Moderate mortality within stand. Occasional shrubs with few grasses and forbs and often rock or bare soil. The mean FRI of replacement fire is 500 years. Mixed-severity fire (mean FRI of 150 years), insects/disease (mean return interval of 100 years) and weather-related stress (mean return interval of 100 years) thin tree cover, therefore causing a transition to class D. Succession maintains vegetation in class E.

Other important ecological processes include drought, insect infestations, pathogens, herbivory, and seed dispersal by birds and mammals. Juniper berry and pinyon nut crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995). Large mammals, such as mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), eat leaves and seeds of both species and they browse woodland grasses, forbs and shrubs, including *Artemisia tridentata, Cercocarpus montanus, Quercus gambelii*, and *Purshia stansburiana* (Short and McCulloch 1977).

The most important dispersers of juniper and pinyon seeds are birds, although many mammals also feed on them. These animals consume juniper berries and excrete viable scarified juniper seeds over extensive areas, which germinate faster than uneaten seeds (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), turkey (*Meleagris gallopavo*), and several species of jays (Scher 2002). Pinyon seeds are a critically important food source for western scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). These birds are the primary dispersers of pinyon seeds and during mast crop years cache hundreds of thousands of pinyon seeds, many of which are never recovered (Balda and Bateman 1971, Vander Wall and Balda 1977, Ligon 1978). Many mammals are also known to eat pinyon seeds, such as several species of mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias* spp.), deer, black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) (Anderson 2002). Because pinyon seeds are heavy and totally wingless, seed dispersal is dependent on vertebrate dispersers that store seeds in food caches, where unconsumed seeds may germinate. This dispersal mechanism is a good example of a co-evolved, mutualistic, plant-vertebrate relationship (Vander Wall et al. 1981, Evans 1988, Lanner 1996) and would be at risk with loss of trees or dispersers.

There are many insects, pathogens, and plant parasites that attack pinyon and juniper trees (Meeuwig and Bassett 1983, Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). For pinyon and juniper, there are at least seven insects, plus a fungus (blackstain root-rot (*Leptographium wageneri*)), juniper mistletoe (*Phoradendron juniperinum*) and pinyon dwarf mistletoe (*Arceuthobium divaricatum*). Both mistletoes reduce vigor and cause occasional dieback but rarely cause mortality (Meeuwig and Bassett 1983). The insects are normally present in these woodland stands, and during drought-induced water stress periods, outbreaks may cause local to regional mortality (Wilson and Tkacz 1992, Gottfried et al. 1995, Rogers 1995). Most insect-related pinyon mortality in the West is caused by pinyon ips beetle (*Ips confusus*) (Rogers 1993). Pinyons cannot repel pinyon ips beetles when weakened by drought and many are killed. During the drought of 2002-2003, populations of ips beetles increased to epidemic levels that killed millions of pinyon trees in the southwestern U.S. (Thorne et al. 2007).

Most pinyon-juniper woodlands in the southwest have high soil erosion potential (Baker et al. 1995). Several studies have measured present-day erosion rates in pinyon-juniper woodlands, highlighting the importance of herbaceous cover and cryptogamic soil crusts (Baker et al. 1995, Belnap et al. 2001) in minimizing precipitation runoff and soil loss in pinyon-juniper woodlands.

ECOLOGICAL INTEGRITY

Change Agents: Before 1900, this system was mostly open woodland restricted to fire-safe areas on rocky ridges and outcrops where the low cover fine fuels reduced the spread of fires. Over the last 100 years fire regimes were altered by fire suppression and grazing by livestock, which reduces the amount of fine fuels (grasses) that carry fire thus reducing fire frequency (Pieper and Wittie 1990, Swetnam and Baisan 1996a, Miller and Tausch 2001). Currently, much of this system distribution has a more closed canopy than historically. Fire suppression has led to a buildup of woody fuels that in turn increases the likelihood of high-intensity, stand-replacing fires. Heavy grazing, in contrast to fire, removes the grass cover and tends to favor shrub and conifer species. Fire suppression combined with grazing creates conditions that support invasion by pinyon and juniper trees into adjacent shrublands and grasslands. Under most management regimes, typical tree size decreases and tree density increases in this habitat.

Other common stressors include invasive species, insect/disease outbreaks, fuel wood cutting, and increased soil erosion, all of which affect stand quality and fire behavior. Significant losses in pinyon-juniper woodlands are a result of shortening of fire-return intervals (FRI) because of invasion by introduced *Bromus tectorum* and other annuals that provide fine fuels that carry fire (Tausch 1999, Miller and Tausch 2001, Tausch and Hood 2007). Livestock are also vectors for invasive species and disturb biological soil crusts.

Currently, epidemics of the native pinyon ips beetle (*Ips confusus*) often occur during drought periods when mature trees are weakened and vulnerable to ips beetle attacks killing many pinyons and creating very high fuel loads throughout much of the system's range (Furniss and Carolin 2002). In addition, many of these communities have been severely impacted by past range practices of chaining, tilling, and reseeding with exotic forage grasses.

Human development has impacted some locations throughout the distribution of this type. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation 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. Management actions such as chaining pinyon-juniper stands creates a large food source of injured pines for ips beetles (*Ips confusus*) to feed on that can quickly multiply creating epidemic outbreaks of beetles that attack and kill many healthy pinyons (Furniss and Carolin 2002). Drought stresses pinyon trees and makes them less able to survive ips beetle attacks (Furniss and Carolin 2002).

Conversion of this type has resulted from catastrophic crown fires and "chaining" or mechanical removal of trees by land management agencies to convert woodlands to grasslands for livestock (Stevens 1999, Tausch 1999, Tausch and Hood 2007). If exotic species are present, post crown fire and post-treatment outcomes may result in conversion to exotic 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.

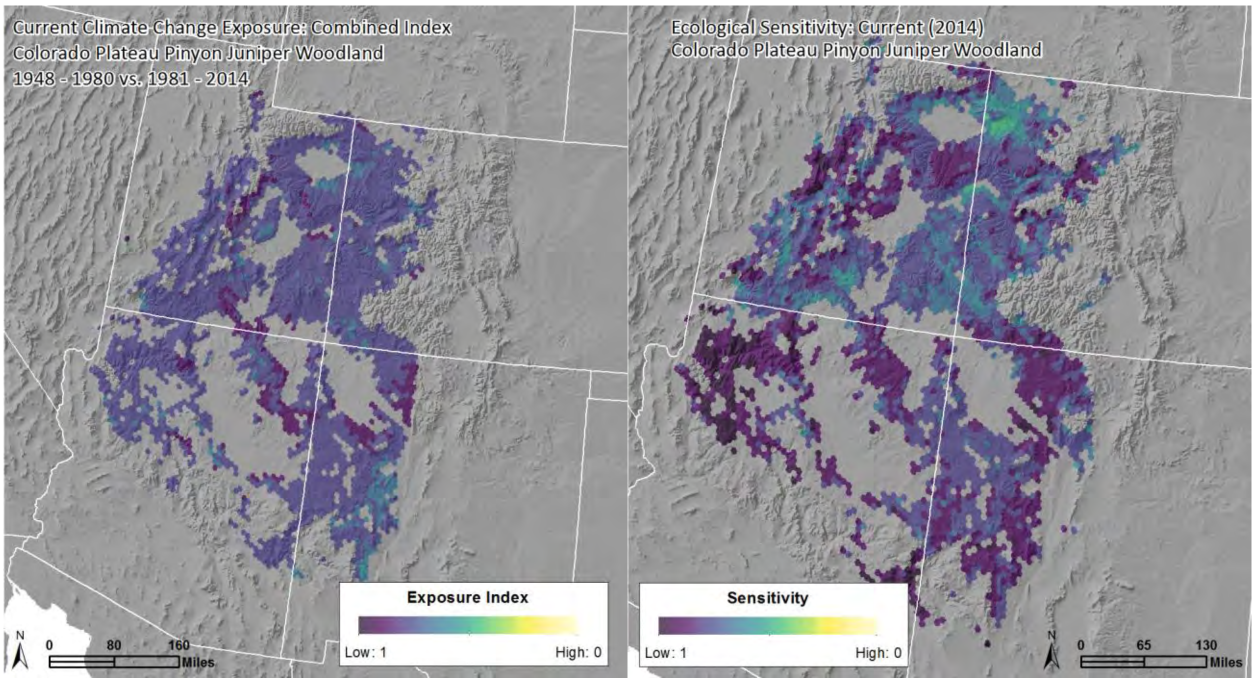

Figure 44. Climate exposure as of 2014 (left) and overall sensitivity (right) for Colorado Plateau Pinyon-Juniper Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 43. Resilience, exposure and vulnerability scores for Colorado Plateau Pinyon-Juniper Woodland 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	Colorado Plateaus	Southern Rockies	Arizona-New Mexico Plateau	Arizona-New Mexico Mountains	Wasatch & Uinta Mountains	Central Basin & Range	Wyoming Basin	Mojave Basin & Range	Madrean Archipelago	Southwestern Tablelands
	Potential square miles within ecoregion	9,228	2,877	2,563	1,209	897	235	108	87	44	20
Contributions to Relative Vulnerability by Factor											
Vulnerability from **Exposure (2014)**		**Low** 0.76	**Low** 0.77	**Low** 0.77	**Mod** 0.74	**Low** 0.77	**Low** 0.75	**Low** 0.76	**Low** 0.76	**Low** 0.75	**Low** Null
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.73	0.74	0.87	0.90	0.74	0.74	0.83	0.97	0.97	0.78
	Fire Regime Departure	0.55	0.61	0.59	0.51	0.61	0.59	0.59	0.64	0.72	0.46
	Invasive Annual Grasses	0.94	1.00	0.99	1.00	1.00	0.99	0.70	0.99	1.00	1.00
	Sensitivity Average	**0.74**	**0.78**	**0.81**	**0.80**	**0.78**	**0.77**	**0.70**	**0.87**	**0.90**	**0.75**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.45	0.46	0.42	0.45	0.56	0.51	0.44	0.50	0.47	0.39
	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	**0.30**	**0.31**	**0.29**	**0.31**	**0.36**	**0.33**	**0.30**	**0.33**	**0.31**	**0.28**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.52	**Mod** 0.55	**Mod** 0.55	**Mod** 0.56	**Mod** 0.57	**Mod** 0.55	**Mod** 0.50	**Mod** 0.60	**Mod** 0.61	**Mod** 0.51
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 these woodlands, climate exposure as of 2014 is low in nearly all ecoregions, and moderate in the Arizona New Mexico Mountains. An emerging pattern of changing climate appears as increases ranging from 0.56° to 0.69°C for Annual Mean Temperature and Mean Temperature of the Warmest Quarter throughout the Arizona/New Mexico Plateau ecoregion and into surrounding ecoregions, especially the Arizona/New Mexico Mountains, Colorado Plateau and Wasatch and Uinta Mountains ecoregions. Across all ecoregions, more than 50% of the system's distribution shows these changes in both variables. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

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 tree recruitment. Without recruitment pinyon and juniper stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may weaken pinyon trees and may make them more susceptible to lethal attacks by forest diseases and insects such as the pinyon ips beetles (*Ips confusus*). Longer milder climate periods may increase the number of generations of ips beetles above the average of two and a half to three annually. Additionally, warmer/drier fuels may result in more frequent fires that could increase rate of loss of mature stands through conversion of these woodland to annual grasslands or shrublands that are adapted to frequent fire (Miller and Tausch 2001).

Many stands of this woodland type occur in the foothill zones of taller mountain ranges, so it may be possible for the species of this system to transition into lower montane zone as suitable climate is diminished at lower elevations. Pinyon and juniper trees are long-lived; *Juniperus osteosperma, Juniperus scopulorum* and *Pinus edulis* frequently live more than 300 years and so may be able to survive as relicts for centuries without regeneration (Burns and Honkala 1990a). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from hotter, drier climate.

Climate change has affected the distribution of pinyon-juniper woodlands in the past and current climate change will likely shift the geographic and elevational distribution species from this system in the future (Van Devender 1977, 1990, Betancourt et al. 1993, McAuliffe and Van Devender 1998). For example, after 500 years BP, winter precipitation increased and caused a re-expansion of pinyon pines and junipers that sharply increased after 1700 and again in the early 1900s (Davis and Turner 1986, Mehringer and Wigand 1990, as cited in Gori and Bate 2007). Shorter term variation in climate has important implications for this system. Regional droughts coupled with stress-induced insect outbreaks (pinyon ips beetle) have caused widespread mortality of pinyons (Breshears et al. 2005). This affects species dominance patterns, tree age structure, tree density, and canopy cover within pinyon-juniper woodlands and will shift dominance to juniper (Betancourt et al. 1993). Conversely, wet periods create conditions for tree recruitment and growth.

Ecosystem Resilience: Sensitivity: Overall sensitivity to the effects of climate change is low across the range of this type, with lowest sensitivity (high numerical score) in stands in 7 of 10 ecoregions.

Landscape condition is good (less development) (**Table 43**), as the ecosystem occurs across extensive and remote mountain ranges primarily in the Colorado Plateaus and western slope of the Southern Rockies. Landscape condition is particularly good in the Mojave Basin and Range and Madrean Archipelago ecoregions, which are on the edge of distribution for these woodlands. However, in the Colorado Plateaus, Southern Rockies, Wasatch and Uintas, and Central Basin and Range ecoregions, landscape condition shows some effects from infrastructure. 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 some areas of urban, suburban and exurban development.

Risk of invasive plants tends to be low overall and is currently concentrated in the southern portion of the Wyoming Basin ecoregion where there is oil and gas development. However, fire regime departure is moderate across the range of this system except in the Southwest Tablelands ecoregion where it is high. Fire suppression and the loss of fine-fuels due to grazing together have changed the fire frequencies in many areas, which in turn leads to a younger age class of both pinyon and juniper, and an increased density of trees. Combined with recent decades of persistent drought and Ips beetle outbreaks with high mortality of pinyons, there has been a significant shift in the proportions of successional classes in these woodlands. Many old-growth stands now have a dense cohort of younger, smaller trees, or have suffered stand-replacing fire. These changes in fire regime have altered the structure of these woodlands making them vulnerable to catastrophic crown fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these woodlands. 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 generally low range wide. Topoclimatic variability is moderate to low across all the ecoregions, as these woodlands tend to occur on a variety of aspects and slopes, and landforms with some topographic relief, mesas, plateaus, 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.

However, the adaptive capacity is even more limited when considering the diversity within functional species groups, which varies from high to low among groups. While two of the three functional species groups have high diversity, nitrogen fixation has low diversity and is the most limiting in relation to adaptive capacity. 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 for the system. Conversely, seed dispersers and substrate developing soils crusts appear to be naturally diverse across the range of this type. Many species of birds and mammals disperse both juniper and pinyon seed. Soil crust taxa include many cyanobacteria, lichens and mosses.

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: These woodlands currently score as moderate overall climate change vulnerability throughout their range. This is primarily due to low scores for low scores for adaptive capacity, and variable contributions from sensitivity measures. Inherent vulnerabilities are high for types such as this with low diversity within key functional species groups, such as with nitrogen fixing species. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Pinyon-Juniper Woodland.

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Anderson 2002, Baker et al. 1995, Balda 1987, Balda and Bateman 1971, Belnap 2001, Belnap et al. 2001, Betancourt et al. 1993, Bradley et al. 1992a, Breshears et al. 2005, Brooks and Minnich 2006, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Davis and Turner 1986, Evans 1988, Evans and Belnap 1999, Eyre 1980, Furniss and Carolin 2002, Gori and Bate 2007, Gottfried et al. 1995, Hess and Wasser 1982, Hollander and Vander Wall 2004, Johnsen 1962, LANDFIRE 2007a, Lanner 1996, Ligon 1978, Little 1987, McAuliffe and Van Devender 1998, McCulloch 1969, Meeuwig and Bassett 1983, Miller and Tausch 2001, Pieper and Wittie 1990, Rogers 1993, Rogers 1995, Romme et al. 2003, Rondeau 2001, Rosentreter and Belnap 2003, Salomonson 1978, Scher 2002, Shiflet 1994, Short and McCulloch 1977, Short et al. 1977, Springfield 1976, Stevens 1999a, Stuever and Hayden 1997a, Swetnam and Baisan 1996a, Tausch 1999, Tausch and Hood 2007, Thorne et al. 2007, Van Devender 1977, Van Devender 1990, Vander Wall and Balda 1977, Vander Wall et al. 1981, Weber et al. 1999, Wilson and Tkacz 1992, Wright et al. 1979, Zlatnik 1999e

CES306.834 Southern Rocky Mountain Juniper Woodland and Savanna

Figure 45. Photo of Southern Rocky Mountain Juniper Woodland and Savanna. Photo credit: Renee Rondeau

CLASSIFICATION AND DISTRIBUTION

Concept Summary: This ecological system occupies the lower and warmest elevations, growing from 1370 to 1830 m in a semi-arid climate, primarily along the east and south slopes of the Southern Rockies and Arizona-New Mexico mountains. It is best represented just below the lower elevational range of ponderosa pine and often intermingles with grasslands and shrublands. This system is best described as a savanna that has widely spaced, mature (>150 years old) juniper trees and occasionally *Pinus edulis*. *Juniperus monosperma* and *Juniperus scopulorum* (at higher elevations) are the dominant tall shrubs or short trees. These savannas may have inclusions of denser juniper woodlands and they have expanded into adjacent grasslands during the last century. Graminoid species are similar to those found in Western Great Plains Shortgrass Prairie (CES303.672), with *Bouteloua gracilis* and *Pleuraphis jamesii* being most common. In addition, succulents such as species of *Yucca* and *Opuntia* are typically present.

Distribution: This system occupies the lower and warmest elevations, growing from 1370 to 1830 m elevation in a semi-arid climate, primarily along the east and south slopes of the Southern Rockies and central New Mexico mountains. This includes the Sacramento Mountains, especially the east side; the west side has Madrean elements but is mostly southern Rocky Mountains. This system also occurs in the canyons and tablelands of the southwestern Great Plains extending some distance from the mountains. It may occur along the Cimarron River in the panhandle regions of Oklahoma and Texas, and in the very southwestern corner of Kansas.

Nations: US

States/Provinces: CO, KS?, NM, OK?, TX?

CEC Ecoregions: Southern Rockies, High Plains, Southwestern Tablelands, Arizona/New Mexico Plateau, Chihuahuan Desert, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Vegetation structure is typically a savanna with widely spaced, mature (>150 years old) juniper trees and moderately dense perennial grasses in between trees but includes inclusions (patches) of denser juniper woodlands with less herbaceous cover. Vegetation is dominated by an open tree canopy of 2- to 10-m tall *Juniperus monosperma*. *Juniperus scopulorum* may be present or dominant at higher elevations. Occasional *Pinus edulis* trees may be present but have low cover and are typically restricted to mesic microsites. The open to dense herbaceous layer is dominated by perennial grasses that vary with environments. Grass species are similar to those found in adjacent shortgrass prairie and piedmont grasslands. *Bouteloua gracilis, Bouteloua curtipendula*, and *Pleuraphis jamesii* are most common with *Koeleria macrantha, Lycurus phleoides, Muhlenbergia torreyi*, and *Piptatheropsis micrantha* often present. Midgrasses such as *Achnatherum hymenoides, Hesperostipa comata*, or *Hesperostipa neomexicana* are more common in foothills and piedmont stands. *Bouteloua eriopoda* and *Bouteloua hirsuta* are more common grass in the southern extent, while *Andropogon hallii* and *Muhlenbergia pungens* are characteristic of deep sandy sites. Forbs such as *Astragalus* spp., *Cryptantha cinerea var. jamesii (= Cryptantha jamesii), Eriogonum jamesii, Erigeron divergens, Hymenopappus filifolius, Ipomopsis multiflora, Mentzelia* spp., and *Penstemon* spp. are also common. Shrubs are poorly represented or absent except the ruderal subshrub *Gutierrezia sarothrae* and succulents such as *Cylindropuntia imbricata, Opuntia phaeacantha, Opuntia polyacantha, Yucca baccata*, and *Yucca glauca*. Other occasional shrubs may include *Artemisia bigelovii, Rhus trilobata*, or *Cercocarpus montanus*.

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 of the Great Plains. Stands would also likely include many of the species from the Colorado Plateau. Cyanobacteria: *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*. When stands extend onto prairie grasslands with more exposed soil, *Agrestia hispida (= Aspicilia hispida), Cladonia cariosa, Collema tenax, Diploschistes scruposus, Endocarpon pusillum*, and *Physconia muscigena* may be common. Calcareous soils which are common on many sites may have *Fulgensia bracteata, Heppia lutosa, Psora decipiens, Caloplaca tominii*, and *Squamarina lentigera* present. Mosses are common on grassland/woodland interface (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*.

Nitrogen Fixation; Species Diversity: Medium
Juniper savannas and woodlands occur in semi-arid climates where soil nutrients such as nitrogen are likely a significant constraint on plant growth. Within this system several species of Fabaceae,

including species of *Astragalus*, many Poaceae (e.g., *Andropogon hallii, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis, Hesperostipa comata, Hesperostipa neomexicana, Pascopyrum smithii, Pleuraphis jamesii*), Rosaceae (*Cercocarpus montanus*), and some Brassicaceae can fix nitrogen. 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).

Perennial Cool-Season/Warm-Season Graminoids; Species Diversity: Medium
The climate for this system has a bi-modal precipitation pattern that favors both cool- and warm-season graminoids. Cool-season graminoids: *Achnatherum hymenoides, Elymus elymoides, Hesperostipa comata, Hesperostipa neomexicana*, and *Pascopyrum smithii*. Warm-season graminoids: *Andropogon hallii, Aristida purpurea, Bouteloua curtipendula, Bouteloua eriopoda, Bouteloua gracilis*, and *Pleuraphis jamesii*.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*, Townsend's solitaire (*Myadestes townsendi*), chipping sparrow (*Spizella passerina*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Johnson 2002, Scher 2002). Mammals: Great Basin pocket mouse (*Perognathus parvus*), chipmunks (*Neotamias* spp.), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), kangaroo rats (*Dipodomys* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and bighorn sheep (*Ovis canadensis*) may inadvertently disperse seeds in caches or have viable seeds pass through their gut.

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this juniper-dominated woodland.

Environment: This ecological system occupies the lower and warmest elevations, growing from 1370 to 1830 m primarily along the east and south slopes of the Southern Rockies and Arizona-New Mexico mountains. It is best represented just below the lower elevational range of ponderosa pine and often intermingles with grasslands. In the canyons and tablelands of the southern Great Plains, this system forms extensive cover at some distance from the mountain front.

Climate: Climate is cool-temperate, continental, and semi-arid. Precipitation ranges from approximately 33-46 cm (13-18 inches) annually and has a bimodal distribution with moisture peaking in winter and summer. However, most precipitation generally occurs during the summer growing season.

Physiography/landform: Stands occur on gentle upland and transitional valley locations, where soil conditions favor grasses (or other grass-like plants) but can support at least some tree cover. Some savannas apparently have sparse tree cover because of edaphic or climatic limitations on woody plant growth (Romme et al. 2009).

Soil/substrate/hydrology: Savannas are found on moderately deep to deep, coarse- to fine-textured soils that readily support a variety of growth forms, including trees, grasses, and other herbaceous plants, and in regions that receive reliable summer rainfall that fosters growth of warm-season grasses (Romme et al. 2009). This type appears to be especially prevalent in the basins and foothills of northeastern New Mexico, where a large portion of annual precipitation comes in the summer via monsoon rains (Romme et al. 2009).

Key Processes and Interactions: *Juniperus monosperma* is a long-lived, slow-growing, drought-tolerant small tree (3-12 m in height) that also occurs as a tall shrub (Johnson 2002). It is more drought tolerant than *Pinus edulis* and often occurs without pinyon on more xeric, lower elevation sites (Johnson 2002). It is also non-sprouting and may be killed by fire (Wright et al. 1979). Juniper stands at cooler, higher elevation sites typically occur on xeric microsites that are too arid for pinyon or on post-disturbance sites such as where extended drought or ips beetle (*Ips confusus*) epidemics have eliminated pinyon from mixed pinyon-juniper stands. In this situation junipers and shrubs may act a nurse plants providing shade for pinyon germination and re-establishment, converting a juniper woodland to pinyon-juniper woodland.

Within a given region, the density of trees, both historically and currently, is strongly related to topo-edaphic gradients. Less steep sites, especially those with finer-textured soils, are where savannas, grasslands, and shrub-steppes have occurred in the past. Juniper stands on these gentler slopes may have been larger but more savanna-like, with very open upper canopy and high grass production. Expansion of juniper into previously non-wooded areas occurred prior to European settlement on some sites, although this expansion may have been more extensive in the 20th century versus the previous. However, loss of juniper from marginal sites also occurred historically and recently in some areas (Romme et al. 2009). Especially in areas in which trees were historically rare or absent, there have been type conversions such that the historical condition is unidentifiable/replaced today. An important result of expansion into formerly non-wooded areas in many regions is that formerly heterogeneous mosaics of small patches of woodland, shrubland, and grassland are becoming more homogeneous as trees become established in the shrubland and grassland patches (Romme et al. 2009).

Past fire regimes in southwestern juniper woodlands were mixed, having both surface and crown fires, reflecting variable intensity and frequency depending on site productivity. "Productive sites" could sustain patchy fires at intervals of 10-50 years and could have attained densities sufficient to carry crown fires at intervals of 200-300 years. In open stands, where grass cover was continuous, fire intervals might have been 10 years or less, and probably maintained grasslands and savannas (Gottfried et al. 1999). Romme et al. (2009) state that low-severity fires were probably uncommon except in savannas and in small patches in persistent woodlands.

Soil texture drives the fire regime. Sites with higher potential for graminoid understory will have higher fine-fuel loading and create the spread component for more frequent and lower intensity fires. Sites with shallow, gravelly soils produce less grass and more shrub components, less fire frequency, more lethal when wind-driven events occur (LANDFIRE 2007a).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 2711190). The model was reviewed and reference to pinyon were removed then summarized as:

A) Early Development 1 All Structures (10% of type in this stage): Grass/forb/shrub/seedling - usually post-fire. Cover is 0-30%. Shrub height is 0-5 m. This class succeeds to B, a mid-open stage after approximately 70 years; however, it could be much longer depending on size of burn. Recruitment is even more episodic in response to optimal climate conditions than in ponderosa. An alternate successional pathway could take this class to class C, a mid-development closed stage, with a probability of 0.015. Replacement fire occurs infrequently, every 400 years. Competition/maintenance can maintain this stage, with a probability of 0.01.

B) Mid Development 1 Open (10% of type in this stage): Tree cover is 11-40%. Tree height is 5.1-10 m. Mid-development, open (<40% cover) juniper stand with mixed shrub/herbaceous community in understory. Review for MZ27 suggested this might even be lower canopy cover to 20%. This class succeeds to class E, a late-open stage after approximately 170 years. An alternate successional pathway could take this class to class D, a late closed stage, with a low probability of 0.002. Replacement fire occurs infrequently, every 500 years. Surface fire occurs every 25 years. Mixed fire occurs every 300 years. Competition/maintenance can maintain this class in class B, with a probability of 0.007.

C) Mid Development 1 Closed (10% of type in this stage): Tree cover is 41-70%. Tree height is 5 m. Mid-development, dense (>40% cover) pinyon-juniper woodland; understory being lost. Review for Map zone 27 suggested this might even be lower canopy cover to 30%. This class succeeds to D, a late-closed stage after 100 years. Mixed fire in this stage either causes no transition (every 1000 years) or brings it to an open mid stage (every 200 years). Surface fire occurs infrequently (every 1000 years) and causes no transition. Replacement fire also occurs infrequently (every 500 years).

D) Late Development 1 Closed (5% of type in this stage): Tree cover is 41-70%. Tree height is 10.1-25 m. Dense, old-growth stands with multiple layers. Late-development, closed pinyon-juniper forest. May have all-aged, multi-storied structure. Moderate mortality within stand. Occasional shrubs with few grasses and forbs and often much rock. Review for MZ27 suggested this might even be lower canopy cover to 11-35%. This class can persist. Mixed fire can cause this class to move to a late open stage, class E, but very infrequently - every 200 years. Replacement fire occurs very rarely (6-700 years), and surface fire also occurs very, very rarely. Insect/disease can also open this class and cause a transition to the late-open stage, class E, every 200 years. This interval may be even longer. Also, drought likely plays a major role, but it was not modeled here.

E) Late Development 1 Open (conifer-dominated - 65% of type in this stage): Tree cover is 11-40%. Tree height is 10-25 m. Late-development, open juniper-pinyon stand with "savannah-like" appearance; mixed grass/shrub/herbaceous community. This class persists. Replacement fire occurs infrequently - every 500 years. Mixed fire also occurs infrequently - every 200 years, and surface fire every 25 years, but neither cause a transition. Insect/disease occurs every 200 years but causes no transition. This interval may be even longer. Also, drought likely plays a major role, but it was not modeled here.

Other important ecological processes include drought, insect infestations, pathogens, herbivory and seed dispersal by birds and mammals. Juniper berries crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978). The most important dispersers of juniper seeds are birds, although many mammals also feed on them. These animals consume juniper berries and excrete viable scarified juniper seeds, which germinate faster than uneaten seeds, over extensive areas (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), but cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), turkey (*Meleagris gallopavo*), and several species of jays are also dispersers (Johnson 2002, Scher 2002).

There are several insects, pathogens, and plant parasites that attack juniper trees (Meeuwig and Bassett 1983, Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). For juniper, there are several insects, plus the fungus blackstain root-rot (*Leptographium wageneri*) and juniper mistletoe (*Phoradendron juniperinum*). Mistletoe reduces vigor and causes occasional dieback but rarely causes mortality (Meeuwig and Bassett 1983). The insects are normally present in these woodland stands, and during drought-induced water-stress periods, outbreaks may cause local to regional mortality (Gottfried et al. 1995)

Many juniper savannas and woodlands in the Southwest have high soil erosion potential (Baker et al. 1995). Several studies have measured present-day erosion rates in juniper woodlands, highlighting the importance of herbaceous cover and cryptogamic soil crusts (Baker et al. 1995, Belnap et al. 2001) in minimizing precipitation runoff and soil loss in juniper woodlands.

ECOLOGICAL INTEGRITY

Change Agents: Although juniper woodlands and savannas are expected to occur naturally on the landscape, the extent and quality of this system have been severely altered since the early 1900s. Numerous studies have shown that juniper has encroached on shrublands and grasslands (e.g., West 1999b). Processes that influence the formation and persistence of juniper savannas include climate, livestock grazing, altered fire regime, tree harvest (fence posts), and insect-pathogen outbreaks (West 1999b, Romme et al. 2009).

The altered fire regime (intensity and frequency) in this savanna system in the form of fire exclusion has also allowed for juniper infill in some stands as well as expansion of juniper trees into the surrounding grasslands (West 1999b, Romme et al. 2009). Heavy grazing by livestock reduces fine fuels and indirectly decreases fire frequency, favoring fire sensitive woody species such as *Juniperus monosperma*. This may result in uncharacteristically high cover of trees (infilling) that shade out the grassy understory as it transitions from savanna to woodland, as well as tree invasion into adjacent grasslands. Some people confuse these younger juniper woodlands with true woodlands dependent on naturally fire-protected features such as rock outcrops. Lacking understory to carry fire, these woodlands only burn under extreme fire conditions resulting in high-intensity, high-severity stand-replacing fires. With loss of perennial grass cover with tree shading, these stands may have difficulty re-establishing the native perennial grass-dominated juniper savanna. Additionally, these stands are vulnerable to invasion by non-native annual grasses such as *Bromus arvensis* that can increase fire frequency beyond the natural fire regime.

Juniper savanna is typically invasive in lower valleys, mesas and rolling plains if deep soils, but natural if medium (shallow) depth soils, e.g., low rises between drainages typically with large seemingly old junipers (LANDFIRE 2007a).

In addition, many stands within this system have been impacted by past range practices of chaining, tilling, and reseeding with exotic forage grasses and prescribed burning to reduce juniper and increase forage production, which have had mixed results. Although the dominant trees appear to regenerate after such disturbances, the effects on understory and soil crust species are poorly known. More study is needed to understand and manage these woodlands ecologically.

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.

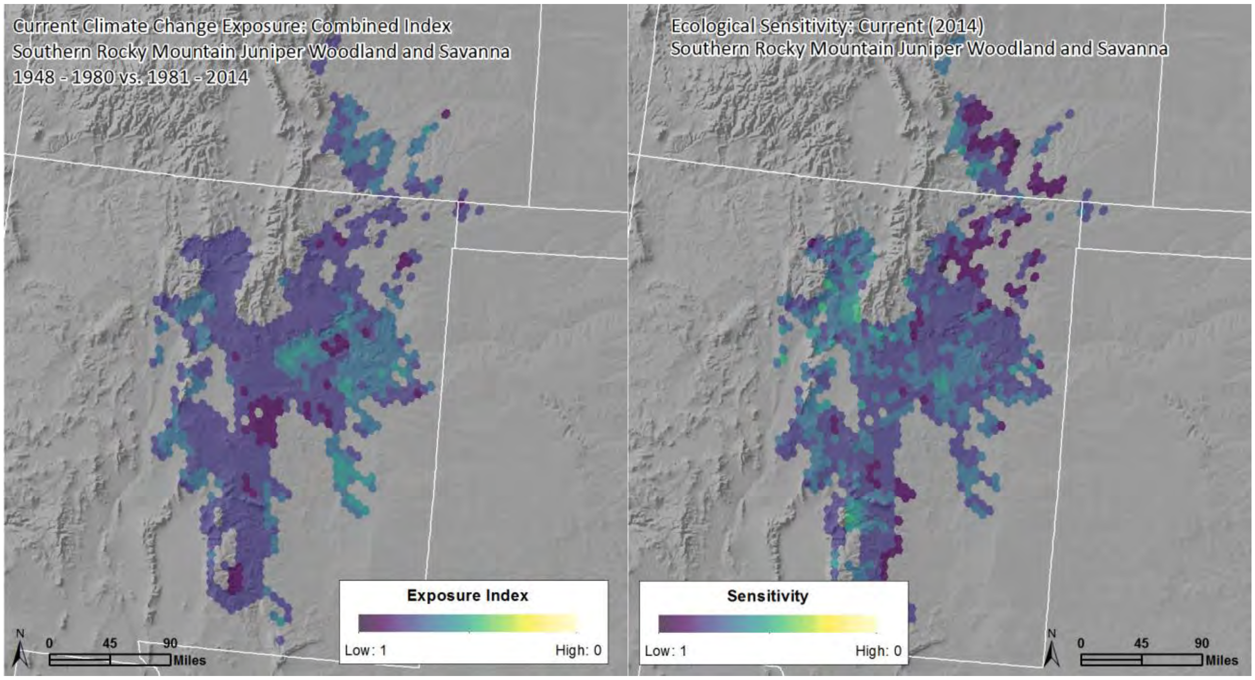

Figure 46. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Juniper Woodland and Savanna. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 45. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Juniper Woodland and Savanna 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	Southwestern Tablelands	Arizona-New Mexico Mountains	Arizona-New Mexico Plateau	Southern Rockies	Chihuahuan Desert
	Potential square miles within ecoregion	2,593	777	465	178	35
Contributions to Relative Vulnerability by Factor						
Vulnerability from **Exposure (2014)**		**Mod** 0.73	**Low** 0.75	**Mod** 0.74	**Mod** 0.73	**Mod** 0.72
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.80	0.79	0.64	0.67	0.82
	Fire Regime Departure	0.33	0.28	0.29	0.30	0.33
	Invasive Annual Grasses	1.00	1.00	0.99	1.00	1.00
	Sensitivity Average	**0.71**	**0.69**	**0.64**	**0.66**	**0.72**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.22	0.30	0.25	0.31	0.23
	Diversity within Functional Species Groups	0.50	0.50	0.50	0.50	0.50
	Keystone Species Vulnerability	Null	Null	Null	Null	Null
	Adaptive Capacity Average	**0.36**	**0.40**	**0.38**	**0.41**	**0.36**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.54	**Mod** 0.55	**Mod** 0.51	**Mod** 0.53	**Mod** 0.54
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: For these savannas and woodlands, climate exposure as of 2014 is moderate in 4 of 5 ecoregions, and low in one ecoregion (Arizona-New Mexico Mountains). An emerging pattern of changing climate appears as increases of 0.53° to 0.59°C for Annual Mean Temperature in all ecoregions. In the Southwest Tablelands, Arizona/New Mexico Plateau, and Southern Rockies ecoregions, some 10% to 25% of the system's distribution shows these increases; in the Arizona/New Mexico Mountains and Chihuahuan Desert ecoregions, in which it is peripheral, the increase is seen in some 90% of its distribution. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

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 tree recruitment. Without recruitment juniper stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may weaken juniper trees and may make them more susceptible to lethal attacks by forest diseases and insects. Additionally, warmer/drier fuels may result in more frequent fires that could increase rates of loss of mature trees. Many stands of this woodland type occur in the foothill zones of taller mountain ranges, so it may be possible for the species of this system to transition into lower montane zone as suitable climate is diminished at lower elevations. Juniper trees are long-lived; *Juniperus osteosperma* and *Juniperus scopulorum* frequently live more than 300 years and so may be able to survive as relicts for centuries without regeneration (Burns and Honkala 1990a, Johnson 2002). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change tends to be low, with some areas that are moderate across the range of this type. Sensitivity scores are lower (equating to higher sensitivity) in the Arizona-New Mexico Plateau and Southern Rockies ecoregions, due to the combination of pervasive development fragmenting occurrences and indirect and direct fire suppression, which in turn alters fire regimes.

Landscape condition is generally very good (little development) (**Table 45**) as the ecosystem occurs across generally remote hills, plateaus, and foothills, and into the plains in the Southwestern Tablelands, Arizona-New Mexico Mountains, and Southern Rockies ecoregions. However, stands in the Arizona-New Mexico Plateau have moderate landscape condition likely because of increased urban, suburban and exurban development and accompanying fragmentation. This system does not occur on sites conducive to agriculture, so these results are likely a reflection of fragmentation due to many small roads, some oil and gas development, transmission corridors, and areas of urban, suburban and exurban development.

The risk of invasive annual grasses is generally low across the range of this type; however, fire regime departure is high across the range of this system. Direct fire suppression, grazing removal of fine fuels, and activities such as cutting for fence-posts have combined to cause a shift in the structure of these woodlands and savannas. Cutting removes trees, especially older, larger individuals; loss of fine fuels and fire suppression reduce fire frequencies leading to stand-replacing fires when fire does occur. These interactions have altered the structural characteristics of the juniper savannas, with significant "infill" of young cohorts of junipers in older savanna stands, or loss of junipers altogether with stand-replacing fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these woodlands and savannas. Together, these result in increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low range wide for this system. Topoclimatic variability is low or very low across all ecoregions, as these savannas occur across generally low-relief landforms and topography, such as on gentle foothill and transitional valley locations, basins and flats where soil conditions favor grasses (or other grass-like plants) but can support at least some tree cover. 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 four identified functional species groups varies from moderate to high. Nitrogen-fixation and the diversity of the mix of cool-season and warm-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. A bi-modal precipitation pattern favors both cool- and warm-season graminoids. 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 CO2 concentrations, high light intensity and higher temperatures and is well-adapted to relatively warm, dry climates where this system occurs.

Seed dispersal is provided by many bird and mammal species and appears to have high within-stand diversity. Substrate developing soil crusts also have high within stand diversity, and include many cyanobacteria, lichens and mosses. Calcareous substrates support more lichens, and mosses are common in the grassland/woodland interface such as in these savannas.

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: These woodlands and savannas score in the moderate range of overall climate change vulnerability throughout their range. This is primarily due to the low to moderate scores for exposure, low scores for adaptive capacity, and moderate sensitivity measures. Inherent vulnerabilities are moderate to high for types such as this with moderate to high scores for fire regime departure and low topoclimate variability. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Southern Rocky Mountain Juniper Woodland and Savanna.

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 and fire breaks.
Moderate	**Emphasize restoration to enhance resilience.** Restoring natural wildfire regimes and tree or shrub canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for

VULNERABILITY SCORE	STRATEGIES AND ACTIONS
	wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: AOU 1983, Baker et al. 1995, Belnap 2001, Belnap et al. 2001, Blackburn and Tueller 1970, Breshears et al. 2005, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Commons et al. 1999, Eager 1999, Eyre 1980, Gottfried et al. 1995, Gottfried et al. 1999, Johnsen 1962, Johnson 2002, LANDFIRE 2007a, McCulloch 1969, Meeuwig and Bassett 1983, Rogers 1995, Romme et al. 2009, Rosentreter and Belnap 2003, Salomonson 1978, Scher 2002, Shiflet 1994, Short et al. 1977, Weber et al. 1999, West 1999b, Wright and Bailey 1982a

CES306.835 Southern Rocky Mountain Pinyon-Juniper Woodland

Figure 47. Photo of Southern Rocky Mountain Pinyon-Juniper Woodland. 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 southern Rocky Mountain ecological system occurs on dry mountains and foothills in southern Colorado east of the Continental Divide, in mountains and plateaus of north-central New Mexico, and extends out onto limestone breaks in the southeastern Great Plains. These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, and ridges. Soils supporting this system vary in texture ranging from stony, cobbly, gravelly sandy loams to clay loam or clay. *Pinus edulis* and/or *Juniperus monosperma* dominate the tree canopy. *Juniperus scopulorum* may codominate or replace *Juniperus monosperma* at higher elevations. Stands with *Juniperus osteosperma* are representative of the Colorado Plateau and are not included in this system. In southern transitional areas between Madrean Pinyon-Juniper Woodland (CES305.797) and Southern Rocky Mountain Pinyon-Juniper Woodland (CES306.835) in central New Mexico, *Juniperus deppeana* may be present. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent. Associated species are more typical of southern Rocky Mountains than the Colorado Plateau and include *Artemisia bigelovii, Cercocarpus montanus, Quercus gambelii, Achnatherum scribneri, Bouteloua gracilis, Festuca arizonica*, or *Pleuraphis jamesii*.

Distribution: This system occurs on dry mountains and foothills east of the Continental Divide in southern Colorado, in mountains and plateaus of northern New Mexico and Arizona, and extends out onto breaks in the Great Plains. It extends south to the Sacramento Mountains, especially the eastern side. The western side of the Sacramento Mountains has Madrean elements (*Quercus grisea*) and may be classified as Madrean woodland.

Nations: US

States/Provinces: CO, NM, OK, TX

CEC Ecoregions: Southern Rockies, High Plains, Southwestern Tablelands, Colorado Plateaus, Arizona/New Mexico Plateau, Chihuahuan Desert, Arizona/New Mexico Mountains

Primary Concept Source: M.S. Reid

Description Author: K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: *Pinus edulis* and/or *Juniperus monosperma* dominate the tree canopy. *Juniperus scopulorum* may codominate or replace *Juniperus monosperma* at higher elevations. Stands with *Juniperus osteosperma* are representative the Colorado Plateau and are not included in this system. In southern transitional areas between Madrean Pinyon-Juniper Woodland (CES305.797) and Southern Rocky Mountain Pinyon-Juniper Woodland (CES306.835) in central New Mexico, *Juniperus deppeana* becomes common. Understory layers are variable and may be dominated by shrubs, graminoids, or be absent. Associated species are more typical of southern Rocky Mountains than the Colorado Plateau and include *Artemisia bigelovii, Cercocarpus montanus, Quercus gambelii, Achnatherum scribneri, Bouteloua gracilis, Festuca arizonica*, or *Pleuraphis jamesii*.

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) from the Great Plains. Stands would also likely include many of the species from the Colorado Plateau and Rocky Mountains. Cyanobacteria: *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*. When stands extend on to grasslands with more exposed soil, *Agrestia hispida (= Aspicilia hispida), Cladonia cariosa, Collema tenax, Diploschistes scruposus, Endocarpon pusillum*, and *Physconia muscigena* may be present. Calcareous soils which are common on many sites may have *Fulgensia bracteata, Heppia lutosa, Psora decipiens, Caloplaca tominii*, and *Squamarina lentigera* present. 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*.

Nitrogen Fixation; Species Diversity: Low
Pinyon-juniper woodlands occur in semi-arid climates typically on rocky substrates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. Within this system several species of Fabaceae (including species of *Astragalus*), many Poaceae (e.g., *Achnatherum scribneri, Bouteloua curtipendula, Bouteloua gracilis, Hesperostipa comata, Hesperostipa neomexicana, Leymus cinereus, Poa fendleriana*), Rosaceae (*Cercocarpus montanus*), and some Brassicaceae can fix nitrogen; however, within stand species diversity is typically low. 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.

Seed Dispersal; Species Diversity: High
Birds: Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), black-throated gray warbler (*Setophaga nigrescens (= Dendroica nigrescens)*), chipping sparrow (*Spizella passerina*), mountain quail (*Oreortyx pictus*), turkey (*Meleagris gallopavo*), blue jay (*Cyanocitta cristata*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*), and western scrub jay (*Aphelocoma californica*) (Scher 2002). The primary dispersers of pinyon seeds are scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*) (Anderson 2002). Mammals: Great Basin pocket mouse (*Perognathus parvus*), chipmunks (*Neotamias* spp.), pinyon mouse (*Peromyscus truei*), deer mouse (*Peromyscus maniculatus*), Kangaroo rats (*Dipodomys* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias (= Tamias)* spp.), deer (*Odocoileus* spp.), black bear (*Ursus americanus*), and bighorn sheep (*Ovis canadensis*) may inadvertently disperse seeds in caches or have viable seeds pass through gut (Balda 1987).

Keystone Species: Keystone species play a vital functional role in the ecosystem. No keystone species were identified for this pinyon-juniper woodland type.

Environment: This southern Rocky Mountain ecological system occurs on dry mountains and foothills in southern Colorado east of the Continental Divide, in mountains and plateaus of north-central New Mexico, and extends out onto limestone breaks in the southeastern Great Plains. Elevations range from near 1500 to 2900 m with high-elevation stands restricted to relatively warm, dry ridges and south and west aspects. Lower-elevation stands are often restricted to cooler north- and east-facing slopes.

Climate: Climate is cool-temperate, continental, and semi-arid. Precipitation ranges from approximately 33-46 cm (13-18 inches) annually. Most of the precipitation occurs during the summer growing season. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountainsides.

Physiography/landform: These woodlands occur on warm, dry sites on mountain slopes, mesas, plateaus, and ridges.

Soil/substrate/hydrology: Soils supporting this system vary in texture ranging from stony, cobbly, gravelly sandy loams to clay loam or clay.

Key Processes and Interactions: Both *Pinus edulis* and *Juniperus monosperma* are relatively short (generally <15 m tall), shade-intolerant, drought-tolerant, slow-growing, long-lived trees (Meeuwig and Bassett 1983, Little 1987, Anderson 2002, Johnson 2002, Romme et al. 2003). Both tree species are also non-sprouting and may be killed by fire (Wright et al. 1979).

Pinyon-juniper woodlands are influenced by drought, fires, grazing, and insect-pathogen outbreaks (West 1999b). Stands vary considerably in appearance and composition, both elevationally and geographically. Juniper tends to be more abundant at the warmer/drier lower elevations, pinyon tends to be more abundant at the higher elevations, and the two species share dominance within a broad middle-elevation zone (Woodin and Lindsey 1954).

The effect of fire on a stand is largely dependent on the tree height and density, fine-fuel load on the ground, weather conditions, and season (Dwyer and Pieper 1967, Wright et al. 1979). Some large trees may survive unless the fire gets into the crown due to heavy fuel loads in the understory or extreme fire conditions.

Site conditions affects the successional pathway following a disturbance. Succession on a site is influenced by the severity and size of the disturbance, and by the composition, longevity, and density of any surviving plants and propagules within the disturbed area and the characteristics of plant communities in adjacent undisturbed areas. According to Gottfried et al. (1999) junipers are the first to return in secondary succession but are often followed and replaced by pinyon.

Site conditions influence the stand density. Sites with fewer trees typically have relatively deep soils and support a dense herbaceous level; those with more trees have shallow, rocky soils and often occur on steeper slopes. Stands may range from even-aged to uneven-aged stands. Some stands may have closed canopies with little or no understory, but many stands are open with widely scattered trees with a wide variety of understory vegetation (Rondeau 2001).

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has four classes in total (LANDFIRE 2007a, BpS 2710590). These classes are summarized as:

A) Early Development 1 Open (10% of type in this stage): Total cover is 0-20% (grass cover <20%, shrub cover <15%, tree cover <10%). Shrub height 0-0.5 m. There would be very little of this class historically. Initial post-fire community grass- and shrub-dominated, consisting of mountain-mahogany with Gambel oak sprouts, perennial grass and various forbs. Pinyon and juniper seedlings and saplings will be in low density. Evidence of past fires may be observed, including charcoal and resprouting woody plants. Duration 50 years with succession to class B, mid-development stand of small trees. Trees exert very little influence until about 50 years in this system. Replacement fire occurs every few centuries. Drought occurs every 30 years and maintains the class but does not set it back to the beginning.

B) Mid Development 1 Open (20% of type in this stage): Tree cover is 0-40%. Tree height <3 m. Young juniper saplings are increasing and growing. Grass and shrubs are still dominant. Grass species that would be present are: blue grama, little bluestem, western wheatgrass, and needlegrass. Pinyon seedlings delayed until shade occurs for better growth. Mixed-severity fire also occurs because sometimes grass density is sufficient to result in pinyon and juniper scorch as well as mortality. Mixed fire occurs every 100-200 years. Replacement fires every several hundred years. This class probably lasts approximately 100 years, i.e., 50 to 150 years. Might remain in class until 10-to-20 year heavy moisture cycle; this increases seedling production, and juveniles mature. Drought occurs every 30 years but does not cause a transition.

C) Mid Development 1 Closed (45% of type in this stage): Tree cover is 21-70%. Tree height 5.1-10 m. Junipers reaching pole-size, and pinyon pine seedlings and saplings are growing dependent on rainfall patterns and shade. Pinyon having rapid growth in this stage. Gambel oak is also forming stand patches. Thinning effect for mountain-mahogany due to space/nutrient competition. Very little recruitment of junipers in this stage. This class lasts from approximately 150-250 years of age, so spending 50-100 years in this class. For the model, this class will last 75 years. Replacement fire unlikely in this class due to open canopy. Mixed fire also modeled infrequently. Drought occurs every 30 years, also maintaining this class.

D) Late Development 1 Closed (25% of type in this stage): Tree cover is 10-40%. Tree height 5-10 m. Mature juniper mixed with maturing pinyon. Understory declining due to canopy closing. Small amount of fine fuels. There is a shift in dominance from juniper to pinyon. This class can persist. Pinyon would be susceptible to drought mortality, disease, and insects. Drought creates conditions for insect disturbance to occur in pinyon pine. Drought itself, however, can impact the understory separate from the insect component. Optional 1 is drought plus insect effect. This takes it back to class C, because pinyon lost but still have mature junipers. Modeled at every 50 years, or 2% of the class each year. Regular drought modeled as every 30 years, as in other classes, not causing a transition. Mistletoe might also be influenced by the drought but not being modeled due to lack of information.

Other important ecological processes include drought, insect infestations, pathogens, herbivory, and seed dispersal by birds and mammals. Juniper berry and pinyon nut crops are primarily utilized by birds and small mammals (Johnsen 1962, McCulloch 1969, Short et al. 1977, Salomonson 1978, Balda 1987, Gottfried et al. 1995). Large mammals, such as mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus elaphus*), eat leaves and seeds of both species and they browse woodland grasses, forbs and shrubs, including *Artemisia tridentata, Cercocarpus montanus, Quercus gambelii*, and *Purshia stansburiana* (Short and McCulloch 1977).

The most important dispersers of juniper and pinyon seeds are birds, although many mammals also feed on them. These animals consume juniper berries and excrete viable scarified juniper seeds over extensive areas, which germinate faster than uneaten seeds (Johnsen 1962, Meeuwig and Bassett 1983). Primary juniper seed dispersers are Bohemian waxwing (*Bombycilla garrulus*), cedar waxwing (*Bombycilla cedrorum*), American robin (*Turdus migratorius*), turkey (*Meleagris gallopavo*), and several species of jays (Anderson 2002, Johnson 2002, Scher 2002). Pinyon seeds are a critically important food source for western scrub jay (*Aphelocoma californica*), pinyon jay (*Gymnorhinus cyanocephalus*), Steller's jay (*Cyanocitta stelleri*) and Clark's nutcracker (*Nucifraga columbiana*). These birds are the primary dispersers of pinyon seeds and, during mast crop years, cache hundreds of thousands of pinyon seeds, many of which are never recovered (Balda and Bateman 1971, Vander Wall and Balda 1977, Ligon 1978, Evans 1988, Hall and Balda 1988, Ronco 1990). Many mammals are also known to eat pinyon seeds, such as several species of mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), squirrels (*Sciurus* spp.), chipmunks (*Neotamias* spp.), deer, black bear (*Ursus americanus*), and desert bighorn sheep (*Ovis canadensis nelsoni*) (Anderson 2002). Because pinyon seeds are heavy and totally wingless, seed dispersal is dependent on vertebrate dispersers that store seeds in food caches, where unconsumed seeds may germinate. This dispersal mechanism is a good example of a co-evolved, mutualistic, plant-vertebrate relationship (Vander Wall et al. 1981, Evans 1988, Lanner 1996) and would be at risk with loss of trees or dispersers.

There are many insects, pathogens, and plant parasites that attack pinyon and juniper trees (Meeuwig and Bassett 1983, Gottfried et al. 1995, Rogers 1995, Weber et al. 1999). For pinyon and juniper, there are at least seven insects, plus fungus blackstain root-rot (*Leptographium wageneri*), juniper mistletoe (*Phoradendron juniperinum*) and pinyon dwarf mistletoe (*Arceuthobium divaricatum*). Both mistletoes reduce vigor and cause occasional dieback but rarely cause mortality (Meeuwig and Bassett 1983). The insects are normally present in these woodland stands, and during drought-induced water-stress periods, outbreaks may cause local to regional mortality (Wilson and Tkacz 1992, Gottfried et al. 1995, Rogers 1995). Most insect-related pinyon mortality in the West is caused by pinyon ips beetle (*Ips confusus*) (Rogers 1993). Pinyons cannot repel pinyon ips beetles when weakened by drought and many are killed. During the drought of 2002-2003, populations of ips beetles increased to epidemic levels that killed millions of pinyon trees in the southwestern U.S.

Most pinyon-juniper woodlands in the Southwest have high soil erosion potential (Baker et al. 1995). Several studies have measured present-day erosion rates in pinyon-juniper woodlands, highlighting the importance of herbaceous cover and biological soil crusts (Baker et al. 1995, Belnap et al. 2001) in minimizing precipitation runoff and soil loss in pinyon-juniper woodlands.

ECOLOGICAL INTEGRITY

Change Agents: Before 1900, this system was mostly open woodland restricted to fire-safe areas on rocky ridges and outcrops where the low cover fine fuels reduced the spread of fires. Since then the distribution and density of pinyon and juniper and accompanying native understory have been significantly altered (Stevens 1999, West 1999b, Romme et al. 2009). Altered fire regimes, overgrazing, and tree cutting can all affect stand quality and fire behavior (Anderson 2002, Johnson 2002). These factors can also disturb microbiotic soil crusts and lead to increased soil erosion and habitat/species loss.

Conversion of this type has resulted from catastrophic crown fires and "chaining" or mechanical removal of trees by land management agencies to convert woodlands to grasslands for livestock (Stevens 1999, Tausch 1999, Tausch and Hood 2007). If exotic species are present, post-crown fire and post-treatment outcomes may result in conversion to exotic species.

Fire regimes were altered by fire suppression and grazing by livestock, which reduces the amount of fine fuels (grasses) that carry fire thus reducing fire frequency (Pieper and Witte 1990, Swetnam and Baisan 1996a, Miller and Tausch 2001). Currently, much of this system's distribution has a more closed canopy than historically. Fire suppression has led to a buildup of woody fuels that in turn increases the likelihood of high-intensity, stand-replacing fires. Long-term heavy grazing reduces perennial grass cover and tends to favor shrub and conifer species. Fire suppression combined with grazing creates conditions that support invasion by pinyon and juniper trees into adjacent shrublands and grasslands. Under most management regimes, typical tree size decreases and tree density increases in this habitat.

Other common stressors include invasive species, insect/disease outbreaks, fuel wood cutting, and increased soil erosion, all of which affect stand quality and fire behavior. Livestock are also vectors for invasive species and disturb biological soil crusts. In addition, many of these communities have been severely impacted by past range practices of chaining, tilling, and reseeding with exotic forage grasses.

Human development has impacted some locations throughout the distribution of this type. For example, residential development has significantly impacted locations within commuting distance to urban areas. Impacts may be direct as vegetation 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. Management actions such as chaining pinyon-juniper stands creates a large food source of injured pines for ips beetles (*Ips confusus*) to feed on that can quickly multiply creating epidemic outbreaks of beetles that attack and kill many healthy pinyons (Furniss and Carolin 2002). Drought stresses pinyon trees and makes them less able to survive ips beetle attacks (Furniss and Carolin 2002).

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.

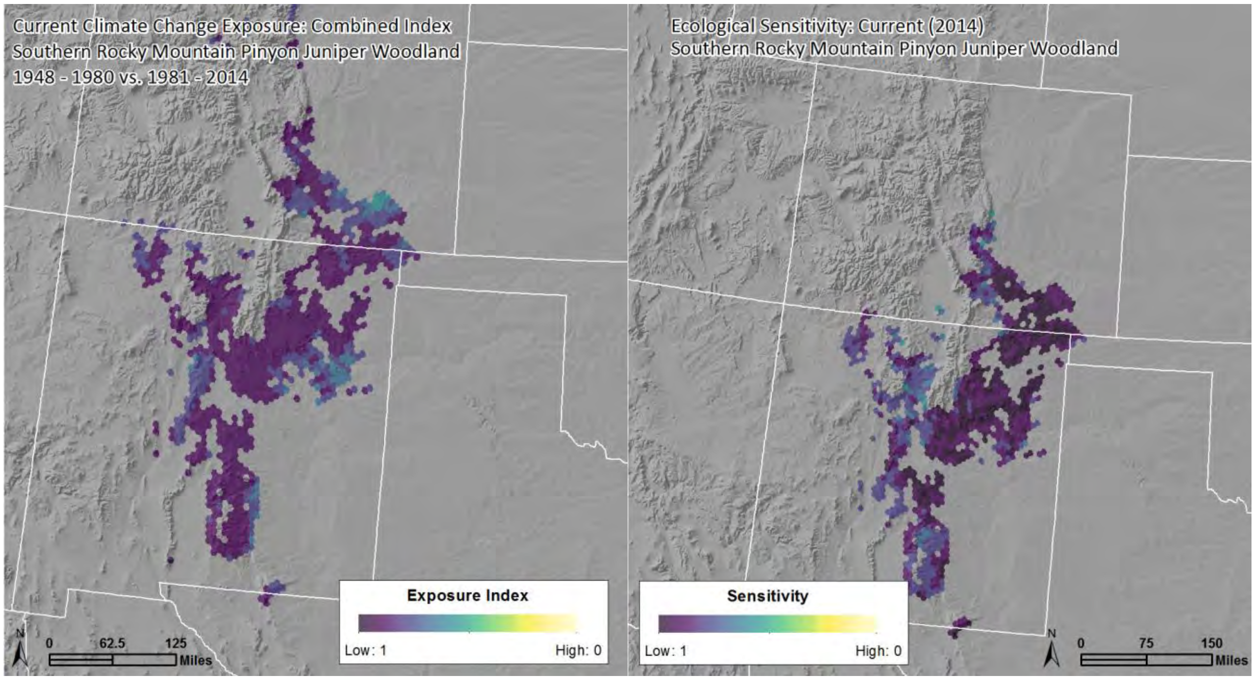

Figure 48. Climate exposure as of 2014 (left) and overall sensitivity (right) for Southern Rocky Mountain Pinyon-Juniper Woodland. The results have been summarized and are displayed in $100km^2$ hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 47. Resilience, exposure and vulnerability scores for Southern Rocky Mountain Pinyon-Juniper Woodland 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	Southwestern Tablelands	Arizona-New Mexico Mountains	Southern Rockies	Arizona-New Mexico Plateau
	Potential square miles within ecoregion	2,433	922	585	168
Contributions to Relative Vulnerability by Factor					
Vulnerability from **Exposure (2014)**		**Low** 0.81	**Low** 0.81	**Low** 0.81	**Low** 0.82
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.82	0.79	0.72	0.76
	Fire Regime Departure	0.86	0.62	0.73	0.48
	Invasive Annual Grasses	1.00	1.00	1.00	0.99
	Sensitivity Average	**0.89**	**0.80**	**0.82**	**0.75**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.33	0.45	0.40	0.37
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16
	Keystone Species Vulnerability	Null	Null	Null	Null
	Adaptive Capacity Average	**0.24**	**0.30**	**0.28**	**0.27**
Vulnerability from Measures of **Overall Resilience**		**Mod** 0.57	**Mod** 0.55	**Mod** 0.55	**Mod** 0.51
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: For these woodlands, climate exposure as of 2014 is low in all ecoregions. An emerging pattern of changing climate appears as increases of 0.56° to 0.59°C for Annual Mean Temperature in all ecoregions. In the Southern Rockies, Southwest Tablelands and Arizona/New Mexico Plateau ecoregions, some 14% to 30% of the system's distribution shows these increases; in the Arizona/New Mexico Mountains, where it is peripheral to the ecoregion, it is 90% of its distribution. Being based on 30-year averages, these observed increases in temperature are not sufficiently sensitive to suggest an increasing probability of severe drought events, which have been observed in recent decades (e.g., Breshears et al. 2005).

Climate Change Effects: Climate change has affected the distribution of pinyon-juniper woodlands in the past and current climate change will likely shift the geographic and elevational distribution in the future (Van Devender 1977, 1990, Betancourt et al. 1993, McAuliffe and Van Devender 1998). For example, after 500 years BP, winter precipitation increased and caused a re-expansion of pinyon-juniper woodland that sharply increased after 1700 and again in the early 1900s (Davis and Turner 1986, Mehringer and Wigand 1990, as cited in Gori and Bate 2007). Shorter term variation in climate also has important implications for this system. Regional droughts coupled with stress-induced insect outbreaks of native pinyon ips beetle (*Ips confusus*) have caused widespread mortality of pinyons. This affects species dominance patterns, tree age structure, tree density, and canopy cover within pinyon-juniper woodlands and will shift dominance to juniper (Betancourt et al. 1993). Conversely, wet periods create conditions for tree recruitment and growth.

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 severely reduced or possibly eliminated, effectively eliminating tree recruitment. Without recruitment current pinyon and juniper stands are essentially relicts of past climate conditions.

A warming climate with more frequent droughts may again weaken pinyon trees and may make them more susceptible to lethal attacks by forest diseases and insects such as the pinyon ips beetles (*Ips confusus*). Longer, milder climate periods may increase the number of generations of ips beetles above the average of two and a half to three annually, increasing potential for epidemics. Additionally, the recent epidemics of the pinyon ips beetle have killed many pinyons creating very high fuel loads throughout much of the system's range (Furniss and Carolin 2002). Furthermore, warmer/drier fuels may result in more frequent and severe fires that could increase rates of loss of mature stands through conversion of these woodland to annual grasslands or shrublands that are adapted to frequent fire (Miller and Tausch 2001).

However, many stands of this woodland type occur in the foothill zones of taller mountain ranges, so it may be possible for the species of this system to transition into lower montane zone as suitable climate is diminished at lower elevations. This process would be slow as pinyon and juniper trees are long-lived, frequently live more than 300 years. Individual trees may be able to survive for centuries at lower elevations without regeneration (Burns and Honkala 1990a) unless impacted by more frequent and extended drought, or more frequent and larger fires resulting from predicted hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is low to moderate across the range of this type, with scores suggesting increased sensitivity (scoring moderate) in stands in the Arizona-New Mexico Plateau ecoregion (peripheral). Landscape condition and fire regime departure are the drivers of the sensitivity results.

Landscape condition is very good (little development) (**Table 47**), as the ecosystem occurs in generally remote hills, plateaus, foothills and ranges in the Southwestern Tablelands, Arizona-New Mexico Mountains, and southern and eastern portions of Southern Rockies ecoregions. While landscape condition is good overall, the scores do suggest some impacts from infrastructure development. 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, some oil and gas development, transmission corridors, and areas of urban, suburban and exurban development.

Risk of invasive annual grasses is low overall. Fire regime departure is also low across much of the range of this system, but moderate departure is scored in the Arizona-New Mexico Mountains and Southern Rockies ecoregions. Direct fire suppression, grazing removal of fine fuels, and activities such as fuel or fence post cutting have combined to cause a shift in the structure of these woodlands. Currently, much of this system's distribution has a more closed canopy than historically. Fire suppression and the loss of fine fuels due to grazing together have changed the fire frequencies in many areas, which in turn leads to a younger age class of both pinyon and juniper, and an increased density of trees. Combined with recent decades of persistent drought and Ips beetle outbreaks with high mortality of pinyons, there has been a significant shift in the proportions of successional classes in these woodlands. Many old-growth stands now have a dense cohort of younger, smaller trees, or have suffered stand-replacing fire. These changes in fire regime have altered the structure of these woodlands making them vulnerable to catastrophic crown fires.

The interactions of the stressors of fragmentation by development, overgrazing and fire suppression have resulted in changes to the composition and structure of these woodlands. Together, these result in increased sensitivity of the system to the effects of changes in temperature or precipitation patterns.

Ecosystem Resilience: Adaptive Capacity: Adaptive capacity is low or very low across the range of this woodland system, primarily due to the low diversity within the nitrogen-fixing functional species group. Topoclimatic variability is low in all ecoregions . These woodlands generally occur in the foothill and lower montane zones on mountain slopes, mesas, plateaus, escarpments, and ridges. Therefore, in some cases, they occur where local climates vary within short distances. For example, both north and south facing slopes as well as steep elevation gradients, can occur within short distances.

Diversity within each of the three identified functional species groups varies from low to high. Within individual stands, the most limiting functional role is that of nitrogen fixation, which is provided by a low number of species. This system has plant taxa in the *Fabaceae, Rosaceae,* and *Poaceae* families of which a several are nitrogen-fixers. Cyanobacteria and cyanolichens in the soil crust also fix nitrogen. Across its range, diversity of nitrogen-fixing taxa is moderate; however, within stand species diversity of nitrogen fixers is typically low. 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 substrates support more lichens, and mosses are common in the grassland/woodland interface at the lower elevation of this system's range. Seed dispersal is provided by many bird and mammal species and appears to have high within-stand 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: These woodlands currently score in the moderate range of overall climate change vulnerability throughout their range. This is primarily due to low scores for exposure, low scores for adaptive capacity. Inherent vulnerabilities are high for types such as this with low diversity within key functional species groups, such as with nitrogen fixing species. Additionally, these woodlands are highly susceptible to effects of drought, increased susceptibility to insect and disease, grazing effects – especially on soils - and long-term effects of fire regime alterations.

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 Southern Rocky Mountain Pinyon-Juniper Woodland.

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 and fire breaks. Protect old-growth stands while maintaining natural wildfire regimes.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring nitrogen fixing species. Localize regional models for wildfire regimes. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration.
High	**Revisit prior desired condition statements.** Update assumptions and models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion and effects of drought stress, including tree regeneration and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes. 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. Restore connectivity among fragmented patches. Monitor for effects of drought stress, including tree regeneration and loss/gain of neighboring species. Consider needs for "assisted migration" of most vulnerable species.

References for the System: Anderson 2002, Baker et al. 1995, Balda 1987, Balda and Bateman 1971, Belnap 2001, Belnap et al. 2001, Betancourt et al. 1993, Breshears et al. 2005, Burns and Honkala 1990a, CNHP 2010, Comer et al. 2003*, Davis and Turner 1986, Evans 1988, Eyre 1980, FNA Editorial Committee 1997, Furniss and Carolin 2002, Gori and Bate 2007, Gottfried et al. 1995, Gottfried et al. 1999, Hall and Balda 1988, Johnsen 1962, Johnson 2002, LANDFIRE 2007a, Lanner 1996, Ligon 1978, Little 1987, McAuliffe and Van Devender 1998, McCulloch 1969, Meeuwig and Bassett 1983, Mehringer and Wigand 1990, Miller and Tausch 2001, Rogers 1993, Rogers 1995, Romme et al. 2009, Ronco 1990, Rondeau 2001, Rosentreter and Belnap 2003, Salomonson 1978, Scher 2002, Shiflet 1994, Short and McCulloch 1977, Short et al. 1977, Stevens 1999a, Swetnam and Baisan 1996a, Tausch 1999, Tausch and Hood 2007, USFWS 1985, Van Devender 1977, Van Devender 1990, Vander Wall and Balda 1977, Vander Wall et al. 1981, Weber et al. 1999, West 1999b, Wilson and Tkacz 1992, Woodin and Lindsey 1954, Wright et al. 1979

1.B.2.Nd. Vancouverian Forest & Woodland

M886. Southern Vancouverian Dry Foothill Forest & Woodland

CES204.085 East Cascades Oak-Ponderosa Pine Forest and Woodland

Figure 49. Photo of East Cascades Oak-Ponderosa Pine Forest and Woodland. 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 narrowly restricted ecological system appears at or near lower treeline in foothills of the eastern Cascades in Washington and Oregon within 65 km (40 miles) of the Columbia River Gorge. It also appears in the adjacent Columbia Plateau ecoregion. Elevations range from 460 to 1920 m. Most occurrences of this system are dominated by a mix of *Quercus garryana* and *Pinus ponderosa* or *Pseudotsuga menziesii*. Isolated, taller *Pinus ponderosa* or *Pseudotsuga menziesii* over *Quercus garryana* trees characterize parts of this system. Clonal *Quercus garryana* can create dense patches across a grassy landscape or can dominate open woodlands or savannas. The understory may include dense stands of shrubs or, more often, be dominated by grasses, sedges or forbs. Shrub-steppe shrubs may be prominent in some stands and create a distinct tree / shrub / sparse grassland habitat, including *Purshia tridentata, Artemisia tridentata, Artemisia nova*, and *Chrysothamnus viscidiflorus*. Understories are generally dominated by herbaceous species, especially graminoids. Mesic sites have an open to closed sodgrass understory dominated by *Calamagrostis rubescens, Carex geyeri, Carex rossii, Carex inops*, or *Elymus glaucus*. Drier savanna and woodland understories typically contain bunchgrass steppe species such as *Festuca idahoensis* or *Pseudoroegneria spicata*. Common exotic grasses that often appear in high abundance are *Bromus tectorum* and *Poa bulbosa*. These woodlands occur at the lower treeline/ecotone between *Artemisia* spp. or *Purshia tridentata* steppe or shrubland and *Pinus ponderosa* and/or *Pseudotsuga menziesii* forests or woodlands. In the Columbia River Gorge, this system appears as small to large patches in transitional areas in the Little White Salmon and White Salmon river drainages in Washington and Hood River, Rock Creek, Moiser Creek, Mill Creek, Threemile Creek, Fifteen Mile Creek, and White River drainages in Oregon. *Quercus garryana* can create dense patches often associated with grassland or shrubland balds within a closed *Pseudotsuga menziesii* forest landscape. Commonly the understory is shrubby and composed of *Ceanothus integerrimus, Holodiscus discolor, Symphoricarpos albus*, and *Toxicodendron diversilobum*. Fire plays an important role in creating vegetation structure and composition in this habitat. Decades of fire suppression have led to invasion by *Pinus ponderosa* along lower treeline and by *Pseudotsuga menziesii* in the gorge and other oak patches on xeric sites in the east Cascade foothills. In the past, most of the habitat experienced frequent low-severity fires that maintained woodland or savanna conditions. The mean fire-return interval is 20 years, although variable. Soil drought plays a role, maintaining an open tree canopy in part of this dry woodland habitat.

Distribution: This narrowly restricted ecological system appears at or near lower treeline in foothills of the eastern Cascades in Washington and Oregon within 65 km (40 miles) of the Columbia River Gorge. It also appears in the adjacent Columbia Plateau ecoregion. Disjunct occurrences in Klamath and Siskiyou counties, Oregon, have more sagebrush and bitterbrush in the understory, along with other shrubs.

Nations: CA, US

States/Provinces: BC, OR, WA

CEC Ecoregions: North Cascades, Cascades, Eastern Cascades Slopes and Foothills, Columbia Plateau

Primary Concept Source: R. Crawford

Description Author: G. Kittel, C. Chappell, M.S. Reid, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: Most occurrences of this system are dominated by a mix of *Quercus garryana* and *Pinus ponderosa* or *Pseudotsuga menziesii*. Isolated, taller *Pinus ponderosa* or *Pseudotsuga menziesii* over *Quercus garryana* trees characterize parts of this system. Clonal *Quercus garryana* can create dense patches across a grassy landscape or can dominate open woodlands or savannas. The understory may include dense stands of shrubs or, more often, be dominated by grasses, sedges or forbs. Shrub-steppe shrubs may be prominent in some stands and create a distinct tree / shrub / sparse grassland habitat, including *Purshia tridentata, Artemisia tridentata, Artemisia nova*, and *Chrysothamnus viscidiflorus*. Understories are generally dominated by herbaceous species, especially graminoids. Mesic sites have an open to closed sodgrass understory dominated by *Calamagrostis rubescens, Carex geyeri, Carex rossii, Carex inops*, or *Elymus glaucus*. Drier savanna and woodland understories typically contain bunchgrass steppe species such as *Festuca idahoensis* or *Pseudoroegneria spicata*. Common exotic grasses that often appear in high abundance are *Bromus tectorum* and *Poa bulbosa*.

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.

Nitrogen Fixation; Species Diversity: Medium
These semi-arid to dry continental woodlands typically have moderate species diversity for nitrogen-fixation, although rangewide diversity may exceed 20 species. Diversity: medium = 11-20 spp. These *Pinus ponderosa, Quercus garryana*, and/or *Pseudotsuga menziesii* woodlands occur in semi-arid to dry-mesic temperate climates with limited soil depth, and soil nutrients such as nitrogen are a

significant constraint on plant growth. Possible nitrogen-fixing plants include species of Fabaceae (including species of *Astragalus* and *Lupinus*); Polygonaceae (*Eriogonum*); Rhamnaceae (*Ceanothus*); Rosaceae (*Amelanchier, Cercocarpus, Potentilla, Purshia*); many species of Poaceae (including *Calamagrostis rubescens, Elymus glaucus, Festuca idahoensis, Poa secunda*, and *Pseudoroegneria spicata*); and some Brassicaceae species.

Cyanobacteria and cyanolichens can be an important source of soil nitrogen in desert and semi-arid ecosystems (Belnap 2001, Belnap et al. 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). Diversity of cyanobacteria and cyanolichens is assumed to be similar to the northern Great Basin described in Rosentreter and Belnap (2001).

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.

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 ponderosa pine woodland type.

Environment: This narrowly restricted ecological system appears at or near lower treeline in foothills of the eastern Cascades in Washington and Oregon within 65 km (40 miles) of the Columbia River Gorge. It also appears in the adjacent Columbia Plateau ecoregion. Elevations range from 460 to 1920 m. In the Columbia River Gorge, this system appears as small to large patches in transitional areas in the Little White Salmon and White Salmon river drainages in Washington and Hood River, Rock Creek, Moiser Creek, Mill Creek, Threemile Creek, Fifteen Mile Creek, and White River drainages in Oregon. *Quercus garryana* can create dense patches often associated with grassland or shrubland balds within a closed *Pseudotsuga menziesii* forest landscape.

Key Processes and Interactions: Fire plays an important role in creating vegetation structure and composition in this habitat. Decades of fire suppression have led to invasion by *Pinus ponderosa* along lower treeline and by *Pseudotsuga menziesii* in the gorge and other oak patches on xeric sites in the east Cascade foothills. Most of the habitat experienced frequent low-severity fires that maintained woodland or savanna conditions. The mean fire-return interval is 20 years, although variable. LANDFIRE VDDT models: #R OAP1 Oregon White Oak-Ponderosa Pine model describes general successional pathways treating drier pine succession separate from more mesic Douglas-fir pathways.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 0710600). These are summarized as:

A) Early Development 1 All Structures (tree-dominated - 10% of type in this stage): Shrub cover is 0-40%. The early stage is the initial post-disturbance community dominated by white oak sprouts from coppice origin. Bunchgrasses and associated forbs dominate understory with bare ground and rock/gravel abundant in interspaces. Native herbivory may maintain oak sprouts in "shrub" form for extended period. Early stage includes oak sprouts or seedling/saplings growth to 4-6 inches dbh. Occasional sites with ponderosa pine or Douglas-fir will have diameters up to 8 inches. Succeeds to class C (mid/open) after about 50 years. Herbivory and surface fires maintain the stand in class A. About a tenth of this area is wet enough to succeed to class B.

B) Mid Development 1 Closed (tree-dominated - 5% of type in this stage): Tree cover is 41-80%. The mid-seral, closed stage occurs at the more mesic end of the environmental gradient and supports a dense canopy of oak and ponderosa pine and/or Douglas-fir. Oak diameter ranges from 6-12 inches dbh with crown closure approaching 70%. Ponderosa pine and Douglas-fir may be 8-20 inches dbh. Sod-forming grasses and shade-tolerant shrubs will be prominent on the majority of sites. Species from more arid sites may be remnants of earlier, more open post-fire communities. Lasts up to 150 years in this class. Replacement fire about every few hundred years; mixed fire opens the stand (to class C).

C) Mid Development 1 Open (tree-dominated - 10% of type in this stage): Tree cover is 10-40%. The mid-seral, open stage occurs on arid slopes and benches and represents that portion of the environmental gradient where fire-tolerant communities develop as oak woodlands. Usually the dry site conditions limit tree density and canopy closure is relatively low (between 10-30%). Conifers may occur sporadically at low coverage. Oak diameter ranges from 6-10 inches dbh. Bunchgrasses and shade-intolerant shrubs, notably antelope bitterbrush, will be prominent on the majority of sites. Replacement fire is infrequent; surface fire maintains it in class C. Moist sites can fill in to late/closed conditions (class E).

D) Late Development 1 Open (tree-dominated - 65% of type in this stage): Tree cover is 10-40%. The late-seral, open stage is characterized by large, principally multi-stemmed (now, although historically wider spaced, giant-trunked trees were more common), white oaks in open stands with bunchgrass, forb, and shrub understories. These woodlands support crown closure between 10-30%. Diameters range from 10-18 inches dbh with ages over 350 years for those individuals surviving fires. Mature, large conifers may occur sporadically at low coverage. Bunchgrasses (*Pascopyrum smithii* and *Festuca idahoensis*) and shade-intolerant shrubs, notably antelope bitterbrush, will be prominent on the majority of sites. Surface fires maintain it in class D. Replacement fire resets to class A.

E) Late Development 1 Closed (tree-dominated - 10% of type in this stage): Tree cover is 41-80%. This stage has mature overstory ponderosa pine and/or Douglas-fir as emergents over a lower canopy layer of white oak. The conifers have survived a few burn cycles and may show fire scars; dbhs are 21+ inches. Oregon white oak may reach its largest diameters in eastside ecosystems in these river and stream terraces attaining a dbh of 18-20 inches. Canopy closure is high (60-80%) with a dense understory dominated by sod-forming grasses and shrubs. Mixed fire opens the stand.

Historical fire frequency is between 5-30 years in this type. Fire intensities were probably low in open stands but increased in severity as woodland vegetation transitioned to a denser, closed-canopy type along water courses. Canopy is fire-tolerant and therefore fire severity is low. The natural fire regime was a type I regime in the upland. In the more mesic river terraces and draws, fire frequency probably decreased with a fire interval of 50-60 years. With dense vegetation and the occurrence of fuel ladders, fire severity would become mixed. The fire regime may reflect a type III in this more mesic habitat (LANDFIRE 2007a, BpS 0710600).

Insects and disease may impact individual trees (either ponderosa pine or white oak) locally. Armillaria root rot, western pine beetle, western oak looper, western tent caterpillar, and the pine engraver have the greatest potential for damage (LANDFIRE 2007a, BpS 0710600).

Nutrient cycling, specifically carbon cycling, is an important ecological process within many ecological systems. However, biological decomposition in ponderosa pine forests is more limited than biological production, resulting in accumulation of organic materials, especially in the absence of fire (Harvey 1994, Graham and Jain 2005).

ECOLOGICAL INTEGRITY

Change Agents: Conversion of this type has commonly come from agriculture and rural and urban development including past homesteading (WNHP 2011). Ongoing threats since European settlement include fire suppression, timber and fuelwood harvest, improper livestock grazing, and introduced species (WNHP 2011). Road building and development increase fragmentation (WNHP 2011).

This system is characterized by frequent (5-30 year fire-return interval) low-intensity ground fires that maintain the open savanna structure that is characteristic of most of this system (LANDFIRE 2007a fire regime I). Direct fire suppression and removal of fine fuels by improper grazing has increased fire-return intervals resulting in higher density of understory shrubs and canopy trees and increased fire severity. Logging and grazing have created scrub-like stands of oak that are more susceptible to stand-replacement fires (WNHP 2011). Improper grazing can result in loss of herbaceous cover or the replacement of native bunchgrasses with non-native species such as *Bromus tectorum, Poa bulbosa*, or *Cynosurus echinatus*. In summary, composition, abundance, and structure of native species in this system are significantly threatened by fire suppression, grazing, homesteading and development, and logging (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 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.

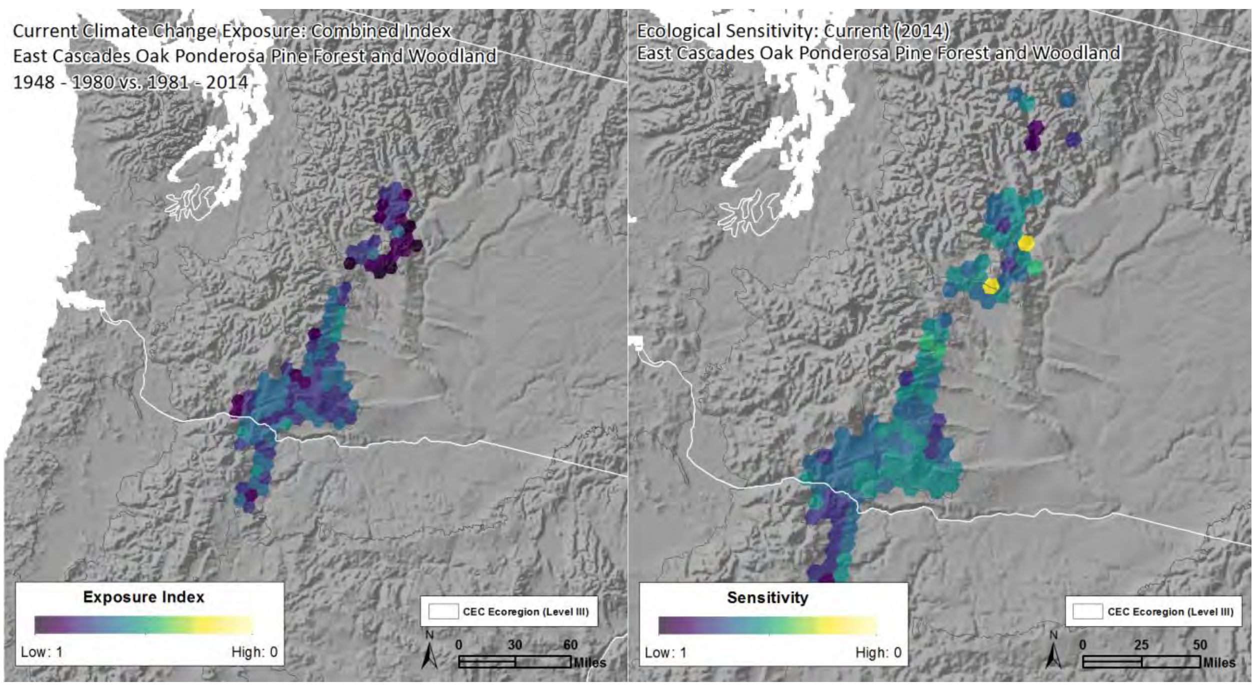

Figure 50. Climate exposure as of 2014 (left) and overall sensitivity (right) for East Cascades Oak-Ponderosa Pine Forest and Woodland. The results have been summarized and are displayed in $100km^2$ hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 49. Resilience, exposure and vulnerability scores for East Cascades Oak-Ponderosa Pine Forest and Woodland 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. 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	Eastern Cascades Slopes & Foothills	Columbia Plateau
	Potential square miles within ecoregion	149	45
Contributions to Relative Vulnerability by Factor			
Vulnerability from **Exposure (2014)**		**Mod** 0.70	**Mod** 0.67
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.24	0.39
	Fire Regime Departure	0.36	0.64
	Invasive Annual Grasses	0.99	0.97
	Forest Insect & Disease	0.85	0.95
	Sensitivity Average	**0.61**	**0.74**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.22	0.24
	Diversity within Functional Species Groups	0.50	0.50
	Adaptive Capacity Average	**0.36**	**0.37**
Vulnerability from Measures of **Overall Resilience**		**High** 0.49	**Mod** 0.55
Climate Change Vulnerability Index		**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: The overall exposure as of 2014 for this woodland system was moderate across both ecoregions for this narrowly distributed woodland type. Although exposure was consistent with an increase in annual mean temperature, substantial deviations from the historic climate affected only a very small portion (<1%) of the Eastern Cascades, Slopes and Foothills ecoregion, which exhibited an increase of approximately 0.5°C.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest region along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2006, Mote et al. 2014). 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 tree recruitment. Without recruitment ponderosa pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as *Ips* spp. by increasing the number of generations within a growing season or by allowing a population buildup over several years, such as with mountain pine beetle (*Dendroctonus ponderosae*), causing outbreaks that could severely impact pine trees regionally (Schmid 1988, Burns and Honkala 1990a, Habeck 1992a, d).

Many stands of this ecological system woodland occur in foothill zone of taller ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so it may be able to survive as relicts for centuries without regeneration (Habeck 1992a, d, Sawyer et al. 2009). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate for this woodland type. This moderate sensitivity was associated with high to very high contributions from landscape condition and moderate to high fire regime departure, in contrast to low contributions from forest insect and disease and invasive annual grass risk.

Vulnerability from landscape condition was very high in the Eastern Cascades, Slopes and Foothills ecoregion (comprising 77% of the range) and high in the Columbia Plateau. Landscape condition reflects fragmentation from agricultural conversion in the Yakima Valley and Columbia River Valley, with additional contributions from urban, suburban and exurban development.

Fire regime departure was high in the Eastern Cascades, Slopes and Foothills ecoregion and moderate in the Colombia Plateau ecoregion. This reflects fire suppression practices across much of the range, leading to increased understory fuel loads and stand densification, which make the system vulnerable to higher intensity fires with increased tree mortality.

Risk from insect and disease was generally low across the range of the system. However, this low risk may be increased by interactions with drought and fire in the region.

The interactions of the stressors of fire suppression and landscape fragmentation have resulted in changes to the structure of these woodlands. 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. Low adaptive capacity is related to very low scores for topoclimate variability, and generally moderate scores for diversity within functional groups. Very low topoclimatic variability reflect the gentle slopes and foothills characteristic of where this woodland type occurs. There is potential for the species in this system to disperse into areas of suitable climate nearby. In terms of vulnerability related to functional groups, the system scores low in terms of diversity of nitrogen fixers, suggesting increased vulnerability. Within individual stands, nitrogen fixation is provided by only a relatively few species and so their individual vulnerabilities to factors such as drought and human disturbance suggest increased overall vulnerability for the 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: Assuming climate exposure as of 2014, these woodlands score in the moderate range of overall climate change vulnerability. This is primarily due to high to moderate contributions to sensitivity from fire regime departure (increasing the likelihood of higher intensity fires with severe tree mortality), and low adaptive capacity scores. The system occurs in areas of very low topoclimate variability. Although insect and disease risk were low for this system, these may be exacerbated by effects of recent drought and fire across the range 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 50. Climate change adaptation strategies relative to vulnerability scores for East Cascades Oak-Ponderosa Pine Forest and Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring nitrogen fixing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. 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. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

References for the System: Burns and Honkala 1990a, Comer et al. 2003*, Dale et al. 2001, Eyre 1980, Graham and Jain 2005, Habeck 1992a, Habeck 1992d, Harvey 1994, John and Tart 1986, LANDFIRE 2007a, Lillybridge et al. 1995, McKenzie et al. 2004, McKenzie et al. 2008, Mote et al. 2014, Sawyer et al. 2009, Schmid 1988, Stevens-Rumann et al. 2017, Topik et al. 1988, WNHP 2011, WNHP unpubl. data 2018, Westerling et al. 2006

M023. Southern Vancouverian Montane-Foothill Forest

CES206.918 California Montane Jeffrey Pine-(Ponderosa Pine) Woodland

Figure 51. Photo of California Montane Jeffrey Pine-(Ponderosa Pine) Woodland. Photo credit: David Prassad, used under Creative Commons license CC BY 2.0, https://www.flickr.com/photos/33671002@N00.

CLASSIFICATION AND DISTRIBUTION

Concept Summary: These forests are found on relatively xeric sites in mountains and plateaus from southern Oregon (600-1830 m [1800-5000 feet] elevation) south into the Sierra Nevada, throughout the Transverse Ranges of California, and into northern Baja California (1200-2740 m [4000-8300 feet]), Mexico. While the two dominant pines tend to segregate by soil fertility and temperature regimes, they may co-occur in certain areas (e.g., Modoc Plateau). These stands are more common on the east side of the Sierra Nevada, although they do occur on the west side. Stands are pure *Pinus jeffreyi, Pinus ponderosa*, or a mix of the two. Ponderosa pine and/or Jeffrey pine on the west slope of the Sierras with other conifer species are part of Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland (CES206.916). This system includes sites where *Pinus ponderosa* and/or *Pinus jeffreyi* are the predominant conifers and other tree species do not occur in high abundance, if at all. The exception to this is in southern California on the edges of the Mojave Desert where *Pinus monophylla* or *Juniperus californica* might occur in a subcanopy under *Pinus ponderosa* or *Pinus jeffreyi*. *Pinus jeffreyi* is more tolerant of colder, drier and poorer sites and replaces *Pinus ponderosa* as the dominant at higher elevations. In the north, *Pinus jeffreyi* may be replaced by *Pinus ponderosa var. washoensis* (Carson Range and Warner Mountains). Throughout California, pure stands of ponderosa pine are relatively uncommon. Only on the Modoc Plateau do these pines co-occur in mixed stands. *Juniperus grandis* [in the south] and *Juniperus occidentalis* can co-occur in these stands but typically are not dominant. On moister and cooler sites, *Abies lowiana* can be present in some stands. There can be well-developed shrub understories with strong Great Basin affinities; species can include *Artemisia tridentata, Purshia tridentata, Symphoricarpos rotundifolius var. parishii, Arctostaphylos patula, Ceanothus cordulatus, Ceanothus prostratus, Ceanothus integerrimus, Chrysolepis sempervirens, Eriogonum wrightii, Quercus vacciniifolia*, and *Lupinus elatus*. *Cercocarpus ledifolius* is common on steeper slopes throughout the range. Historically, frequent localized surface fires maintained these systems. Stands of ponderosa pine on the east side of the Cascades transition into East Cascades Oak-Ponderosa Pine Forest and Woodland (CES204.085), or Northern Rocky Mountain Ponderosa Pine Woodland and Savanna (CES306.030) north of the Warm Springs Reservation of central Oregon.

Distribution: This system occurs in foothills and mountains from southern Oregon south into the Sierra Nevada, throughout the Transverse Ranges of California and into northern Baja California, Mexico.

Nations: MX, US

States/Provinces: CA, MXBC, NV, OR

CEC Ecoregions: Cascades, Eastern Cascades Slopes and Foothills, Klamath Mountains, Sierra Nevada, Coast Range, Northern Basin and Range, Central Basin and Range, Mojave Basin and Range, California Coastal Sage, Chaparral, and Oak Woodlands, Southern and Baja California Pine-Oak Mountains

Primary Concept Source: P. Comer and T. Keeler-Wolf

Description Author: P. Comer, T. Keeler-Wolf, G. Kittel, K.A. Schulz

ECOSYSTEM COMPOSITION AND KEY ECOLOGICAL ATTRIBUTES

Floristic Composition: This system includes sites where *Pinus ponderosa* and/or *Pinus jeffreyi* are the predominant conifers and other tree species do not occur in high abundance, if at all. The exception to this is in southern California on the edges of the Mojave Desert where *Pinus monophylla* or *Juniperus californica* might occur in a subcanopy under *Pinus ponderosa* or *Pinus jeffreyi*. *Pinus jeffreyi* is more tolerant of colder, drier and poorer sites and replaces *Pinus ponderosa* as the dominant at higher elevations. In the north, *Pinus jeffreyi* may be replaced by *Pinus ponderosa var. washoensis (= Pinus washoensis)* (Carson Range and Warner Mountains). Throughout California, pure stands of ponderosa pine are relatively uncommon. Only on the Modoc Plateau do these pines co-occur in mixed stands. *Juniperus grandis (= Juniperus occidentalis var. australis)* [in the south] and *Juniperus occidentalis* can co-occur in these stands but typically are not dominant. On moister and cooler sites, *Abies lowiana (= Abies concolor var. lowiana)* can be present in some stands. There can be well-developed shrub understories with strong Great Basin affinities; species can include *Artemisia tridentata, Purshia tridentata, Symphoricarpos rotundifolius var. parishii (= Symphoricarpos parishii), Arctostaphylos patula, Ceanothus cordulatus, Ceanothus prostratus, Ceanothus integerrimus, Chrysolepis sempervirens, Eriogonum wrightii, Quercus vacciniifolia*, and *Lupinus elatus*. *Cercocarpus ledifolius* is common on steeper slopes throughout the range.

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.

Nitrogen Fixation; Species Diversity: Medium
Diversity of cyanobacteria and cyanolichens is assumed to be similar to the northern Great Basin described in Rosentreter and Belnap (2003).

These semi-arid to dry-mesic temperate woodlands typically have moderate diversity. Diversity: medium = 11-20 spp. These *Pinus ponderosa* and/or *Pinus jeffreyi* woodlands occur in semi-arid to dry-mesic climates with limited soil depth, and soil nutrients such as nitrogen are likely a significant constraint on plant growth. Possible nitrogen-fixing plants include species of Fabaceae (including

Lupinus adsurgens, Lupinus andersonii, and *Lupinus argenteus*); Polygonaceae (*Eriogonum*); Rhamnaceae (*Ceanothus*); Rosaceae (*Amelanchier, Cercocarpus, Potentilla, Purshia*); many species of Poaceae (such as *Achnatherum lemmonii, Achnatherum occidentale, Achnatherum webberi, Bromus carinatus, Elymus elymoides, Poa secunda*, and *Poa wheeleri*); and some Brassicaceae (perhaps *Arabis bodiensis*).

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 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).

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 Graminoids; Species Diversity: Low
Diversity: low = 6-15 spp. *Achnatherum lemmonii, Achnatherum occidentale, Achnatherum webberi, Bromus carinatus, Elymus elymoides, Poa secunda*, and *Poa wheeleri*.

Seed Dispersal; Species Diversity: Low
Diversity: low = 1-5 spp. Ponderosa pine seeds are primarily dispersed by wind; however, the heavier Jeffrey pine seeds are dispersed by a combination of gravity, wind, small mammal and birds (Gucker 2007). Yellow pine chipmunks (*Tamias amoenus*) commonly disperse and cache Jeffrey pine seeds in the Carson Range, especially during mast years (Vander Wall 1992, 1995, 2002). Clark's nutcracker (*Nucifraga columbiana*) also disperse and bury Jeffrey pine seeds (Tomback 1977). Other information on species of animals that disperse Jeffrey pine seeds is limited; however, other small mammals and birds also likely disperse and cache Jeffrey pine seeds.

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 Jeffrey pine - ponderosa pine woodland type.

Environment: This system occupies xeric (mean annual rainfall 200-430 mm, as winter snow), cool (cold winters; January minimums range from -13° to -5°C), and nutrient-poor sites in mountains and plateaus (600-2740 m elevation), in the rainshadow of the Sierra Nevada. Frequent (8-10 years) low-intensity and moderately frequent (44 years) mixed-intensity fires maintain this system. Greater moisture increases tree diversity (*Abies lowiana* at higher altitudes).

Key Processes and Interactions: *Pinus jeffreyi* and *Pinus ponderosa* trees are structurally and physiologically fire-adapted (Habeck 1992a, d, Gucker 2007). Both species have thick, insulating bark, insulating bud scales that protect terminal buds, self-pruning branches, open crowns, and high moisture content of needles, which make them moderately fire-resistant as saplings and highly fire-resistant as mature trees (Habeck 1992a, d, Gucker 2007). Historically, frequent localized surface fires maintained open canopy woodland stands in this system.

LANDFIRE developed a state-and-transition vegetation dynamics VDDT model for this system which has five classes in total (LANDFIRE 2007a, BpS 1210310). These are summarized as:

A) Early Development 1 All Structures (shrub-dominated - 15% of type in this stage): Shrub cover is 0-100%. Fire-dependent shrubs such as greenleaf manzanita and mountain whitethorn resprout and germinate from seed vigorously after fire. Scattered Jeffery pine seedlings sprout but may take several years to dominate over the shrub community. Perennial bunchgrasses and some forbs cover small portions of the area.

B) Mid Development 1 Closed (tree-dominated - 5% of type in this stage): Tree cover is 51-90%. This class has developed after escaping significant fire and it is modeled as an alternative pathway when three fire cycles have been missed. In the absence of fire, a closed forest with a dense stand of multi-layered pole and medium-sized Jeffery pine and white fir trees (5-16 inches dbh) develops. This multi-layered forest is often dominated by Jeffery pine in the overstory with white fir dominant in the mid and regeneration layers. The understory vegetation is almost absent due to the lack of sunlight and heavy litter and woody debris accumulations. In some cases, on the east side of the Sierra Nevada, both white fir and Jeffrey pine are pretty equally stocked and have a number of older individuals present suggesting that there is not always a low cover of white fir of small size classes in such settings (e.g., Buckeye Creek and other drainages northeast of Yosemite National Park). The understory vegetation is generally sparse, but not always due to lack of sunlight. *Poa wheeleri* and *Elymus elymoides* can be main understory species.

C) Mid Development 1 Open (tree-dominated - 20% of type in this stage): Tree cover is 0-50%. This class has developed with frequent low-intensity surface fires. Pole to medium-sized (5-21 inches dbh) Jeffery pine has become dominant over the shrub layer. Several conifer species could also be present depending on location. Shrubs are prevalent in the understory with scattered forbs and perennial grasses. East of the Sierra crest (e.g., Truckee Basin north of Tahoe), this class can have substantial amounts of white fir, but usually exists where the shrubs are mostly *Purshia tridentata* and other Great Basin species.

D) Late Development 1 Open (conifer-dominated - 65% of type in this stage): Tree cover is 0-50%. This class is a continuation of class C which has developed with frequent low-intensity surface fires. Large to very large (>21 inches dbh) Jeffery pine is dominant with an open canopy. Scattered shrubs are found in the canopy openings, with a diversity of forbs such as lupines and woolly mule's-ears. Perennial grasses are also present.

E) Late Development 1 Open (conifer-dominated - 5% of type in this stage): Tree cover is 51-90%. This class has developed in time from class B or class D after escaping significant fire (>3 years fire-return intervals). In the absence of fire, a closed forest structure continues to develop with a dense stand of multi-layered medium- to large-sized Jeffery pines and white fir trees (16+ inches dbh). The diameter remains smaller than in the open forest due competition. This overstory canopy is often codominated by Jeffery pine and white fir, with white fir dominating the understory. There is severe competition for sunlight and water. This stress combined with insect and disease infestation create a high level of tree mortality. The understory vegetation is almost absent due to the lack of sunlight and heavy litter and woody debris accumulations. Current conditions where there are large Jeffery pine trees along with multi-age classes of white fir suggest that historically there were low-intensity fires that maintained stands without killing white fir, but more recently white fir has become dominant in the understory.

Where stands are relatively dense and sufficient fuels are available, this type is dependent on relatively frequent low-intensity surface fire intervals of about 30 years (LANDFIRE 2007a, BpS 1210310). The mixed-intensity fire interval is about 130 years, and the stand-replacement fire interval is 250 years. The mean fire interval for all fires is 20 years with a range from 8-28 years. Intervals may be longer for relatively open stands with low understory fuels, as over shallow granitic soils in the Kern Plateau or over serpentine substrate in the Klamath Mountains. The fire regimes in this type are more variable and somewhat longer than the ponderosa pine types, due to slower fuel accumulation rates (LANDFIRE 2007a, BpS 1210310).

ECOLOGICAL INTEGRITY

Change Agents: This system is characterized by frequent (5-30 years fire-return interval) low-intensity ground fires that maintain the open structure. Fire suppression has increased fire-return intervals resulting in higher density of understory shrubs and canopy trees, increased presence of ladder fuels resulting in high-severity, stand-replacing fires. On a landscape scale, a mixed-severity fire regime occurs in Jeffery pine habitats (Habeck 1992a, d, Gucker 2007).

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.

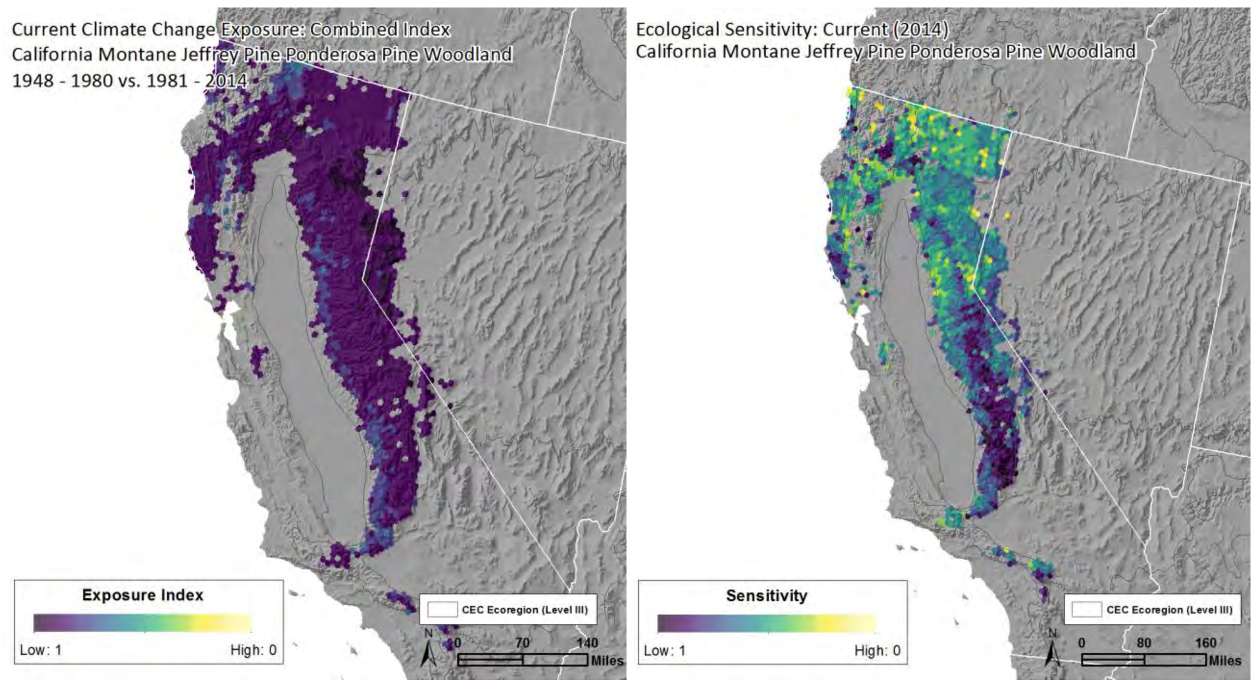

Figure 52. Climate exposure as of 2014 (left) and overall sensitivity (right) for California Montane Jeffrey Pine-(Ponderosa Pine) Woodland. The results have been summarized and are displayed in 100km^2 hexagons. In both maps, the dark purple indicates low exposure or low sensitivity, with progressively higher exposure or sensitivity (and hence higher vulnerability) indicated by the bright green to yellow.

Table 51. Resilience, exposure and vulnerability scores for California Montane Jeffrey Pine-(Ponderosa Pine) Woodland 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. 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	Sierra Nevada	Eastern Cascades Slopes & Foothills	Central Basin & Range	Southern & Baja California Pine-Oak Mountains	Northern Basin & Range	Klamath Mountains	California Coastal Sage, Chaparral, & Oak Woodlands	Mojave Basin & Range
	Potential square miles within ecoregion	3,291	919	448	196	155	42	38	23
Contributions to Relative Vulnerability by Factor									
Vulnerability from **Exposure (2014)**		**Low** 0.87	**Low** 0.86	**Low** 0.89	**Low** 0.82	**Low** 0.89	**Low** 0.81	**Low** 0.81	**Low** 0.85
Vulnerability from Measures of **Sensitivity**	Landscape Condition	0.68	0.69	0.72	0.71	0.72	0.51	0.62	0.89
	Fire Regime Departure	0.58	0.34	0.61	0.59	0.47	0.43	0.62	0.84
	Invasive Annual Grasses	Null	Null	Null	Null	Null	Null	Null	Null
	Forest Insect & Disease	0.78	0.75	0.93	0.86	0.91	0.93	0.91	0.87
	Sensitivity Average	**0.68**	**0.59**	**0.75**	**0.72**	**0.70**	**0.62**	**0.71**	**0.87**
Vulnerability from Measures of **Adaptive Capacity**	Topoclimate Variability	0.40	0.24	0.46	0.51	0.29	0.38	0.33	0.49
	Diversity within Functional Species Groups	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
	Adaptive Capacity Average	**0.28**	**0.20**	**0.31**	**0.33**	**0.22**	**0.27**	**0.24**	**0.33**
Vulnerability from Measures of **Overall Resilience**		**High** 0.48	**High** 0.40	**Mod** 0.53	**Mod** 0.53	**High** 0.46	**High** 0.45	**High** 0.48	**Mod** 0.60
Climate Change Vulnerability Index		**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**	**Mod**

Exposure Summary for 1981-2014 Timeframe: Overall, the exposure as of 2014 for this woodland system is low across all ecoregions. Annual mean temperature has increased by 0.56°C across approximately 90% of its potential distribution. Changes were most pronounced for winter temperatures (coldest quarter) with increases of 1.2° to 1.5°C across the range. The most substantial changes were observed in the Sierra Nevada ecoregion which comprises over 60% of the potential distribution of this type. Additionally, a doubling of summer precipitation or precipitation of the driest month was observed in small portions of many regions (<3%). However, as monthly summer precipitation represents <1% of annual precipitation and is generally less than 1 cm, the effects of this are unclear.

Climate Change Effects: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, windstorms, ice storms, or landslides (Dale et al. 2001). Potential climate change effects on this ecosystem would likely include a shift to plant species more common on hotter, drier sites. Average annual temperature is projected to continue to increase in the Pacific Northwest and Southwest regions (includes Sierra Nevada) along with increasing number and severity of wildfires and insect outbreaks (McKenzie et al. 2004, 2008, Westerling et al. 2011, Garfin et al. 2014, Mote et al. 2014). 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 tree recruitment. Without recruitment pine stands are essentially relicts of past climate conditions. 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 because of regeneration failure is especially true for dry woodlands that are already on the edge of their climate tolerance (Stevens-Rumann et al. 2017).

Indirect effects of a warming climate with more frequent droughts could weaken pine trees and may make them more susceptible to lethal attacks by forest diseases and insects. Longer, milder climate periods may increase the abundance of insect pests such as *Ips* spp. by increasing the number of generations within a growing season or by allowing a population buildup over several years, such as with mountain pine beetle (*Dendroctonus ponderosae*), causing outbreaks that could severely impact pine trees regionally (Schmid 1988, Burns and Honkala 1990a, Habeck 1992a, d).

Many stands of this ecological system woodland occur in foothill zone of taller ranges, so it may be possible for the species of this system to move up into the lower montane zone while suitable climate is diminished at lower elevations. *Pinus ponderosa* frequently live more than 300-500 years and are known to live over 700 years, so it may be able to survive as relicts for centuries without regeneration (Sawyer et al. 2009). However, there could be accelerated loss of mature trees because of more frequent and extended drought, or more frequent and larger fires resulting from a hotter, drier climate.

Ecosystem Resilience: Sensitivity: Overall sensitivity to climate change is moderate across the range of this type; six of the eight ecoregions scored as moderate sensitivity (comprising >80% of the range) and two ecoregions scored as low sensitivity.

Landscape condition was moderate in seven of the eight ecoregions (comprising 99% of the area of the system). This system does not occur on sites conducive to agriculture, so these scores are likely a reflection of fragmentation due to many small roads, energy and transmission development, and areas of urban, suburban and exurban development. Fragmentation is more severe at lower elevations in the northern portion of the range and adjacent to urban areas in the southern portion of the range.

Fire regime departure was high in three ecoregions, moderate in four and low in one ecoregion. Higher departure reflects fire suppression practices across much of the region leading to increased fuel loads and stand densification, which make the system vulnerable to catastrophic stand-replacing fires.

Risk from insect and disease was generally low across the range of the system, although the two largest ecoregions (Sierra Nevada and Eastern Cascades) scored close to moderate sensitivity for this factor. However, this low risk may be increased by interactions from recent extreme droughts within the region.

The interactions of the stressors of fire suppression and landscape fragmentation have resulted in changes to the structure of these woodlands. 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 generally low across the range of this system, with scores in the low range in three ecoregions, and scores in the lower range of moderate for the remaining five regions. This low adaptive capacity is related to low scores for functional diversity for the type, and generally moderate scores for topoclimatic variability. Topoclimatic variability was moderate in six ecoregions, although it was low in the Eastern Cascades region which includes plateaus and slopes (18% of the range of the system) and high in the Southern and Baja California region where the system occurs in more mountainous terrain. Although this system occurs in large mountain ranges, it tends to occur at lower elevations and on more moderate slopes. There is potential for the species in this system to move upslope into areas of suitable climate and increased topographic variability. In terms of vulnerability related to functional groups, the system scores low in terms of diversity of seed dispersers 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, these woodlands score in the moderate range of overall climate change vulnerability. This is primarily due to moderate contributions from sensitivity measures (particularly fire regime departure), and low adaptive capacity scores. The system occurs in areas of moderate to low topoclimatic variability and has inherent vulnerabilities due to low diversity within key functional species groups (such as seed dispersers). Many stands occur on lower elevation slopes, so there may be potential for upslope migration of species. Although insect and disease risk were low for this system, these may be exacerbated by effects of recent severe droughts across the range 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 52. Climate change adaptation strategies relative to vulnerability scores for California Montane Jeffrey Pine-(Ponderosa Pine) Woodland.

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 and fire breaks. Protect old-growth stands while maintaining or restoring natural wildfire regimes. Maintain or restore connectivity with adjacent natural vegetation to support species dispersal.
Moderate	**Emphasize restoration to enhance resilience.** Protect old-growth stands while restoring natural wildfire regimes and tree canopy densities in surroundings. Restore native herb and shrub diversity and evaluate needs for restoring cool season graminoids and seed dispersing species. Anticipate effects of warmer temperatures and drier conditions. Localize regional models for wildfire regimes in anticipation of steadily increasing fire frequency and drought stress. Identify zones to anticipate invasions from neighboring vegetation. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration.

High	**Revisit prior desired condition statements.** Anticipate effects of warmer temperatures and drier conditions. Anticipate effects of severe drought stress and insect/disease outbreaks beyond historic patterns. Update assumptions and models for wildfire regimes with consideration of increased frequency and intensity. Identify zones to anticipate invasions from neighboring vegetation. Restore native herb diversity, considering trends in soil moisture regime, and evaluate needs for restoring cool season graminoids and seed dispersing species. Restore connectivity among fragmented patches. Monitor for invasive expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species.
Very High	**Plan for transformation to novel conditions.** Create new models for wildfire regimes factoring together likely effects of insect and disease events well beyond historic patterns. Anticipate transitions from woodland to savanna and/or shrubland and steppe conditions. Identify zones of likely invasion from exotics and from neighboring vegetation found along drier ends of local gradients. Restore native herb diversity, considering increasing drought tolerance, and evaluate needs for maintaining all identified functional species groups. Restore connectivity among fragmented patches. Monitor for cool season graminoids and seed dispersing species, invasive species expansion, trends in soil moisture regime and effects of drought stress, including tree regeneration, and loss/gain of neighboring species. Consider needs for “assisted migration” of most vulnerable species.

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