Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Sagebrush

CWHR types[1]: SGB: Sagebrush species (*Artemisia* spp.), **BBR**: Rabbitbrush species (*Chrysothamnus* spp., *Ericameria* spp., *Lorandersonia* spp.), **LSG**: Horsebrush (*Tetradymia* spp.)

Background and Key Terminology

This document summarizes the primary factors that influence the vulnerability of a focal resource to climate change over the next century. In this context, vulnerability is a function of the sensitivity of the resource to climate change, its anticipated exposure to those changes, and its capacity to adapt to changes. Specifically, sensitivity is defined as a measure of whether and how a resource is likely to be affected by a given change in climate, or factors driven by climate; exposure is defined as the degree of change in climate or climate-driven factors a resource is likely to experience; and adaptive capacity is defined as the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011). The purpose of this assessment is to inform forest planning by government, non-profit, and private sector partners in the Sierra Nevada region as they work to integrate climate change into their planning documents.

Executive Summary

The overall vulnerability of the sagebrush system is ranked moderate, due to its moderate sensitivity to climate and non-climate stressors, moderate adaptive capacity, and moderate-high exposure.

Sagebrush systems are sensitive to climate and climate-driven changes such as:

- altered precipitation,
- increased temperature,
- increased climatic water deficit, and
- altered fire regimes.

Temperatures are predicted to increase over the next century due to climate change, with an associated increase in evaporation and climatic water deficit. Drought negatively affects seedling survival in sagebrush systems, and contributes to fire events and conversion to more disturbance tolerant systems.

Sagebrush systems are also sensitive to several non-climate stressors including:

- landscape conversion (e.g. agriculture and development),
- invasive annuals grasses,
- grazing, and
- off highway vehicle (OHV) use.

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[1] Following the California Wildlife Habitat Relationship (CWHR) System found at: http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

Landscape conversion directly reduces sagebrush extent, and may limit its dispersal ability, hindering the capacity of sagebrush systems to track elevational shifts. Grazing and OHV use both disturb habitat, and are a method of non-native annual plant introduction. The adaptive capacity of the sagebrush system may be facilitated by its taxonomic diversity, broad distribution, as well as drought and fire tolerance.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

The sagebrush system's sensitivity to climate change will likely be driven by changes in temperature, precipitation, climatic water deficit, and fire regimes. The proportion of herbaceous species in the sagebrush understory has been positively correlated with precipitation. However, greater precipitation and cooler temperatures are also correlated with areas experiencing tree invasion (Slaton and Stone 2013). The effects of climate change on water balance and vegetation activity across the climatic and elevational gradient of sagebrush ecosystems, however, are often nonlinear (Schlaepfer et al. 2012b). Implications for big sagebrush ecosystems in the semiarid western United States under declining snow conditions depend on area-specific climatic conditions determined by the snow:precipitation ratio (Schlaepfer et al. 2012b). However, the influence of timing and amount of precipitation on the ability of water to percolate into deeper soil layers plays a greater role than whether precipitation falls as rain or snow (Schlaepfer et al. 2012c).

Artemisia species are largely drought tolerant (Lenihan et al. 2008), although big sagebrush (*Artemisia tridentata*) is limited by summer moisture stress, and aridity defines its southern range limit (Shafer et al. 2001). Drought negatively affects seedling survival in sagebrush systems, and seedling establishment occurs intermittently in pulses during years with favorable conditions (Maier et al. 2001). Although lightning-ignited fires historically created disturbances necessary to maintain the sagebrush-grassland community (Bates et al. 2009; Hanna 2012), post-fire succession varies among sagebrush steppe plant communities (Baker 2006). For example, frequent fire may limit recovery in Wyoming big sagebrush communities, while low frequency fire in mountain big sagebrush communities may result in conifer encroachment (Davies et al. 2011). Fire may also reduce suitable habitat for sage-grouse (Hanna 2012) and facilitate invasion by annual grasses (Lenihan et al. 2008).

Future climate exposure

Important climate and climate-driven factors to consider for sagebrush systems include warming temperature, changes in precipitation, increased climatic water deficit, and altered wildfire regimes. Bioclimate modeling predicts that sagebrush habitat in the Great Basin will decline due to synergistic effects of increased temperature, fire and disease, and displacement by species encroaching from the Mojave Desert in response to the northward shift in frost lines (Friggens et al. 2012). MC1 simulations are consistent with results from other scenario models (e.g., Lenihan et al. 2003; Hayhoe et al. 2004) and project a decline in shrubland cover in California (Lenihan et al. 2008). However, modeling of ecohydrological niche distributions suggests that increased habitat suitability may be expected at high elevations (Schlaepfer et al. 2012a), with fragmentation of sagebrush ecosystems likely to occur (Schlaepfer et al. 2012a, 2012b). The resultant patchiness, size of patches, and overall fragmentation will be important factors influencing genetic structure and dynamics of populations and communities of sagebrush obligate species, such as greater sage-grouse (Schlaepfer et al. 2012a).

Temperature: Over the next century, annual temperatures in the Sierra Nevada are expected to rise between 2.4-3.4˚C varying by season, geographic region, and elevation (Das et al. 2011; Geos Institute 2013). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008), with changes of least magnitude during both seasons anticipated in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation and snow volume: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). Projections for future precipitation in the Sierra Nevada vary among models; in general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008), with decreases in summer and fall (Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 18-55% by the end of the century (Das et al. 2011). Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack and earlier timing of runoff (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004 b; Young et al. 2009; Null et al. 2010). Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (Thorne et al. 2012; Flint et al. 2013), with declines of 10-25% above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006).

Climatic water deficit: Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, is a function of actual evapotranspiration and potential evapotranspiration. Increases in potential evapotranspiration will likely be the dominant influence in future hydrologic cycles in the Sierra Nevada, decreasing runoff even under forecasts of increased precipitation, and driving increased climatic water deficits (Thorne et al. 2012). In the Sierra Nevada, climatic water deficit has increased slightly (~4%) in the past 30 years compared with the 1951-1980 baseline (Flint et al. 2013). Future downscaled water deficit modeling using the Basin Characterization Model predicts increased water deficits (i.e., decreased soil moisture) by up to 44%, with the greatest increases in the northern Sierra Nevada (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013).

Wildfire: Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Fire severity in the Sierra Nevada also rose from 17% to 34% high-severity (i.e. stand replacing) fire, especially in middle elevation conifer forests (Miller et al. 2009). In the Sierra Nevada, increases in large fire extent have been correlated with increasing temperatures and earlier snowmelt (Westerling and Bryant 2006), as well as current year drought combined with antecedent wet years (Taylor and Beaty 2005). Occurrence of large fire and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing by up to 74% by 2085 (Westerling et al. 2011). The area burned by wildfire in the Sierra Nevada is projected to increase between 35-169% by the end of the century, varying by bioregion, with the greatest increases projected at mid-elevation sites along the west side of the range (Westerling et al. 2011; Geos Institute 2013).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the system may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

Sensitivity to non-climate stressors

Sagebrush systems also experience stress from various non-climate factors that may interact with climate to increase vulnerability, including landscape alterations (e.g. agriculture and development), non-native annual grass invasion, off-highway vehicle use, and grazing (USFWS 2013). Landscape conversion reduces sagebrush extent, and may limit its dispersal ability, hindering the capacity of sagebrush systems to track climate-driven elevational shifts. The restoration potential of sagebrush communities is uncertain (Hemstrom et al. 2002), and once impacted, alteration of vegetation, nutrient cycles, and living (cryptobiotic) soil crusts may exceed recovery thresholds, impeding the restoration of suitable sagebrush habitat (Knick et al. 2003). Processes to restore healthy native sagebrush systems are largely unknown and may require decades or centuries (Hemstrom et al. 2002; Knick et al. 2003). A bioclimate envelope model for invasive cheatgrass suggests that decreases in precipitation, particularly in summer, facilitate expansion of cheatgrass and elevate the risk of invasion in the intermountain west and California (Bradley 2009). Cheatgrass expansion contributes to increase fire frequency in sagebrush communities (Knick et al. 2003; Baker 2006), and can change the fire return interval from the natural 20 to 100 years for sagebrush grassland ecosystems to 3 to 5 years (Ypsilantis 2003). A combination of cheatgrass fuels and dry winters and springs has already resulted in the fire season shifting from late summer to early spring in some parts of the eastern Sierra Nevada (Slaton and Stone 2013 unpublished report). Populations of sagebrush-obligate species, such as greater sage-grouse (*Centrocercus urophasianus*) (Finch et al. 2012) and pygmy rabbits (*Brachylagus idahoensis*) are likely not capable of adapting to loss of sagebrush in their ranges because it provides essential food and cover, likely restricting these populations to areas where sagebrush will persist. Some protected high-elevation desert mountains may serve as refugial communities.

Adaptive Capacity

The adaptive capacity of the sagebrush system is unclear and may differ between the northern and southern Sierra Nevada, as well as by elevation. The sagebrush system's capacity to accommodate climate changes may be facilitated by its taxonomic diversity, broad distribution, as well as drought and fire tolerance. Thirty native taxa of sagebrush (*Artemisia* spp.) exist in California (Goodrich 2005; Hanna 2012), with southern taxa differing from northern taxa in habitat affinity, structure, or both (Montalvo et al. 2010). Sagebrush (*Artemisia* spp.) occur under a variety of topographic, edaphic, and climatic conditions (West 1983 cited in Hanna 2012) and big sagebrush (*A. tridentata*), a dominant species in sagebrush systems, is one of the most widespread shrubs in the western U.S (Freeman et al. 1991). During the summer dry period, moisture extraction is facilitated by concentration of fine roots and water-use near the main axis of the tap root, complemented by a broadly spreading superficial root system found in mature sagebrush plants (Welch and Jacobson 1988; Welch 1997; Schlaepfer et al. 2012c). In addition, *A. tridentata* roots appear to maintain nutrient uptake even in dry soil layers, contributing to growth and reproduction during moisture-limiting summer and fall (Matzner and Richards 1996).

In addition, big sagebrush grows rapidly and the seeds are wind dispersed. Although big sagebrush shrubs do not resprout after fire or other disturbance, and the shrubs are killed by most fires, abundant seed production from nearby unburned plants, coupled with high germination rates, enables rapid sagebrush establishment following fire (Tirmenstein 1999).

Several factors may limit sagebrush ability to track climate changes. For example, approximately 90% of big sagebrush seed disperses within 30 feet (9 m) of the parent plant, and few seeds are dispersed more than 100 feet (30 m) (Goodrich et al. 1985 cited in Tirmenstein 1999). In addition, the presence of fungi (e.g. genus *Glomus*) may be required for the successful establishment of some big sagebrush (e.g. *A. tridentata* subsp. *tridentata*) seedlings (Rosentreter and Jorgensen 1986 cited in Tirmenstein 1999). Areas that experience frequent fire and are subsequently dominated by non-mycorrhizal cheatgrass may no longer maintain soil fungi. These sites may experience inhibited sagebrush reestablishment (Rosentreter and Jorgensen 1986 cited in Tirmenstein 1999). Larger fires perpetuated by changing climate in conjunction with non-native annual invasion may decrease proximity to parent shrub seed sources, slowing or impeding future regeneration.

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