Focal Resource: SAGEBRUSH

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

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop[2]. The following document represents the vulnerability assessment results for the **SAGEBRUSH ECOSYSTEM**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, http://www.taccimo.sgcp.ncsu.edu/) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

The project centers on the Sierra Nevada region of California, from foothills to crests, encompassing ten national forests and two national parks. Three geographic sub-regions were identified: north, central, and south. The north sub-region includes Modoc, Lassen, and Plumas National Forests; the central sub-region includes Tahoe, Eldorado, and Stanislaus National Forests, the Lake Tahoe Basin Management Unit, and Yosemite National Park; and the south sub-region includes Humboldt-Toiyabe, Sierra, Sequoia, and Inyo National Forests, and Kings Canyon/Sequoia National Park.

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption[3].

Sensitivity: A measure of whether and how a species or system is likely to be affected by a given change in climate or factors driven by climate.

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[1] From California Wildlife Habitat Relationship (CWHR) habitat classification scheme http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

[2] For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at: http://ecoadapt.org/programs/adaptation-consultations/calcc.

[3] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Adaptive Capacity: The degree to which a species or system can change or respond to address climate impacts.

Exposure: The magnitude of the change in climate or climate driven factors that the species or system will likely experience.

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: direct sensitivity of the system to temperature and precipitation, sensitivity of component species within the system, ecosystem sensitivity to disturbance regimes (e.g., wind, drought, flooding), sensitivity to other climate and climate-driven changes (e.g., snowpack, altered hydrology, wildfire), and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: ecosystem extent, integrity, and fragmentation; ecosystem ability to resist or recover from stressors; landscape permeability; ecosystem diversity (e.g., physical, topographical, component species, functional groups); and ecosystem value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the ecosystem and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation[4]. For more information on each of these elements of sensitivity, adaptive capacity, and exposure, including how and why they were selected, please refer to the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[5].

During the workshop, participants assigned one of three rankings (High (>70%), Moderate, or Low (<30%)) to each finer resolution element and provided a corresponding confidence score (e.g., High, Moderate, or Low) to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure score) (see table below). Results presented in a range (e.g. from moderate to high) reflect variability assessed by participants. Additional information on ranking and overall scoring can be found in the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[5].

Recommended Citation

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This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

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[4] Geos Institute. 2013. *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis report in support of the Vulnerability Assessment/Adaptation Strategy process.* Ashland, OR. http://ecoadapt.org/programs/adaptation-consultations/calcc.

[5] Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada.* Version 1.0. EcoAdapt, Bainbridge Island, WA. http://ecoadapt.org/programs/adaptation-consultations/calcc.

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Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	**2 Moderate**	**3 High**
Direct Sensitivities – Precipitation	**2 Moderate**	**3 High**
Component Species	**No answer provided by participants**	**2 Moderate**
Disturbance Regimes	**3 High**	**3 High**
Climate-Driven Changes	**2.5 Moderate–High**	**2.5 Moderate-High**
Non-Climatic Stressors – Current Impact	**2.5 Moderate–High**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**1 Low**	**3 High**
Other Sensitivities	**None**	**No answer provided by participants**

Overall Averaged Confidence (Sensitivity)[6]: High

Overall Averaged Ranking (Sensitivity)[7]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	**2.5 Moderate-High**	**3 High**
Extent and Integrity – Fragmentation	**2 Moderate**	**2 Moderate**
Resistance and Recovery	**1.5 Low-Moderate**	**2.5 Moderate-High**
Landscape Permeability	**2.5 Moderate-High**	**1-3 Low to High**
System Diversity – Physical/Topographical	**Variable**	**3 High**
System Diversity – Component Species/Functional Groups	**2.5 Moderate-High**	**3 High**
System Value	**1.5 Low-Moderate**	**2 Moderate**
Specificity of Management Rules	**2 Moderate**	**3 High**
Other Adaptive Capacities	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Adaptive Capacity)[6] : Moderate

Overall Averaged Ranking (Adaptive Capacity)[7]: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**3 High**
Precipitation	**3 High**
Dominant vegetation type	**3 High**

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[6] 'Overall averaged confidence' is the mean of the entries provided in the confidence column for sensitivity, adaptive capacity, or exposure, respectively.

[7] 'Overall averaged ranking' is the mean of the perceived rank entries provided in the respective evaluation columns.

Relevant Exposure Factor	Confidence
Climatic water deficit	**3 High**
Wildfire	**3 High**
Snowpack	**2 Moderate**
Runoff	**2 Moderate**
Timing of flows	**2 Moderate**
Low flows	**2 Moderate**
High flows	**2 Moderate**

Exposure Region	Exposure Evaluation	Confidence
Northern Sierra Nevada	**2 Moderate**	**1.5 Low-Moderate**
Central Sierra Nevada	**2 Moderate**	**1.5 Low-Moderate**
Southern Sierra Nevada	**3 High**	**1.5 Low-Moderate**
East	**3 High**	**1.5 Low-Moderate**

Overall Averaged Confidence (Exposure)[6]: Low-Moderate

Overall Averaged Ranking (Exposure)[7]: Moderate-High

Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): Moderate
  - i. Participant confidence: High
- b. Sensitivity to precipitation (means & extremes): Moderate
  - i. Participant confidence: High

Additional comments: Many attributes of sagebrush ecosystem structure are sensitive to temperature and precipitation. For example, the transition from sagebrush to desert shrublands is driven by a combination of temperature and seasonality of precipitation. The proportion of herbaceous species in the understory has been correlated to precipitation, and tree invasion has been correlated to cooler temperatures and greater precipitation.

References identified by participants: Slaton and Stone 2013.

References:
Precipitation: *Artemisia* species are largely drought tolerant (Lenihan et al. 2008). However, big sagebrush is limited by summer moisture stress, and aridity defines its southern range limit (Shafer et al. 2001). 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). Drought negatively affects seedling survival in sagebrush systems, and seedling establishment occurs intermittently in pulses during years with favorable conditions (Maier et al. 2001). The proportion of herbaceous species in the sagebrush understory has also been positively correlated with precipitation. However, greater precipitation and cooler temperatures are also correlated with areas experiencing tree invasion (Slaton and Stone 2013).

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2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: no answer provided by participants
  - i. Participant confidence: Moderate

Additional comments: Differences exist among sagebrush taxa, and vulnerability varies across the landscape. Sensitivity of cheatgrass was ranked as High. Sensitivity of bitterbrush was ranked as Moderate or High (participant opinions differed). Sensitivity of pinyon and juniper were ranked as High. Component species distribution is driven more by precipitation than temperature, although animal interactions (e.g. deer) are also important.

References identified by participants: Flint suggests cold air pooling may provide habitat in the future (L. Flint, pers. comm.; http://ecoadapt.org/data/documents/Flint_CAHydrology.pdf). The Nature Conservancy has Sierra Nevada wide projections on sagebrush distributions (e.g., see maps available on Data Basin: http://databasin.org/galleries/8c5db744f9fe4d3e9375b100dc695c4d).

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3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire (high), drought (moderate), flooding (moderate or low), other – cattle grazing (moderate or high)
- b. Sensitivity to these disturbance regimes: High
  - i. Participant confidence: High

Additional comments: Participants ranked wildfire sensitivity as High because wildfire may lead to cheatgrass invasion. Participants ranked drought sensitivity as Moderate because drought affects seedling survival and fire. Participants ranked flooding sensitivity as Moderate or Low (participant opinions differed) because flooding is localized, but could become more pervasive. Participants ranked grazing sensitivity as Moderate or High (participant opinions differed) because grazing controls the understory growth and affects soil surface stability.

The sagebrush species *Artemisia californica* from coastal scrub systems resprouts, but the sagebrush species from the intermountain sagebrush systems does not.

References identified by participants: Slaton and Stone 2013.

References:
Wildfire: Although lightning-ignited fires historically created disturbances necessary to maintain the sagebrush grassland community (Bates et al. 2009; Hanna 2012), sagebrush steppe plant communities can vary in their post-fire succession (Hanna 2012). Big sagebrush shrubs do not resprout after fire or other disturbance, and the shrubs are killed by most fires (Tirmenstein 1999). 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 fire and drought lead to annual grassland invasion (Lenihan et al. 2008).

Drought: *Artemisia* spp. is drought tolerant. 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, in addition to a broadly spreading superficial root system found in older sagebrush plants (Sturgis 1977; 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).

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4. Sensitivity to other types of climate and climate-driven changes.

a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, altered hydrology, evapotranspiration and soil moisture, extreme temperature and precipitation events, storms
b. Sensitivity to these climate and climate-driven changes: Moderate-High
    i. Participant confidence: Moderate-High

Additional comments: Invasion by exotic annual grasses that change the fire regime and are very difficult to exclude from burned areas are becoming a major threat to sagebrush systems as fire frequencies increase. As fire frequency and intensity increases, many sagebrush species (e.g. big sagebrush) might be killed and may not have the ability to re-sprout.

References:
Altered hydrology: Sagebrush is sensitive to the presence and timing of winter precipitation (Schlaepfer et al. 2012a).

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5. Sensitivity to impacts of other non-climate stressors.

a. Sensitivity to other non-climate stressors including: Residential and commercial development, agriculture, energy production and mining, transportation and service corridors, biological resource use, human intrusions and disturbance, invasive and other problematic species

   b. <u>Current effects of these identified stressors on system</u>: Moderate-High
      i. Participant confidence: High
   c. <u>Degree stressors increase sensitivity to climate change</u>: Low
      i. Participant confidence: High

Additional comments: Participants rank the system sensitivity to non-climate stressors as follows: Grazing: Moderate; Energy production: Moderate; Transportation: Moderate (because of the risk of introducing cheatgrass); Human intrusion; Moderate (because of the risk of introducing cheatgrass); Invasive species: High (prinicipally cheatgrass); Juniper expansion: High (altered fire regime and change in wildlife habitat). Additional non-climate disturbances affecting recruitment and dispersal of sagebrush vegetation include agriculture, land development, geologic features such as mountain ranges, and extremely arid lands. Off-highway vehicle use, mining, and energy production represent additional use conflicts.

References: Changes in historic fire regimes, poor grazing management, and other factors may also contribute to woody encroachment in semiarid systems in the Interior West, for example, the invasion of juniper (*Juniperus spp*.) species into sagebrush steppe (Meyer 2012). Fire suppression policies, which increased the mean fire return interval, have resulted in sagebrush stands becoming more dense thereby reducing the productivity of annual grasses and forbs (Hanna 2012).

<u>Residential and commercial development</u>: The sagebrush steppe landscape has been fragmented by urban expansion, agriculture and energy and mining operations in the Intermountain West (Hanna 2012).

<u>Invasive and other problem species</u>: A bioclimate envelope model for invasive cheatgrass suggests that decreases in precipitation, particularly in summer, may facilitate expansion of cheatgrass and elevate the risk of invasion in the intermountain west and California (Bradley 2009). Spread of invasive species and overgrazing has led to degradation of sagebrush communities (Hanna 2012). Cheatgrass expansion contributes to increase fire frequency in sagebrush communities (Knick et al. 2003; Baker 2006; USFWS 2013), 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).

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6. Other sensitivities.

   a. <u>Other critical sensitivities not addressed</u>: No
      i. Participant confidence: no answer provided by participants
   b. <u>Collective degree these factors increase system sensitivity to climate change</u>: N/A

References:
<u>Soil:</u> The ability of cold desert soils in the Interior West to retain soil organic carbon could be reduced by the effects of ongoing climate change. Aanderud et al. (2010) showed in an 11-year rain manipulation study that near-surface (0-300 mm or 0-12 in) soil organic carbon stocks in a sagebrush steppe (*A. tridentata*) community were significantly reduced when precipitation was shifted from a winter pattern to a spring-summer pattern. They credited this loss to increased microbial activity in wet surface soil at warm temperatures. Shifts from winter to spring-summer rainfall patterns are predicted for many parts of the Interior West as climate continues to warm. Rainfall timing impacts on deep soil organic carbon would be expected to be lower, however, because deep soil organic carbon is more buffered from seasonal temperature changes. This would tend to mitigate the effects of increased warm-season precipitation on soil C storage (Meyer 2012).

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).

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7. **Overall user ranking.**
    a. Overall sensitivity of this system to climate change: Moderate-High
        i. Participant confidence: High

Additional comments: Sagebrush systems are not as sensitive as alpine or riparian systems, although an altered fire regime, invasive species (cheatgrass), and grazing make the sensitivity fairly high.

Adaptive Capacity

1. **System extent and integrity.**
    a. System extent throughout the Sierra Nevada (e.g., widespread to narrow distribution): Moderate-High
        i. Participant confidence: High
    b. Level of fragmentation across the Sierra Nevada: Moderate
        i. Participant confidence: Moderate

Additional comments: Sagebrush occurs across a large area in the eastern Sierra Nevada and in the Great Basin to the east and north. Its extent is moderately fragmented by transportation corridors, fire and invasive cheatgrass. It is also fragmented by desert shrubland in the southern Sierra Nevada, and by pinyon juniper and yellow pine throughout the Sierra Nevada.

References:
Geographic extent: The sagebrush biome is the largest semi-arid ecosystem in the western United States, comprised of 62.7 x 106 ha (155 x 262 ac) (West 1983) and two ecosystem types: sagebrush steppe and Great Basin sagebrush (Miller and Eddleman 2000). Sagebrush (*Artemisia* spp.) occurs in the eastern Sierra Nevada and the Great Basin to about 1200 m (3937 ft) (Schlaepfer et al. 2012b) 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).

Shrublands (including sagebrush steppe, southern coastal scrub and chamise chaparral) currently cover approximately 21% of the Sierra Nevada landscape and about 3 % of Sierra Nevada Foothills, and grasslands currently cover approximately 10% of the Sierra Nevada landscape and 50% of the Sierra Nevada foothills. Subtropical arid lands (creosote brush scrub, saltbrush scrub, Joshua tree woodland) currently make up only about 2% of current Sierra Nevada Foothills landscape (Lenihan et al. 2008; North 2012).

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2. **Resistance, recovery, and refugia.**
    a. Ability of system to resist or recover from impacts: Low-Moderate
        i. Participant confidence: Moderate-High
    b. Suitable microclimates within the system that could support refugial communities: Some of the high-elevation desert mountains to the south may serve as refugial communities because they have been protected. At higher elevations and in the northern Sierra Nevada, refugial communities may exist on slopes or soils that do not have the potential to support trees, and, thus, may persist as sagebrush shrublands. Sagebrush restoration time is variable. In some cases it may recover in less than 50 years from disturbance, so recovery may be faster than in forests that require more time, but the presence of grazing and invasive cheatgrass create new steady states, which can slow sagebrush recovery.

Additional comments: Sagebrush reproduction is highly dependent upon distance from parent plant. Patchy fires that leave seed sources intact may recover more quickly than ones that remove seed sources.

References:
Seed dispersal: 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 (Goodwin 1956, and Sheehy and Winward 1991 cited in Tirmenstein 1999). However, approximately 90% of big sagebrush

seed disperses within 9 m (30 ft) of the parent plant, and few seeds are dispersed more than 30 m (100 ft) (Goodrich et al. 1985, and Shuman and Anderson 1986 cited in Tirmenstein 1999).

Recovery: 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).

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3. Landscape permeability.

- a. Degree of landscape permeability: Moderate-High
    - i. Participant confidence: Low-High
- b. Potential types of barriers to dispersal that apply: Agriculture, industrial or urban development, suburban or residential development, geologic features, arid lands, mountains

Additional comments: Sagebrush is widespread, wind pollinated and dispersed. Mountain ranges and valleys can block dispersal. Some sagebrush regions exhibit high permeability, others exhibit moderate permeability.

References: Seedling survival and establishment occurs intermittently, in pulses each year, during favorable conditions (Maier et al. 2001).

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4. System diversity.

- a. Level of physical and topographic diversity: Variable
    - i. Participant confidence: High
- b. Level of component species/functional group diversity: Moderate-High
    - i. Participant confidence: High
- c. Description of diversity: Sagebrush systems exhibit high evolutionary diversity, including bitterbrush, snowberry, ceanothus, rabbitbrush, as well as diverse forbs and graminoids found in the understory. The sagebrush genus contains multiple taxa and hybrids, and different species and subspecies occupy different areas. Higher diversity occurs at the lower and upper elevational boundaries of the system.

References identified by participants: Dave Tart (USFS, Regional Vegetation Ecologist), Dr. Robin Tausch (USFS, Research Range Scientist), and Jeanne C. Chambers (USFS, Research Ecologist).

References:
Component species: 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). Varying edaphic, climatic and topographic conditions help to diversify the sagebrush landscape (West 1983 cited in Hanna 2012). Sagebrush landscape provides habitat for approximately 100 bird species and 70 mammal species (Hanna 2012).

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5. Management potential.

- a. Value level people ascribe to this system: Low-Moderate
    - i. Participant confidence: Moderate
- b. Specificity of rules governing management of the system: Moderate
    - i. Participant confidence: High

c. Description of use conflicts: Multiple use conflicts include grazing, hunting, recreation and off-highway vehicle (OHV) use, mining and energy production, and transportation.
d. Potential for managing or alleviating climate impacts: There is a high potential to manage grazing. Improved management over last decade has resulted in much restoration.

Additional comments: There is a moderate level of regulation for sagebrush, primarily on federal lands with general regulation. In contrast, there is very high degree of regulation concerning sage-grouse.

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6. Other adaptive capacity factors.

a. Additional factors affecting adaptive capacity: no answer provided by participants
    i. Participant confidence: no answer provided by participants
b. Collective degree these factors affect the adaptive capacity of the system: no answer provided by participants

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7. Overall user ranking.

a. Overall adaptive capacity of the system: Variable
    i. Participant confidence: Variable

Additional comments: The participants have very diverse views and consensus was not reached. Adaptive capacity is variable, and depends on several factors, including elevation and geographic region (i.e. whether it is in the northern or southern Sierra Nevada). Some participants believe sagebrush displays very high adaptive capacity and that the system will move north and west, while others believe it displays low capacity, which will be exacerbated with pinyon-juniper encroachment.

References:
Vegetation changes: MC1 simulations are consistent with results from other scenario models (e.g., Lenihan et al. 2003; Hayhoe et al. 2004), projecting a decline in shrubland cover in California (Lenihan et al. 2008). Of 146 evergreen species in the southwest US modeled by Notaro et al. (2012), the two evergreen species with the largest projected range contractions are limber pine (*Pinus flexilis*) and big sagebrush (*A. tridentata*). Bioclimate modeling predicts that big sagebrush in the interior American West will shift northward, in response to increases in the mean temperature of the coldest month, and exhibit substantial range contraction due to increased summer moisture stress (Shafer et al. 2001). These results support the Neilson et al. (2005) bioclimate model prediction that sagebrush habitat in the Great Basin will decline due to synergistic effects of temperature increases, fire and disease, and to displacement by species moving north from the Mojave Desert in response to the northward shift in frost lines (Friggens et al. 2012). Areas currently occupied by big sagebrush are expected to become occupied by the northward expansion of the creosote bush (*Larrea tridentata*) (Shafer et al. 2001; Friggens et al. 2012). As the frequency of extreme drought increases, plant mortality is likely to occur in rapid pulses rather than gradual declines. This may result in isolated relict patches, which may inhibit the ability of the plant to recover and expand into more hospitable environments in northwestern Arizona (Gitlin et al. 2006).

Exposure

1. **Exposure factors[8].**
   a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, dominant vegetation type, climatic water deficit, wildfire, snowpack, runoff, timing of flows, low flows, high slows
      i. Participant confidence: High (temperature), High (precipitation), High (dominant vegetation type), High (climatic water deficit), High (wildfire), Moderate (snowpack), Moderate (runoff), Moderate (timing of flows), Moderate (low flows), Moderate (High flows)

2. **Exposure region.**
   a. Exposure by region: North – Moderate; Central – Moderate; South – High; East - High
      i. Participant confidence: Low-Moderate (all regions)

3. **Overall user ranking.**
   a. Overall exposure of the species to climate changes: Moderate
      i. Participant confidence: Moderate

Additional comments: Geographic area of interest makes difference in interpretation. Consistent maps are needed.

References: Using applied ecohydrology variables, Schlaepfer et al. (2012a) also project substantial decreases in big sagebrush in the southern part of the range and increases in the northern parts, with small increases at higher elevations (e.g. at the interface with coniferous forests). Increases in habitat-suitability for big sagebrush ecosystems at high elevations may be a result of earlier and longer growing season (Schlaepfer et al. 2012a). While both the climatic and ecohydrological species distribution models run by Schlaepfer et al. (2012a, 2012c) suggest large scale splitting of sagebrush ecosystem into disjunct areas, the ecohydrologic model predicts many smaller regions (i.e. Sierra Nevada, Washington, areas in Oregon and northern Nevada, central Idaho, and an area in eastern Utah, Wyoming, Colorado, and eastern Montana), while the climatic model predicts fewer, larger areas.

Temperature: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004: Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). 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; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[9] and PCM[10]) predict summer temperatures to increase 1.6-2.4˚C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0˚C, with changes of least

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[8] Participants were asked to identify exposure factors most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

[9] Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. Journal of Climate, 19:643-674.

[10] Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. Climate Dynamics 16:755-744.

magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9˚C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation: 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; some demonstrate little to no change (e.g. PCM) while others demonstrate more substantial changes (e.g. GFDL). 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; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; 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, 2004b; Young et al. 2009; Null et al. 2010).

Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (2060-2079) (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013). Under scenarios of 2-6˚C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Several models project greatest losses in snowmelt volume between 1750 m to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009), because snowfall is comparatively light below that elevation, and above that elevation, snowpack is projected to be largely retained. The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with the current patterns of snowpack retention in higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007).

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b). Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to advance the runoff center of mass by 1-7 weeks by 2100 (Maurer 2007), although advances will likely be non-uniformly distributed in the Sierra Nevada (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). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds, decreasing meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

Climatic water deficit: 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). 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. 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 projections using the Basin Characterization Model (Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (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). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007 (Miller et al. 2009).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

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).

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