Focal Resource: SAGE-GROUSE

Taxonomy and Related Information

Greater sage-grouse (*Centrocercus urophasianus)*; eastern Sierra Nevada mountains.

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[1]. The following document represents the vulnerability assessment results for the **SAGE-GROUSE**, 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[2].

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.

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

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[1] 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.

[2] 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.

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: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species 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[3]. 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*[4].

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*[4].

Recommended Citation

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

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[3] 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.

[4] 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.

Table of Contents

Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**3 Specialist**	**3 High**
Physiology	**2 Moderate**	**1 Low**
Habitat	**3 High**	**3 High**
Life History	**2 In-between**	**2 Moderate**
Ecological Relationships	**2 Moderate**	**2 Moderate**
Disturbance Regimes	**3 High**	**3 High**
Non-Climatic Stressors – Current Impact	**3 High**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**2 Moderate**	**1 Low**
Other Sensitivities	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Sensitivity)[5]: Moderate

Overall Averaged Ranking (Sensitivity)[6]: Moderate-High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**2 Moderate**	**2 Moderate**
Barriers Affect Dispersal Ability	**3 High**	**3 High**
Plasticity	**1 Low**	**1 Low**
Evolutionary Potential	**1 Low**	**3 High**
Intraspecific Diversity/Life History	**1 Low**	**3 High**
Species Value	**3 High**	**3 High**
Specificity of Management Rules	**1 Low**	**3 High**
Other Adaptive Capacities	**1 Low**	**1 Low**

Overall Averaged Confidence (Adaptive Capacity)[5]: Moderate-High

Overall Averaged Ranking (Adaptive Capacity)[6]: Low-Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**1 Low**
Precipitation	**1 Low**
Dominant vegetation type	**1.5 Low-Moderate**
Climatic water deficit	**1 Low**
Wildfire (biomass consumed)	**1 Low**

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

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

Relevant Exposure Factor	Confidence
Snowpack	**2 Moderate**
Runoff	**2 Moderate**
Timing of flows	**2 Moderate**
Low flows	**2 Moderate**
High flows	**1.5 Low-Moderate**

Exposure Region	Exposure Evaluation (2010-2080)	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**
Eastern Sierra Nevada	**3 High**	**1.5 Low-Moderate**

Overall Averaged Confidence (Exposure)[5]: Low-Moderate

Overall Averaged Ranking (Exposure)[6]: Moderate – High

Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: Specialist
    - i. Participant confidence: High
- b. Factors that make the species more of a specialist: Predator/prey relationship, foraging dependency, host plant dependency

References: Greater sage-grouse are obligate users of big sagebrush (*Artemisia tridentata)* (Braun et al. 1976 cited in Connelly et al. 2000; Beck et al. 2009), and their distribution is strongly correlated with sagebrush habitats (Schroeder et al. 2004). Big sagebrush habitats are important for greater sage-grouse nesting, brood-rearing, and foraging (USFWS 2013 and references therein).

Sagebrush cover of 15-25% provides sage-grouse productive breeding habitat in arid sites, while sage-grouse select sagebrush canopy cover between 12-43% in winter to counter the effects of snow (Connelly et al. 2000). Years of greater forb availability have been linked to increased sage-grouse productivity (Barnett & Crawford 1994 cited in Beck et al. 2009), as sage-grouse rely on forbs to provide highly nutritious food during reproduction, nesting and brood-rearing.

2. Physiology.

- a. Species physiologically sensitive to one or more factors including: Temperature, precipitation
- b. Sensitivity of species' physiology to one or more factors: Moderate
    - i. Participant confidence: Low

Additional comments: Sage-grouse can withstand high and low temperatures.

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Wetlands/vernal pools, seeps/springs, grasslands/balds, other – perennial water
- b. Species dependence on one or more sensitive habitat types: High
    - i. Participant confidence: High

References: Once impacted, alteration of vegetation, nutrient cycles, and living (cryptobiotic) soil crusts in sagebrush communities 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).

4. Life history.

- a. Species reproductive strategy: In between
    - i. Participant confidence: Moderate
- b. Species polycyclic, iteroparous, or semelparous: Iteroparous

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Forage, habitat, hydrology, competition
- b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation
- c. Sensitivity of species to other effects of climate change on its ecology: Moderate
    - i. Participant confidence: Moderate

Additional comments: Big sagebrush distribution 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 (Maier et al. 2001), and contributes to fire events and conversion of sagebrush systems to grassland (Callaway and Davis 1993; Keeley 2002).

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6. **Disturbance regimes.**
   a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, flooding
   b. Sensitivity of species to one or more disturbance regimes: High
      i. Participant confidence: High

Additional comments: Sage-grouse mainly inhabit (mountain and Wyoming) big sagebrush communities. Fire is now too frequent in Wyoming big sagebrush communities and not frequent enough in mountain big sagebrush communities, where conifer encroachment has become a problem (see Davies et al. 2011 for more information).

References: Availability of big sagebrush habitat for greater sage-grouse is also influenced by fire. Fire is a primary factor linked to loss of sagebrush habitat (Connelly and Braun 1997 cited in USFWS 2013; Miller and Eddleman 2000; Hanna 2012). Although post-fire recovery rate of sagebrush varies (Baker 2006), structurally mediated habitat features required by sage-grouse for food and cover in winter, and for nest and brood concealment in spring, have displayed slow recovery (>14 years) following fire (Beck et al. 2009). Some studies suggest that fires enhance the grasses and forbs important to sage-grouse, potentially doubling herbaceous production in the short-term (Davies et al. 2007), Beck et al. (2012) conclude that evidence is lacking to suggest that treatments in Wyoming big sagebrush, including fire, result in positive population responses from sage-grouse. In contrast, low frequency fire in mountain big sagebrush communities may result in conifer encroachment (Davies et al. 2011), and sage-grouse appear to avoid areas where woodlands have encroached on shrublands (Atamian et al. 2010, Doherty et al. 2010 cited in Finch et al. 2012).

An increase in fire frequency in sagebrush communities is facilitated in part by cheatgrass (*Bromus tectorum*) expansion (Miller and Eddleman 2000; Knick et al. 2003; Baker 2006), which can change the fire return interval from the natural 20 to 100 years for sagebrush grassland ecosystems to 3 to 5 years (Ypsilantis 2003), and may reduce native grasses and forbs essential for sage-grouse food and cover (USFWS 2013). Cheatgrass grows rapidly and dies early in the season, producing a continuous layer of dry fuels in the late spring and early summer (Slaton and Stone 2013). 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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7. **Interacting non-climatic stressors.**
   a. Other stressors that make the species more sensitive include: Residential and commercial development, agriculture, energy production and mining, transportation and service corridors, altered interspecific interactions, human intrusions and disturbance, natural system modifications, invasive and other problematic species
   b. Current degree to which stressors affect the species: High
      i. Participant confidence: High
   c. Degree to which non-climate stressors make species more sensitive: Moderate
      i. Participant confidence: Low

References identified by participants: Bi-state (California, Nevada) Local Working Group (http://www.ndow.org/wild/conservation/sg/index.shtm) is coming up with sage-grouse conservation strategies.

References: Loss and fragmentation of sagebrush habitats is a primary cause of sage-grouse population decline (Connelly and Braun 1997, Braun 1998 cited in Schroeder et al. 2004; USFWS 2013; Dinkins et al. 2012). Habitat loss and fragmentation contribute to the population's isolation and increased risk of extirpation, and can result in reductions in lek persistence, lek attendance, population recruitment, yearling and adult annual survival, nest selection, nest initiation, and complete loss of leks in winter habitat (Holloran 2005, Aldridge and Boyce 2007, Walker et al. 2007, and Doherty et al. 2008 cited in USFWS 2013). Habitat loss also results from development, agricultural conversion, transportation corridors, and energy development activities (USFWS 2013). Functional habitat loss, in which greater sage-grouse avoid areas even though sagebrush remains intact, may also result from human activity (Blickley et al. 2012 cited in USFWS 2013).

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8. Other sensitivities.

- a. Other critical sensitivities not addressed: No answer provided by participants
    - i. Participant confidence: No answer provided by participants
- b. Collective degree these factors increase species' sensitivity to climate change: No answer provided by participants

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9. Overall user ranking.

- a. Overall sensitivity of this species to climate change: High
    - i. Participant confidence: High

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: 50-75 km (31-46 mi)
        i. Participant confidence: Low
    b. Ability of species to disperse: Moderate
        i. Participant confidence: Moderate
    c. General types of barriers to dispersal include: Road – highway, agriculture, industrial or urban development, suburban or residential development, mountains, geologic features, arid lands
    d. Degree barriers affect dispersal for the species: High
        i. Participant confidence: High
    e. Possibility for individuals to seek out refugia: No answer provided by participants

References: Adult sage-grouse exhibit strong site fidelity (Connelly et al. 2011), limiting their ability to respond to changes in their local environment (Schroeder et al. 1999 cited in USFWS 2013). However, the geographic isolation of the greater sage-grouse populations in the eastern Sierra Nevada has resulted in genetic distinctiveness that may be important to the local adaptation and population survival (Oyler-McCance et al. 2005).

2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Low
        i. Participant confidence: Low
    b. Description of species' ability to modify physiology or behavior: Unknown

References: As a sagebrush-obligate, greater sage-grouse will likely be restricted to areas where sagebrush persists in the future (Aldridge et al. 2008 cited in Finch et al. 2012).

3. **Evolutionary potential.**
    a. Ability of species to adapt evolutionarily: Low
        i. Participant confidence: High
    b. Description of characteristics that allow species to adapt evolutionarily: Sage-grouse displays small populations that are geographically isolated.

References: In addition, the genetic structure and dynamics of greater sage-grouse communities are influenced by the patchiness, patch size, and fragmentation of sagebrush systems (Loveless and Hamrick 1984, Kareiva et al. 1990 cited in Schlaepfer et al. 2012b).

4. **Intraspecific diversity/life history.**
    a. Degree of diversity of species' life history strategies: Low
        i. Participant confidence: High
    b. Description of diversity of life history strategies: Sage-grouse displays little diversity in its specific dietary needs and nest sites.

5. **Management potential.**
    a. Value level people ascribe to this species: High
        i. Participant confidence: High
    b. Specificity of rules governing management of the species: Low
        i. Participant confidence: High

   c. Description of use conflicts: Sage-grouse is listed as candidate species because of conflicts with grazing and agriculture.
   d. Potential for managing or alleviating climate impacts: There is high potential to manage grazing allotments and fire prescription regime.

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6. **Other adaptive capacity factors.**
   a. Additional factors affecting adaptive capacity: No answer provided by participants
      i. Participant confidence: Low
   b. Collective degree these factors affect the adaptive capacity of the species: Low

Additional comments: Predator management, such as management of raptor perches and mammals, may also influence adaptive capacity of sage-grouse.

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7. **Overall user ranking.**
   a. Overall adaptive capacity of the species: Low
      i. Participant confidence: High

Exposure

1. **Exposure factors[7].**
    a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, dominant vegetation type, climatic water deficit, wildfire, snowpack, runoff, timing of flows, low flows, high flows
        i. Participant confidence: Low (temperature), Low (precipitation), Low-Moderate (dominant vegetation type), Low (climatic water deficit), Low (wildfire), Moderate (snowpack), Moderate (runoff), Moderate (timing of flows), Moderate (low flows), Low-Moderate (high flows)

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

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

References:

Vegetation changes: Bioclimate modeling predicts that sagebrush habitat in the Great Basin will decline due to synergistic effects of temperature increases, fire, and disease, and to displacement by species encroaching from the Mojave Desert in response to the northward shift in frost lines (Friggens et al. 2012). Big sagebrush and other similar semiarid ecosystems could decrease in viability or disappear in dry areas and likely increase only in the areas with greatest snowfall (Schlaepfer et al. 2012a). The effects of climate change on water balance and vegetation activity across the climatic and elevational gradient of sagebrush systems, however, are often nonlinear (Schlaepfer et al. 2012a). 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).

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[8] and PCM[9]) 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 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

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[7] 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.

[8] 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.

[9] 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.

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: In the Californian Great Basin, changes in vegetation communities will be important for wildlife. These changes will include projected increases in the amount of pine and juniper forest and desert scrub and grasslands, and a loss of and sagebrush and other shrub habitats. This shift may be hastened by changes in fire severity and frequency (PRBO Conservation Science 2011). 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, especially in middle elevation conifer forests (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 species 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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