Focal Resource: SIERRA NEVADA BIGHORN SHEEP

Taxonomy and Related Information

Sierra Nevada bighorn sheep (*Ovis canadensis)*; occur in southern Sierra, White and Inyo 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 **SIERRA NEVADA BIGHORN SHEEP**, 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.

[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

Hauptfeld, R.S., J.M. Kershner, and K.M. Feifel, eds. 2014. Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis: Sierra Nevada Bighorn Sheep *in* Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*. Version 1.0. EcoAdapt, Bainbridge Island, WA.

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.

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Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**1 Generalist**	**2 Moderate**
Physiology	**3 High**	**3 High**
Habitat	**3 High**	**3 High**
Life History	**2 Mid-range**	**3 High**
Ecological Relationships	**3 High**	**3 High**
Disturbance Regimes	**3 High**	**3 High**
Non-Climatic Stressors – Current Impact	**3 High**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**3 High**	**3 High**
Other Sensitivities	**2 Moderate**	**3 High**

Overall Averaged Confidence (Sensitivity)[5]: High

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	**2 Moderate**	**2 Moderate**
Plasticity	**1 Low**	**3 High**
Evolutionary Potential	**1 Low**	**2 Moderate**
Intraspecific Diversity/Life History	**1 Low**	**2 Moderate**
Species Value	**3 High**	**3 High**
Specificity of Management Rules	**3 High**	**3 High**
Other Adaptive Capacities	**3 High**	**2 Moderate**

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

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

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EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**2 Moderate**
Precipitation	**2 Moderate**
Dominant vegetation type	**2 Moderate**
Climatic water deficit	**2 Moderate**
Snowpack	**2 Moderate**

[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
Runoff	**2 Moderate**
Timing of flows	**2 Moderate**
Low flows	**2 Moderate**
High flows	**2 Moderate**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**Not applicable**	**Not applicable**
Central Sierra Nevada	**Not applicable**	**Not applicable**
Southern Sierra Nevada	**3 High**	**No answer provided by participants**

Overall Averaged Confidence (Exposure)[5]: No answer provided by participants

Overall Averaged Ranking (Exposure)[6]: High

Sensitivity

1. Generalist/Specialist.

a. Where does species fall on spectrum of generalist to specialist: Generalist
    i. Participant confidence: Moderate
b. Factors that make the species more of a specialist: Predator/prey relationship, foraging dependency, other dependencies – topography

Additional comments: Bighorn sheep migrate elevationally. They use multiple ecosystems but need specific forage and good visibility to escape from predators.

References: Bighorn sheep use forage areas such as alpine meadows with an abundance of forbs, and precipitous escape terrain with good visibility (Schroeder et al. 2010). Habitat requirements differ between summer range and winter range, and between sexes (Schroeder et al. 2010). Annual precipitation and snowfall vary considerably in the Sierra Nevada where bighorn sheep occur (Schroeder et al. 2010).

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2. Physiology.

a. Species physiologically sensitive to one or more factors including: Precipitation, other – soils
b. Sensitivity of species' physiology to one or more factors: High
    i. Participant confidence: High

Additional comments: Bighorn sheep need water sources, forage, and certain minerals in their diet from the soils.

References: Females occur in areas of greater visibility and spend more time foraging and less time ruminating than males (Schroeder et al. 2010). Males may be able to digest low-quality forage more easily than females (McCullough 1979, Barboza 1984, cited in Barboza and Bowyer 2000), and in winter males use ranges with more shrub and overall biomass than females (Schroeder et al. 2010).

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3. Sensitive habitats.

a. Species dependent on sensitive habitats including: Alpine/subalpine, grasslands/balds, ecotones, seeps/springs
b. Species dependence on one or more sensitive habitat types: High
    i. Participant confidence: High

Additional comments: Bighorn sheep have different habitat needs for summer range, winter range, and lambing.

Sierra Nevada bighorn sheep are highly dependent on alpine habitats, which will likely drive their sensitivity to climate change.

References: Proximity to escape terrain appears to be associated with increased forage efficiency for females (Schroeder et al. 2010), which occur in areas of greater visibility and spend more time foraging than males, and in winter, males use ranges with more shrub and overall biomass than females (Schroder et al. 2010).

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4. Life history.

a. Species reproductive strategy is r-strategy, mid-range, or k-strategy: Mid-range
    i. Participant confidence: High
b. Species is polycyclic, iteroparous, or semelparous: Iteroparous

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5. **Ecological relationships.**
    a. Sensitivity of species' ecological relationships to climate change including: Predator/prey relationship, forage, habitat, hydrology, competition
    b. Types of climate and climate-driven changes that affect these ecological relationships including: Precipitation
    c. Sensitivity of species to other effects of climate change on its ecology: High
        i. Participant confidence: High

References: Snow can affect the timing of green-up and availability of vegetation used by mountain sheep (Rachlow and Bowyer 1991, 1994), and rain in spring and summer is important for growth of forage plants used by bighorn sheep (Wehausen 1992, and Oehler et al. 2003 cited in Schroeder et al. 2010). Sierra Nevada bighorn sheep prefer terrain that allows for visibility of predators, and thus may be negatively impacted by conifer encroachment (Latham 2010; Greene et al. 2012).

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

Additional comments: Sensitivity to disturbance regimes including diseases such as sheep lungworm. They may be less sensitive to wildfire as it may increase habitat by regenerating forage and increasing openings.

References: Wildfire may benefit bighorn sheep by increasing forb availability, forage quality and predator visibility (Greene et al. 2012), however, due to differences in habitat selection, males and females may be differentially impacted by fires (Schroeder et al. 2010).

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7. **Interacting non-climatic stressors.**
    a. Other stressors that make the species more sensitive include: Agriculture, transportation and service corridors, altered interspecific interactions, human intrusions and disturbance, natural system modifications, invasive and other problematic species, other – possibly hunting
    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: High
        i. Participant confidence: High

Additional comments: Domestic sheep are a problematic species, and sheep grazing presents an agricultural stressor. Mountain lion protection may alter the interspecific interactions between bighorn sheep and their predators. Transportation corridors cause mortality and present barriers to travel. Off road vehicles (ORVs) are among human disturbances. There is no recreational hunting for Sierra Nevada Bighorn Sheep.

References: Contact with domestic sheep may transmit pulmonary pathogens that appear to lead to pneumonia-associated mortality in bighorn sheep (Goodson 1982, Foreyt and Jessup 1982, and Martin et al. 1996 cited in Tomassini et al. 2009; Wehausen et al. 2011). Predation by cougar (*Puma concolor*) is a permanent pressure on bighorn sheep populations (USFWS 2008). Although bighorn sheep and mule deer do not strongly compete for forage, spatial proximity to deer may exacerbate cougar predation (Johnson et al. 2013).

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8. **Other sensitivities.**
    a. Other critical sensitivities not addressed: None recorded
        i. Participant confidence: Moderate
    b. Collective degree these factors increase species' sensitivity to climate change: Moderate

Additional comments: Mountain lion protection may influence predation levels on sheep. Domestic sheep lungworm weakens sheep.

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9. **Overall user ranking.**
    a. Overall sensitivity of this species to climate change: High
        i. Participant confidence: High

Additional comments: Bighorn sheep are already a species of concern, and are more at risk with climate change. However, bighorn sheep are rather adaptable in the absence of disease so may be less sensitive overall.

Adaptive Capacity

1. Dispersal ability.

a. Maximum annual dispersal distance: >100 km (>62 mi)
   i. Participant confidence: High
b. Ability of species to disperse: Moderate
   i. Participant confidence: Moderate
c. General types of barriers to dispersal include: Road-highway, geologic features, dams, rivers
d. Degree barriers affect dispersal for the species: Moderate
   i. Participant confidence: Moderate
e. Possibility for individuals to seek out refugia: No answer provided by participants

Additional comments: Suitable habitat is limited given the connectivity needs of winter and summer range, and the most suitable habitat may be occupied. If suitable habitat remains unoccupied, bighorn sheep could be transplanted.

References: Bighorn sheep exhibit seasonal upslope and downslope migration, utilizing a range of systems, from alpine to pinyon-juniper and sagebrush steppe at lower elevations (Schroeder et al. 2010).

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2. Plasticity.

a. Ability of species to modify physiology or behavior: Low
   i. Participant confidence: High
b. Description of species' ability to modify physiology or behavior: Some live in close proximity to traffic and human activity, and at other times, they are highly sensitive to intrusion. However, tolerance to traffic and human activity is unknown for Sierra Nevada bighorn sheep.

Additional comments: Bighorn have significant plasticity when considered in terms of the wide range of habitats that three subspecies occupy.

References: Sierra Nevada bighorn sheep utilize of a range of systems, from alpine to pinyon-juniper and sagebrush steppe at lower elevations (Schroeder et al. 2010) during seasonal upslope and downslope migrations.

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3. Evolutionary potential.

a. Ability of species to adapt evolutionarily: Low
   i. Participant confidence: Moderate
b. Description of characteristics that allow species to adapt evolutionarily: No answer provided by participants

Additional comments: Bighorn sheep are already highly stressed, and their range is limited.

References: The Sierra Nevada bighorn sheep population has the lowest number and most restricted range of any bighorn species (Sierra Nevada Bighorn Sheep Recovery Program 2013) and is listed as endangered under the U.S. Endangered Species Act. The population is estimated at fewer than 500 individuals and distributed in herd units occupying three distinct areas along the crest of the southern Sierra Nevada.

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4. Intraspecific diversity/life history.

a. Degree of diversity of species' life history strategies: Low

        i. Participant confidence: Moderate

b. Description of diversity of life history strategies: No answer provided by participants

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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: High
    i. Participant confidence: High
c. Description of use conflicts: No answer provided by participants
d. Potential for managing or alleviating climate impacts: The potential exists to manage the species, for instance by transplanting, inoculating against disease, and captive breeding. There may be some limitations on managing habitat in protected areas.

Additional comments: Inoculation of free ranging bighorn is unlikely in the near future, as no suitable vaccine exists, and administering vaccines to entire herds of wild sheep would be stressful. Preventing disease transmission from domestic sheep and goats is most effective by removing such livestock from adjacent ranges to prevent contact with wild sheep. Captive breeding is less preferred since the population has increased from a low of 100. Source stock for translocation is preferred from existing free ranging herds that can support conservative removals.

References: Protecting connectivity between areas occupied by bighorn sheep may reduce habitat fragmentation and increase future gene flow (Williams 2008).

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6. Other adaptive capacity factors.

a. Additional factors affecting adaptive capacity: Assisted migration
    i. Participant confidence: Moderate
b. Collective degree these factors affect the adaptive capacity of the species: High

Additional comments: Free water is not likely to be limited in the Sierra. Climate effects on Sierra bighorn are more likely to be manifested through the premature drying of meadows fed by snowfields and glaciers that provide forage, and treeline that eliminates alpine habitats important to bighorn.

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7. Overall user ranking.

a. Overall adaptive capacity of the species: Low-Moderate
    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, Snowpack, Runoff, Timing of flows, Low flows, High flows

i. Participant confidence: Moderate (for all)

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2. Exposure region.

a. Exposure by region: North – Not Applicable; Central – Not Applicable; South – High

i. Participant confidence: No answer provided by participants

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3. Overall user ranking.

a. Overall exposure of the species to climate changes: High

i. Participant confidence: High

References:

Vegetation distribution: Increased temperatures are projected to lead to declines in alpine and subalpine habitat extent by 75-90% by the end of the century (Lenihan et al. 2003; Hayhoe et al. 2004), potentially resulting in large reductions of alpine forage availability near escape terrain. However, models also predict advancement of shrubland into alpine/subalpine habitats (Lenihan et al. 2003), which may provide alternate forage sources.

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). 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 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)

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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.

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).

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: Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011; Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites -Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 2013) and other high elevation vegetation. 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 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).

We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science to support this exposure assessment. Support of this database is provided by the Eastern Forest & Western Wildland Environmental Threat Assessment Centers, USDA Forest Service.

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Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834