Focal Resource: MOUNTAIN QUAIL

Taxonomy and Related Information

Mountain quail (*Oreortyx pictus)*; Terrestrial.

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 **MOUNTAIN QUAIL**, 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 4
Sensitivity 6
Adaptive Capacity 9
Exposure 11
Literature Cited 14

Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**2 Between generalist & specialist**	**2.5 Moderate-High**
Physiology	**2 Moderate**	**2 Moderate**
Habitat	**2 Moderate**	**2 Moderate**
Life History	**No answer provided by participants**	**No answer provided by participants**
Ecological Relationships	**2 Moderate**	**1 Low**
Disturbance Regimes	**No answer provided by participants**	**No answer provided by participants**
Non-Climatic Stressors – Current Impact	**2 Moderate**	**2 Moderate**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**2 Moderate**	**2 Moderate**
Other Sensitivities	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Sensitivity)[5]: Moderate

Overall Averaged Ranking (Sensitivity)[6]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**2 Moderate**	**2 Moderate**
Barriers Affect Dispersal Ability	**2 Moderate**	**2 Moderate**
Plasticity	**2 Moderate**	**2 Moderate**
Evolutionary Potential	**1 Low**	**1 Low**
Intraspecific Diversity/Life History	**3 High**	**2 Moderate**
Species Value	**2 Moderate**	**2 Moderate**
Specificity of Management Rules	**2 Moderate**	**2 Moderate**
Other Adaptive Capacities	**None**	**1 Low**

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

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

EXPOSURE

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

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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**
Wildlife (biomass consumed)	**2 Moderate**
Snowpack	**2 Moderate**

Exposure Region	**Exposure Evaluation (2010-2080)**	**Confidence**
Northern Sierra Nevada	**2 Moderate**	**2 Moderate**
Central Sierra Nevada	**2 Moderate**	**2 Moderate**
Southern Sierra Nevada	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Exposure)[5]: Moderate

Overall Averaged Ranking (Exposure)[6]: Moderate

Sensitivity

1. Generalist/Specialist.

a. Where does species fall on spectrum of generalist to specialist: In between
    i. Participant confidence: Moderate-High
b. Factors that make the species more of a specialist: None

Additional comments: The mountain quail has no specific requirements for snags, or specific geologic features. It uses chaparral, early seral forest, and conifer near riparian areas. In California it largely uses coniferous areas interspersed with chaparral.

The high tree coverage use likely refers to areas with young, or at least small, shrubby trees. Post-fire, as trees recolonize shrub communities, the trees provide greater coverage as Christmas tree-sized shrubby plants, not as heavy, mature forest.

References: Mountain quail exhibit flexible biotic and abiotic dietary and habitat requirements (Vogel and Reese 1995; Gutierrez and Delehanty 1999). Mountain quail have a diet of vegetal and animal matter (Judd 1905 cited in Vogel and Reese 1995), consisting primarily of forbs. Although mountain quail have a strong behavioral avoidance of open ground at the macrohabitat level (Gutierrez 1977 cited in Vogel and Reese 1995), at the ecosystem level, mountain quail have the ability to inhabit different types of mixed shrub and early seral plant communities in the different segments of their range (Vogel and Reese 1995). In California, mountain quail occupy montane chaparral, shrublands, early- and mid-seral conifer forests and woodland habitats (Brennan and Block 1986; Brennan et al. 1987; Roberts et al. 2011) with high tree crown coverage and abundant shrubs, and avoid areas of open ground, such as annual grasslands (Gutierrez 1977 cited in Vogel and Reese 1995; Brennan et al. 1987). They generally use macrohabitats in proportion to the relative areas of available cover types (Brennan et al. 1987).

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: Moderate

Additional comments: The mountain quail is an altitudinal migrant, moving downslope in winter to avoid snow. Severe winters and droughts present its biggest natural threats.

Mountain quail regularly endure cold temperatures and seem to manage these conditions provided they have adequate food and shelter from wind and precipitation. Like other members of the New World Quail (family Odontophoridae), mountain quail feed primarily on the ground and do not scrape through snow to find forage during winter (they need exposed food sources). Also, mountain quail do not engage in snow burrowing for shelter. Mountain quail distribution appears to be limited by snow cover rather than cold temperatures.

3. Sensitive habitats.

a. Species dependent on sensitive habitats including: Ecotones
b. Species dependence on one or more sensitive habitat types: Moderate
    i. Participant confidence: Moderate

Additional comments: The mountain quail needs streams nearby, within perhaps 100 m (328 ft). The population is stable in California, but has declined precipitously in arid areas of Idaho and Washington. The distribution and abundance of mountain quail may become a concern if water sources become more limiting in the Sierra Nevada with increased temperatures or changes in timing of snow melt.

References: Mountain quail, particularly juveniles, may require a significant intake of preformed water to regulate body temperatures during hot months (Dawson and Bartholomew 1968 cited in Delehanty et al. 2004), through consumption of vegetation (Campbell 1960, Leopold 1977, Prasad and Guthrey 1986, Guthrey 1999, and Stromberg 2000 cited in Delehanty et al. 2004), insects (Dawson and Bartholomew 1968, Leopold 1977 cited in Delehanty et al. 2004), and tubers (Stromberg 2000 cited in Delehanty et al. 2004).

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4. Life history.

a. Species reproductive strategy: No answer provided by participants
    i. Participant confidence: No answer provided by participants
b. Species polycyclic, iteroparous, or semelparous: Iteroparous

Additional comments: The mountain quail has one brood per year with 7-10 eggs.

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5. Ecological relationships.

a. Sensitivity of species' ecological relationships to climate change including: Forage, habitat, hydrology
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: Low

Additional comments: Participants are unsure whether changes in hydrology will increase species' sensitivity to climate change, and unsure of the extent of the mountain quail's disease susceptibility.

Mountain quail reproduction is linked to spring green-up of non-herbaceous plants (forbs). However, mountain quail naturally occupy very arid desert mountains from northern Baja to the western Mojave. These habitats are often dry and they seem to be good mountain quail habitat even when moist springs are irregular. Light winter snow and rain can be enough for reproduction even though summers are always in a state of drought.

References identified by participants: Gutiérrez and Delehanty (1999)

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6. Disturbance regimes.

a. Disturbance regimes to which the species is sensitive include: Wildfire, drought
b. Sensitivity of species to one or more disturbance regimes: No answer provided by participants
    i. Participant confidence: No answer provided by participants

Additional comments: Because mountain quail are poor flyers, they may experience high fire mortality. They are reluctant to cross open areas and may seek dense cover during fire, placing them at direct risk to increased frequency and severity of fire. Vogel and Reese 1995.

Fire destroys mountain quail habitat in the very short term. However, fire also results in early seral state plant communities in the fire recovery period. When montane forests burn, the post-fire shrub community can form high quality mountain quail habitat. It is when fire causes the conversion of native early seral stage shrub communities to invasive annual grass communities that mountain quail are jeopardized.

References: Fire may benefit mountain quail by returning plant communities to early-seral stages, and producing high quality habitat. However, increased severity and frequency of fires that reduce resprouting success of chaparral shrubs (Rundel et al. 1987, Moreno and Oechel 1991, and Borchert and Odion 1995 cited in Keeley et al. 2005) and result in the conversion of native early-seral shrub communities to annual grassland may reduce mountain quail habitat.

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7. Interacting non-climatic stressors.

   a. Other stressors that make the species more sensitive include: Residential and commercial development, agriculture, biological resource use, natural system modifications, invasive and other problematic species, pollution and poisons
   b. Current degree to which stressors affect the species: Moderate
      i. Participant confidence: Moderate
   c. Degree to which non-climate stressors make species more sensitive: Moderate
      i. Participant confidence: Moderate

Additional comments: Other stressors include water development affecting streams (included under 'natural system modifications') and biological resource use (i.e., as a game species). The following stressors have been documented as reasons for declines in the Great Basin listing petition (Kavanaugh et al. 2000): habitat loss, overgrazing, cheatgrass invasion, rangeland fire, and herbicide use.

References: Destruction of riparian shrub plants due to livestock grazing, dams, cheatgrass, weeds, and brush clearing are cited as reasons for the decline in these populations of mountain quail (Brennan 1994 cited in Winter 2002). Grazing may damage habitat, and development of private inholdings may fragment habitat and introduce domestic pet predators (Winter 2002). Type-conversion of shrublands to non-native grasslands is believed to be partially responsible for the decline of mountain quail populations in the intermountain west (Gutierrez and Delehanty 1999).

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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: Moderate
      i. Participant confidence: Moderate

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: No answer provided by participants
        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, road-arterial, agriculture, industrial or urban development, suburban or residential development, clear cut
    d. Degree barriers affect dispersal for the species: Moderate
        i. Participant confidence: Moderate
    e. Possibility for individuals to seek out refugia: Possibly

Additional comments: Could not find information on range distance. However, mountain quail engage in a seasonal upslope/downslope migration, during which they walk more than fly, which may make them sensitive to all barrier types. In addition, mountain quail do not like to fly over open spaces.

There is no question that mountain quail can and do run and fly across roads. There appears to be no good evidence indicating that gravel roads and paved 2-lane highways, for example, prevent mountain quail movements.

Mountain quail distribution is increasing in Oregon, but whether or not this is in response to climate change appears not to have been investigated to date.

References: Mountain quail occur from Baja California, Mexico to the Coast Range of central California (AOU 1983 cited in Brennan et al. 1987). Mountain quail are considered among the more mobile of the order Odontophoridae (Gutierrez 1975; Gutierrez and Delehanty 1999) with individual movements up to 25 km (15.5 mi) in the non-breeding season (Delehanty et al. 2004), which may support potential future dispersal. Although non-migratory resident populations exist (Roberts et al. 2011), many populations engage in seasonal migrations, moving upslope to breed, and downslope in fall to avoid deep snow (Brennan et al. 1987; Vogel and Reese 1995). Range limitations resulting from water dependence of breeding mountain quail may be influenced by the availability and location of water 'guzzlers', which experience heavy use once they are colonized by quail (Delehanty et al. 2004).

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2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Moderate
        i. Participant confidence: Moderate
    b. Description of species' ability to modify physiology or behavior: Fairly flexible diet and fairly mobile

Additional comments: Evidence that Mountain Quail can occupy a range of early seral stage habitats comes from the ability to occupy: Baja, western Mojave, moist west slopes of the Sierra Nevada and Cascades, dry east slopes of the Sierra Nevada, and some interior ranges of the Great Basin.

References identified by participants: Gutiérrez and Delehanty (1999)

References: Mountain quail exhibit flexible biotic and abiotic dietary and habitat requirements (Vogel and Reese 1995; Gutierrez and Delehanty 1999). Mountain quail have a diet of vegetal and animal matter (Judd 1905 cited in Vogel and Reese 1995), consisting primarily of forbs. Although mountain quail have a strong behavioral avoidance of open ground at the macrohabitat level (Gutierrez 1977 cited in Vogel and Reese 1995), at the ecosystem level, mountain quail have the ability to inhabit different types of mixed shrub and early seral plant communities in the different segments of their range (Vogel and

Reese 1995). In California, mountain quail occupy montane chaparral, shrublands, early- and mid-seral conifer forests and woodland habitats (Brennan and Block 1986; Brennan et al. 1987; Roberts et al. 2011) with high tree crown coverage and abundant shrubs, and avoid areas of open ground, such as annual grasslands (Gutierrez 1977 cited in Vogel and Reese 1995; Brennan et al. 1987). They generally use macrohabitats in proportion to the relative areas of available cover types (Brennan et al. 1987).

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3. **Evolutionary potential.**
    - a. Ability of species to adapt evolutionarily: Low
        - i. Participant confidence: Low
    - b. Description of characteristics that allow species to adapt evolutionarily: No answer provided by participants

Additional comments: The ability of mountain quail to adapt evolutionarily is unknown. Several subspecies of mountain quail have been described but it is unclear how genetically distinct they are. There are no known recent genetic bottlenecks.

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4. **Intraspecific diversity/life history.**
    - a. Degree of diversity of species' life history strategies: High
        - i. Participant confidence: Moderate
    - b. Description of diversity of life history strategies: Mountain quail require riparian habitat in arid areas, but are less dependent on riparian habitat in mesic areas.

References: In California, mountain quail occupy montane chaparral, shrublands, early- and mid-seral conifer forests, and woodland habitats (Brennan and Block 1986; Brennan et al. 1987; Roberts et al. 2011) with high tree crown coverage and abundant shrubs, and avoid areas of open ground, such as annual grasslands (Gutierrez 1977 cited in Vogel and Reese 1995; Brennan et al. 1987). They generally use macrohabitats in proportion to the relative areas of available cover types (Brennan et al. 1987).

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5. **Management potential.**
    - a. Value level people ascribe to this species: Moderate
        - i. Participant confidence: Moderate
    - b. Specificity of rules governing management of the species: Moderate
        - i. Participant confidence: Moderate
    - c. Description of use conflicts: Mountain quail is a managed game species in California. As such, the potential to adjust allowable take and other regulations exists.
    - d. Potential for managing or alleviating climate impacts: None recorded

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6. **Other adaptive capacity factors.**
    - a. Additional factors affecting adaptive capacity: None known
        - i. Participant confidence: Low
    - b. Collective degree these factors affect the adaptive capacity of the species: No answer provided by participants

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

Exposure

1. **Exposure factors[7].**
    a. Factors likely to be most relevant or important to consider for the species: Precipitation, shifts in vegetation, climatic water deficit, wildfire, snowpack
        i. Participant confidence: Moderate (all)

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

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

References identified by participants: Vogel and Reese 1995; NatureServe explorer (http://www.natureserve.org/explorer/); Kavanaugh et al. 2000 (listing petition for Idaho Distinct Population Segment).

References: The forecast for chaparral distribution in response to climate change is not uniform throughout California, and for mountain quail it is unclear whether projected loss of habitat in the southern portion of its range will be offset by gains further north. In northwestern California, the predominant effects of climate change by 2070 are predicted to include increases in the distribution of chaparral, oak and pine, and a loss of conifer dominated vegetation, while in the southwestern and central-western California, chaparral is predicted to decrease (PRBO Conservation Science 2011).

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).

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).

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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.

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, 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).

Snowpack: 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). 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 (Null et al. 2010).

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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