Focal Resource: RED FIR SPECIES

Taxonomy and Related Information

Red fir (*Abies magnifca)*; occurs across the Sierra Nevada

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 **RED FIR**, 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.

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Overview of Vulnerability Component Evaluations

SENSITIVITY

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

Overall Averaged Confidence (Sensitivity)[5]: High

Overall Averaged Ranking (Sensitivity)[6]: High

ADAPTIVE CAPACITY

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

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

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

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**2.5 Moderate-High**
Precipitation	**1.5 Low-Moderate**
Dominant vegetation type	**3 High**
Climatic water deficit	**2 Moderate**
Wildfire (biomass consumed)	**2 Moderate**
Snowpack	**3 High**

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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.

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**2.5 Moderate – High**	**2 Moderate**
Central Sierra Nevada	**2.5 Moderate – High**	**2 Moderate**
Southern Sierra Nevada	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Exposure)[5]: 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: Other dependencies – climate

Additional comments: Red fir is considered a specialist because it tolerates a narrow range of climatic conditions. It is reliant on snowpack and soil moisture, and riparian refugia.

In Yosemite, 56% of red fir occurs above 2133 m (7000 ft).

References: Red firs are confined to cool/moist areas, where summer temperatures rarely exceed 84˚F (29˚C), typically in the upper montane zone at elevations above approximately 6000 ft to 7500 ft (1829 m to 2286 m) along Sierra Nevada's western slope (Laacke 1990; North et al. 2002; Long et al. 2013). Their occurrence, however, is strongly correlated with long-term mean April 1 snow water equivalence (SWE) rather than elevation (Barbour et al. 1991). The upper montane red fir forests of northern California experience the highest snowpack of any vegetation type in the state (Barbour et al. 1991). Almost all precipitation occurs between October and March, 80% of it falling as snow (Laacke 1990).

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2. **Physiology.**
    a. Species physiologically sensitive to one or more factors including: Temperature, precipitation, other – snow
    b. Sensitivity of species' physiology to one or more factors: High
        i. Participant confidence: High

Additional comments: See comment above under Sensitivity Question 1: 'Generalist/Specialist'.

References: The red fir is considered a climax species (Laacke 1990), and the shift of dominance from white fir (*Abies concolor*) to red fir closely corresponds with the freezing level during months of maximum precipitation (Barbour et al. 1991). The shift in dominance to red fir may relate to snowpack characteristics and tolerance of sapling to snowpack (Kunz 1988 cited in Barbour et al. 1990; Barbour et al. 1991). For example, red fir saplings bent by the snow can straighten during the growing season (Gordon 1978).
Alternatively, association of red fir recruitment with El Niño events may relate to increased soil moisture levels from enhanced winter snowpack (Barbour et al. 1991; North et al. 2005). For example, the sandy loam soil 20 cm below the surface of a red fir site in Stanislaus National Forest contained 50% moisture in late May and 17% in late August, while similar texture soil beneath the white fir site contained only 28% and 10% respectively (Barbour et al. 1990). In comparison, red fir growth is poor and stands are open on steep slopes where soils are shallowest (Laacke 1990).

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3. **Sensitive habitats.**
    a. Species dependent on sensitive habitats including: Seeps/springs
    b. Species dependence on one or more sensitive habitat types: High
        i. Participant confidence: High

Additional comments: Red fir depends on areas that are moist and cool. Red fir depends on well-drained, young soils but does best in gravelly-loam soils. It tolerates shallow soils but grows sparsely on them. With increasing heat in shallow soils, red fir will likely not do as well, relegating it to deep, well-developed soils.

References: *See references above in Question 1: 'Generalist/Specialist' and Question 2: Physiology.*

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4. Life history.

  a. Species reproductive strategy: K-selection
    i. Participant confidence: High
  b. Species polycyclic, iteroparous, or semelparous: Polycyclic

Additional comments: Red fir has 6 to 7 year seed production, with low recruitment and survival.

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5. Ecological relationships.

  a. Sensitivity of species' ecological relationships to climate change including: Predator/prey relationship, competition, hydrology
  b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation, other – snow
  c. Sensitivity of species to other effects of climate change on its ecology: High
    i. Participant confidence: High

Additional comments: Red fir is sensitive to indirect stressors of fire, and inter- and intraspecific competition.

References: Pest pressure can increase tree sensitivity to drought (Waring et al. 1987), and vice versa. The syncopated stressors of tree pests with fire and drought may result in greater mortality in red fir forests than solely from future increases in area burned. Because seed cones are located in the crown, damages to the crown, for example, from windthrow, insects, and crown fires, may restrict cone production (Laacke 1990) and dispersal. The burrowing activity of pocket gophers (*Thomomys sp.*) reduces red fir establishment (Laacke 1990; Laurent et al. 1994).

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6. Disturbance regimes.

  a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, disease, other – gophers
  b. Sensitivity of species to one or more disturbance regimes: High
    i. Participant confidence: High

Additional comments: Red fir is adapted to long fire intervals of more than 50 years.

References: Fire effects on red fir forests are generally poorly understood (Caprio 2000; see Long et al. 2013 for a discussion of relevant fire research). For red fir forests in Sequoia National Park, the average fire-free interval prior to 1886 was 65 years (Pitcher 1987), and fires appear to be a major historic element in creating small openings in dense red fir forests and preparing seedbeds for regeneration (Laacke and Tappeiner 1996). Fire regimes in red fir forests were historically dominated by low- and moderate-intensity fires that resulted in small, scattered groups of regeneration (Taylor and Halpern 1991; Laacke and Tappeiner 1996) and a patchwork of tree ages (Kane et al. 2013). Intense fires, however, resulted in high mortality of red firs (Kane et al. 2013) and comparatively benefit species that are more fire-tolerant or regenerate quickly after fire. Although fire intervals for individual trees in red fir dominated systems varied from frequent to infrequent (25-110 years) in the Southern Cascade region (Skinner and Taylor 2006), red firs may have limited capacity to adapt to increased frequency of fire due to low recruitment and retarded seed production. Red fir seedlings often establish 3-4 years following fire (Chappell and Agee 1996), but reconstructed regeneration patterns in Sequoia National Park indicate that red fir regeneration can be delayed 60 years following fire, with the delay attributed to variations in fire behavior (Pitcher 1987).

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7. **Interacting non-climatic stressors.**
    1. Other stressors that make the species more sensitive include: Biological resource use, altered interspecific interactions, human intrusions and disturbance, natural system modifications
    2. Current degree to which stressors affect the species: Moderate
        - i. Participant confidence: Moderate
    3. Degree to which non-climate stressors make species more sensitive: High
        - i. Participant confidence: High

Additional comments: Red fir is valuable timber, making extraction a stressor. Other stressors include recreation (as a disturbance) and water diversions (alter the sediment regime).

References: Major causes of red fir and white fir mortality include fir engraver beetle (*Scolytus ventralis*), dwarf mistletoe (*Arceuthobium abietinum f. sp. magnificae*), and annosus root disease (*Heterobasidion annosum*), while infestations of broom rust (*Melamsporella caryophyllacearum)*, trunk rot (*Echinodontium tinctorium*), and the Douglas fir-tussock moth (*Orygia pseudotsgata)* have been shown to cause growth-loss in both red and white fir (Laacke 1990; North et al. 2002).

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8. **Other sensitivities.**
    1. Other critical sensitivities not addressed: Persistence of soil moisture throughout the year; lodgepole pine and white fir encroachment
        - i. Participant confidence: High
    2. Collective degree these factors increase species' sensitivity to climate change: High

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

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: 1 km (0.62 mi)
        i. Participant confidence: High
    b. Ability of species to disperse: Low
        i. Participant confidence: High
    c. General types of barriers to dispersal include: Clear cut, arid lands
    d. Degree barriers affect dispersal for the species: High
        i. Participant confidence: High
    e. Possibility for individuals to seek out refugia: Yes, possible refugia include areas with snowpack that provide cool, moist climate and soil type.

Additional comments: Clear-cut is a barrier because of species k-selected strategy.

References: Red fir exists in fragmented patches in a relatively narrow elevational band, approximately 6000 ft to 9000 ft (1829 m to 2743 m) (Laacke 1990; North et al. 2002)

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2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Low
        i. Participant confidence: Moderate
    b. Description of species' ability to modify physiology or behavior: Red fir does not modify its physiology or behavior.

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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: Evolutionary potential is influenced by its long generation time, low recruitment, limited dispersal, and occurrence in patchy environments (can reduce hybridization).

References: Red firs produce heavy seed crop sufficient for reliable regeneration every 1 to 4 years, after sexual maturity is reached after 35-45 years (Laacke 1990). Seed production varies with tree age, size and dominance (Laacke 1990).

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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: Moderate
        i. Participant confidence: Moderate
    c. Description of use conflicts: Recreation and water diversions
    d. Potential for managing or alleviating climate impacts: Potential actions could include facilitating dispersal, genetic selection for most viable/disease resistant individuals, thinning dense stands, protection from high severity fire, or identifying climate stable zones.

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6. **Other adaptive capacity factors.**
    a. Additional factors affecting adaptive capacity: Currently stressed population and fire return intervals are more frequent.
        i. Participant confidence: Moderate
    b. Collective degree these factors affect the adaptive capacity of the species: Moderate

Additional comments: Unsure how “healthy” the current population is.

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

Additional comments: Overall adaptability of red fir is rather low, but with restoration, adaptability could be improved to moderate.

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
        i. Participant confidence: Moderate-High, Low-Moderate, High, Moderate, Moderate, High (respectively)

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

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

References:

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 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

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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.

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).

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).

The change in water deficit from present to future (2020-2049) climate for Yosemite National Park (YNP) is projected to exceed a 25% increase for plots occupied by red fir, lodgepole pine, western juniper, whitebark pine, western white pine, giant sequoia and mountain hemlock (Lutz et al. 2010).

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).

Fire activity within the Sierra Nevada is influenced by distinct climate patterns and diverse topography. Higher fire activity is weakly associated with El Niño (warm) conditions in parts of the southern Cascades (Taylor et al. 2008) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), while in Yosemite National Park (YNP) large fires are associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). Some evidence suggests that fire frequency is higher on southern aspect than northern aspect slopes in mid- and upper-montane forests (Taylor 2000); however, in YNP mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010). Burn condition heterogeneity may promote different forest understory responses in mixed conifer forests across a landscape, with lower intensity burns promoting tree regeneration, and higher intensity or more frequent burns creating shrub habitat (Lydersen and North 2012).

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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