Focal Resource: CHAPARRAL

CWHR Types[1]: MCP: *Ceanothus* spp., manzanita (*Arctostaphylos spp.*), bitter cherry (*Prunus emarginata*); **MCH**: Scrub oak (*Quercus* spp.), *Ceanothus* spp., manzanita (*Arctostaphylos spp.*); **CRC**: Chamise (*Adenostoma fasciculatum*), *Ceanothus* spp.

General Overview of Process

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

Geographic Scope

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

Key Definitions

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

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

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

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

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

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

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

Methodology

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

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

Recommended Citation

Hauptfeld, R.S., J.M. Kershner, and K.M. Feifel, eds. 2014. Sierra Nevada Ecosystem Vulnerability Assessment Technical Synthesis: Chaparral *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).

[4] Geos Institute. 2013. *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis report in support of the Vulnerability Assessment/Adaptation Strategy process.* Ashland, OR. http://ecoadapt.org/programs/adaptation-consultations/calcc.
[5] Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada.* Version 1.0. EcoAdapt, Bainbridge Island, WA. http://ecoadapt.org/programs/adaptation-consultations/calcc.

Table of Contents

Overview of Vulnerability Component Evaluations

SENSITIVITY

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

Overall Averaged Confidence (Sensitivity)[6]: Moderate

Overall Averaged Ranking (Sensitivity)[7]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	**2 Moderate**	**2 Moderate**
Extent and Integrity – Fragmentation	**2 Moderate**	**2 Moderate**
Resistance and Recovery	**3 High**	**3 High**
Landscape Permeability	**2 Moderate**	**2 Moderate**
System Diversity – Physical/Topographical	**2 Moderate**	**3 High**
System Diversity – Component Species/Functional Groups	**2 Moderate**	**3 High**
System Value	**1 Low**	**3 High**
Specificity of Management Rules	**1 Low**	**3 High**
Other Adaptive Capacities	**3 High**	**3 High**

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

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

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature (*BENEFICIAL)	**2 Moderate**
Precipitation	**1 Low**
Shifts in vegetation type	**2 Moderate**
Climatic water deficit	**1 Low**

---

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

Relevant Exposure Factor	Confidence
Wildfire (*BENEFICIAL)	**3 High**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**2 Moderate**	**No answer provided by participants**
Central Sierra Nevada	**No answer provided by participants**	**No answer provided by participants**
Southern Sierra Nevada	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Exposure)[6]: Moderate

Overall Averaged Ranking (Exposure)[7]: Moderate

Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

a. Sensitivity to temperature (means & extremes): Low
    i. Participant confidence: Moderate

b. Sensitivity to precipitation (means & extremes): Moderate
    i. Participant confidence: Moderate

Additional comments: Chaparral systems accommodate a fairly wide range of temperature, and are more sensitive to changes in precipitation, particularly increases that may contribute to crowding from adjacent trees.

References:
Temperature: Distributional limits of some chaparral species are set by sensitivity to frost, especially as it affects seedlings (Pratt et al. 2005).

Precipitation: Chaparral species display varied sensitivity to water availability. Non-sprouters and post-fire seeding species may be favored by comparatively wet conditions, while dry conditions may select for facultative sprouters (Cornwell et al. 2012). Germination of some species typically occurs within several weeks of the first fall or winter rains (Keeley 1991).

---

2. Sensitivity of component species.

a. Sensitivity of component species to climate change: Low
    i. Participant confidence: Low

Additional comments: Manzanita, madrone, buckeye, toyon and other woody plants are susceptible to the *Phytophthora* fungus (sudden oak death), making them vulnerable to large dieback events under more extreme climactic conditions.

References: The distribution of chaparral shrubs is thought to be strongly controlled by minimum temperature, precipitation, and fire probability. There are three general classifications for chaparral vegetation: (1) Obligate resprouter: seeds are killed by fire but plants can resprout from deep roots; (2) Facultative resprouter: employ both deep roots and seeds to repopulate after a fire; and (3) Post-fire seeding/non-sprouter plants: produce seeds that are stimulated to germinate after a fire (Hanes 1971, Keeley 1991, 1995, and Keeley et al. 2012 cited in Ramirez et al. 2012).

Lawson et al. (2010) indicate that for long-lived obligate seeders, such as barranca brush (*Ceanothus verrucosus)*, climate change poses a greater risk than more proximal threats of altered fire regime or future urban development. This is in contrast to other studies of obligate seeders, which suggest they are potentially more vulnerable to altered fire regimes than climate change (Lawson et al. 2010).

For more information on the life history of plants in the chaparral, see Keeley (1991) and Keeley (1992).

---

3. Sensitivity to changes in disturbance regimes.

a. Sensitivity to disturbance regimes including: Wildfire, drought

b. Sensitivity to these disturbance regimes: High
    i. Participant confidence: High

Additional comments: Too little disturbance produces little or no chaparral, or a lack of diversity of species and ages within the system, while too frequent disturbance can shift the species composition to a grassland system dominated by annuals. The precise mix of disturbance frequency and intensity could benefit chaparral, especially on upper and south facing slopes.

References:
Wildfire: Chaparral relies on disturbance regimes (Long et al. 2013), and the absence of disturbance such as fire can facilitate conifer encroachment (Nagel and Taylor 2005; Beaty and Taylor 2008) and deterioration of soil-stored seeds (Keeley and Keeley 1977, Zammit and Zedler 1988, 1994 cited in Keeley et al. 2005). Fire facilitates seedling recruitment (Keeley et al. 2005; Ramirez et al. 2012); for example, obligate seeders and facultative seeders are generally dependent upon fire for seedling recruitment (Keeley et al. 2005).

However, chaparral stands can persist at least 90 years without fire, with little evidence of seed deterioration (Keeley et al. 2005). Further, fire-free periods are required for obligate-resprouters to recruit seedlings (Keeley 1992b cited in Keeley et al. 2005). Thus, chaparral is resilient to long fire-free periods (Keeley et al. 2005).

Chaparral areas that experience very frequent fires (i.e., <20 years) favor plant species that are obligate resprouters and survive from underground structures like lignotubers or roots. Some obligate resprouters can also produce a seed but these seeds can only establish during long fire return intervals to allow the understory to develop (Keeley 1992). Increasing fire frequency may favor facultative sprouters species, while decreasing fire may favor obligate resprouter species (Ramirez et al. 2012). However, if fire is too frequent, the regeneration of some native woody species can be inhibited, allowing for alien invasion (Keeley and Brennan 2012). For example, very short fire intervals (<10 years) may cause type conversion to grassland annuals (Keeley 1995), resulting in loss of primarily obligate seeders, and survival of sprouters and annual grasses (Keeley 1995; Keeley and Brennan 2012). Increased severity fires have negative impacts on resprouting success (Rundel et al. 1987, Moreno and Oechel 1991, and Borchert and Odion 1995 cited in Keeley et al. 2005).

Drought: Post-fire seeding species are more resistant to water stress tissue damage but obligate sprouters are more sensitive to drought stress. Scrub oaks (obligate sprouters) avoid drought stress by having deep roots and have a preference for moist sites. Under drought-like conditions, non-sprouters survive best in full sun while facultative and obligate sprouters survive better in the shade (Pratt et al. 2008).

Post-fire seeding species tend to be more resistant to the stress of drought in their tissues; species with deep roots that can resprout after a fire are more sensitive to drought stress in their tissues but are able to survive by utilizing deep roots to find moisture (Keeley et al. 2005).

---

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

a. Sensitivity to climate and climate-driven changes including: Altered fire regimes
b. Sensitivity to these climate and climate-driven changes: High
    i. Participant confidence: High

Additional comments: Please see the response to the previous question.

Of the varying reproductive types of species in chaparral systems, primarily obligate seeders are lost following short fire intervals because they cannot set seed following the first fire and fail to regenerate following the second. In some places there are hillsides with sprouter species surviving, while the obligate seeders are replaced by annual grasses.

References identified by participants: Nagel et al. 2005

References:
Altered fire regimes: Average fire return interval in the Lake Tahoe Basin historically was 28 years (range 16-40 yrs) (Nagel and Taylor 2005), however, at six sites in the Lake Tahoe Basin, fire had not burned for

over 100 years. The exclusion of fire due to fire suppression is estimated to have stimulated the conversion of montane chaparral to forest by an average area of 62.4% (Nagel and Taylor 2005). In contrast, a Keeley et al. (2005) study estimated that most chaparral has experienced a fire in the past 100 years except in the southern Sierra Nevada, where roughly 45% of the chaparral landscape has not burned since record keeping began in 1910.

Evapotranspiration and soil moisture: Chaparral species are generally well-adapted to low water availability and have evolved strategies to reduce water loss due to evapotranspiration (Pratt et al. 2008).

---

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

a. Sensitivity to other non-climate stressors including: Residential and commercial development, biological resource use, human intrusions and disturbance, invasive and other problematic species
b. Current effects of these identified stressors on system: Moderate
    i. Participant confidence: High
c. Degree stressors increase sensitivity to climate change: Moderate
    i. Participant confidence: Low

Additional comments: Participants categorized logging under 'biological resource use', and marijuana cultivation was included under 'human intrusions and disturbance'. Fire suppression to protect homes and infrastructure, or commercial timber can have a negative impact on chaparral distribution. Chaparral communities are sensitive to competition with invasive species, such as cheatgrass, for disturbed habitat.

References:
Pathogens: Several component species (including manzanita, madrone, buckeye, and toyon) within the chaparral system are susceptible to the sudden oak death (i.e. fungus *Phytophthora*). Moisture is essential for survival and sporulation of *P. ramorum*, and the duration, frequency, and timing of rain events during winter and spring play a key role in inoculum production. Increases in winter precipitation may produce optimal conditions for the pathogen in some areas, resulting in increased rates of infection in Washington, Oregon and California (Venette and Cohen 2006, and Venette 2009 cited in Sturrock et al. 2011).

Non-native exotic grasses: Historic use of non-native annuals for post-fire rehabilitation has been associated with increased fires, as these species can form a more continuous cover and dry out sooner in spring than natives (Keeley 1995). In turn, short-interval fires have been shown highly effective in converting chaparral to grasslands dominated by alien annuals (Sampson 1944, Burcham 1955 cited in Keeley and Brennan 2012). Conversion of California shrublands to invasive annual grasslands may also be facilitated by livestock grazing and trampling disturbance (Keeley and Brennan 2012).

---

6. Other sensitivities.

a. Other critical sensitivities not addressed: None
    i. Participant confidence: No answer provided by participants
b. Collective degree these factors increase system sensitivity to climate change: N/A

---

7. Overall user ranking.

a. Overall sensitivity of this system to climate change: High
    i. Participant confidence: Moderate

Additional comments: The chaparral system is highly responsive, but the response can be positive or negative to the disturbance.

Adaptive Capacity

1. System extent and integrity.

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

Additional comments: Chaparral is widespread in the Sierra Nevada, but its distribution may be better clarified in the future by additional mapping. Chaparral displays natural fragmentation in the Sierra Nevada, at a level between moderate and high. The Sierra Nevada foothill region is more fragmented for the foothill chaparral system type. The central Sierra Nevada regions display a checkerboard pattern of chaparral fragmentation due to ownership of commercial timberlands and consequent habitat alteration.

References:
Geographic extent: Chaparral is one of the most extensive vegetation types in the Sierra Nevada, covering 5% of the state (California Legislature 1987) but displaying considerable natural fragmentation.

---

2. Resistance, recovery, and refugia.

   a. Ability of system to resist or recover from impacts: High
      i. Participant confidence: High
   b. Suitable microclimates within the system that could support refugial communities: Serpentine or gabbro soils could provide refugia for certain endemic species since unfavorable soil conditions are likely to limit competitive effects from other plant species.

Additional comments: Chaparral display several attributes supporting recovery, such as temperature tolerance, drought tolerance, long generation time and tolerance of long periods of seed dormancy, which provides seed sources post-disturbance. For chaparral plant species that are post-fire resprouters, too long duration between fires may adversely affect sprouting success.

References: Adaptations supporting post-disturbance recovery vary among chaparral species, and include fire dependence, extensive seed dormancy and long lifespan of obligate reprouters (i.e. species that survive fire and re-establish by resprouting), as well as high fecundity and tolerance of drought and soil infertility by obligate seeders (i.e. species that are killed by fire and recruit from soil seed banks) (see Anacker et al. 2011 for a list of relevant primary research).

---

3. Landscape permeability.

   a. Degree of landscape permeability: Moderate
      i. Participant confidence: Moderate
   b. Potential types of barriers to dispersal that apply: no answer provided by participants

Additional comments: It is difficult to assess the system's landscape permeability since montane chaparral is naturally fragmented. Private and commercial land ownership and land use regimes, such as residential development and timber harvest, increase fragmentation, particularly in the central Sierra Nevada. In addition, residential development is a key driver for fire suppression, which negatively impacts chaparral distribution. Management options may support chaparral systems if the resistance to using managed fire can be overcome.

Seed dispersal mechanisms are also broad, utilizing mammal and bird dispersers, as well as spring release.

---

4. System diversity.

a. Level of physical and topographic diversity: Moderate
   i. Participant confidence: High
b. Level of component species/functional group diversity: Moderate
   i. Participant confidence: High
c. Description of diversity: no answer provided by participants

Additional comments: Chaparral has two conditions: (1) it can have high adaptive capacity, given that it occurs on a variety of slopes, aspects, and soil types. It may also take diverse physical forms. (2) In contrast, it is relatively shade intolerant, allowing it to become overgrown and outcompeted. In addition, some component shrub species are dependent on certain soil types (e.g., serpentine soils). Some chaparral systems exhibit diversity in terms of plant and animal species present, but chaparral systems may also occur as uniform stands of only 1-2 species.

References:
Community structure: Chaparral is thought to establish in locations that experienced severe fire (Nagel and Taylor 2005).

---

5. Management potential.

a. Value level people ascribe to this system: Low
   i. Participant confidence: High
b. Specificity of rules governing management of the system: Low
   i. Participant confidence: High
c. Description of use conflicts: Tree farming gives preference to space for trees rather than brush species. Residential development is the driver for fire suppression, and general fire suppression policies have indirect negative impacts on chaparral distribution.
d. Potential for managing or alleviating climate impacts: Barriers can be reduced if the resistance to using managed fire can be overcome.

References identified by participants: Hubbert et al. 2012.

---

6. Other adaptive capacity factors.

a. Additional factors affecting adaptive capacity: Habitat Area Expansion
   i. Participant confidence: Moderate
b. Collective degree these factors affect the adaptive capacity of the system: High

Additional comments: In the Sierra Nevada, chaparral exhibits high adaptive capacity to the scenario of large and high intensity fires, and increased temperatures. In places in the Sierra Nevada where this scenario plays out, much of the ridgelines and south-facing slopes that are currently forested but would be suitable for chaparral would become exposed, allowing for expansion of nearby extant chaparral habitat into these now open areas. In places where the fire is highly frequent, then it is more likely that these areas (and current chaparral habitat) would turn to grassland or other invasive forbs. However, we think such places/scenarios will be limited in distribution (e.g., the tail end of the distribution curve), and most places on the landscape would be experiencing the fire frequency and severity that would support chaparral range expansion. These factors are key in our thinking that the adaptive capacity of chaparral is high, as it is high compared to the other habitats in the region.

Chaparral will probably only expand into new areas following fires, though for areas with no chaparral seed bank, the successional sequence is unclear in the Sierra. Not just montane chaparral will depend on appropriate fire regimes.

---

7. Overall user ranking.

a. Overall adaptive capacity of the system: High

i. Participant confidence: High

Additional comments: Overall adaptive capacity of the system is likely high, although exceptions might be true for certain species (endemics).

Exposure

1. Exposure factors[8].

a. Factors likely to be most relevant or important to consider for the system: Temperature (beneficial), precipitation, climatic water deficit, wildfire (beneficial), shifts in vegetation type

   i. Participant confidence: Moderate (temperature); Low (precipitation); Low (climatic water deficit); High (wildfire); Moderate (vegetation)

---

2. Exposure region.

a. Exposure by region: North – Moderate; no answer provided by participants for central and south sub-regions

   i. Participant confidence: no answer provided by participants

---

3. Overall user ranking.

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

   i. Participant confidence: Moderate

Additional comments: Exposure to changing temperature, and decreased water may be beneficial to montane chaparral system, as long as management regimes include restoring appropriate fire regimes for montane chaparral. However, decreased water could also result in increased grassland conversion, particularly cheatgrass.

Many chaparral species are cold sensitive (e.g., see work by Steve Davis at Pepperdine), so upper elevational limits may be able to expand due to reduced exposure to freezing events at upper elevational limits along Sierra Nevada foothills.

References:

Vegetation Change: The forecast for chaparral distribution in response to climate change is not uniform throughout California. The Random Forests algorithm portrays an appealing view of the effects of global warming on the distribution of grasslands, chaparrals, and montane forests. Increases in these habitat types would occur largely at the expense of subalpine forests, tundra, and Great Basin woodlands (Rehfeldt et al. 2006). The forecast for chaparral distribution in response to climate change is not uniform throughout California, some models predict increases in the distribution of chaparral in northern California and decreases in chaparral in central western California by 2070 (PRBO Conservation Science et al. 2011). Distributional shifts of chaparral into new areas are likely to occur as temperatures warm (Pratt et al. 2005) and following fires (Keeley 1991). Reduced exposure to freezing events at upper elevational limits along Sierra Nevada foothills may facilitate elevational expansion of chaparral range (Pratt et al. 2005). However, future drought conditions may cause manzanita to become limited to ephemeral washes (Gitlin et al. 2006).

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;

---

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

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).

Chaparral may benefit from increased fire frequency, because in the absence of fire, montane chaparral–dominated landscapes become invaded by fire intolerant species (Beaty and Taylor 2008). In a Sierra Nevada ranger unit, modeled climate change resulted in a 124% increase in escapes and area burned by contained fire in areas covered in chaparral (Fried et al. 2004). However, there is no consensus on how climate change will influence Santa Ana events or fire in southwestern California (PRBO Conservation Science 2011).

Temperature: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004: Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[9] and PCM[10]) predict summer temperatures to increase 1.6-2.4˚C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0˚C, with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9˚C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). Projections for future precipitation in the Sierra Nevada vary among models; some demonstrate little to no change (e.g. PCM) while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in

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

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

snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010).

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

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b). Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to advance the runoff center of mass by 1-7 weeks by 2100 (Maurer 2007), although advances will likely be non-uniformly distributed in the Sierra Nevada (Young et al. 2009). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds, decreasing meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

Climatic water deficit: Increases in potential evapotranspiration will likely be the dominant influence in future hydrologic cycles in the Sierra Nevada, decreasing runoff even under forecasts of increased precipitation, and driving increased climatic water deficits (Thorne et al. 2012). Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, is a function of actual evapotranspiration and potential evapotranspiration. In the Sierra Nevada, climatic water deficit has increased slightly (~4%) in the past 30 years compared with the 1951-1980 baseline (Flint et al. 2013). Future downscaled water deficit projections using the Basin Characterization Model (Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (Geos Institute 2013).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the system may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

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.

Literature Cited

Anacker, B., N. Rajakaruna, D. Ackerly, S. Harrison, J. Keeley and M. Vasey (2011). "Ecological strategies in California chaparral: interacting effects of soils, climate, and fire on specific leaf area." Plant Ecology & Diversity **4**(2-3): 179-188.

Beaty, R. M. and A. H. Taylor (2008). "Fire history and the structure and dynamics of a mixed conifer forest landscape in the northern Sierra Nevada, Lake Tahoe Basin, California, USA." Forest Ecology and Management **255**(3-4): 707-719.

California Legislature. Senate Committee on Natural Resources. Jones & Stokes Associates and California Nature Conservancy (1987). Sliding toward extinction: the state of California's natural heritage. Sacramento, California.

Cayan, D., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio and D. H. Peterson (2001). "Changes in the Onset of Spring in the Western United States." Bulletin of the American Meteorological Society **82**(3): 399-145.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree and K. Hayhoe (2008). "Climate change scenarios for the California region." Climatic Change **87**(S1): 21-42.

Cornwell, W. K., S. A. Stuart, A. Ramirez, C. R. Dolanc, J. H. Thorne and D. D. Ackerly (2012). Climate change impacts on California vegetation: Physiology, life history, and ecosystem change. California Energy Commission California Climate Change Center. **CEC-500-2012-023**.

Das, T., M. D. Dettinger, D. R. Cayan and H. G. Hidalgo (2011). "Potential increase in floods in California's Sierra Nevada under future climate projections." Climatic Change **109**(S1): 71-94.

Dettinger, M. D. (2005). "From climate-change spaghetti to climate-change distributions for 21st Century California." San Francisco Estuary and Watershed Science **3**(1): Article 4.

Dettinger, M. D., D. R. Cayan, N. Knowles, A. Westerling and M. K. Tyree (2004a). Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada, USDA Forest Service. **Gen. Tech. Report PSW-GTR-193**.

Dettinger, M. D., D. R. Cayan, M. K. Meyer and A. E. Jeton (2004b). "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099." Climate Change **62**: 283-317.

Flint, L. E., A. L. Flint, J. H. Thorne and R. Boynton (2013). "Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance." Ecological Processes ***2***: 25.

Fried, J. S., M. S. Torn and E. Mills (2004). "The impact of climate change on wildfire severity: A regional forecast for northern California." Climatic Change **64**: 169-191.

Geos Institute (2013). Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy (VAAS) process, Available online at: http://www.geosinstitute.org/climatewiseservices/completed-climatewise-projects.html.

Gitlin, A. R., C. M. Sthultz, M. A. Bowker, S. Stumpf, K. L. Paxton, K. Kennedy, A. Munoz, J. K. Bailey and T. G. Whitham (2006). "Mortality gradients within and among dominant plant populations as barometers of ecosystem change during extreme drought." Conservation Biology **20**(5): 1477-1486.

Hamlet, A. F., P. W. Mote, M. P. Clark and D. P. Lettenmaier (2007). "Twentieth-Century Trends in Runoff, Evapotranspiration, and Soil Moisture in the Western United States*." Journal of Climate **20**(8): 1468-1486.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan and J. H. Verville (2004). "Emissions pathways, climate change, and impacts on California." Proceedings of the National Academy of Sciences **101**(34): 12422-12427.

Keeley, J. E. (1991). "Seed Germination and Life History Syndromes in the California Chaparral." Botanical Review **57**(2): 81-116.

Keeley, J. E. (1992). "Recruitment of Seedlings and Vegetative Sprounts in Unburned Chaparral." Ecology **73**(3): 1194-1208.

Keeley, J. E. (1995). "Future of California Floristics and Systematics: Wildfire threats to the California Flora." Madroño **42**(2): 175-179.

Keeley, J. E. and T. J. Brennan (2012). "Fire-driven alien invasion in a fire-adapted ecosystem." Oecologia **169**(4): 1043-1052.

Keeley, J. E. and S. C. Keeley (1977). "Energy Allocation Patterns of a Sprouting and a Nonsprouting Species of Arctostaphylos in the California Chaparral." The American Midland Naturalist **98**(1): 1-10.

Keeley, J. E., A. H. Pfaff and H. Safford (2005). "Fire suppression impacts on postfire recovery of Sierra Nevada chaparral shrublands." International Journal of Wildland Fire **14**: 255-265.

Knowles, N. and D. Cayan (2004). "Elevational dependence of projected hydrologic changes in the San Francisco Estuary and Watershed." Climate Change **62**: 319-336.

Knowles, N., M. D. Dettinger and D. Cayan (2006). "Trends in Snowfall versus Rainfall in the Western United States." Journal of Climate **19**(18): 4545-4559.

Lawson, D. M., H. M. Regan, P. H. Zedler and J. Franklin (2010). "Cumulative effects of land use, altered fire regime and climate change on persistence ofCeanothus verrucosus, a rare, fire-dependent plant species." Global Change Biology.

Long, J., C. Skinner, M. North, P. Winter, W. Zielinski, C. Hunsaker, B. Collins, J. Keane, F. Lake, J. Wright, E. Moghaddas, A. Jardine, K. Hubbert, K. Pope, A. Bytnerowicz, M. Fenn, M. Busse, S. Charnley, T. Patterson, L. Quinn-Davidson, H. Safford, chapter authors and Synthesis team members, R. Bottoms, J. Hayes, team coordination and review, M. Meyer, D. Herbst, K. Matthews and additional contributors (2013). Science Synthesis to Support Land and Resource Management Plan Revision in the Sierra Nevada and Southern Cascades. USDA Forest Service Pacific Southwest Research Station. Albany, CA**:** 504. Available at: http://www.fs.fed.us/psw/publications/reports/psw_sciencesynthesis2013/index.shtml.

Maurer, E. P. (2007). "Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios." Climatic Change **82**(3-4): 309-325.

Maurer, E. P., I. T. Stewart, C. Bonfils, P. B. Duffy and D. Cayan (2007). "Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada." Journal of Geophysical Research **112**(D11).

McKenzie, D., Z. Gedalof, D. L. Peterson and P. W. Mote (2004). "Climate Change, Wildfire, and Conservation." Conservation Biology **18**(4): 890-902.

Miller, J. D., H. D. Safford, M. Crimmins and A. E. Thode (2009). "Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA." Ecosystems **12**: 16-32.

Miller, N. L., K. E. Bashford and E. Strem (2003). "Potential impacts of climate change on California hydrology." Journal of American Water Resources Association **39**(4): 771-784.

Moser, S. C., G. Franco, S. Pittiglio, W. Chou and D. Cayan (2009). The Future Is Now: An Update On Climate Change Science Impacts And Response Options For California, Prepared for: California Energy Commission, Public Interest Energy Commission. **CEC-500-2008-071**.

Mote, P. W. (2006). "Climate-Driven Variability and Trends in Mountain Snowpack in Western North America." Journal of Climate **19**(23): 6209-6220.

Mote, P. W., A. F. Hamlet, M. P. Clark and D. P. Lettenmaier (2005). "Declining Mountain Snowpack in Western North America*." Bulletin of the American Meteorological Society **86**(1): 39-49.

Nagel, T. A. and A. H. Taylor (2005). "Fire and persistence of montane chaparral in mixed conifer forest landscapes in the northern Sierra Nevada, Lake Tahoe Basin, California, USA." The Journal of the Torrey Botanical Society **132**(3): 442-457.

Null, S. E., J. H. Viers and J. F. Mount (2010). "Hydrologic response and watershed sensitivity to climate warming in California's Sierra Nevada." PLoS One **5**(4).

Pratt, R. B., F. W. Ewers, M. C. Lawson, A. L. Jacobsen, M. M. Brediger and S. D. Davis (2005). "Mechanisms for tolerating freeze-thaw stress of two evergreen chaparral species: Rhus ovata and Malosma laurina (Anacardiaceae)." American Journal of Botany **92**(7): 1102-1113.

Pratt, R. B., A. L. Jacobsen, R. Mohla, F. W. Ewers and S. D. Davis (2008). "Linkage between water stress tolerance and life history type in seedlings of nine chaparral species (Rhamnaceae)." Journal of Ecology **96**(6): 1252-1265.

PRBO Conservation Science (2011). Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife. **Version 1.0:** 68. Available at http://data.prbo.org/apps/bssc/uploads/Ecoregional021011.pdf.

Ramirez, A., W.K. Cornwell and D. D. Ackerly. (2012). Section 4: Fire, Climate and the Distribution of Shrub Life History Strategies across the California Landscape. Climate Change Impacts on California Vegetation: Physiology, Life History, and Ecosystem Change. W. K. Cornwell, S. Stuart, A. Ramirez et al., California Energy Commission California Climate Change Center.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell and J. S. Evans (2006). "Empirical Analyses of Plant-Climate Relationships for the Western United States." International Journal of Plant Sciences **167**(6): 1123-1150.

Safford, H., M. North and M. D. Meyer (2012). Chapter 3: Climate Change and the Relevance of Historical Forest Condition. Managing Sierra Nevada Forests, USDA Forest Service, Pacific Southwest Research Station. **Gen. Tech. Rep. PSW-GTR-237**.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa, N. C. Lau, C. Li, J. Velez and N. Naik (2007). "Model projections of an imminent transition to a more arid climate in southwestern North America." Science **316**(5828): 1181-1184.

Sheffield, J., G. Goteti, F. Wen and E. F. Wood (2004). "A simulated soil moisture based drought analysis for the United States." Journal of Geophysical Research: Atmospheres (1984-2012) **109(D24)**.

Stewart, I., D. Cayan and M. D. Dettinger (2005). "Changes toward Earlier Streamflow Timing across Western North America." Journal of Climate **18**: 1136-1155.

Sturrock, R. N., S. J. Frankel, A. V. Brown, P. E. Hennon, J. T. Kliejunas, K. J. Lewis, J. J. Worrall and A. J. Woods (2011). "Climate change and forest diseases." Plant Pathology **60**: 133-149.

Thorne, J. H., R. Boynton, L. Flint, A. Flint and T.-N. G. Le (2012). Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies, Prepared for California Energy Commission, Prepared by University of California, Davis. **CEC-500-2012-010**.

Westerling, A. L. and B. P. Bryant (2006). Climate Change and Wildfire in and around California: Fire Modeling and Loss Modeling. Prepared for California Climate Change Center. **CEC-500-2005-190-SF:** 33.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das and S. R. Shrestha (2011). "Climate change and growth scenarios for California wildfire." Climatic Change **109**(S1): 445-463.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan and T. W. Swetnam (2006). "Warming and earlier spring increase western U.S. forest wildfire activity." Science **313**: 940-943.

Young, C. A., M. I. Escobar-Arias, M. Fernandes, B. Joyce, M. Kiparsky, J. F. Mount, V. K. Mehta, D. Purkey, J. H. Viers and D. Yates (2009). "Modeling The Hydrology Of Climate Change In California's Sierra Nevada For Subwatershed Scale Adaptation." Journal of American Water Resources Association **45**(6): 1409-1423.

Zammit, C. A. and P. H. Zedler (1988). "The Influence of Dominant Shrubs, Fire, and Time since Fire on Soil Seed Banks in Mixed Chaparral." Vegetation **75**(3): 175-187.

Zammit, C. A. and P. H. Zedler (1994). "Organisation of the Soil Seed Bank in Mixed Chaparral." Vegetation **111**(1): 1-16.

EcoAdapt™

Meeting the challenges of climate change

EcoAdapt, founded by a team of some of the earliest adaptation thinkers and practitioners in the field, has one goal - creating a robust future in the face of climate change. We bring together diverse players to reshape planning and management in response to rapid climate change.

P.O. Box 11195
Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834