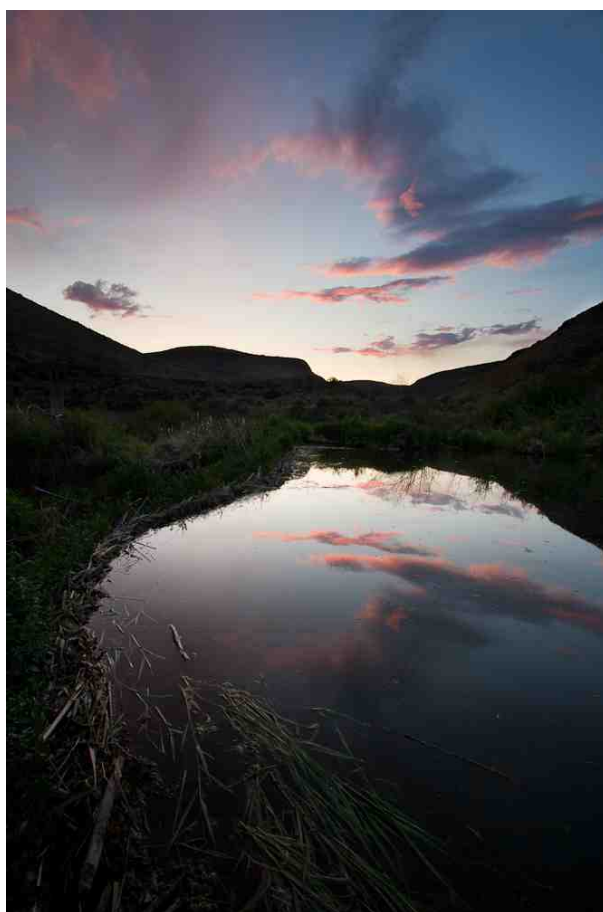


A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada



**A report to the California Landscape Conservation Cooperative
and U.S. Forest Service Pacific Southwest Region**

EcoAdapt

February 2014

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Executive Summary

This vulnerability assessment is an initial science-based effort to identify how and why focal resources (ecosystems, species populations, and ecosystem services) across the Sierra Nevada region are likely to be affected by future climate conditions. The overarching goal is to help resource managers and stakeholders plan their management of these focal resources in light of a changing climate. Specifically, this information can facilitate priority setting for management action and responses, helping to sustain optimal conditions for and productivity of focal resources. Twenty-seven focal resources including eight ecosystems, populations of fifteen species, and four ecosystem services were identified as important by the U.S. Forest Service (USFS) as part of their forest plan revision process or by Sierra Nevada stakeholders and are considered in this assessment. This assessment centers on the Sierra Nevada region of California, from foothills to crests, including ten national forests and two national parks (Figure 1).

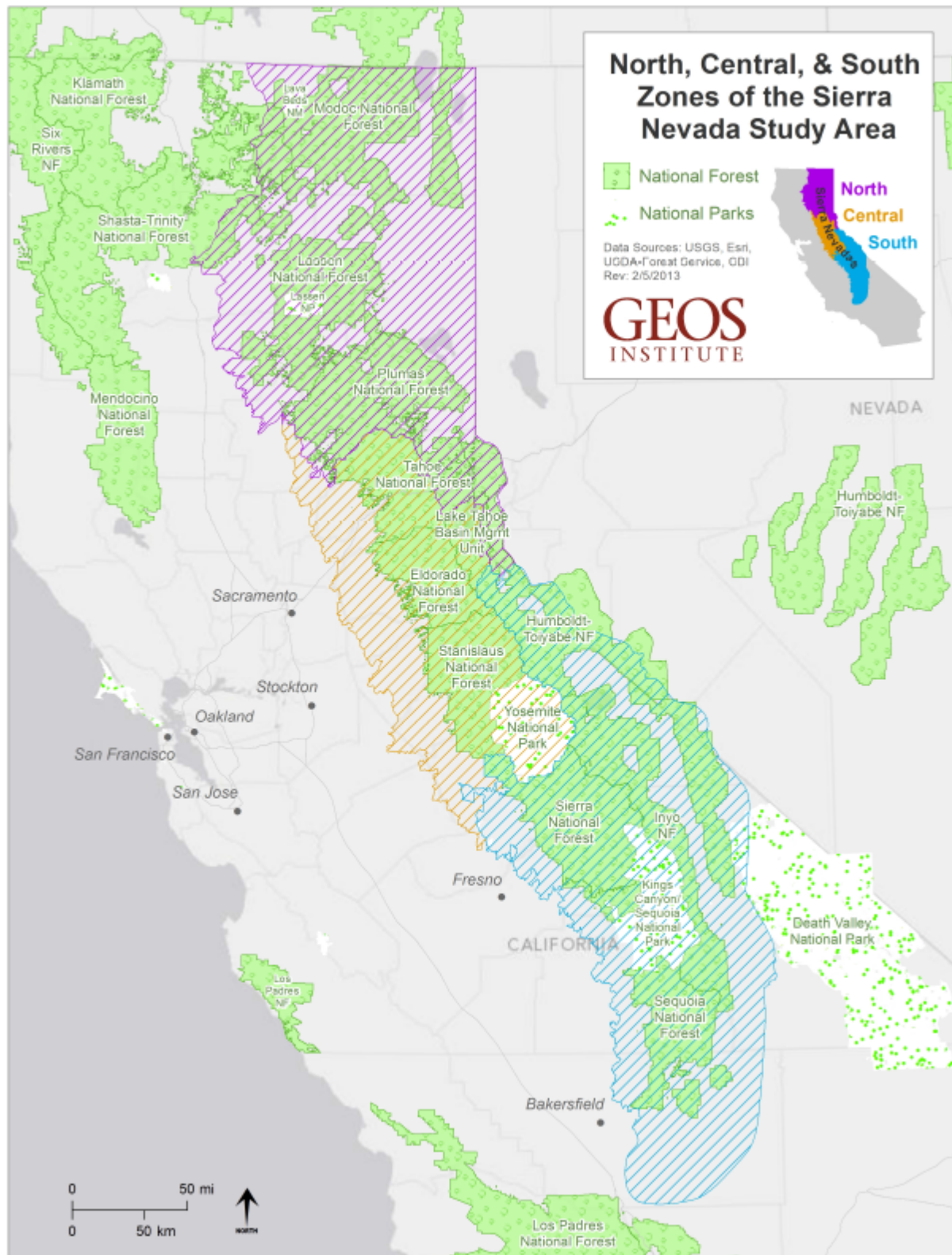


Figure 1. Sierra Nevada geographic sub-regions including national forests and parks (Geos Institute 2013).

General Overview

Climate change vulnerability of twenty-seven focal resources was assessed by considering exposure to climate change, sensitivity to climate and non-climate stressors, and adaptive capacity. The twenty-seven focal resources were identified by Sierra Nevada stakeholders from federal and state agencies, non-governmental organizations, universities, and other groups, and particular attention was given to those resources of management, cultural, or social concern in existing land management plans. Climate exposure information for the Sierra Nevada was provided by the Geos Institute in the form of a synthesis report summarizing regional past and projected climate trends and change data, and included information on temperature and precipitation, wildfire, vegetation dynamics, and hydrology (i.e., snowpack, runoff, recharge, and soil moisture) (Geos Institute 2013). Sensitivity and adaptive capacity information from the scientific literature was provided by EcoAdapt in the form of background summaries for focal resources¹. The Template for Assessing Climate Change Impacts and Management Options (TACCIMO, <http://www.taccimo.sgcp.ncsu.edu/>) provided additional exposure information for specific focal resources.

A vulnerability assessment workshop was convened to evaluate the vulnerability of each focal resource and included participants from over fifteen representative agencies and organizations. Each component of vulnerability (i.e., sensitivity, adaptive capacity, exposure) was assessed to be low, moderate, or high based on participant expertise and their interpretation of the information provided. Each ranking also included a confidence evaluation.

The Report Section-by-Section

Section 1 provides a brief introduction to the project and how the information from vulnerability assessments can be used. Section 2 provides a summary of past and projected climate trends for three sub-regions of the Sierra Nevada: north, central, and south. Section 3 describes in greater detail the methods used to select focal resources, as well as the development of the vulnerability assessment model and its application. Section 4 explores the results of the vulnerability assessments for the final suite of focal resources.

Most Vulnerable Ecosystems and Species

Alpine/Subalpine ecosystems and red fir, willow flycatcher, and whitebark pine species

The vulnerabilities for seven ecosystems (alpine/subalpine, red fir, yellow pine/mixed conifer, wet meadows and fens, oak woodlands, chaparral, and sagebrush) are summarized in Figure 2². This figure is arranged such that ecosystems listed in the upper left region were judged to be less vulnerable than those listed in the lower right region. Exposure for each ecosystem was assessed separately for three different Sierra Nevada sub-regions: north, central, and south.

¹ Available online at: <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>.

² The vulnerability ranking of the eighth ecosystem, aquatic, was not calculated due to missing exposure information.

The exposure, sensitivity and adaptive capacity of most of the ecosystems were judged to be in the middle of the range.

The alpine/subalpine ecosystem was judged to be more vulnerable than the other systems, having a combination of moderate to high exposure/sensitivity to climate change and low to moderate adaptive capacity. Further, vulnerability of this system increases in the northern Sierras due to increases in climate exposure. In contrast, oak woodlands were considered the least vulnerable system having low to moderate exposure, moderate to high sensitivity, and moderate to high adaptive capacity. Oak woodlands were identified as the focal ecosystem with the highest adaptive capacity due to their wide distribution throughout the Sierra Nevada, their general resistance to short-term changes, high tolerance for varying soil types, temperature and precipitation range tolerance, and high faunal and flora species diversity. Vulnerability of oak woodlands is greater in the southern Sierras, but decreases in the central and northern regions.

Similarly, vulnerability of sagebrush also decreases in the central and northern Sierras compared with the southern and eastern Sierras (data not shown). Vulnerabilities of wet meadows and yellow pine/mixed conifer ecosystems were considered similar to each other and did not vary by geographic sub-region. Climate change exposure for chaparral was only assessed for the northern sub-region³, although this ecosystem does occur across the Sierra Nevada and it is possible that vulnerabilities of this system may vary geographically. More in-depth explorations of ecosystem vulnerabilities are presented in Section 4.

³ Participants were unable to evaluate exposure for the central and southern Sierras in the time allotted at the workshop.

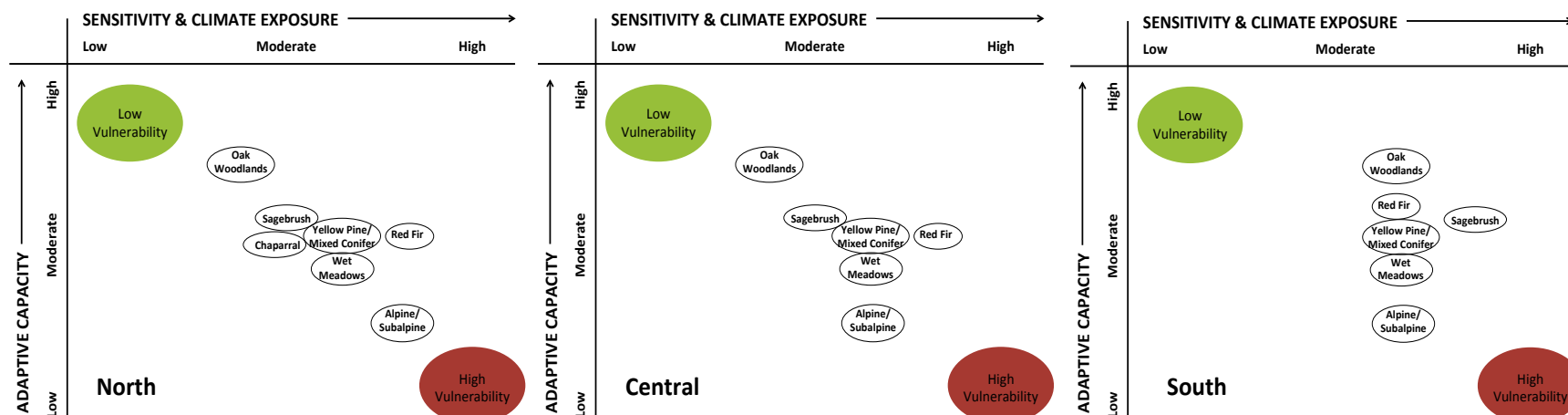


Figure 2. Relative vulnerabilities of seven Sierra Nevada ecosystems based on the climate change exposure/sensitivity and adaptive capacity assessment of each for three Sierra Nevada sub-regions: north, central, and south. Overall vulnerability increases with increasing exposure/sensitivity and decreasing adaptive capacity. Ecosystems listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence for ecosystem sensitivities and adaptive capacities ranged from moderate to high. Overall confidence for exposure was generally moderate.

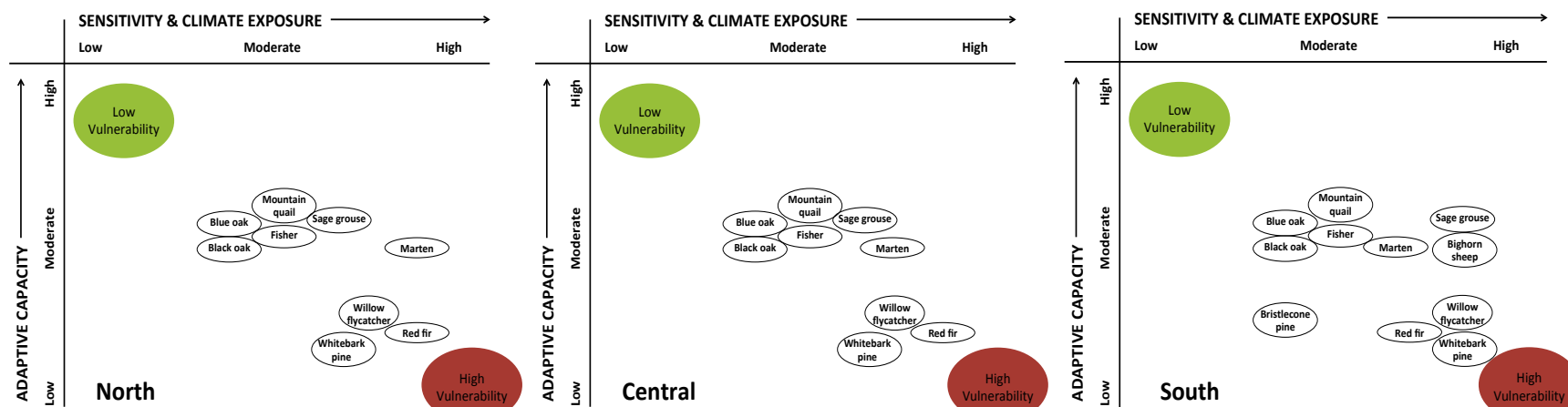


Figure 3. Relative vulnerabilities of twelve Sierra Nevada species populations based on the climate change exposure/sensitivity and adaptive capacity assessment of each for three Sierra Nevada sub-regions: north, central, and south. Overall vulnerability increases with increasing exposure/sensitivity and decreasing adaptive capacity. Species listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence for species sensitivities and adaptive capacities ranged from moderate to high. Overall confidence for exposure was generally moderate.

Figure 3 summarizes the vulnerability of eleven focal species populations considered including bristlecone pine, whitebark pine, red fir, blue oak, black oak, bighorn sheep, willow flycatcher, fisher, marten, mountain quail, and sage grouse¹. This figure is arranged similarly to Figure 2 in that species listed in the upper left region were judged to be less vulnerable than species listed in the lower right region. Exposure for each species was assessed for three different Sierra Nevada sub-regions: north, central, and south.

Species' vulnerabilities fell into one of two categories: moderate (e.g., blue oak, black oak, mountain quail, fisher) or moderate to high (e.g., sage grouse, marten, bighorn sheep, willow flycatcher, whitebark pine, red fir). Several species shifted from moderate vulnerability to moderate to high vulnerability or vice versa due to sub-regional differences in exposure. Red fir, willow flycatcher, and whitebark pine populations were the outlier species due to high climate change exposure/sensitivity and low to moderate adaptive capacity. Climate change exposure was higher for a number of species in the southern Sierras compared with the northern sub-region including whitebark pine, sage grouse, and willow flycatcher. In contrast, marten and red fir demonstrate increased vulnerability due to greater climate exposure in the northern and central sub-regions. Vulnerabilities for blue oak, black oak, mountain quail, and fisher were considered similar to each other and did not vary by geographic sub-region. Climate change exposure for bristlecone pine and bighorn sheep was only assessed for the southern sub-region, as these species populations are confined to the southern Sierras. Individual species vulnerability is discussed in greater depth in Section 4.

All of the ecosystems and species considered in this project were judged to have some vulnerability to climate change. Red fir, whitebark pine, and willow flycatcher species and alpine/subalpine ecosystems were identified as the most vulnerable to projected climate change in the Sierra Nevada. Red fir and willow flycatcher occur in higher elevations and are particularly sensitive to changes in hydrology (e.g., snowpack, soil moisture, runoff), which either affect the species directly (red fir) or the habitat the species depends upon (willow flycatcher – wet meadows). Hydrologic changes and loss of snowpack predicted across the Sierras may render previously habitable areas unsuitable for both species. Whitebark pine is sensitive to changes in temperature and precipitation as well as insect (pine beetle) and disease (blister rust) outbreak. Warmer, drier climates combined with increased mobility and efficacy of insects may lead to loss of whitebark pine forests in the future (e.g., see Millar et al. 2004). The information presented in Section 4 details climate change exposure, sensitivity and adaptive capacity for red fir, willow flycatcher, and whitebark pine within the Sierra Nevada region.

Section 4 also provides greater detail on the climate change exposure, sensitivity and adaptive capacity of the alpine/subalpine ecosystem, which was judged to be the most vulnerable ecosystem in this assessment. This ecosystem was assessed as having the lowest adaptive

¹ Vulnerability assessment information was collected for 15 species total. However, participants were unable to rank exposure and/or adaptive capacity for several resources in the time allotted at the workshop. Consequently, an overall vulnerability score for wood rat, aspen, Sierra Nevada and southern mountain yellow-legged frog species could not be calculated and thus are not represented in this figure.

capacity among the focal ecosystems considered, and is one that is confined to high elevations with limited room to vertically migrate. As this system is already located at higher elevations in the Sierra Nevada, it may decrease in area, become more isolated, or may be lost entirely as temperatures increase. For example, habitat models for the region have predicted a 70-95% loss in alpine/subalpine forest area relative to 1961-1990 stands (Hayhoe et al. 2004).

Vulnerability of this system is greater in the northern Sierra sub-region compared to central and southern sub-regions due to a combination of increased climate exposure and decreased adaptive capacity. In the northern sub-region, lower adaptive capacity is likely a result of current fragmentation and limited habitat extent. Much of this ecosystem occurs in Wilderness or other special designation areas where management options may be limited however, given its vulnerability to climate change, it may warrant additional consideration in management planning.

Each of the remaining ecosystems and species under investigation were judged to have at least moderate vulnerability to climate change, suggesting that climate change has the potential to affect the Sierra Nevada region and the current ecosystem services it provides to society. The details for these vulnerability rankings are presented in Section 4. This vulnerability assessment can be used as a foundation from which management and planning can be strengthened by better integrating the effects of climate change. However, it is also important to continue to gather information to better understand local climate, its interactions with non-climate stressors, and the impacts to focal resources. This assessment is intended to be updatable so that as new information becomes available on ecosystem or species' sensitivity, adaptive capacity, or exposure it can be integrated.

The overall vulnerabilities presented above are comparable only within the focal resources considered here and are not standardized in any way to other climate change vulnerability assessments. The information supporting these results is available in Section 4 and should be referred to before using the overview results in decision-making. The information in this vulnerability assessment is intended to help managers develop and prioritize adaptation strategies to conserve resources in the face of climate change. The information from this assessment has already served as the foundation in the development of proposed regional climate change adaptation strategies for a smaller suite of focal resources. These adaptation strategies can be found in the companion document *Climate Change Adaptation Strategies for Focal Resources of the Sierra Nevada* (EcoAdapt 2013).

1. Introduction

This vulnerability assessment is an initial science-based effort to identify how and why focal resources (ecosystems, species populations, and ecosystem services) across the Sierra Nevada region are likely to be affected by future climate conditions. The assessment centers on the Sierra Nevada region of California, from foothills to crests, including ten national forests and two national parks (Figure 1). It focuses on twenty-seven resources including eight ecosystems, fifteen species, and four ecosystem services identified as important by the U.S. Forest Service (USFS) as part of their forest plan revision process or by Sierra Nevada stakeholders, and is therefore expected to be relevant to decisions that affect the resources. The analyses and conclusions are based on available information and expert opinion.

Climate change vulnerability assessments provide two kinds of information: (1) they identify which resources are likely to be most affected by changing climate conditions, and (2) they improve understanding as to why these resources are likely to be vulnerable. Knowing which resources are most vulnerable better enables managers to set priorities for conservation action, while understanding why provides a basis for developing appropriate adaptation responses (Glick et al. 2011).

The overarching goal of this assessment is to provide vulnerability information and supporting tools and resources that will help Sierra Nevada managers and stakeholders plan their management of focal resources in a changing climate. To meet this goal, the assessment has three main objectives:

1. To use the latest scientific information and expert knowledge to evaluate vulnerabilities of focal resources to climate change including assessing sensitivity, exposure, and adaptive capacity.
2. To quantify vulnerabilities of focal resources to climate change, and how these vulnerabilities vary spatially across the Sierra Nevada.
3. To work with resource managers and planners to increase their institutional knowledge and capabilities to respond to climate change by providing vulnerability assessment training, resources, support, and tools.

To achieve these objectives, we developed and applied a vulnerability assessment model consistently across the Sierra Nevada that improves understanding of why resources may be vulnerable, how these vulnerabilities may vary across the region (e.g., northern Sierras vs. southern Sierras), and where and how management could intervene to reduce vulnerabilities. In this report we describe how this vulnerability model was developed, including how focal resources were selected, and summarize the results that were obtained when the model was applied to focal resources of the Sierra Nevada (ecosystems, species populations, ecosystem services). In two separate companion documents we summarize current scientific understanding of projected climate, wildfire, hydrology, and vegetation change in the Sierra Nevada region over the next century (Geos Institute 2013), and synthesize adaptation strategies for focal resources of the region (EcoAdapt 2013).

We recommend that resource managers and planners refer to the comments and supporting material provided for each assessment rather than only the rankings. While rankings can be a valuable tool, the comments and supporting material more clearly describe resource vulnerabilities, including any sub-regional differences, which can be used to better refine management options for limiting potential impacts.

2. An Overview of Climate Change in the Sierra Nevada Region

Climate models have projected major changes across the Sierra Nevada over the next century. The Sierra Nevada region is heterogeneous, spanning over 400 miles north-to-south, with multiple types of ecosystems ranging from meadows to forests to sagebrush. Due to its heterogeneous landscape, climate-related changes are expected to vary spatially across the Sierra Nevada region. Consequently, exposures and vulnerabilities of ecosystems and species populations will also vary temporally and geographically over the coming century. An improved understanding of the magnitudes and geographical variations of projected climate-related impacts will help managers be better prepared.

This chapter and the companion Geos Institute report “Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California” describe current understanding of the changes in climate the Sierra Nevada is predicted to experience and potential influences on major physical and ecological processes such as wildfire, hydrology, and vegetation cover (Geos Institute 2013). This is not an exhaustive quantitative analysis, but a framework to better understand magnitudes and directions of change in order to support management decision-making. Results can be used to begin to spatially and temporally assess relative vulnerabilities of ecosystems and species populations across the Sierra Nevada region.

Climate in the Western U.S., including the Sierra Nevada, is strongly influenced by naturally occurring climate cycles such as the 20-30 year Pacific Decadal Oscillation (PDO) and the 1-2 year El Niño-Southern Oscillation (ENSO). These large-scale climate patterns influence the climate in the Sierra Nevada by causing warmer/cooler and drier/wetter conditions depending on the phase of the PDO and ENSO. Currently, there is relatively low ability to predict changes in the PDO and ENSO, and it has proven difficult to understand how climate change may influence these naturally occurring phenomena. Climate models are better at predicting general trends in climate rather than detailing year-to-year variability.

This report and the companion Geos Institute (2013) synthesis have divided the Sierra Nevada landscape into three sub-regions: north, central, and south. Historic data and future projections for temperature, precipitation, hydrology (i.e., snowpack, runoff, climatic water deficit), wildfire, and vegetation patterns were analyzed for each sub-region. Historic trends were based on PRISM data. Future projections were developed using two global coupled ocean-atmospheric climate models - the GFDL (Geophysical Fluid Dynamics Laboratory) and Parallel Climate Model (PCM; National Center for Atmospheric Research, USA) - based on the IPCC “business-as-usual” A2 emissions scenario. The Geos Institute report provides spatially explicit maps of projected changes for key climate parameters in the north, central and south Sierra Nevada relative to historic norms (roughly 1961-1990) to three future time periods (roughly 2010-2029, 2030-2049, and 2060-2079) using downscaled results (270 m) from the two global climate models. Vegetation change projections were derived differently and were generated using the HadCM, MIROC, and CSIRO models. All the downscaled climate data layers presented here and in the Geos Institute (2013) report are available for viewing and download on Data

Basin². Additionally, dominant vegetation type change projections using the GFDL and PCM climate models are also available for viewing and download on Data Basin.

Over the next century, annual temperatures across the Sierra Nevada are expected to increase, with summer temperatures projected to rise more than winter temperatures. Exact precipitation patterns in the future are uncertain, but in general, summer and fall are projected to be drier while winter will be wetter relative to historic averages. Precipitation will fall more often in the form of rain rather than snow, decreasing seasonal snowpack and increasing flood risk. Warmer temperatures in the summer and fall will increase evapotranspiration rates causing more severe summer low flows in rivers and reduced soil moisture. Warmer and drier conditions will increase the likelihood of wildfire across the Sierra Nevada. Climate models are better at predicting some climate-driven changes, such as higher temperatures and lower snowpack, than others (e.g., precipitation change). Specifically, the following changes are projected for the Sierra Nevada:

- By 2060-79, average annual temperature across the Sierra Nevada is expected to increase by 2.7 to 3.4°C, with warmer annual and seasonal temperatures generally occurring in the south Sierra and during summers.
- By 2060-79, precipitation is generally expected to decrease in summer and fall across the entire Sierra Nevada. Model predictions range from -52% to +16% in summer and -27% to -1% in fall. Winters are expected to be wetter, ranging from -8% to +22%.
- By 2060-79, annual runoff is expected to change by -41 to +15% as more precipitation falls in the form of rain rather than snow.
- Annual snowpack is expected to decrease by -64 to -87% by 2060-79 across the entire Sierra Nevada.
- Climatic water deficit is projected to increase due to less precipitation and higher evapotranspiration rates, and may increase by +19 to +44% across the entire Sierra Nevada by 2060-79.
- By 2060-79, the area burned by wildfire in the Sierra Nevada is expected to increase by +35 to +169%, with forested areas in the north and central Sierra demonstrating greater increases in area burned.

² Spatial climate data layers are accessible through the EcoAdapt-CA LCC: Climate Adaptation Project for the Sierra Nevada group page - <http://databasin.org/groups/e6cfbd4218f54b32b695fad7af8cce31>.

3. Vulnerability Assessment Model and Methods

Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: A function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007).

Development of Collaborative Process

This project evolved from an existing collaboration called the Vulnerability Assessment/Adaptation Strategy (VA/AS) Working Group that was established by the Pacific Southwest Region of the U.S. Forest Service. It was recognized early in the process that the active participation of stakeholders throughout the Sierra Nevada region was essential. This stakeholder group not only had extensive knowledge about the ecology, management, and threats to Sierra Nevada ecosystems and species, but also comprises many of the professionals who will use the results of the project. This collaboration allowed the project to use an expert elicitation-based approach. Expert elicitation has a long history in conservation and regulation. These approaches are effective where there is greater uncertainty about current system function or future projections but where there is a reservoir of detailed knowledge and expertise. Expert elicitation also has the benefits of being relatively rapid, encouraging ownership and buy-in, and lower cost.

Members of the collaborative working group, as well as other key stakeholders identified in the Sierra Nevada region, were invited to participate in the project through one of three ways: (1) through the Stakeholder Advisory Committee, (2) through the Science Advisory Group, and/or (3) as a participant at the Vulnerability Assessment Workshop. Invited participants included land managers, planners, natural resource specialists, science and community partners, and conservation practitioners, among others.

Roles of the Stakeholder Advisory Committee and Science Advisory Group

The purpose of the Stakeholder Advisory Committee was to convene a smaller group of engaged resource managers, decision makers, scientists, conservationists, and others to provide input and review of project elements. Their roles included guiding the selection of focal resources, participating in workshops, and reviewing workshop results. The Science Advisory Group consisted of leading climate scientists, ecologists, hydrologists, and others for the Sierra Nevada region. Members of this group reviewed the climate science synthesis produced by the Geos Institute (2013), presented information on projections and ecological effects of climate

change for the region at the Vulnerability Assessment Workshop, provided spatial climate data for the project, and reviewed resource vulnerability findings. Committee members for both groups are listed in Appendix II.

Roles of the Vulnerability Assessment Workshop Participants

Using the vulnerability assessment model described below as a guide, workshop participants were asked to apply their knowledge and expertise about a selected focal resource (ecosystem, species populations, or ecosystem service) to evaluate its vulnerability to climate change and non-climate stressors. Following the synthesis of vulnerability assessment rankings and comments, participants were asked to review findings and provide any revisions or additional clarifying comments.

Focal Resources

Selection Process

The initial list of focal resources (~33 focal resources including species, ecosystems, and ecosystem services) was developed internally by the USFS and reviewed by the VA/AS collaborative working group. The draft list was then reviewed and revised by the Stakeholder Advisory Committee as well as several additional stakeholders and members of the Science Advisory Group. The final list included 9 ecosystems, 45 species or species assemblages, and 11 ecosystem services. These were organized according to a set of agreed upon coarse filters (i.e., ecosystems) and fine filters (i.e., species or assemblages). Ecosystem services remained in a separate category altogether.

Given the time and resources available, it was not feasible to apply the vulnerability assessment model to all 65 resources individually (the list of 65 resources is available on the EcoAdapt workshop support page³). Therefore, the following criteria were applied to select a subset of resources for consideration:

Ecosystems

Ecosystems were selected based on those that linked best with the USFS Bioregional Assessment for the Pacific Southwest Region of the USFS and represented the major ecosystems of the Sierra Nevada. The final list of 9 ecosystems were presented for consideration during the Vulnerability Assessment Workshop. Due to underrepresented participant expertise, however, only eight of nine ecosystem types were assessed at the workshop (Pinyon-Juniper Ecosystem was not evaluated). Further, vulnerability assessment rankings for the Aquatic Ecosystem were not completed due to time constraints. In sum, vulnerability rankings were completed for seven ecosystems while vulnerability assessment syntheses (described in Section 4) were completed for all eight ecosystems.

³ <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>

Species

Species were originally selected using a range of criteria including threatened and endangered species, keystone or foundational species, and indicator species, among others. To narrow down this list of 42 species and assemblages, 2 prioritization exercises were organized – one prior to and one during the Vulnerability Assessment Workshop.

First, the Stakeholder Advisory Committee developed a list of 8 resource evaluation criteria, each of which was weighted according to importance to consider (Table 1). Each species or assemblage was then evaluated by a participating expert and used to score and rank the resource.

Second, Vulnerability Assessment Workshop participants were then asked to apply one last culling criteria to the list of ranked resources. Based on the coarse filter/fine filter approach, wherein coarse filters represent ecosystems and fine filters focus on individual species not accounted for under the coarse filter, participants were asked to consider whether each species under a coarse filter was captured by the coarse filter level vulnerability assessment or whether species vulnerability needed to be assessed separately. For example, both mountain quail and woodrat were selected for further assessment because they were identified as being more sensitive to drought, catastrophic wildfire, and rising temperatures than the supporting chaparral ecosystem.

In total, fifteen species were considered in the vulnerability assessment process. Due to time constraints, however, vulnerability assessment rankings were only completed for eleven of the fifteen species considered. Rankings remain incomplete for aspen, woodrat, southern mountain yellow-legged frogs, and Sierra Nevada yellow-legged frogs. Nonetheless, vulnerability assessment syntheses for these species were compiled and are described in Section 4.

Ecosystem Services

A subset of the 11 ecosystem services were evaluated during the Vulnerability Assessment Workshop based on participant expertise. Ecosystem services were selected based on those necessary to consider as part of the Forest Plan revision process and were grouped into one of four categories according to Burkhard et al. (2009): ecological integrity, provisioning services, regulating services, or cultural services. Five of 11 ecosystem services were selected for consideration in the vulnerability assessment process based on participant expertise. One ecosystem service, biodiversity, was insufficiently addressed in the time allotted and is therefore not included in this report. In total, vulnerability assessments for four ecosystem services (rankings and syntheses) were completed.

Table 1. Resource evaluation criteria and weightings applied to species and species assemblages.

Evaluation Criteria	Weight
1. Is the resource federally listed as threatened, endangered (proposed or candidate) or is the resource a species of conservation concern (e.g., G/T 1-2 on NatureServe, state listed, Birds of National Conservation Concern, etc.)?	High (3)
2. Is the resource considered to be rare or endemic?	Moderate (2)
3. Is the resource considered to be: ecologically foundational, a dominant	High (3)

Evaluation Criteria	Weight
species, an ecosystem engineer, keystone species, strong interactor, or umbrella species? Please indicate which applies.	
4. Does the resource have available data and information upon which to do the vulnerability assessment?	Moderate (2)
5. Does the resource have substantial management implications?	Moderate (2)
6. Does the resource have socio-economic significance?	Low (1)
7. Is the resource considered to be or used as an indicator species for a larger group?	Moderate (2)
8. Is the resource widely or narrowly represented across the Sierra Nevada? (This question was intended to help select a balance between broad and narrow representations of species)	<i>No rank.</i>

Final Resource List

The final 27 resources considered in the vulnerability assessment process included:

Ecosystems	Species	Ecosystem Services
Alpine/Subalpine	Bristlecone pine Whitebark pine Bighorn sheep	Timber production/Forest products Carbon storage Fire Recreation
Red Fir	Red fir Marten	
Chaparral	Mountain quail Woodrat*	
Sagebrush	Sage grouse	
Wet Meadows and Fens	Willow flycatcher Aspen*	
Aquatic*	Mountain yellow-legged frog* Sierra Nevada yellow-legged frog*	
Oak Woodlands	Blue oak Black oak	
Yellow Pine/Mixed Conifer	Pacific fisher	

* Not fully evaluated

Vulnerability Assessment Model⁴

The vulnerability assessment model used in this process comprises three vulnerability components (sensitivity, adaptive capacity, and exposure), confidence evaluations for all components, and overall vulnerability and confidence for a focal resource (Figure 4). In this report, each component of vulnerability includes participant assigned rankings as well as narratives summarizing participant and additional expert comments, and information from peer-reviewed literature. The aim of the narratives that accompany rankings is to make transparent the rationales and assumptions underlying the rankings and confidences assigned to each variable.

Sensitivity, adaptive capacity, and exposure components were broken down into specific elements better suited to assessing the vulnerability of particular resources for this assessment. For example, sensitivity comprises five elements for ecosystems and ecosystem services, and seven elements for species. Sensitivity elements for ecosystems and ecosystem services include: direct sensitivity to temperature and precipitation, component species, disturbance regimes, other climate and climate-driven changes, and non-climate stressors. Disturbance regimes and non-climate stressors are also included in species sensitivity however, several other elements are better suited to assessing species' sensitivity including: generalist/specialist, physiology, life history, ecological relationships, and dependence on sensitive habitats. Sensitivity and adaptive capacity elements for ecosystems and species were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2012, and Lawler 2010. Exposure elements were created by EcoAdapt. Elements for assessing sensitivity, adaptive capacity, and exposure of ecosystem services were generated by EcoAdapt. Elements for each vulnerability component are described in more detail below.

Participants assigned one of three rankings (High, Moderate, or Low) for each component of vulnerability. Participant assigned rankings for each component were then averaged (mean) to generate an overall score. For example, rankings for each element of ecosystem sensitivity were averaged to generate an overall ecosystem sensitivity score. Rankings for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure) were then combined into an overall vulnerability score that was calculated as follows:

$$\text{Vulnerability} = \text{Climate Exposure} * \text{Climate Sensitivity} * (1/\text{Adaptive Capacity})$$

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). This ensured the degree of confidence assessors had in ranking each variable was explicit. Confidence rankings for each vulnerability component were averaged (mean) to generate an overall confidence score.

⁴ This process was modeled after the Northeast Association of Fish & Wildlife Agencies (NEAFWA) Habitat Vulnerability Model (Manomet Center for Conservation Sciences 2012).

The user of these vulnerability results is encouraged to pay close attention to the narratives and individual rankings of sensitivity and adaptive capacity for each focal resource, rather than overall vulnerability rankings and syntheses. Familiarity with each vulnerability component in addition to a resource's overall ranking allows one to better adapt one's understanding as exposure information varies (e.g., climate change projections vary depending on models used, greenhouse gas emissions scenarios, timeframes, etc.). This finer level of understanding better supports *why* a particular resource is vulnerable and *what* management actions may reduce vulnerabilities.

Further, the elements of adaptive capacity may not be independent. For example, areas with minimal human footprints are likely to be less fragmented, provide higher permeability, offer more refuge habitat, and exhibit higher levels of biotic and abiotic diversity (McKinney and Lockwood 1999). In contrast, the protected areas that tend to be more intact and diverse may also have laws that constrain management options for adaptation strategies. For example, many national parks prohibit prescribed burning, which is a common tool for increasing resilience through adaptive capacity. Stakeholders may want to consider these tradeoffs as they develop adaptation strategies and management options for a focal resource.

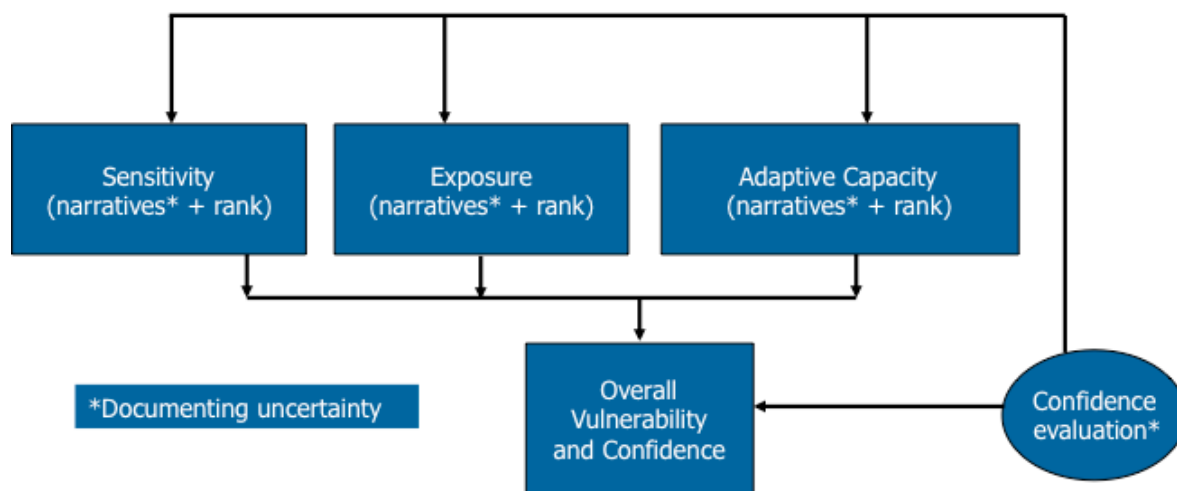


Figure 1. Structure of the vulnerability assessment model.

Model Elements – Ecosystems

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for ecosystems. This list of elements for sensitivity and adaptive capacity were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2012, and Lawler 2010. Exposure elements were generated by EcoAdapt. The expert elicitation vulnerability assessment worksheets for ecosystems can be found on the EcoAdapt workshop support page⁵.

⁵ <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>

Ecosystem Sensitivity

1. Direct Sensitivities to Temperature and Precipitation. The two ways ecosystem sensitivity to changes in temperature and precipitation were considered in this project were: (1) does the system inhabit a relatively narrow climatic zone, and (2) does the system experience large changes in composition or structure with small climatic changes in temperature or precipitation? Systems that inhabit a narrow climatic zone and/or experiences large changes in composition or structure in response to small changes in climate have higher sensitivity (Lawler 2010).

2. Component Species. The sensitivities of dominant, keystone/foundation, flagship and indicator species, as well as ecosystem engineers and “strong interactors” are likely to significantly influence the sensitivity of an ecosystem (Glick et al. 2011; Manomet Center for Conservation Sciences 2012). For example, keystone species exert strong effects on the structures of their communities even in low numbers, thus if these species are vulnerable to climate changes they are likely to increase the sensitivity of the overall system.

3. Disturbance Regimes. Ecosystems may be sensitive to particular disturbance regimes such as wildfire, flooding, drought, insect and disease outbreak, or wind, among others. Ecosystems that experience larger changes in composition or structure due to small changes in disturbance regimes are likely more sensitive (Lawler 2010).

4. Other Climate and Climate-Driven Changes. Other climate-driven changes may also impact the sensitivity of a system including altered hydrology (e.g., snowpack, snowmelt, runoff), fire regimes, evapotranspiration and soil moisture, extreme events, and water temperature, among others. Ecosystems that experience large changes due to small changes in these climate-driven factors are likely more sensitive.

5. Non-Climate Stressors. Other non-climate stressors have the potential to exacerbate the effects of climate change on ecosystems, or vice versa. Systems that have to endure multiple non-climate stressors are likely more sensitive to climate changes. Non-climate stressors can include residential and commercial development, agriculture and/or aquaculture, energy production and mining, transportation and service corridors, human intrusions and disturbance, natural system modifications, biological resource use (e.g., hunting, fishing), altered interspecific interactions, invasive and other problematic species, or pollution and poisons, among others (Glick et al. 2011; Manomet Center for Conservation Sciences 2012).

Ecosystem Adaptive Capacity

1. Extent and Integrity. Ecosystems that are currently widespread in their extent and relatively unfragmented may be better able to withstand and persist into the future despite climate and non-climate stressors. Similarly, ecosystems that have low current rates of loss or fragmentation may also have greater adaptive capacity compared with systems that are rarer, more fragmented, or narrow in extent (Manomet Center for Conservation Sciences 2012).

2. Resistance, Recovery, and Refugia. Some ecosystems may be more resistant to changes or stressors, or able to recover more quickly from stressors, resulting in greater adaptive capacity (NEAFA 2012). For example, systems that take several hundred years to recover from wildfire or disease outbreak have lower adaptive capacity than those systems that have shorter

recovery periods. Also, microclimates that exist within an ecosystem range may allow refugial communities to persist during climate changes thus increasing adaptive capacity.

3. Landscape Permeability. More permeable landscapes with fewer barriers to dispersal will likely result in greater adaptive capacity. The relative permeability of a landscape depends on natural and anthropogenic factors; for example, barriers to dispersal can include roads, urban or suburban development, clear cuts, dams and culverts, rivers and waterfalls, mountains or arid lands, or agriculture, among others (Lawler 2010; Glick et al. 2011).

4. System Diversity. Ecosystems with diverse physical and topographical characteristics (e.g., variety in aspects, slopes, and soil types) may be better able to persist under changing climate conditions than habitats that are less varied because they exist across widely differing conditions (Manomet Center for Conservation Sciences 2012). The level of diversity of component species and functional groups in the ecosystem may also affect the system's adaptive capacity to climate change impacts. For example, in ecosystems where each functional group is represented by multiple species, response to changes in climate varies among the species resulting in greater adaptive capacity (Glick et al. 2011).

5. Management Potential. Humans have the potential to intervene and change ecosystems in ways that reduce the impacts of climate change. For example, humans already control the flow regimes of most stream ecosystems (through dams) (Poff et al. 1997), so flow regimes could be manipulated to minimize stressful effects of climate change, such as low flows during late summer (Xu et al. 2010). The costs and benefits of management actions will vary among systems. Actions will be most feasible when resources are culturally and economically valued and the costs of implementing new management strategies are low.

Ecosystem Exposure

1. Elements of Exposure. A number of climate and climate-driven factors may be important to consider for a focal resource. These factors may include, but are not limited to: temperature, precipitation, climatic water deficit (i.e., soil moisture), wildfire, snowpack, runoff, timing of flows, low flows, high flows, and stream temperature. Participants were asked to select which climate and climate-driven factors were most relevant to consider for the resource and why, and document confidence.⁶

2. Exposure Assessment for Different Regions. Broadly, the Sierra Nevada can be represented by three major regions: north, central, and south. Because regional differences in climate and climate-driven changes occur across the Sierra Nevada, this question was intended to capture both where and when (early: 2010-2029; mid: 2030-2049; and late century: 2060-2079) those changes may occur.

⁶ Exposure worksheets were also created to gather additional information as to what climate data layers would be most important to consider for a focal resource, which was intended to inform additional mapping for the project. The results of this were used to help inform the assembling of climate data layers and resource distribution information for the project's Data Basin group page (found at: <http://databasin.org/groups/e6cfbd4218f54b32b695fad7af8cce31>). Comparative mapping of climate data and resource data was used to inform adaptation strategy development.

Model Elements – Species

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for species. This list of elements for sensitivity and adaptive capacity were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2012, and Lawler 2010; exposure elements were generated by EcoAdapt. The expert elicitation vulnerability assessment worksheets for species can be found on the EcoAdapt workshop support page⁷.

Species Sensitivity

1. Generalist/Specialist. Generalists are those species that use multiple habitats, have multiple prey or forage species, or have multiple host plants whereas specialists may have very narrow habitat needs, single forage or prey species, or a single host-plant species. Those species able to utilize a variety of habitats and/or prey or forage species are likely less sensitive to climate change (Glick et al. 2011).

2. Physiology. Physiological sensitivity is directly related to a species' physiological ability to tolerate changes in temperature, moisture, salinity, pH, or CO₂ concentrations that are higher or lower than the range that they currently experience. Species that are able to tolerate a wide range of variables are likely less sensitive to climate change (Glick et al. 2011).

3. Sensitive Habitats. Species that depend on habitats that are sensitive to climate change are also likely to have greater sensitivity to changes. For example, species that depend on vernal pools or ephemeral wetlands, or live in alpine environments are likely to be susceptible to climate impacts such as increased temperatures or changes in precipitation regimes (Glick et al. 2011).

4. Life History. Species reproductive strategy may influence sensitivity to climate change; for example, species with longer generation times and fewer offspring (K-selection) may be at increased extinction risk under long-term climate change. Species with a short generation time that produce many offspring (r-selection) may be better able to take advantage of climate changes (Glick et al. 2011).

5. Ecological Relationships. Species sensitivity also likely depends on the sensitivities of ecological relationships and/or interspecific interactions that affect the focal species. For example, the effects of climate change on predator/prey relationships, forage, habitat, or competition, among others that impact a focal species are likely to influence its sensitivity to climate change.

6. Disturbance Regimes. Species may be sensitive to particular disturbance regimes such as wildfire, flooding, drought, insect and disease outbreak, or wind, among others. Changes in those disturbance regimes as a result of climate changes could affect species sensitivity.

7. Interacting Non-Climatic Stressors. Other non-climate stressors have the potential to exacerbate the effects of climate change on species or vice versa. Species that have to endure multiple non-climate stressors are likely more sensitive to climate changes. Non-climate stressors can include things such as residential and commercial development, agriculture and/or aquaculture, energy production and mining, transportation and service corridors, human intrusions and disturbance, natural system modifications, biological resource use (e.g.,

⁷ <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>

hunting, fishing), altered interspecific interactions, invasive and other problematic species, or pollution and poisons, among others (Glick et al. 2011; Manomet Center for Conservation Sciences 2012).

Species Adaptive Capacity

1. Dispersal Ability and Barriers to Dispersal. In general, species that are poorer dispersers (disperse slowly and over short distances) are more susceptible to climate change (Glick et al. 2011). Similarly, the adaptive capacity of species with high innate dispersal ability may decrease if there are significant barriers to dispersal. Barriers to dispersal can include roads, urban or suburban development, clear cuts, dams and culverts, rivers and waterfalls, or agriculture, among others (Lawler 2010).

2. Plasticity. Species able to express different and varying traits (e.g., phenology, behavior, physiology) in response to environmental variation have greater adaptive capacity than those that cannot modify their physiology or vary behavior to better cope with climate changes and its associated effects. Many species exhibit phenotypic plasticity in response to inter-annual variation in temperature and precipitation.

3. Evolutionary Potential. Some species and/or populations will be better able to adapt evolutionarily to climate change. For example, species may have greater adaptive capacity if they exhibit characteristics such as faster generation times, genetic diversity, heritability of traits, larger population size, or multiple populations with connectivity among them to allow for gene flow.

4. Intraspecific Diversity/Life History. Species that demonstrate a diversity of life history strategies (e.g., variations in age at maturity, reproductive or nursery habitat use, or resource use) are likely to have greater adaptive capacity.

5. Management Potential. Humans have the potential to intervene in ways that reduce the impacts of climate change on a particular species. For example, if a species is listed as threatened or endangered, it can provide opportunities for implementing specific management measures likely to help populations persist. The costs and benefits of management actions will vary among species. Actions will be most feasible when resources are culturally and economically valued and the costs of implementing new management strategies are low.

Species Exposure

See description above under Model Elements – Ecosystems.

Model Elements – Ecosystem Services

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for ecosystem services. The expert elicitation vulnerability assessment worksheets for ecosystem services can be found on the EcoAdapt workshop support page⁸.

⁸ <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>

Ecosystem Services Sensitivity

1. Direct Sensitivities to Temperature and Precipitation. Services likely to be greatly affected by changes in temperature and precipitation are more sensitive compared with services able to withstand a range of temperatures and precipitation amounts. For example, extractable water supply is often directly influenced by regional precipitation and temperature.

2. Component Species. The sensitivities of a service may largely be determined by the sensitivities of those components that provide or support the service (e.g., species, habitats, hydrology, etc.). For example, timber production is dependent on the sensitivity of harvestable tree species to climate changes. Similarly, wildlife viewing services may be affected if a particular bird or wildlife species is likely to decline as a result of climate change.

3. Disturbance Regimes. Ecosystem services may also be sensitive to particular disturbance regimes such as wildfire, flooding, drought, insect and disease outbreak, or wind, among others. Ecosystem services that depend on components significantly influenced by these disturbances are likely more sensitive.

4. Other Climate and Climate-Driven Changes. Other climate-driven changes may also impact the sensitivity of an ecosystem service including altered hydrology (e.g., snowpack, snowmelt, runoff), altered fire regimes, extreme events, and water temperature, among others. For example, services that depend on snowpack (e.g., downhill or cross-country skiing) or water-based recreation (e.g., boating, fishing) may be more sensitive to changes in hydrology.

5. Non-Climate Stressors. Other non-climate stressors have the potential to exacerbate the effects of climate change on ecosystem services and vice versa. Services that endure multiple non-climate stressors are likely more sensitive to climate changes. Non-climate stressors can include residential and commercial development, agriculture and/or aquaculture, energy production and mining, transportation and service corridors, human intrusions and disturbance, natural system modifications, biological resource use (e.g., hunting, fishing), altered interspecific interactions, invasive and other problematic species, or pollution and poisons, among others.

Ecosystem Services Adaptive Capacity

1. Intrinsic Value. Some ecosystem services may have higher intrinsic value than others (e.g., water supply or water quality). Because of this, people may be willing to change their behavior to continue to access the service, thus conferring greater adaptive capacity. However, economic and social drivers may also need to be considered as they can significantly affect adaptive capacity.

2. Management Potential. Ecosystem services may have less adaptive capacity if they occur in areas where management options are limited, where use conflicts exist, or where current ecosystem service value limits management flexibility. For example, if the service itself falls under specific management guidelines (e.g., narrow water quality requirements), or occurs in areas with specific management rules (e.g., headwater streams that provide water in high alpine wilderness areas), it likely has less adaptive capacity. Similarly, services that conflict with one another may have limited adaptive capacity whereas areas with multiple, mutually beneficial services may provide important opportunities for management.

Ecosystem Services Exposure

See description above under Model Elements – Ecosystems.

Confidence Evaluation

Each of the sensitivity, adaptive capacity, and exposure elements described above for focal resources were assigned a confidence rank: High, Moderate, or Low. These approximate confidence levels of high, moderate, and low were based on Manomet Center for Conservation Sciences (2012), which collapsed the IPCC Third Assessment Report 5-category scale into a 3-category scale to avoid implying a greater level of certainty precision. This vulnerability assessment model not only assesses the confidence associated with the individual element rankings, but also uses these rankings to estimate the overall level of confidence for each component of vulnerability by calculating mean confidence rankings across elements.

Vulnerability Assessment Application

Model Application

EcoAdapt, in collaboration with the USFS and CA LCC, convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada*, held March 5-7, 2013 at Modoc Hall on the California State University Sacramento campus in Sacramento, California. The main focus of the workshop was assessing the vulnerabilities of focal resources (ecosystems, species, and ecosystem services). Participants also were asked to identify spatial analysis and mapping needs that would support the vulnerability assessment and adaptation planning. Thirty experts participated in this workshop representing the breadth of stakeholders involved in the region. Participants are listed in Appendix I. Information from the workshop such as the agenda, presentations, handouts, readings, and other resources can be found on the workshop support page⁹.

This workshop was structured to provide participants with a foundation of information from which they could assess the vulnerabilities of the selected resources. Participants were introduced to general vulnerability assessment theory and approaches (following the process described in Glick et al. 2011), provided with past and projected climate trends in the Sierra Nevada¹⁰ – specifically temperature and precipitation, vegetation dynamics, wildfire, and hydrology – and organized into several different small working group arrangements to discuss and evaluate the vulnerability of focal resources. Background reference information was also provided in the form of focal resource summaries containing peer-review references on sensitivity and adaptive capacity components. The information on climate exposure for resources included in the summaries was primarily provided by TACCIMO¹¹.

Workshop participants were directed to apply the vulnerability assessment model described above to the 27 resources. As this was an expert elicitation process, participants were encouraged to make decisions based on their knowledge and expertise, and the workshop process and vulnerability assessment model were designed to be flexible to support collaborative on-the-fly modification and improvement.

Participant assessments and comments were compiled and assembled into two main products:

- 1. Resource Vulnerability Briefings.** Participant comments and peer-review references were synthesized into short vulnerability briefings for each resource, which were then reviewed by topic experts who did not attend the workshop.
- 2. Resource Vulnerability Technical Syntheses.** Participant rankings and comments, peer-review references including information from the background resource summaries, and expert reviews were compiled into vulnerability syntheses for each resource (~8-20

⁹ <http://ecoadapt.org/workshops/sierra-nevada-va-workshop>

¹⁰ Climate trends presentations for the region included temperature and precipitation, hydrology, dominant vegetation, and wildfire. Additionally, information on climate trends was provided in the climate synthesis report prepared by the Geos Institute (2013).

¹¹ <http://www.taccimo.sgcp.ncsu.edu/>

pages each). The purpose of creating these longer syntheses was to make transparent all of the information collected from the process for each resource.

These two collections of results are further summarized in the next section of this report and will be available as individual resource documents on the EcoAdapt (<http://ecoadapt.org>) and California Climate Commons websites (<http://climate.calcommons.org>).

Model Application – peer review process

Each resource vulnerability briefings was reviewed by at least one topic expert. Reviewing experts were identified and selected based on their publications in the peer-review literature. Comments and revisions from experts were incorporated into final briefings and vulnerability forms. The reviewing topic experts are listed in the Appendix.

4. Vulnerability Assessment Results

Climate change is the most pressing challenge of our time, yet resource managers struggle to incorporate climate change into management decisions. Vulnerability assessments provide a foundation for understanding how and to what degree resources are threatened by climate change, and can help resource managers and conservation planners set management and planning priorities as well as enable more efficient allocation of resources. Vulnerability assessments are also the first step in developing strategies and improving management practice to better prepare for and respond to projected changes. Specifically, vulnerability assessments can be used to inform the development and implementation of adaptation strategies designed to reduce the vulnerability of resources to actual or expected climate change effects. Incorporating vulnerability and adaptation actions into management decisions will facilitate our ability to meet long-term goals for focal resources.

The following section presents individual climate change vulnerability assessment results for all 27 Sierra Nevada focal resources¹². The results are intended to help managers develop and prioritize adaptation strategies to conserve these resources in the face of climate change. Information from this assessment has already been used to inform the development of regional climate change adaptation strategies for a smaller suite of focal resources including alpine/subalpine, yellow pine/mixed conifer, red fir, oak woodland, and wet meadow ecosystems and mountain yellow-legged frog and marten species populations. These adaptation strategies can be found in the companion document *Climate Change Adaptation Strategies for Focal Resources of the Sierra Nevada* (EcoAdapt 2013).

¹² Results are also available as individual documents on the EcoAdapt project web page (<http://ecoadapt.org>) and the California Climate Commons web site (<http://climate.calcommons.org>).



Focal Resource: **ALPINE/SUBALPINE SYSTEMS**

CWHR Types¹: SCN-Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*)

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 workshop². The following document represents the vulnerability assessment results for the **ALPINE/SUBALPINE 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 disruption³.

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/cw/hr/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 evaluation⁴. 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: Alpine/Subalpine 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.

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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	3 High	3 High
Direct Sensitivities – Precipitation	3 High	2 Moderate
Component Species	3 High	2 Moderate
Disturbance Regimes	3 High	2 Moderate
Climate-Driven Changes	3 High	2 Moderate
Non-Climatic Stressors – Current Impact	1 Low	2 Moderate
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	2 Moderate	No answer provided by participants
Other Sensitivities	3 High	2 Moderate

Overall Averaged Confidence (Sensitivity)⁶: Moderate

Overall Averaged Ranking (Sensitivity)⁷: High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	2 Moderate	3 High
Extent and Integrity – Fragmentation	2 Moderate (subalpine) 1 High (alpine)	3 High
Resistance and Recovery	1 Low	3 High
Landscape Permeability	1.5 Low-Moderate	1 Low
System Diversity – Physical/Topographical	1.5 Low-Moderate	2.5 Moderate-High
System Diversity – Component Species/Functional Groups	No answer provided by participants	No answer provided by participants
System Value	3 High	2.5 Moderate-High
Specificity of Management Rules	3 High	3 High
Other Adaptive Capacities	No answer provided by participants	No answer provided by participants

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

Overall Averaged Ranking (Adaptive Capacity)⁷: Low-Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	2 Moderate
Precipitation	2 Moderate
Dominant vegetation type	1.5 Low-Moderate

⁶ Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure, respectively.

⁷ Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.



Relevant Exposure Factor	Confidence
Climatic water deficit	1 Low
Wildfire	1 Low
Snowpack	2 Moderate
Runoff	1.5 Low-Moderate
Timing of flows	1.5 Low-Moderate
Other – precipitation type	1 Low

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	Moderate-High	3 High
Central Sierra Nevada	Moderate	3 High
Southern Sierra Nevada	Moderate	3 High

Overall Averaged Confidence (Exposure)⁶: High

Overall Averaged Ranking (Exposure)⁷: Moderate



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): High
 - i. Participant confidence: High
- b. Sensitivity to precipitation (means & extremes): High
 - i. Participant confidence: Moderate

Additional comments: The alpine/subalpine systems are sensitive to the type and timing of precipitation, more than the amount of precipitation. Currently, the subalpine zone is considered fairly protected. The confidence ratings of high and moderate are a result of participant discussion, as well as existing science and literature.

References:

Temperature: Over the past century, high elevation forests have seen pronounced increases in temperature. In the Central Sierra Nevada, daily minimum temperature has increased by 1.2°C since 1929-34 (Dolanc et al. 2013). From 1910-20, average minimum temperature was 3.8°C; in 1990-2000, average minimum temperature increased to 7.5°C in upper elevation forests of the central Sierra Nevada (Millar et al. 2004). A positive relationship exists between temperature in the Sierra Nevada and ring-width growth of treeline bristlecone pine (Salzer et al. 2009), branch growth of whitebark pine and lodgepole pine, and establishment of western white pine (Millar et al. 2004).

Precipitation: Some studies indicate that responses of high elevation forests may be largely dictated by water supply (Lloyd and Graumlich 1997; Fites-Kaufman et al. 2007), and evidence suggests that warming, plus higher precipitation in some cases, may have improved growing conditions for some tree species in the subalpine zone since the 1930s (Bouldin 1999; Dolanc et al. 2013). Precipitation averages from 750-1250 mm (30-50 in) per year, most of which falls as snow (Fites-Kaufman et al. 2007). In the Central Sierra Nevada, precipitation has increased by 15-48% since 1929-34, resulting in less stressful conditions (Dolanc et al. 2013). From 1910-20, precipitation averaged 417 mm (16.4 in); in 1990-2000, average precipitation increased to 632 mm (24.9 in) in upper elevation forests of the central Sierra Nevada (Millar et al. 2004).

Although steady or increased precipitation and warming temperatures have led to less stressful conditions for recruitment and survival of small trees, these changes may also contribute to increased mortality of large subalpine trees (Dolanc et al. 2013). For example, whitebark pine experienced significant mortality from 2007-2010 in Sierra Nevada subalpine sites (mean elevation 2993 m)(9820 ft) that were warmer and drier relative to species distribution (Millar et al. 2004).

In addition, rising temperatures between 1987-2007 indicates 73% of 'Köppen' alpine tundra classification in the western United States now exceeds the 10°C (50°F) temperature threshold for this habitat classification during in the warmest month (Diaz and Eischeid 2007). Our understanding of limiting factors such as temperature means and extremes, and moisture availability in species establishment and survival in alpine habitats remains poor (Graham et al. 2012).

Topographic features (such as slope or aspect) can affect evaporative demands of the forest, influencing forest types found at the same elevation (Fites-Kaufman et al. 2007).

2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: High
 - i. Participant confidence: Moderate



Additional comments: Overall, subalpine and alpine species are highly sensitive to changes in temperature and precipitation, although many species have been tolerant of climate fluctuations during the late Holocene. For example, limber pine is more tolerant of drier and steeper landscapes, and both whitebark pine and limber pine likely exhibit lower sensitivity to drought stress in less dense and short-statured (e.g., krummholtz) stands. A critical research question in the higher elevation southern Sierra Nevada is whether edaphic (i.e., soil) or other limitations (e.g., dispersal potential) will preclude effective migration of subalpine tree species upslope.

References identified by participants: Eric Beever (USGS, pika research); Grinnell resurvey project (UC Berkeley).

References: For the foxtail pine, lodgepole pine, and western white pine, maximum growth occurs with high winter precipitation and warm summers but there is substantial species to species variation (Fites-Kaufman et al. 2007).

From the early 1930s to the 1990s, young mountain hemlock increased their density and basal area but large western white pine populations decreased; whitebark pine density increased and had more young trees. Similarly, lodgepole pine appears to be responding favorably to warming trends and increased precipitation. Lodgepole pine, western white pine, and mountain hemlock all show decreased mortality (Bouldin 1999).

The comparative stasis of foxtail pine (*Pinus balfouriana*) in Sequoia National Park during the last 100-200 years indicates that there are steep gradients of vulnerability to climate change at treeline in the Sierra Nevada (Lloyd and Graumlich 1997).

Foxtail Pine: A study by Lloyd and Graumlich (1997) found that historic records of foxtail pines (*Pinus balfouriana*) in Sequoia National Park exhibited a lack of population sensitivity to paleoclimate summer temperatures and winter precipitation in treeline forests during the last 1000 years. Foxtail pine recruitment displayed less variability than mortality, and while rates of recruitment and changes in treeline stand density were inversely correlated with summer temperature, mortality rates were uncorrelated with precipitation and temperature. The inverse correlation of temperature and recruitment may indicate an important role for water balance in regulating population growth (Lloyd and Graumlich 1997).

Life history characteristics which reduce moisture and nutrient requirement (Bunn et al. 2005) and moderate densities of adult trees, which are able to moderate their microclimate, may provide resistance to climate change, while trees in marginal locations do not experience the full protective influence of this buffering (Lloyd and Graumlich 1997). Foxtail pines in drier regions of the cold and dry eastern crest of Sequoia National Park may lose the ability to grow in warm temperatures if insufficient water leads to drought stress (Bunn et al. 2005).

The downslope expansion of foxtail pine is correlated with the distribution of shade-tolerant conifers, which are in turn correlated with habitat heterogeneity (i.e., boulder cover and ultramafic substrates). This implies that although climate change may be the driving force behind expansions, within the Klamath Mountains, downslope expansion can be facilitated by habitat heterogeneity (Eckert and Eckert 2007).

Western White Pine: Millar et al. 2004 found that in the Sierra Nevada, response of colonization rate of western white pine (*Pinus monticola*) into formerly persistent snowfields below treeline to warming and climate variability throughout the 20th century were directional and ongoing, from minimal to significant establishment.



Mountain Hemlock: The temperature driven change in the mountain hemlock (*Tsuga mertensiana*) forest in the last 150 years suggests that predicted warming (Houghton et al. 1992 cited in Taylor 1995) will have a significant effect on these forests in Lassen Volcanic Park and elsewhere in the Pacific Northwest. During that period, near treeline mountain hemlock forests have increased in density, warming triggered population expansion, and initial recruitment peaked during a warm mesic period. Recruitment response is spatially variable, however, because high precipitation (i.e., high snowpack) retards recruitment on mesic flats with late lying snow and promotes it on xeric sites (Taylor 1995).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, disease, wind, insects, other – ecosystem species shifted
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: Moderate

Additional comments: The alpine/subalpine system is relatively moderate in its sensitivity to these (above mentioned) disturbance regimes. However, high sensitivity to disturbance regimes applies especially to high-elevation white pines (whitebark pine, limber pine, foxtail pine, bristlecone pine, western white pine), and the subalpine system will become highly sensitive if fire increases. Wildfire is expected to have the greatest impact in denser stands and at lower elevations adjacent to relatively productive upper montane forests, where fuel loading is higher and spatially contiguous. Subalpine forests are most sensitive to disease (e.g., white pine blister rust) and insect outbreaks (especially mountain pine beetle), especially in denser and more productive stands dominated by whitebark pine or other high-elevation white pines. Range of the parasite dwarf mistletoe is thought to be currently limited by climate, but climate change may extend its range to higher elevations and further north as temperatures warm and the growing season lengthens.

References identified by participants: NCAR Artic/Alpine Research Lab; Betty Willard; Michelle Slaton, Inyo NF; U.C. Research Lab in White Mountains; Ecologists: Hugh Stafford (USFS), Sarah Sawyer (USFS); Insects: (Sheri Smith) Forest Self Protection Team.

References:

Wildfire: Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011; Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites-Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 2013). Historical fires were often not severe enough to be stand-replacing (Caprio and Narog 2008).

Fire frequency increases with earlier snowmelt and warmer temperatures (Fites-Kaufman et al. 2007). Since the late Holocene, forest fires at high elevations seem to be driven by the intensification of ENSO; warmer temperatures may cause a greater number of extreme convective storms, including enhanced occurrence of lightning strikes (Hallett and Anderson 2010).

Disease: Native fungal diseases include annosus root disease, armillaria root disease and black-stain root disease. Annosus root disease may be spreading more easily to the more dense forests that have been created by fire suppression (Slaughter and Rizzo 1999, Rizzo and Slaughter 2001 cited in Fites-Kaufman et al. 2007). White pine blister rust was introduced from Asia; it attacks five-needled pine species but the sugar pine is particularly susceptible (van Mantgem et al. 2004 cited in Fites-Kaufman et al. 2007).



Insects: The most significant ongoing mortality episode in subalpine forests of western North America is occurring in whitebark pine (Millar et al. 2012) with mortality trends increasing since 1998 (Gibson et al. 2008 cited in Millar et al. 2012). Despite low levels of mountain pine beetle mortality reported from 1998-2005 (Gibson et al. 2008 cited in Millar et al. 2012), a major mortality event in eastern California occurred from 2007-2010 (Millar et al. 2012). Events occurred in monotypic, closed-canopy, relatively young stands located on the eastern edge of escarpments on north/northeast aspects with slopes >40% at elevations between 2740-2840 m (8990-9318 ft). Infestation of bark beetles is enhanced by increasing minimum temperatures combined with drought (Millar et al. 2012).

Wind: Winds can be high in the alpine and sub-alpine and can limit plant growth by battering plants or through enhanced evapotranspiration. Trees in the subalpine and alpine region can develop twisted or bent forms due to the high winds (Fites-Kaufman et al. 2007).

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

- a. Sensitivity to climate and climate-driven changes including: Altered hydrology, evapotranspiration and soil moisture, extreme temperature
- b. Sensitivity to these climate and climate-driven changes: High
 - i. Participant confidence: Moderate

Additional comments: Air pollution impacts are negligible over near to mid-term future, but this stressor is worth monitoring in the long-term. Other climate-related disturbances that may impact subalpine forests include avalanche, extreme wind events, and altered hydrologic patterns. For example, earlier runoff and snowmelt will lead to increased climatic water deficit for subalpine trees, resulting in increased climate exposure of subalpine forests.

References identified by participants: Information from NPS Southern Sierra Adaptation Workshop 2013⁸.

References:

Altered fire regimes: At elevations above 2500 m (8202 ft), the fire-return interval before the mid-1800s could be 200 years or greater (Skinner and Chang 1996, Caprio and Lineback 2002, and van Wagtenonk and Fites-Kaufman 2006 cited in Fites-Kaufman et al. 2007). Because fire has historically been relatively rare at higher elevations, the fire management and suppression strategy implemented in the early 1900s did not impact high altitude forests as much as it did its lower elevation counterparts (Fites-Kaufman et al. 2007; Miller et al. 2009).

Altered hydrology: Over the past 50 years, spring snowpack in the Sierra Nevada has decreased by 70-120% although there is a high degree of spatial heterogeneity; snowpack in the southern portion of the Sierra Nevada has increased. The reduction in snowpack will likely be greater at lower elevations in northern Sierra than in the higher elevations in the southern Sierra (Safford et al. 2012). Avalanches on steep, north-facing slopes can disturb vegetation (Fites-Kaufman et al. 2007).

Further, warmer temperatures are causing the spring thaw to occur earlier in the year; in 2002 it occurred 5-30 days earlier than in 1948. Peak streamflow occurred 5-15 days earlier in 2002 relative to 1948; March flows were higher by 5-20% but June flows were mostly lower (Safford et al. 2012).

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

⁸ NPS Southern Sierra Adaptation Workshop Information: <http://climate.calcommons.org/aux/sscaw/index.htm>



- a. Sensitivity to other non-climate stressors including: Commercial development, human intrusions and disturbance, other – outdoor recreation.
- b. Current effects of these identified stressors on system: Low
 - i. Participant confidence: Moderate
- c. Degree stressors increase sensitivity to climate change: Moderate
 - i. Participant confidence: No answer provided by breakout group

Additional comments: The potential exists for increased incidence of invasive species, especially cheatgrass, at higher elevations.

There is little commercial or residential development at these high elevations. Primary commercial development in high-elevation areas is related to ski area development, but the overall footprint of these developments is limited in extent. The stressors from development and outdoor recreation are currently considered low due to limited accessibility at high elevation. The participants' confidence is moderate for these stressors.

References identified by participants: Trent Proctor - Region 5 Air Pollution Specialist; possibly Forest Health Protection Group; California Air Resource Board - Mary Nichols; Nate Stephenson - (USGS) Sequoia and Kings Canyon Field Station.

References:

Pollution and poisons: Ozone and nitrogen levels are relatively low at high elevations and do not appear to harm the ecosystem (Fenn et al. 2003).

Insects: Mountain pine beetle and whitebark pine beetle infestations have resulted in major mortality events for subalpine species, such as whitebark pine and limber pine in recent decades in western North America (Logan and Powell 2001, Logan et al. 2010 cited in Millar et al. 2012). In whitebark pine forests, significant ongoing mortality is also caused by white pine blister rust (*Cronartium ribicola* A. Dietr.) (Tomback and Achuff 2010 cited in Millar et al. 2012). Rising minimum temperatures, combined with drought, contribute to bark beetle infestations in the Sierra Nevada (Millar et al. 2007 cited in Millar et al. 2012), and can aggravate climate-driven mortality.

6. Other sensitivities.

- a. Other critical sensitivities not addressed: Soils
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase system sensitivity to climate change: High

Additional comments: The alpine zone is sensitive due to its isolation. Connectivity among isolated mountain peaks is required to allow migration as ecosystem components attempt to move to more hospitable habitats in response to climate shifts. The sensitivity of the alpine system is in part related to the soil belt, limited soil productivity, and the time required for cryogenic soil evolution.

7. Overall user ranking.

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

Additional comments: The alpine/subalpine system is highly susceptible to climate change because it occurs within a small band, and has limited opportunity for system expansion.



Adaptive Capacity

1. System extent and integrity.

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

Additional comments: Total acreage of alpine/subalpine ecosystems is small and getting smaller. The subalpine runs continuously south of Tahoe, but is somewhat more disconnected north of Tahoe. The alpine system appears much more fragmented than subalpine. Portions of the southern Sierra Nevada have consistent but limited alpine zones, and a fairly continuous subalpine zone. North of Tahoe the alpine zone is relatively sporadic and fragmented.

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Low
 - i. Participant confidence: High
- b. Suitable microclimates within the system that could support refugial communities: Because the alpine and subalpine systems may require up to 300 years to recover, the participants' assessed the recovery rating as low. In the alpine/subalpine system there is very little connectivity and soil mass. Topography would also impact the system's ability to resist or recover from impacts. Some of the narrow, deep canyons, and riparian areas will be more resilient. The north / northeast facing slopes are considered more biologically diverse and provide a dense microclimate for diversity and will remain cooler and retain more snowpack as climate changes. However, precipitation and snowpack vary depending on rain shadow, slope orientation, tree cover, and elevation.

3. Landscape permeability.

- a. Degree of landscape permeability: Low-moderate
 - i. Participant confidence: Low
- b. Potential types of barriers to dispersal that apply: Geologic features

Additional comments: The alpine system has low landscape permeability, while the subalpine system has moderate landscape permeability. However, narrow and deep canyons may provide cool, wet refugia. The alpine zone has very few existing developments and little development potential, while the subalpine is more vulnerable to development impact. The alpine system is very fragile once disturbed, due in part to the shallow soil layer and slow growing plants. The isolated nature of mountaintops, particularly in the north, represent barriers to alpine species dispersal. Species that have elevational migrations (like bighorn sheep) may experience dispersal barriers from development in lower elevation ecosystems.

References: Many species in the subalpine and alpine area have limited room to vertically migrate because they are already located at the higher elevations of the Sierra Nevada. The area available to occupy decreases with elevation. Because of this, models have predicted a 70-95% loss in alpine/subalpine forest relative to 1961-1990 stands (Hayhoe et al. 2004).

4. System diversity.

- a. Level of physical and topographic diversity: Low



- i. Participant confidence: Moderate-High
- b. Level of component species/functional group diversity: No answer provided by breakout group
 - i. Participant confidence: No answer provided by breakout group
- c. Description of diversity: No answer provided by breakout group

Additional comments: Physical and topographic diversity is low for alpine zones, and moderate for subalpine zones. There is diversity in topographic features running south of Tahoe, somewhat consistent with granite along the crest, and eastern slopes are more granitic. Participants believe that differences exist in faunal diversity between the Sierra Nevada and the southern Cascades, as well as between the east and west slopes of the Sierra Nevada. However, there is consistency in species in the alpine zones in both the southern and northern parts of the state.

References:

Community structure: In general, many species in the alpine and subalpine are experiencing enhanced growth. Since 1929-34, 6 of 8 tree species increased small tree densities at both the upper and lower boundaries of subalpine; tree composition was the same (Dolanc et al. 2013). Trees are colonizing historically subalpine meadows (Millar et al. 2004). Trees are also increasingly occupying formerly persistent snowfields since the 1900s with pulses correlated to Pacific Decadal Oscillation (PDO) and minimum temperature (Millar et al. 2004). High elevation ecosystems experience harsh conditions and suitable growing conditions only exist for an average of 6-9 weeks a year (Fites-Kaufman et al. 2007). Most plants are very slow growing but long lived; plants in this zone can remain reproductively active for decades to centuries. There is a strong decline in the forest turnover with increasing elevation (Fites-Kaufman et al. 2007).

The limber pine appears to be more drought-hardy and may have higher genetic diversity, allowing for adaptation to drought conditions relative to the whitebark pine. The whitebark pine does not appear to have the adaptive genetic diversity for drought and warmth (Millar et al. 2010). Despite cooling since the 1940s, mountain hemlock populations have continued to expand, suggesting that tree patches provide microclimatic amelioration and cause recruitment despite unfavorable climatic conditions (Taylor 1995).

5. Management potential.

- a. Value level people ascribe to this system: High
 - i. Participant confidence: Moderate-high
- b. Specificity of rules governing management of the system: High
 - i. Participant confidence: High
- c. Description of use conflicts: Both alpine and subalpine zones are largely covered by protected area designations such as wilderness, national park, or national forest roadless areas. However, options for active management are very limited due to the various environmental rules and geologic constraints. A potential management option includes reducing non-climate stressors, particularly those originating outside of the protected areas. Other options include taking action to address invasive species and address wildfire management. Limiting and channeling visitor use impacts within protected areas is also an option.
- d. Potential for managing or alleviating climate impacts: See above

Additional comments: There may be a need to increase artificial snowpack in light of future projected climate temperatures in the Sierra. Other adaptive capacity options may include developing connectivity routes for species migration.



References identified by participants: Aplet and Gallo 2012.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: Artificial snowpack (see above)
 - i. Participant confidence: No answer provided by breakout group
 - b. Collective degree these factors affect the adaptive capacity of the system: No answer provided by breakout group
-

7. Overall user ranking.

- a. Overall adaptive capacity of the system: Low
 - i. Participant confidence: Moderate

Additional comments: For alpine zone the capacity is low. For subalpine zone, the capacity is low to moderate.



Exposure

1. Exposure factors⁹.

- a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, dominant vegetation type, climatic water deficit, wildfire, snowpack, runoff, timing of flows, other – type of precipitation
 - i. Participant confidence: Moderate (temperature), moderate (precipitation), low-moderate (dominant vegetation type), low (climatic water deficit), low (wildfire), moderate (snowpack), low-moderate (runoff), low-moderate (timing of flows), low (other – type of precipitation)

2. Exposure region.

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

3. Overall perceived user ranking.

- a. Overall exposure of the species to climate changes: High
 - i. Participant confidence: High

References:

Vegetation changes: Models of climate change in the Sierra Nevada predict uphill migration (Van de Ven et al. 2007) and restricted distribution of alpine/subalpine plant communities (Lenihan et al. 2006; Van de Ven et al. 2007,). In the three scenarios modeled by Lenihan et al. (2006) to the end of the century, alpine/subalpine forest experienced significant declines in extent, particularly under the warmest conditions. Similarly, Lenihan et al. (2003) and Hayhoe et al. (2004) project declines in alpine and subalpine habitat extent by 75-90% by the end of the century. Scenarios with longer and warmer growing seasons resulted in replacement of alpine/subalpine forest at high elevations with other vegetation types. For example, some models predict advancement of shrubland into alpine/subalpine habitats (Lenihan et al. 2003). Van de Ven et al. (2007) modeled predicted distributions of 14 alpine and subalpine species in the (arid) White and Inyo Mountains to an increased temperature of 6°C, in 1°C increments. All species are predicted to shift upslope and decrease their ranges due to this shift. Some shifted from south to north facing slopes, and previously continuous habitat became fragmented. At an increase of 3°C, 2 species became extinct, and the new ranges of the remaining species areas were 68% or less of current areas. At an increase of 6°C, 10 out of 14 species disappeared from the study area, and the remaining 4 shrank to 1% of their current ranges.

Millar et al. (2006) found that Medieval climatic conditions were similar to those projected for 2070-2099 in Whitewing Mountain and San Joaquin, Mono County, but produced a significant increase in subalpine forest extent and diversity, in contrast to the estimated 75-90% reduction of subalpine forest projected based on vegetation-climate projections.

Although warming at high elevations is commonly assumed to exert primary effect by causing altitudinal shifts in treeline, complex changes in spatial distribution, productivity, and type conversions below treeline may be more important, at least in the early decades of the 21st century (Millar et al. 2004). A warming-induced rise in treeline elevation is likely to involve landscape-scale increases in biomass, productivity, and carbon pools as a result of increases in forested area and density (Lloyd & Graumlich

⁹ 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.



1997). However, the paleoecological record indicates that future warming is unlikely to cause an expansion of subalpine forests if it is accompanied by a reduction in water supply (Lloyd & Graumlich 1997).

Moreover, data on alpine microclimate traits suggest that models predicting upslope movements of species under increasing temperatures may not be entirely realistic, and that sufficient microclimate heterogeneity may slow such migration. Graham et al. (2012) built upon work by Scherrer and Körner (2011) which revealed large and persistent microhabitat temperature variations over mesoscale alpine landscape, mimicking temperature gradients of several hundred meters of elevation, suggesting that alpine plants may find appropriate thermal niches for establishment and survival without elevational shifts. Graham et al. (2012) found that alpine fellfield topographic variability in the White Mountains creates thermal microhabitat conditions at a scale of centimeters, due to the presence of low-lying plants, which transpire and shade the soil surface. Fellfield habitats may offer significant buffering from climate warming because the temperature differences are greater than the range of warming scenarios over the next century in projects by the Intergovernmental Panel on Climate Change (IPCC). However, understanding of the relative significance of limiting factors such as temperature means and extremes, and moisture availability in species establishment and survival in alpine habitats remains poor (Graham et al. 2012).

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004; Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GFDL¹⁰ and PCM¹¹) 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).

¹⁰ 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.

¹¹ 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.



Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation that falls as snow at the high elevations that characterize this part of the range (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 pattern 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 mean annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

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



Wildfire: 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).

Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011, Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites-Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 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). The area burned by fire and the fire severity is expected to increase with a changing climate in the alpine and sub-alpine. Models indicate that there may be a 125% increase in small wildfires that cannot be readily suppressed and turn into large wildfires. This could cause a potential increase in the area burned at high elevation by 41% (Fites-Kaufman et al. 2007).

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/602b58f9bbd44dfffb487a04a1c5c0f52>).

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Focal Resource: **AQUATIC SYSTEMS**

CWHR Types¹: N/A

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 workshop². The following document represents the vulnerability assessment results for the **AQUATIC 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 disruption³.

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

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

¹ From California Wildlife Habitat Relationship (CWHR) habitat classification scheme

http://www.dfg.ca.gov/biogeodata/cw/hr/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.



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 evaluation⁴. 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

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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	3 High	2 Moderate
Direct Sensitivities – Precipitation	3 High	2 Moderate
Component Species	3 High	2 Moderate
Disturbance Regimes	3 High	2 Moderate
Climate-Driven Changes	3 High	2 Moderate
Non-Climatic Stressors – Current Impact	3 High	2 Moderate
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	2 Moderate
Other Sensitivities	No answer provided by participants	No answer provided by participants

Overall Averaged Confidence (Sensitivity)⁶: Moderate

Overall Averaged Ranking (Sensitivity)⁷: High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	3 High	3 High
Extent and Integrity – Fragmentation	3 High	1 Low
Resistance and Recovery	No answer provided by participants	3 High
Landscape Permeability	1 Low	2 Moderate
System Diversity – Physical/Topographical	3 High	3 High
System Diversity – Component Species/Functional Groups	3 High	1 Low
System Value	3 High	2 Moderate
Specificity of Management Rules	3 High	2 Moderate
Other Adaptive Capacities	No answer provided by participants	No answer provided by participants

Overall Averaged Confidence (Adaptive Capacity)⁶: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁷: High

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	1 Low
Precipitation	1 Low

⁶ Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure, respectively.

⁷ Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.



Relevant Exposure Factor	Confidence
Dominant vegetation type	1 Low
Snowpack	1 Low
Runoff	1 Low
Timing of flows	1 Low
Low flows	1 Low
High flows	1 Low
Stream temperature	1 Low
Other – water quality	1 Low

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	No answer provided by participants	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: Not applicable

Overall Averaged Ranking (Exposure)⁷: Not applicable



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): High
 - i. Participant confidence: Moderate
- b. Sensitivity to precipitation (means & extremes): High
 - i. Participant confidence: Moderate

Additional comments: More specific analysis on the sensitivity of aquatic systems could be determined by incorporating elevation and climatic zones information.

References:

Temperature: Stream temperatures have increased in recent decades as air temperatures have increased (Hari et al. 2006, Webb and Nobilis 2007, Kaushal et al. 2010 cited in Null et al. 2012).

Stream temperatures are strongly correlated with climate (Morrill et al. 2005). Relationship between air and stream temperature is not linear, particularly as stream temperature exceeds 20°C, when evaporative cooling slows heating (Null et al. 2012). Stream temperatures directly influence the biological, physical, and chemical properties of lotic ecosystems, including metabolic rates and life histories, dissolved oxygen levels, nutrient cycling, productivity, and rates of chemical reactions (Vannote and Sweeney 1980; Poole and Berman 2001). Stream warming may alter stream habitat conditions, change the distribution and abundance of native species, drive local extinctions, reduce community biodiversity, and ease the introduction of invasive species (Eaton and Scheller 1996, Rahel and Olden 2008 cited in Null et al. 2012). In addition, warming temperatures influence the partitioning of precipitation between rain, snow, runoff and infiltration, and these changes in the nature, frequency, and abundance of precipitation also impact water temperature (Null et al. 2012).

Precipitation: Mean precipitation at watershed outlets of 15 streams (5-7 Strahler stream order) in the Sierra Nevada averaged 1080 mm/yr (42.5 in/yr) and ranged between 560-1675 mm/yr (22-66 in/yr) (Null et al. 2012). The frequency, abundance and nature of precipitation events impact water temperature (Null et al. 2012), level, and velocity (Meyers et al. 2010). Flow changes may result in altered channel topography and substrate (Yarnell et al. 2010), ephemeral streams, and altered dynamics of salmon redd scour and dewatering (Meyers et al. 2010).

Changes in precipitation can also impact primary productivity in lakes (Coats 2010; Sadro and Melack 2012).

2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: High
 - i. Participant confidence: Moderate

Additional comments: Coldwater species won't be able to adapt to temperature changes because they are physically restricted to their river and cannot move to a new one.

The number of endemic fishes in the Sierra Nevada is high for both warm and cold water species. Many of these fish and amphibians have reduced ranges and are sensitive to large-scale disturbances and warming temperatures.

References: Aquatic species in California are likely to be impacted by changes associated with climate change, including changes in water temperature, quality, and the frequency, intensity and timing of stream flow (Coats 2010; Null et al. 2010; Yarnell et al. 2010; Kiernan and Moyle 2012). Most native fish species requiring cold water (<22°C) and all native anadromous fish were rated highly or critically



vulnerable to climate change (Moyle et al. 2012). Fishes in the families *Cyprinodontidae*, *Embiotocidae*, *Osmeridae*, *Petromyzontidae*, *Salmonidae*, for example, were almost all rated highly or critically vulnerable to climate change (Moyle et al. 2012). However, uncertainty remains regarding temperature thresholds for coldwater guild species, and thresholds are variable by life stage, previous acclimation, duration of thermal maxima and minima, food abundance, competition, predation, body size and condition (McCullough 1999). All California salmonid populations are adversely impacted by the shrinking availability of coldwater habitats (Katz et al. 2012). Because they are at the southern boundary of their range, small thermal increases in summer water temperatures can result in suboptimal and lethal conditions with consequent reductions in distribution and abundance of California's endemic salmon, trout and steelhead (Katz et al. 2012). The maximum thermal tolerance for Chinook salmon (*O. tshawytscha*) and steelhead trout is reported as 24°C (Eaton and Scheller 1996), although both can tolerate warmer temperatures for shorter periods (Myrick and Cech 2001). Water temperatures above 20°C can have adverse spawning and rearing effects in Chinook salmon (Yates et al. 2008). The egg and alevin life stages require <24°C temperatures for optimal growth and survival. Bull trout (*Salvelinus confluentus*) in North America have an optimal temperature range lower than other salmonids, and are threatened by climate change directly through thermally stressful temperatures and indirectly by increased competitive ability of other trout species (Rahel et al. 2008).

Freshwater fish species native to California tend to be more affected by climate change than alien fish species (Moyle et al. 2012). Longer warm, low-flow seasons may expand abundance of nonnative fauna (Yarnell et al. 2010). Amphibians that breed in ephemeral and often isolated bodies of water (e.g., vernal pools and intermittent headwater streams) are especially vulnerable to changes in temperature and precipitation (Blaustein et al. 2010). Downstream species, such as the delta smelt (*Hypomesus transpacificus*), may also be particularly vulnerable to temperature changes. Rising temperatures are likely to reduce spawning season, or eliminate spawning entirely (Hanak and Lund 2011).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, flooding, disease
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: Moderate

Additional comments: Post-fire impacts represent a considerable disturbance.

References:

Flooding and drought: The frequency, abundance and nature of precipitation events impact water temperature (Null et al. 2012), level, and velocity (Meyers et al. 2010). Flow changes may result in altered channel topography and substrate (Yarnell et al. 2010), ephemeral streams, and altered dynamics of salmon redd scour and dewatering (Meyers et al. 2010).

Disease: Stream warming is projected to magnify the distribution and virulence of disease organisms and parasites, increasing the impact on native salmonids (Rahel et al. 2008).

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

- a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, evapotranspiration and soil moisture, altered hydrology, extreme temperature or precipitation events, water temperature, storms, air pollution/ozone, other – disease, water pollution
- b. Sensitivity to these climate and climate-driven changes: High
 - i. Participant confidence: Moderate



Additional comments: Each non-climate factor listed above contributes to changes in water temperature, sediment load, inorganic / organic nutrient load, oxygen deficiencies, resulting in lower habitat availability and lower overall biodiversity in aquatic systems. These factors also lead to reduced primary productivity in lakes. In addition, wildfire can impact pH of the system.

References:

Altered hydrology: Predicted quick pulses of higher winter rainfall in contrast to slower snowmelt will change how sediments are sorted and deposited, resulting in more homogenous channel substrates; channel bars may become more steeply sloped, creating less habitat availability and less overall biodiversity (Yarnell et al. 2010). Reduced streamflow may shift some streams into intermittent flow (Perry et al. 2012), which could affect coldwater species (including amphibians and macro-invertebrates) (Blaustein et al. 2010; Null et al. 2012). Increased terrestrial inputs to Sierran lakes, precipitated by increased frequency of rain events, may result in reduced primary production, increased periods of hypoxia and anoxia, and shift toward net heterotrophy during ice-free seasons (Coats 2010; Sadro and Melack 2012).

Water temperature: According to modeling by Null et al. (2012), average annual stream temperatures warmed approximately 1.6°C for each 2°C rise in average annual air temperature. The greatest rise in stream temperatures in response to air temperatures was projected at mid elevation (1500-2500 m) (4921-8202 ft), where climate warming shifted precipitation from snowmelt to rainfall. The largest thermal change occurred during spring in the models, when stream warming could exceed 5°C for each 2°C rise in air temperature (Null et al. 2012). Stream temperatures are also affected by riparian vegetation species, height, density and location, as well as stream orientation (LeBlanc and Brown 2000) and topographic shading (Null et al. 2012). However, above 2750 m (9022 ft) elevation, shading may be negligible due to short growing season and poor soils (Null et al. 2012).

In turn, stream temperatures directly influence the biological, physical, and chemical properties of lotic ecosystems, including metabolic rates and life histories, dissolved oxygen levels, nutrient cycling, productivity, and rates of chemical reactions (Vannote and Sweeney 1980; Poole and Berman 2001). Predicted reduction in the magnitude of snowmelt rate is forecast to cause longer, warmer low-flow seasons, with shorter duration of cold water in the system (Yarnell et al. 2010). Stream warming may alter stream habitat conditions, reduce community biodiversity, change the distribution and abundance of organisms, drive local extinctions, and ease the introduction of invasive species (Null et al. 2012). Warmer stream temperatures may inhibit distribution and survival of coldwater species, including abundance of aquatic insects (Perry et al. 2012) and amphibian species that breed in vernal pools and intermittent headwater streams (Blaustein et al. 2010). Modeling results indicate that habitat for coldwater species declined with climate warming (Null et al. 2012). In lakes, increased temperature decreases the solubility of gases, and processes such as denitrification and nitrogen fixation are accelerated. Such changes can lead to water quality problems in Lake Tahoe and other lakes (Coats 2010).

Wildfire: Changes in wildfire regimes may also impact temperature, sediment load and pH of aquatic systems. Wildfires alter riparian vegetation and stream shade (Dwire and Kauffman 2003, Pettit and Naiman 2007 cited in Isaak et al. 2010), and combined with altered forest and riparian communities, may change inputs of sediment and large wood (Miller et al. 2003, Barnett et al. 2008 cited in Rieman and Isaak 2010).

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

- a. Sensitivity to other non-climate stressors including: Residential and commercial development, agriculture and aquaculture (e.g., logging and grazing), energy production and



mining (e.g., hydropower dams and water diversions), transportation and service corridors, biological resource use (e.g., fish stocking), human intrusions and disturbance, natural system modifications (e.g., hydropower dams and water diversions), invasive and other problematic species, pollution and poisons

- b. Current effects of these identified stressors on system: High
 - i. Participant confidence: Moderate
- c. Degree stressors increase sensitivity to climate change: High
 - i. Participant confidence: Moderate

Additional comments: Aquatic systems are highly sensitive to the impacts of various resource uses (e.g., fish stocking, logging, and grazing), natural system modification (hydropower facilities and dams), and residential and commercial development. Aquatic systems are also highly sensitive to transportation and service corridors, human intrusions and disturbance, pollution and poisons, and agriculture. Aquatic systems have low sensitivity to invasive species, aquaculture, energy production, and mining (due to a moratorium on mining).

References identified by participants: State of Sierra Waters: A Sierra Nevada Watersheds Index⁸.

References: Non-climate stressors include biological resource use, such as fish stocking (Null et al. 2012); natural system modification, such as water diversion and hydropower production (Yoshiyama et al. 1998; Null et al. 2012); and residential and commercial development (Null et al. 2012). Rivers above 2000 m (6562 ft) on the western slope of the Sierra Nevada were mostly fishless prior to stocking with native rainbow trout (*Onchorhynchus mykiss*) and golden trout (*O. mykiss aguabonita*), as well as non-native brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) (Null et al. 2012). Water regulation and land use changes have altered the thermal regime of Sierra Nevada rivers, degrading habitat and creating a dispersal barrier to cold water assemblages (Null et al. 2012; Perry et al. 2012). After construction of large dams, salmon runs, once among the most productive on the Pacific coast, have largely been extirpated from Sierra Nevada rivers (Yoshiyama et al. 1998).

Grazing and timber harvest intensifies mercury contamination moving from mining areas into rivers and streams in northern Sierra Nevada catchments (Alpers et al. 2005 cited by Viers and Rheinheimer 2011). Timber harvest and grazing also results in erosion, which degrades or eliminates fish spawning habitat (Moyle 2002 cited in Viers and Rheinheimer 2011).

6. 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 system sensitivity to climate change: no answer provided by participants

7. Overall user ranking.

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

References: Scenarios run by Moyle et al. (2012) identify most native species requiring cold water (<22°C) as highly or critically vulnerable to climate change.

⁸ http://www.sierranevadaalliance.org/publications/db/pics/1143036971_22153.f_pdf.pdf



Adaptive Capacity

1. System extent and integrity.

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

Additional comments: The many dams in the Sierra Nevada region contribute to the fragmentation of aquatic systems.

References:

Geographic extent: Outlets of major watersheds in the Sierra Nevada range in elevation from 39-4418 m (128-14495 ft) (Null et al. 2010). Water regulation and land use changes have altered the thermal regime of Sierra Nevada rivers, degrading habitat and creating a dispersal barrier to cold water assemblages (Null et al. 2012; Perry et al. 2012).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: no answer provided by participants
 - i. Participant confidence: High
- b. Suitable microclimates within the system that could support refugial communities: Yes, deep pools and dense riparian zones.

Additional comments: Aquatic systems have been able to recover from past climatic fluctuations however, recovery is not guaranteed in the future.

References: It is likely that southern salmonid gene pools reflect a history of resilience as well as adaptations to watersheds characterized by aridity and extreme seasonal variation (Nielsen et al. 1999). Modeling results suggest the American and Mokelumne Rivers are most vulnerable to the three metrics run by Null et al. (2010), and that the Kern River is the most resilient, in part due to the high elevations of the watershed.

3. Landscape permeability.

- a. Degree of landscape permeability: Low
 - i. Participant confidence: Moderate
- b. Potential types of barriers to dispersal that apply: agriculture, industrial or urban development, suburban or residential development, geologic features, culverts, dams

Additional comments: Participants are confident concerning the low permeability among aquatic systems, but are less confident on how to gauge the impact of the barriers to dispersal to the aquatic system.

References: Reduced streamflow may shift some streams into intermittent flow (Perry et al. 2012). Increasing temperatures may result in a thermal block for coldwater species migration, such as Chinook salmon (Null et al. 2012). Dams operating without consideration of thermal management, and without adequate passage to coldwater habitat, impact coldwater fish populations (Null et al. 2012). As stream flows become more variable and water temperature and quality change, fish extinction rates are likely to increase (Moyle et al. 2011).

4. System diversity.

- a. Level of physical and topographic diversity: High



- i. Participant confidence: High
- b. Level of component species/functional group diversity: High
 - i. Participant confidence: Low
- c. Description of diversity: no answer provided by participants

Additional comments: Diversity in the aquatic system is great across the Sierra Nevada, but within individual streams and rivers, diversity is limited. The geographic isolation of rivers and lakes makes it difficult to evaluate diversity.

References:

Component species diversity: Evidence exists that fishes can adapt relatively quickly to changing conditions through behavioral or phenotypic plasticity and rapid evolution (Crozier et al. 2008 cited in Rieman and Isaak 2010). Many salmonids can exploit new habitats almost as they become available (Isaak and Thurow 2006, Isaak et al. 2007, Milner 1987, Milner et al. 2000, 2008 cited in Rieman and Isaak 2010). This may be due in part to a diversity of life histories. Multiple life histories within a population or closely allied populations of sockeye salmon (*Oncorhynchus nerka*), for example, may stabilize overall numbers, as certain life histories are better suited to emerging conditions (Hillborn et al. 2003 cited in Rieman and Isaak 2010). Changes in thermal conditions may also lead to local adaptations in thermal tolerances. For example, fall Chinook salmon in the Snake River appear to be evolving novel rearing and migration timing in response to changes in flow and temperature caused by water development over the last 40 years (Williams et al. 2008 cited in Rieman and Isaak 2010). The capacity for rapid evolution in thermal tolerance, however, is unclear and may be more limited than with others (McCullough et al. 2009).

In addition, the southernmost steelhead (*O. mykiss*) populations are characterized by a relatively high genetic diversity compared to populations further north (McCusker et al. 2000 cited in Katz et al. 2012). It is likely that southern salmonid gene pools reflect a history of resilience as well as adaptations to watersheds characterized by aridity and extreme seasonal variation (Nielsen et al. 1999). Extinction of these highly endangered southern populations will likely result in loss of traits adapted to the very environmental characteristics that embody predicted climatic changes to watersheds further north (Katz et al. 2012).

5. Management potential.

- a. Value level people ascribe to this system: High
 - i. Participant confidence: Moderate
- b. Specificity of rules governing management of the system: High
 - i. Participant confidence: Moderate
- c. Description of use conflicts: Dams, logging, grazing, development, water diversions.
- d. Potential for managing or alleviating climate impacts: There is high potential for management of aquatic systems, because there is a great deal of public interest in water issues, especially pertaining to water needs for residential and agriculture use.

Additional comments: The potential exists to manage roads to improve habitat connectivity as well as to manage grazing and logging for the functioning of sensitive watersheds. In addition, restoration will improve the adaptive capacity of meadows and streams to adjust to floods and droughts. However, the inherent geographic isolation of bodies of water is a barrier to species distribution and movement in the steeply dissected Sierra Nevada. Also, it is important to define the biological diversity of aquatic systems, including cold and warm water fishes, amphibians, reptiles, birds, and mammals dependent on functioning and healthy aquatic systems.



References: The effects of human development have largely eroded the mechanisms that support adaptive capacity in aquatic populations (i.e. connectivity among habitats and populations, local adaptations, and genetic and phenotypic diversity) (Rieman and Dunham 2000, McClure et al. 2008, Bisson et al. 2009 cited in Rieman and Isaak 2010). In the future, climate-induced flow reductions in the northern Sierra Nevada will likely stress traditional water uses for irrigation and urban water storage, as well as aquatic and riparian ecosystems (Null et al. 2010).

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: no answer provided by participants
 - i. Participant confidence: no answer provided by participants
 - b. Collective degree these factors affect the adaptive capacity of the system: no answer provided by participants
-

7. Overall user ranking.

- a. Overall adaptive capacity of the system: High
 - i. Participant confidence: Moderate

References: Despite the high level of projected climate stress, California has landscape features that may reduce exposure of species to climate change, including high topographic diversity, abundant perennial water sources, broad elevation and climatic gradients, and long riparian corridors (Klausmeyer et al. 2011).



Exposure

1. Exposure factors⁹.

- a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, dominant vegetation type, snowpack, runoff, timing of flows, low flows, high flows, stream temperature, other – water quality
 - i. Participant confidence: Low (all)

2. Exposure region.

- a. Exposure by region: no answer provided by participants
 - i. Participant confidence: no answer provided by participants

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: no answer provided by participants
 - i. Participant confidence: no answer provided by participants

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 (GDFL¹⁰ and PCM¹¹) 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).

The effects of a 2°C or 4°C increase in climate temperature on stream temperature will be temporally and spatially variable, depending on coldwater inputs, summer low flows, and vegetative cover—but they would not be greater than the increase in air temperature (Meyers et al. 2010). Scenarios modeling increased atmospheric temperatures at 2°C, 4°C and 6°C run by Null et al. (2010) forecast that, overall, watersheds in the northern Sierra Nevada are most vulnerable to decreased mean annual flow, southern-central watersheds are most susceptible to runoff timing changes, and the central portion of the range is most affected by longer periods with low flow conditions. Increasing atmospheric temperatures, coupled with reductions in summer flows, will increase water temperatures and potentially the suitability of stream reaches as habitat for temperature-sensitive aquatic species (Myrick and Cech 2004). On the South Fork American River in the Sierra Nevada, model results of projected air temperature increases of 2°C, 4°C and 6°C reduced available coldwater habitat (with stress threshold

⁹ 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.

¹⁰ 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.

¹¹ 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.



21°C) by 57%, 91% and 99.3%, respectively (Null et al. 2012). Warming may cause thermal refuges to disappear from streams in many areas, leaving coldwater fishes no escape from unfavorable conditions (Moyle et al. 2011). Yates et al. (2008) suggest that cold pool reservoirs, such as Shasta, may offset the impacts of 2°C warming throughout the 21st century, but maintenance of a cold pool with warming of 4°C could be challenging.

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

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

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



meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010). Changes in stream flow and temperature are expected to be most significant in streams fed by the relatively lower elevation Cascades and northern Sierra Nevada (Katz et al. 2012).

Flows: A reduction in the magnitude of flow at the start of spring snowmelt also implies lower redistribution of sediment, creating large abiotic changes in stream systems (Yarnell et al. 2010). In contrast, predicted quick pulses of higher winter rainfall in California's Mediterranean-montane basins, in contrast to slower snowmelt, may change how sediments are sorted and deposited. Channel substrates may become more homogenous; channel bars may be more steeply sloped, creating less habitat availability (Yarnell et al. 2010). A flashy spring hydrograph may lead to a system dominated by two flow stages (i.e., flood and low-flow), rather than multiple stages, resulting in a stream with greater habitat homogeneity and less overall biodiversity (Yarnell et al. 2010). A flashier runoff with higher flow magnitudes is also expected to result in less water stored within watersheds and decreased mean annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

During summer and fall, rising water temperatures are exacerbated by lower base flows resulting from reduced snowpack (Stewart et al. 2004; Hamlet et al. 2005; Stewart et al. 2005). Reduced summer base flow may result in shorter duration of cold water in the system, and increased frequency or duration of warm, low-flow and zero-flow periods, lower water tables, and reduce riparian wetland inundation (Seavy et al. 2009; Yarnell 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).

Lower late-spring and summer flows on snow-melt rivers, and groundwater declines, may reduce survival and growth of shallow-rooted plants, such as seedlings and juveniles trees, as well as phreatophytic trees, when water tables drop too far or too quickly. Surviving phreatophytes may increase root depth in response to declining low flows, shifting plant community composition toward more drought tolerant native and introduced species (Shafroth et al. 2000, Rood et al. 2003, and Rood et al. 2008 cited in Perry et al. 2012).

Many riparian plants are adapted to hydrologic and geomorphic disturbances and tolerate both seasonal and annual variation in environmental conditions (Naiman and Decamps 1997 cited in Seavey et al. 2009). Long-term reduction in sediment transport and deposition and rates of channel migration and abandonment eventually shrinks the areas where pioneer species establish (Scott et al. 1996, Friedman et al. 1998, Shafroth et al. 2002 cited in Perry et al. 2012).

Salmonid species: Where mountain ranges provide 'islands' of habitat and species cannot easily migrate to higher latitude reaches, climate warming is likely to reduce total habitat for coldwater species such as salmonids (Null et al. 2012). Consequently, an elevational shift in the distribution of cold- and warm-water fish species will occur as cold-water species are limited to higher elevations (Yarnell et al. 2010).



Exposures of Chinook salmon (*Oncorhynchus tshawytscha*) to water temperatures above 20°C can result in adverse effects during spawning and rearing (Yates et al. 2008). Increased water temperatures in the Sacramento Valley could jeopardize Chinook (*O. tshawytscha*), particularly in drought years.

Temperatures exceeding 24°C are expected slightly earlier in the spring, and to last later into August and September, when peak numbers of fall-run Chinook, the most abundant run in California, historically immigrated into freshwater streams (Yates et al. 2008). Yates et al. (2008) predict the percentage of years in which temperatures at stream outlets will exceed 24°C (for at least 1 week) is likely to increase with climate change. If air temperatures rise by 6°C, most Sierra Nevada rivers are expected to exceed 24°C at watershed outlets for several weeks each year, with the Feather River a notable exception (Null et al. 2012). It is possible that a majority of California's endemic salmon, trout and steelhead could become extinct within the next 50 to 100 years, particularly pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) (Katz et al. 2012).

According to the model run by Jager et al. (1999), a shift to earlier high streamflows had a strong positive effect on brown trout (*Salmo trutta*) abundance in the Sierra Nevada. This shift increased redd scouring for winter spawning brown trout, but construction of redds during lower fall flows mitigated dewatering and compensated for scouring. Under a scenario of 2°C increase in average annual temperature, brown trout populations increased in upstream reach and decreased in the downstream reaches of the Sierra Nevada (Jager et al. 1999). In spite of an increased incidence of summer starvation of brown trout in the upstream reach (with elevated temperature of 2°C), growth and fecundity of the survivors was enhanced.

For spring-spawning rainbow trout (*O. mykiss*), on the other hand, the Jager et al. (1999) model predicted that a shift to earlier high streamflows would lead to reduced redd scouring, but increased dewatering events as spring flow was reduced (Jager et al. 1999). Rainbow trout increase in upstream reaches under the 2°C increase is attributed to better growth conditions and therefore, lower predation mortality. Increased temperatures during incubation of rainbow trout caused them to spawn earlier (Jager et al. 1999).

In the Jager et al. (1999) model, temperature in the Tule River had significant effects on the timing of spawning and incubation. For brown trout, spawning was delayed by several weeks, but eggs and alevins developed faster and fry emerged earlier. For rainbow trout, spawning was earlier, particularly in warmer downstream reaches (Jager et al. 1999). However, in these simulations, the effects of streamflow and temperature were not additive, as shown by the tremendous increase in rainbow trout abundance in upstream reach when both temperature and flow (higher winter flows during rain-on-snow events) effects were simulated (Jager et al. 1999).

Under 2°C and 4°C warming scenarios run by Meyers et al. (2010) a shift to increased winter floods predicted a likely long-term decline in the number of brook trout (*Salvelinus fontinalis*) and increase in number of rainbow trout (*O. mykiss*) in Sagehen Creek. In the Sagehen Creek scenarios, brook trout were less able to recover between winter flood events, which were expected to increase both in intensity, and to increase in frequency five-fold under moderate 2°C warming (Meyers et al. 2010). While it is unlikely that temperatures will exceed the functional range of rainbow trout (25°C) in Sagehen Creek, maximum temperatures already surpass functional maximum temperatures (19°C) of brown trout (Meyers et al. 2010).

Disease: Stream warming will magnify the distribution and virulence of disease organisms and parasites (Marcogliese 2001) that are temperature dependent, increasing the impact on native salmonids (Rahel et al. 2008).



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/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **CHAPARRAL**

CWHR Types¹: **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 workshop². 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 disruption³.

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 evaluation⁴. 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

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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>.



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 reproters (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 factors⁸.

- 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 Science⁹ 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

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.

⁹ PRBO Conservation Science now called "Point Blue".



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).

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 (GDFL¹⁰ and PCM¹¹) 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

¹⁰ 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.

¹¹ 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.



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

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

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

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

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Focal Resource: **WET MEADOWS**

CWHR Types:¹ WTM- Sedge species (*Carex spp.*), rush species (*Juncus spp.*), tufted hairgrass (*Deschampsia cespitosa*)

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 workshop². The following document represents the vulnerability assessment results for the **WET MEADOWS 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 disruption³.

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/cw/hr/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 evaluation⁴. 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: Wet Meadows 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.

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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	1 Low	2 Moderate
Direct Sensitivities – Precipitation	3 High	2 Moderate
Component Species	2 Moderate	2 Moderate
Disturbance Regimes	3 High	3 High
Climate-Driven Changes	3 High	3 High
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	3 High
Other Sensitivities	3 High	No answer provided by participants

Overall Averaged Confidence (Sensitivity)⁶: Moderate-High

Overall Averaged Ranking (Sensitivity)⁷: Moderate-High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	3 High	3 High
Extent and Integrity – Fragmentation	3 High	3 High
Resistance and Recovery	2 Moderate	2 Moderate
Landscape Permeability	1 Low	3 High
System Diversity – Physical/Topographical	Low and High	2 Moderate
System Diversity – Component Species/Functional Groups	3 High	2 Moderate
System Value	3 High	3 High
Specificity of Management Rules	3 High	No answer provided by participants
Other Adaptive Capacities	No answer provided by participants	3 High

Overall Average Confidence (Adaptive Capacity)⁶: Moderate-High

Overall Averaged Ranking (Adaptive Capacity)⁷: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Climatic water deficit	2 Moderate
Snowpack	2 Moderate
Runoff	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
Timing of flows	2 Moderate
Low flows	2 Moderate
High flows	3 High

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)⁶: Moderate

Overall Averaged Ranking (Exposure)⁷: Moderate–High



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): High
 - i. Participant confidence: Moderate

Additional comments: This system does not inhabit narrow climatic zones, but is mostly found above 1219 m (4000 ft) in the northern Sierra Nevada, and above 1524 m (5000 ft) in the southern Sierra Nevada.

References:

Temperature: Warmer temperatures will increase evapotranspiration rates, increasing groundwater extraction and the drying of meadows during warmer months (Stillwater Sciences 2012).

Precipitation: Meadow distribution, type and vegetation density are primarily determined by hydrology (Ratliff 1985; Weixelman et al. 2011; Viers et al. 2013). Wet meadows, for example, are found where the groundwater table depth during the growing season is approximately 0-40 cm deep; mesic meadows at 40-100 cm; and dry meadows where the water table is below 100 cm (Chambers et al. 2011; Lord et al. 2011). A high groundwater table is essential for meadow plants, which often have elevated rates of transpiration (Elmore et al. 2006; Loheide and Gorelick 2007). Wet meadows are highly sensitive to changes in snowmelt (Stillwater Sciences 2012), precipitation, groundwater and hydrology (Cooper and Wolf 2006, Loheide et al. 2009; Howard and Merrifield 2010; Viers et al. 2013) and particularly to the amplitude, duration and timing of surface and subsurface flows (Viers et al. 2013). Peat soil meadows require the buildup of soils with high organic matter and moisture; they take hundreds to thousands of years to develop but can be lost through drying and oxidation in years to decades (Stillwater Sciences 2012).

2. Sensitivity of component species.

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

Additional comments: Component species include sedges, rushes and grasses, willows and other deciduous shrubs, forbs, amphibians, birds, fish, and insects. However, the composition of meadow species is less important to meadow classification than its structure and function, and meadows are very sensitive to drying, and potential extreme temperatures. Meadows are also sensitive to non-climate stressors.

References: According to an analysis by Gardali et al. (2012), bird taxa in wetlands are the most vulnerable, while bird taxa in grassland and oak woodland habitats are the least vulnerable to climate change in California. Reduced snowpack in the Sierra Nevada, together with earlier, more rapid snowmelt could have substantial effects on meadow-nesting birds (Siegel et al. 2008). Small or young birds may be particularly vulnerable to dehydration during extreme heat waves because of their limited water storage capacity, and, for nestlings, their lack of access to water (Perry et al. 2012). Further loss, degradation, and fragmentation of riparian areas, may not only affect breeding and wintering populations of many bird species but may also disrupt migration (loss of stopover habitat) and precipitate further population declines of species such as the endangered southwestern willow flycatcher (*Empidonax traillii extimus*), which requires moist habitats (Finch and Stoleson 2000), and yellow-billed cuckoo (*Coccyzus americanus*), which requires large patches of suitable riparian wooded habitat (Finch et al. 2012).



Please see the documents on focal species Willow flycatcher and Aspen for additional information.

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, flooding, other – succession
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: High

Additional comments: Wet meadows are projected to be less sensitive in the short-term, however, over the longer-term, prolonged drought may enable tree and shrub encroachment into meadows. Change in snowmelt timing and amplitude may also have a large impact on meadows. For example, meadows are sensitive to extreme floods (e.g. rain on snow), which can wash out meadows and exacerbate stream incision and down-cutting. Meadows are not directly sensitive to changes in fire frequency or severity but fire suppression can aid conifer encroachment. Amphibians are sensitive to changes in disease regimes.

References:

Wildfire: Fire on the edge of the meadow/forest border can help the meadow to expand its range further into the area formally occupied by the forest (Ratliff 1985). Stand replacing fires upstream of a meadow can diminish evapotranspiration losses to upstream vegetation and cause temporary surface and groundwater increases for a few years following a fire. Large fires can also increase the amount and alter the type of sediments that are delivered to a meadow (Stillwater Sciences 2012).

Drought: Alder have deeper roots than willows and can survive multiple years of drought (Stillwater Sciences 2012). Prolonged drought and altered hydrology may enable tree and shrub encroachment (Millar et al. 2004).

Flashy precipitation events: Extreme precipitation can lead to flood events and threatens stream incision, down-cutting, loss of moist peat, and drying (Micheli and Kirchner 2002; Weixelman et al. 2011; Austin 2012; Viers et al. 2013). Sedge and rush rooting structures create more erosion resistance to channel banks than do grass species (Micheli and Kirchner 2002).

Succession: In some areas, trees are colonizing historically subalpine meadows (Millar et al. 2004). Subalpine meadows in the Sierra Nevada have been experiencing episodic invasion of pine during the 20th century, changing from meadows previously dominated by grasses, sedges and forbs, and displaying abrupt borders with surrounding forest, to having less distinct borders, with pines scattered throughout the meadow (Millar et al. 2004; Stillwater Sciences 2012). Lodgepole seedling establishment may also be favored in years with low snowpack and early snowmelt (Ratliff 1985).

(Please refer to Null et al. 2010 for a discussion on differential watershed responses across the Sierra Nevada).

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

- a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, evapotranspiration and soil moisture, altered hydrology, extreme precipitation events
- b. Sensitivity to these climate and climate-driven changes: High
 - i. Participant confidence: High

Additional comments: Meadows are highly sensitive to extreme precipitation events, stream isolation, and altered hydrology, particularly the amplitude, duration, and timing of run-off. Altered hydrology, in part due to changes from snow to rain, may lead to channel erosion, meadows shrinking, and meadow conversion to trees and shrubs at both high and low elevations.



In addition, insects and fish are sensitive to changes in water temperature, and amphibians are sensitive to air pollution/ozone.

References identified by participants: Loheide et al. 2009; Cooper and Wolf 2006; Howard and Merrifield 2010; and Viers et al. 2013.

References:

Altered fire regimes: Reduced frequency of low intensity fire in meadows may partially explain the recent trend of conifer encroachment observed in meadows (Stillwater Sciences 2012). Over time, the willow and alder thickets typically found along the meadow-forest boundary are being replaced with dense under- and mid-story fir trees (Stillwater Sciences 2012). Fire suppression may indirectly reduce soil moisture in downstream meadows if upstream forests become dense and increase their evapotranspiration rate, and may contribute to conifer encroachment in meadows (Stillwater Sciences 2012).

Evapotranspiration and soil moisture: Evapotranspiration rates depend on temperature, relative humidity, rooting depth, water table and vegetation cover. Sedges and other wet plant species tend to have a higher evapotranspiration rate relative to mesic and dry meadow plants (Stillwater Sciences 2012).

Altered hydrology: The majority of inflowing water enters meadow systems as surface runoff in streams, groundwater or through the infiltration of direct precipitation. Many meadows are snowmelt dependent systems, and reduction in spring snowpack, or change in the ratio of snow to rain precipitation could convert some wet meadows to drier systems (Stillwater Sciences 2012).

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

- a. Sensitivity to other non-climate stressors including: Agriculture and aquaculture, energy production and mining, transportation and service corridors, human intrusions and disturbance, invasive species, other – water diversions
- b. Current effects of these identified stressors on system: High
 - i. Participant confidence: High
- c. Degree stressors increase sensitivity to climate change: High
 - i. Participant confidence: High

Additional comments: Among the available categories, participants selected ‘agriculture and aquaculture’ to reflect grazing of horses and cows, and the category ‘energy production and mining’ to reflect the stressors of dams and water storage, especially in the northern Sierra Nevada. The participants also chose ‘transportation and service corridors’ to reflect the stressors of roads and culverts; the category ‘human intrusions and disturbance’ to reflect recreation impacts; and ‘invasive species’ to reflect grasses, particularly *Poa pratensis*.

Channel incision, gully, or other modifications to a meadow’s hydrology can be highly destructive. These features can alter the groundwater level in meadows, as well as the rate of water transport away from meadows, altering seasonal overflow patterns. Stream incisions are also formed as a secondary effect of grazing, rail and auto grades, culverts, and extreme high flows.

Roads or trails are commonly installed near or in meadows, because meadows often form in the flatlands or valleys. The construction of roads can cause localized compaction of soil, which reduces water holding capacity and infiltration, and once installed, roads adjacent to meadows can increase surface runoff, which can increase localized erosion. Use of off-roading vehicles where roads are not installed can also damage meadows due to soil compaction.



The disturbance of construction can also serve as vectors for the introduction of non-native species, as can hikers on recreational trails, while construction of trails and campsites may fragment meadows.

The conversion of forested lands to residential or commercial developments has been a primary cause of destruction to Sierra Nevada meadows. Meadows and rivers are considered prime locations for human settlements and these developments often destroy meadows. Hardened surfaces can reduce the amount of groundwater recharge, altering the hydrology and likely reducing the water availability of downstream meadows.

References:

Natural system modification: Meadow sensitivity may be exacerbated by the current impacted state of meadows (Loheide et al. 2009). In six National Forests in the Sierra Nevada and Southern Cascade ranges, 46% of riparian meadows are not significantly incised while 54% are (Living Assessment 2013).

Agriculture and aquaculture: Livestock grazing causes soil compaction and channel incision, lowering streambeds and groundwater tables (Stillwater Sciences 2012), and potentially exacerbating the hydrologic changes anticipated with climate change. Grazing causes permanent changes to features of meadows such as compacting of soil, increase in erosion, and channel incision (Ratliff 1985). In a study of 24 meadows that were open to cattle grazing, located on the western slope of the central Sierra Nevada at elevations of 2200-2700 m (7217-8858 ft), cattle use was negatively correlated to meadow wetness (Roche et al. 2012). At higher elevation meadows, packstock associated with recreational activities may have greater impact than feedstock due in part to soil compaction, along with campgrounds (Menke et al. 1996 cited in Stillwater Sciences 2012). A list of primary research on grazing impacts in meadows can be found in Stillwater Sciences (2012).

Invasive and other problem species: Invasive and non-native plant species often invade meadows after a soil disturbance. Some of these plants have a shallow root system, which can enhance localized erosion. High elevation Sierra Nevada meadows have a low occurrence of non-native species (D'Antonio et al. 2004).

6. Other sensitivities.

- a. Other critical sensitivities not addressed: Connectivity
 - i. Participant confidence: no answer provided by participants
- b. Collective degree these factors increase system sensitivity to climate change: High

Additional comments: Meadows and fens are sensitive to climate change due to a lack of connectivity among sites. They have limited ability to move or shift upslope and it takes thousands of years to form new meadows naturally. Loss of peat in fens occurs due to lower water, higher evapotranspiration and oxidation.

7. Overall user ranking.

- a. Overall sensitivity of this system to climate change: High
 - i. Participant confidence: no answer provided by participants

Additional comments: This system is highly sensitive to climate change and other non-climate stressors primarily as a result of its dependence on water, fragmented ownership pattern with relatively high percentage in private ownership, its current degraded state, and inability to shift upslope.



Adaptive Capacity

1. System extent and integrity.

- a. System extent throughout the Sierra Nevada (widespread to narrow distribution): High
 - i. Participant confidence: High
- b. Level of fragmentation across the Sierra Nevada: High
 - i. Participant confidence: High

Additional comments: Meadows occur across the Sierra Nevada, but are one of the rarest and most isolated/fragmented habitat types in the Sierra Nevada. They represent a tiny fraction of the land base (~1%), and as such are patchy in distribution.

References:

Geographic extent: Meadows are well distributed across the Sierra at different elevations (Whitney 1979) but are among the rarest and most isolated habitat types in the Sierra Nevada, representing approximately 1% of the land base (Davis and Stoms 1996; Viers et al. 2013). The non-uniform distribution and lack of connectivity between meadows may exacerbate the effects of altered hydrology (Viers et al. 2013).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Moderate
 - i. Participant confidence: Moderate
- b. Suitable microclimates within the system that could support refugial communities: There are regional differences in meadows between north, central and south Sierra Nevada. Refugia could be possible at elevational zones with stable climates. Meadows that currently occur at elevations where future predicted snowpack is projected to be retained may be more resilient to future climate conditions. Meadows within predicted climate refugia (cold sinks) and fed by northerly exposed watersheds may also be more resilient to future conditions. Wetter meadows and fens may be more stable and able to resist climate impacts and conifer encroachment, and resilient to an increase in extreme flow events if they are found in a healthy state. In contrast, meadows with altered hydrologic function (isolated floodplains) will be less resilient to climate impacts and less able to recover from extreme events or adapt to changing conditions.

3. Landscape permeability.

- a. Degree of landscape permeability: Low
 - i. Participant confidence: High
- b. Potential types of barriers to dispersal that apply: geologic features, other – natural topography

Additional comments: Geologic features are identified as barriers to dispersal, and include soil types and basin shape and depth. Concerns exist regarding landscape permeability, since upslope shifts are unlikely, given the complexity of mountain basins. Groundwater-fed systems (e.g. those associated with volcanic soils in the southern Cascades) may be more resilient to climate impacts.

References: Although meadows occur within a diverse range of elevations (Whitney 1979), permeability across the landscape is limited by topography and geologic features, including soil type, basin shape and depth, and slope (Weixelman et al. 2011). Non-uniform distribution and lack of connectivity may exacerbate sensitivity of meadows to altered hydrology (Viers et al. 2013).



4. System diversity.

- a. Level of physical and topographic diversity: Physical – Low; Topographic – High
 - i. Participant confidence: Moderate
- b. Level of component species/functional group diversity: High
 - i. Participant confidence: Moderate
- c. Description of diversity: The participants marked both Low and High for Question 4a (above) to reflect the low diversity of slopes on which meadows and fens are found, and the high diversity of elevations and soils on which they occur. Meadows exhibit multiple vegetation types and hydrologic processes, and high floral and faunal diversity. Meadows are dominated by graminoids and forbs, and natural oscillation of dominant groups in meadows depends on multiple factors, especially hydrology, soils, elevation, and current and past disturbance (e.g. grazing). Wetter, more stable meadows tend towards dominance by sedges and rushes, while drier sites and those with significant disturbance tend towards dominance by forbs. Shifts from rhizomatous species to annuals would be problematic, increasing erosion potential.

References identified by participants: Weixelman et al. 2011.

5. Management potential.

- a. Value level people ascribe to this system: High
 - i. Participant confidence: High
- b. Specificity of rules governing management of the system: High
 - i. Participant confidence: no answer provided by participants
- c. Description of use conflicts: Grazing and stock use; recreation; non-native fisheries; water rights and water use issues (some users don't want water held in meadows).
- d. Potential for managing or alleviating climate impacts: There is high restoration potential for meadows. Management can include engineered solutions, and management options may include moving trails, campsites, roads away from meadows, and most importantly, restoring floodplain connectivity. Fens may be harder to restore when degraded.

Additional comments: There are lots of historic uses which hinder management, making planning for meadows and fens complicated. For example, grazing is frequently grandfathered in management policies, and recent concerns of water rights and fish may hamper future meadow restoration options. The specificity of regulations regarding meadow management by the USFS is relatively low. Utilization by livestock is the primary element guiding management. There is very little oversight of NEPA for meadow management by USFS or environmental groups.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: See comment below
 - i. Participant confidence: no answer provided by participants
- b. Collective degree these factors affect the adaptive capacity of the system: no answer provided by participants

Additional comments: Groundwater recharge relates to hydrologic regime and topography, as well as to the surrounding vegetation and evapotranspiration.

7. Overall user ranking.



- a. Overall adaptive capacity of the system: Low *and* Moderate (depending on management)
 - i. Participant confidence: no answer provided by participants

Additional comments: The participants rate the adaptive capacity of meadows ‘low’ without management, but ‘moderate’ with focused management and restoration. Without management intervention, meadows and fens cannot move and are limited in the landscape. Meadows are already stressed and highly degraded and management potential is expensive and limited by private ownership. However, restoration can result in recovery and is currently being practiced throughout the Sierra, so the body of knowledge on restoring these systems is increasing.

References: Despite the high level of projected climate stress, California has landscape features that may reduce exposure of species to climate change, including high topographic diversity, abundant perennial water sources, broad elevation and climatic gradients, and long riparian corridors (Klausmeyer et al. 2011).



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the system: Climatic water deficit, snowpack, runoff, timing of flows, low flows, high flows
 - i. Confidence: Moderate (climatic water deficit); Moderate (snowpack); Low (runoff); Moderate (timing of flows); Moderate (low flows); High (high flows)

2. Exposure region.

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

3. Overall user ranking.

- a. Overall perceived exposure of the species to climate changes: High
 - i. Participant confidence: Moderate

References identified by participants: Austin 2012.

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 (GDFL⁹ and PCM¹⁰) 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).

Scenarios modeling increased atmospheric temperatures at 2°C, 4°C and 6°C run by Null et al. (2010) forecast that, overall, watersheds in the northern Sierra Nevada are most vulnerable to decreased mean annual flow, southern-central watersheds are most susceptible to runoff timing changes, and the central portion of the range is most affected by longer periods with low flow conditions.

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;

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.

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.



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). An increase in flashy precipitation events may lead to erosion of moist peat and topsoil due to flooding (Weixelman et al. 2011; Viers et al. 2013), as well as drying of meadows caused by channel incision (Viers et al. 2013).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

Shifts from rain to snow are also largely expected between 1500 to 3000 m (4921 ft to 9843 ft) (Viers et al. 2013; Young et al. 2009), where the majority of montane meadows occur (Viers et al. 2013). 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 mean 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).

Lower late-spring and summer flows on snow-melt rivers, and groundwater declines, may reduce survival and growth of shallow-rooted plants, such as seedlings and juveniles trees, as well as phreatophytic trees, when water tables drop too far or too quickly. Surviving phreatophytes may increase root depth in response to declining low flows, shifting plant community composition toward more drought tolerant native and introduced species (Shafroth et al. 2000, Rood et al. 2003, Rood et al. 2008, cited in Perry et al. 2012).

Many riparian plants are adapted to hydrologic and geomorphic disturbances and tolerate both seasonal and annual variation in environmental conditions (Naiman and Decamps 1997 cited in Seavey et al. 2009). Long-term reduction in sediment transport and deposition and rates of channel migration and abandonment eventually shrinks the areas where pioneer species establish (Scott et al. 1996, Friedman et al. 1998, Shafroth et al. 2002 cited in Perry et al. 2012).

Aspen (*Populus termuloides*): For more information on aspen and climate change exposure, please refer to the aspen document.

Willow flycatcher: For more information on willow flycatcher and climate change exposure, please refer to the willow flycatcher document.

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/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **OAK WOODLANDS**

CWHR Types¹: MHC-Ponderosa pine (*Pinus ponderosa*), Incense cedar (*Calocedrus decurrens*), California black oak (*Quercus kelloggii*); MHW-Canyon live oak (*Quercus chrysolepis*), California black oak (*Quercus kelloggii*), Oregon white oak (*Quercus garryana*); **ASP**-Aspen (*Populus tremuloides*), Willow (*Salix spp.*), Alders (*Alnus 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 workshop². The following document represents the vulnerability assessment results for the **OAK WOODLANDS 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 disruption³.

¹ From California Wildlife Habitat Relationship (CWHR) habitat classification scheme
http://www.dfg.ca.gov/biogeodata/cw/hr/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.



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.

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 evaluation⁴. 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.

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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	1.5 Low-Moderate	2.5 Moderate-High
Direct Sensitivities – Precipitation	2 Moderate	3 High
Component Species	1 Low	2 Moderate
Disturbance Regimes	3 High	3 High
Climate-Driven Changes	3 High	2 Moderate
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	3 High
Other Sensitivities	None	2 Moderate

Overall Averaged Confidence (Sensitivity)⁶: Moderate-High

Overall Averaged Ranking (Sensitivity)⁷: Moderate-High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	3 High	3 High
Extent and Integrity – Fragmentation	2 Moderate	3 High
Resistance and Recovery	2 Moderate	2 Moderate
Landscape Permeability	2 Moderate	2 Moderate
System Diversity – Physical/Topographical	3 High	3 High
System Diversity – Component Species/Functional Groups	3 High	2 Moderate
System Value	2 Moderate	1 Low
Specificity of Management Rules	2 Moderate	2 Moderate
Other Adaptive Capacities	None	2 Moderate

Overall Confidence (Adaptive Capacity)⁶: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁷: Moderate-High

EXPOSURE

Relevant Exposure Factor	Confidence
Precipitation	2 Moderate
Climatic water deficit	3 High
Wildfire	3 High
Runoff	2.5 Moderate-High

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.



Exposure Region	Exposure Evaluation	Confidence
Northern Sierra Nevada	1 Low	1 Low
Central Sierra Nevada	1 Low	More certainty about impacts
Southern Sierra Nevada	2 Moderate	1 Low

Overall Averaged Confidence (Exposure)⁶: Moderate

Overall Averaged Ranking (Exposure)⁷: Low



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): Low – Moderate
 - i. Participant confidence: Moderate – High
- b. Sensitivity to precipitation (means & extremes): Moderate
 - i. Participant confidence: High

Additional comments: The participants rate the overall sensitivity of oaks as moderate, because while mature oaks can be fairly resilient to variability in precipitation, seedlings can be substantially affected by rainfall amounts. Oak woodlands are a large ecosystem, and the different oak species have a broad range of sensitivities. (1) Temperature: Oaks are thought to have fared better during warmer times in the past, and established individuals generally do well in drought environment because they are long-lived and have deep root systems. (2) Precipitation: Precipitation affects regeneration and recruitment. Established trees are more tolerant to fluctuations in precipitation, although precipitation can affect their fecundity. Oak woodlands are likely more sensitive to precipitation than temperature, although these systems are also thought to have expanded their ranges during past times of drier climates.

References: Oak woodlands are a large ecosystem, composed of oak species displaying a broad range of sensitivities (Jimerson and Carothers 2002; Waddell and Barrett 2005).

Precipitation: precipitation is a key discriminant variable determining oak series, with higher rainfall on western slopes associated with black oaks, and drier, more inland and southerly sites associated with white oak and blue oak (Jimerson and Carothers 2002). Environmental gradients within oak series are favored by different component species. For instance, Douglas fir is found on mesic sites within white and black oak series, while California buckeye (*Aesculus californica*) is found on warm, dry sites (Jimerson and Carothers 2002), and valley oak may be dependent on groundwater (McLaughlin and Zavaleta 2012).

Oaks are masting species and yearly acorn crop sizes can vary significantly, potentially with water availability (Koenig et al. 1999 cited in Waddell and Barrett 2005). With blue oaks, wet years can produce nearly double the seedling emergence of dry years (Borchert et al. 1989 cited in Tyler et al. 2006), and all published studies on the regeneration of blue oak woodlands reviewed by Tyler et al. (2006) found saplings to be more common on mesic sites.).

2. Sensitivity of component species.

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

Additional comments: In addition to oaks, component species include understory grasses, as well as deer, pocket gophers, ground squirrels, acorn woodpeckers, songbirds, and insects. High faunal diversity is tied to acorns as a primary food source. Like many flowering plants, oaks are masting species and acorn crop sizes can vary significantly year-to-year, thus affecting the fauna that utilize acorns as food. Component wildlife species that are dependent upon acorns may suffer if climate changes force them to shift their distributions to be disjunct with oak woodlands; wildlife species are likely to be able to shift their distributions much more rapidly than the long-lived oaks in response to changing climate. Oaks, especially younger individuals, are likely to be more sensitive to increased fire frequency that could occur as a result of warming and drying climate than the animals within the system. Soil types and depth to water table are also likely to be factors affecting species shifts and future ranges of oak species. In general, different oak species display a broad range of sensitivities.



References: Mean significant discriminant function analysis of sites in northwest California showed highest precipitation is associated with black oak woodlands in northwest California, while white oak is associated with mid-level precipitation (Jimerson and Carothers 2002). Blue oak series at inland and southern sites had the lowest average annual precipitation of common forest types, with a median precipitation of 21 inches (533 mm) and a range of 19-25 in/yr (482-635 mm/yr) (Waddell and Barrett 2005). Two-thirds of the white oak forest type was found in areas with 39-58 inches (990-1473 mm) of precipitation per year (Waddell and Barrett 2005). Median average annual precipitation for canyon live oak forest was 42 in/yr (1066 mm/yr) with a range of 35-53 in/yr (889-1346 mm/yr) (Waddell and Barrett 2005). Individual large California black oak trees (*Q. kelloggii*) established circa 1700, and are located near their range limit for the species and may be at risk of water deficit related mortality (Lutz et al. 2010).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, insects, other – grazing
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: High

Additional comments: Among the choices of disturbance regimes, wind is not selected because windthrow is typically not a significant source of tree mortality for oaks. To date, confirmed sudden oak death disease has been confined to coastal California since it is associated with cooler and moister areas. There are many suspected cases in the central Sierra Nevada foothills, but no confirmed cases in the broader Sierra Nevada currently. The gold-spotted oak borer beetle currently only affects oaks in San Diego County where they have contributed to significant oak mortality. The disturbance regimes selected -- wildfire, drought and insects -- are all related to some extent. Although fire can be a significant factor in shaping oak population structure, both insects and disease are not a present factor (though may become significant in the future), leaving grazing as probably the largest source of disturbance to oak woodlands. In addition, grazing may shift in intensity from lower to higher elevations as the temperature warms (and cattle are moved from the valleys further upslope). However, under a future warmer climate, fire regimes may change, becoming more frequent and intense, which may negatively impact oak woodlands.

References: Seral status is determined by disturbance regimes of grazing, fire, drought, and competition from invasive species (Jimerson and Carothers 2002).

Wildfire: Although the literature indicates that mature oaks generally withstand moderate fire (Holmes et al. 2008), fire response seems to vary among California's oak species, and by life stage. While many native species of oak in California are relatively fire resistant (Horney et al. 2002) either due to innate low fuel conditions or vegetative adaptation (Spero 2002), smaller individuals often experience topkill (Holmes et al. 2008). Swiecki and Bernhardt (1998) found that a relatively light grassfire in 1996 that burned an oak stand killed 6% of saplings and almost all saplings less than 1500 mm (59 in) tall. Nearly a year after a fire, post-fire shoot biomass was still much lower than pre-fire biomass for all but the smallest topkilled saplings (Spero 2002). Canyon live oak (*Quercus chrysolepis*) is extremely sensitive to fire, and blue oak (*Quercus douglasii*) is more fire resistant than interior live oak (*Quercus wislizenii*) (Plumb 1980).

Several authors have suggested that, at least in the short term, frequent, low intensity fire benefits oak by inhibiting conifer encroachment (Fritzke 1997; Swiecki and Bernhardt 2002; Jimerson and Carothers 2002) and by preparing adequate seedbed conditions (Kauffman and Martin 1987). Conversely, other studies have shown that fire is negatively associated with blue oak sapling recruitment in California (Swiecki et al. 1997b cited in Tyler et al. 2006). Similarly, moderate intensity fire resulting in partial or



complete topkill was found to confer no survival or regrowth benefits to blue oak saplings, but instead to prolong the period that saplings were susceptible to subsequent fire and other damaging agents (Spero 2002). The long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

Drought: Mature oaks generally fare well in warm weather and withstand drought (McCreary 1991), owing to deep root systems, long lifespans, and drought deciduousness. Young valley oaks may be especially vulnerable to drought effects of climate change (McLaughlin and Zavaleta 2012).

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

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

Additional comments: As mentioned above, a warmer future climate is likely to lead to increased fire frequency and severity. While oaks are generally adapted to survive most fires, young trees are at the highest risk of mortality from fires, therefore, increased fire frequency and severity could negatively impact recruitment of new trees, leading to overall population declines. Although oaks are deep rooted and often take advantage of deeper perennial water, a reduction in soil moisture, lowering of the water table, and increases in evapotranspiration under a warmer climate would be likely to increase tree stress and mortality, especially for younger trees. Mature oaks generally fare well in warm weather, withstand drought due to deep root systems, long lifespans and drought deciduousness, and are fairly resistant to fire, a characteristic directly related to bark thickness. Seedling recruitment and sapling survival, in contrast, are sensitive to reduced soil moisture and precipitation, which affect tree stress and mortality.

References:

Altered fire regimes: Due to fire suppression over the past 50 years, Douglas fir has become increasingly common on oak woodland sites. Fewer fires have increased the fuel load within oak woodland forests, which can cause more intense, stand-replacing fires when they do occur. Northwest California oak woodlands would naturally be subjected to frequent low intensity fires that tend to kill invading Douglas fir seedlings and saplings. High cover of Douglas fir under an oak canopy is an indication of an altered fire regime (Jimerson and Carothers 2002).

Evapotranspiration and soil moisture: Groundwater availability may be an important factor in local refugia. Valley oak is thought to be dependent on groundwater (McLaughlin and Zavaleta 2012).

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

- a. Sensitivity to other non-climate stressors including: residential and commercial development, agriculture and aquaculture, biological resource use, natural system modifications, invasive and other problematic species, other – firewood harvesting
- b. Current effects of these identified stressors on system: High
 - i. Participant confidence: High
- c. Degree stressors increase sensitivity to climate change: High
 - i. Participant confidence: High

Additional comments: The participants chose the category ‘biological resource use’ to reflect wood harvest, and recognize that energy production may be a disturbance in the future. The categories ‘residential and commercial development’, ‘agriculture and aquaculture’, and ‘invasive species’ all have substantial impact on oak woodland systems.



Oaks are probably more sensitive to development and agriculture because their range occurs at low elevation (which is closer to human population centers). Significant losses of oak habitat have already resulted from urban and suburban development, and conversion of lands to high intensity agriculture. As human populations expand, loss of oak woodlands to these expansion processes will worsen. The reduction or elimination of top predators (i.e. natural system modification) has probably led to higher densities of their prey, such as deer and rodents. The herbivory of these animals (e.g., cattle, deer, rodents, and insects) on seeds and seedlings has been implicated in low recruitment rates for many plant species, including oaks. Grazing may affect surface and subsurface water quality through expansion of bare ground and concentrated nutrient inputs. In addition, wild pigs (i.e. problem species) disrupt surface soils, and Eurasian grasses (many of which are invasive species) outcompete native annual and perennial grasses for water. The potential exists for the goldspotted oak borer beetle to spread from southern California and impact oak woodlands in the Sierra Nevada. Overall, the impacts discussed so far are greater in the central Sierra Nevada due to more extensive development and conversion of lands to agriculture.

References: Threats to oak woodlands in California include urbanization, conversion to agriculture, fragmentation, low rates of regeneration, competition from introduced species and sudden oak death (Jimerson and Carothers 2002).

Grazing: Several studies identify herbivory of acorns, seedlings and saplings by cattle, deer, rodents and insects as a major source of oak mortality (Plumb 1980; Borchert et al. 1989, Callaway 1992, and Adams and McDougald 1995 cited in Tyler et al 2006; Hall et al. 1992), while other studies suggest that grazing intensity may play a smaller role in seedling survival than the seasonality of grazing. Grazing of seedlings by livestock and wildlife in both spring and summer is associated with significantly lower survivorship than grazing in winter only (Hall et al. 1992). Grazing may also impact oak woodlands by introducing exotic annuals through the cattle feces vector (Jimerson and Carothers 2002).

Other problem species: While still on the tree, acorns are susceptible to mortality due to insects (predominantly weevils and moth larvae), birds (including jays, magpies, and acorn woodpeckers), and mammals (including mice, squirrels, deer, pigs, and cattle) (Griffin 1980b, and Koenig et al. 2002 cited in Tyler et al. 2006). In addition, wild pigs can disrupt soil surfaces and facilitate an increase in introduced annual grasses, which can lead to soil erosion (Jimerson and Carothers 2002).

Invasive flora: Oak woodlands have a lower frequency of invasive weeds when compared to adjacent grasslands. Annual grasses are the primary non-native invaders of oak woodland. Invasive weeds are a potential threat because of the proximity of annual grasslands to oak woodlands. The alien grass hedgehog dogtail increases on overgrazed sites, and can lead to soil erosion. In general, invasive weeds are more common in oak woodlands if there has been significant surface disturbance the leads to bare ground being exposed (Jimerson and Carothers 2002). Modern oak understory communities are mainly dominated by exotic European annuals (Roche et al. 2012).

Pathogens and insects: Oaks are sensitive to both insects and disease (Jimerson and Carothers 2002; Rizzo et al. 2002), especially introduced ones, which may become significant in the future. Sudden oak death, caused by the introduced pathogen *Phytophthora ramorum*, affects oaks in coastal and montane forests of California (Rizzo et al. 2002). 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. Heavy late-spring rain associated with El Niño events (e.g., 1998) may have played a key role in the current distribution of *P. ramorum* in California (Meentemeyer et al. 2004). Increases in winter rain may produce optimal conditions for the pathogen in some areas, and modeling projects future oak infection risk to be moderate and high in scattered areas of the Sierra Nevada foothills in Butte and Yuba counties (Meentemeyer et al. 2004).



A study in Utah suggests that incremental temperature increases in the next century will facilitate widespread introductions of gypsy moth into previously temperature-limited elevation zones containing hardwoods with no previous exposure to gypsy moth, which may lead to the destruction of large stands of quaking aspen (*Populus tremuloides*), bigtooth maple (*Acer grandidentatum*) and Gambel oak (*Quercus gambelii*) (Shepperd et al. 2006).

6. Other sensitivities.

- a. Other critical sensitivities not addressed: None
 - i. Participant confidence: Moderate

References: Low rates of regeneration of oaks have been noted in oak woodlands (Jimerson and Carothers 2002). Recruitment from acorns and survival can be affected by predation from insects, rodents, deer, and cattle (Hall et al. 1992; Adams and McDougald 1995). Because saplings are largely impacted by fire, current low rates of regeneration in many oak species (Jimerson and Carothers 2002) may be exacerbated by the impact of increased fire frequency on seedling and sapling mortality. However, Tyler et al. (2006) do not find that sufficient quantitative data exist to indicate a regeneration problem currently exists in California oak woodlands.

Past management strategies: Management to remove native oak and shrub species to enhance understory forage production have significantly impacted ecosystem services, including soil and water resources (Roche et al. 2012).

7. Overall user ranking.

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

Additional comments: Sensitivity of oaks to climate and non-climate stressors varies according to the life stage in which the species finds itself. In general, adult oaks are less sensitive, and seedlings are more sensitive. Water availability is a concern to oak woodlands, and the effects of browsing pressure (on young trees) by both cattle and deer are a concern. Likewise, development pressure and land use conversion to agriculture is also a concern on private lands.



Adaptive Capacity

1. System extent and integrity.

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

Additional comments: Although participants ranked level of fragmentation ‘moderate’ for oak woodlands as a whole in the Sierra Nevada, at lower elevations on privately held lands, oak woodlands are highly fragmented, while on public land further upslope, they are widespread with low fragmentation from north to south and across elevations (121-1829 m) (400-6000 ft). Blue oak woodlands in the western Sierra Nevada display more fragmentation than the system as a whole.

References: Kueppers et al. (2005) modeled regional climate change and California endemic oak ranges.

Geographic extent: The total estimated area of hardwood forest in California was 11.29 million acres in the 1990s, excluding reserved lands outside of national forests. Oak woodlands occurring within national forest lands in California cover an estimated 725,000 acres (293,397 ha) (Jimerson and Carothers 2002). The most common hardwood forest type inventoried in California was blue oak. Blue oak occurs predominantly on private lands in California where habitat conversion to agriculture and residential development reduce blue oak extent and abundance (Bolsinger 1988; Pavlik et al. 1991). Canyon live oak was the most numerous hardwood tree species in California forestlands, with an estimated 2.22 billion trees (Waddell and Barrett 2005).

Fragmentation: Oak woodlands are found in small patches (averaging 29.3 ac/patch or 11.9 ha/patch), nested within a mosaic of annual grasslands and conifer forests, and contain species common to both respective vegetation types (Jimerson and Carothers 2002).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Moderate
 - i. Participant confidence: Moderate
- b. Suitable microclimates within the system that could support refugial communities: Some species (e.g. canyon live oak) are confined to cooler canyon bottoms and north-facing slopes and would be further limited to these location in a warmer/drier future. Most species of oak, however, are more broadly distributed over a wider range of microclimates and site conditions. For these species, a substantial contraction to the most favorable sites (based on water, temperature, soils, and fire regime conditions) would be a likely outcome, although this contraction may be slow and uneven. Many species of oaks grow larger when on deep soils where access to perennial groundwater is best, and so in these areas, adults may be more resilient to future climate changes. Generally however, soil types and depth to water table are likely to influence future shifts of species to future ranges.

Additional comments: Being long-lived, oaks are resistant to short-term climatic changes, but populations are slow to recover from major disturbances, in part because recruitment and masting are affected by age structure. Really old trees can depress acorn production, while really young trees take a while to produce acorns. In addition, oaks are somewhat adapted to survive fire. Adults may be able to resist increases in fire frequency in the short term, but may exhibit higher mortality in the longer term. While oaks survive fire regime changes in the long-term because they are able to sprout, acorns may shift in abundance for dependent species that utilize acorns. Since many oak species appear to lack sufficient recruitment, an increase in fire frequency and consequent increase in seedling mortality would



further reduce oak recruitment rates. Warming and drying of the climate may also reduce acorn production and mast size.

References: Due to the long generation time of valley oak (*Quercus lobata*), population adaptation to new climate is unlikely (Sork et al. 2010). Geographic analysis shows a strong association of genetic structure of valley oak with climate variables, indicating that regional populations are likely adapted to local climate conditions. This climatically based genetic structure may constrain the ability of valley oak populations to tolerate rapid shifts in climate zones expected in some regions in California, and result in region-specific climate impacts to valley oak populations (Sork et al. 2010). However, local populations might include individuals that can tolerate new conditions, especially in regions where present climate conditions are variable, such as the Sierra foothills (Sork et al. 2010).

3. Landscape permeability.

- a. Degree of landscape permeability: Moderate
 - i. Participant confidence: Moderate
- b. Potential types of barriers to dispersal that apply: Road-highway, agriculture, industrial or urban development, suburban or residential development, geologic features

Additional comments: The participants chose the category 'geologic features' to reflect soil types.

Land use conversion to urban or suburban development, or intensive agriculture will significantly reduce oak population sizes and densities, and reduce available habitat. These landscape conversion processes will reduce or eliminate dispersal to new areas. Oak woodlands not directly converted, but used as rangelands are also known to experience increased adult mortality and low recruitment rates. These problems are greatest at lower elevations, where agriculture and development is greatest, resulting in low connectivity and low permeability at the lower elevations of oak woodland range. At high elevations however, on public lands, there is much higher connectivity and permeability than at lower elevations.

References: Recruitment from blue oak acorns and survival can be affected by predation from insects, rodents, deer, and cattle (Hall et al. 1992; Adams and McDougald 1995). Poor natural regeneration of blue oak has been noted in portions of its range (Bartolome et al. 1987; Bolsinger 1988; Tyler et al. 2006). Blue oak seedlings and saplings are present but relatively rare in many stands, and absent from others. Some stands show no evidence of tree recruitment within the past 50 years. However, low mortality rates of adults, estimated between 2 to 4% per decade (Swiecki et al. 1993) may be sufficient to allow replacement even at low sapling survival rates.

4. System diversity.

- a. Level of physical and topographic diversity: High
 - i. Participant confidence: High
- b. Level of component species/functional group diversity: High
 - i. Participant confidence: Moderate
- c. Description of diversity: Oak woodlands exhibit high faunal species diversity and faunal functional group diversity, and display high tolerance for varying soil, temperature and precipitation.

Additional comments: Oak woodlands display high biodiversity. If one species of seed disperser is lost, others can fill its functional role. However, if climate changes force shifts in a group of related wildlife, such as dispersers, seed dispersal could be reduced.

References: A total of 714 species were identified within oak woodlands at 446 field sites in northwest California, including 20 species of oak (Jimerson and Carothers 2002; Nixon 2002). Oak woodlands can



be found in nearly pure stands or in association with other tree species like the Douglas fir, Ponderosa pine, gray pine, canyon live oak, California buckeye or bigleaf maple (Jimerson and Carothers 2002). Compared to annual grasslands, meadows, or chaparral, oak woodlands have a higher index of species richness and within the oak woodlands series, blue oak tends to have the highest number of associated species (29.8 species/plot) and black oak had the lowest (23.1 species/plot). Species richness can be correlated with tree canopy closure, with open canopies displaying higher species richness (Jimerson and Carothers 2002).

Vegetation cover in oak woodlands is high compared to other vegetation types in northwestern California. Trees accounted for 64% of cover, shrubs 22%, grass 26%, and forbs 14% (Jimerson and Carothers 2002). Oaks may facilitate a spatial niche for some native plant species within drier regions, however it may suppress understory productivity on in more mesic and productive regions in California (Roche et al. 2012). It is well established that blue oak (*Q. douglasii*) supports islands of greatly enhanced soil quality and fertility among the annual grassland matrix (Dahlgren et al. 1997; Camping et al. 2002; Dahlgren et al. 2003).

According to an analysis by Gardali et al. (2012), bird taxa in grassland habitats, along with oak woodland habitats, are the least vulnerable to climate change in California.

5. Management potential.

- a. Value level people ascribe to this system: Moderate
 - i. Participant confidence: Low
- b. Specificity of rules governing management of the system: Moderate
 - i. Participant confidence: Moderate
- c. Description of use conflicts: Conflicts include private ownership of oak woodlands, suburban development, and conversion to agriculture. When all oak species are lumped together, the large majority of their distribution (>80%) exists on privately held lands, which severely limits the potential for management of the system. Although valued for their aesthetics, as a wood source, and historically as important components of Native American heritage, oak woodlands and the habitats they provide are unfortunately located in areas also valued for other land uses. These conflicts will make it difficult to manage for oak woodland persistence and health, now and under future climates. As an example, groundwater depletion (for human uses) could prove detrimental to oaks.
- d. Potential for managing or alleviating climate impacts: Oak recruitment and restoration could be facilitated on private lands to protect seedlings from cattle and deer. Groundwater use (for human uses) could be limited. Movement to wetter microclimates (either upslope or to other sites within the same elevation range) could be assisted.

Additional comments: Some counties highly value oaks, but in the Sierra Nevada, a higher value is placed on rangeland. Oaks have high aesthetic value, but since they are not a timber species, they have low economic value. Oak woodlands exist within a public/private dichotomy. The management potential on public lands is high, but most oak woodlands occur on private lands, where management potential is low.

References: Aggressive fire suppression policy has led to increase in cover of Douglas fir on oak woodland sites (Jimerson and Carothers 2002). Several studies have suggested that, at least in the short term, frequent, low intensity fire benefits oaks by inhibiting conifer encroachment (Fritzke 1997; Jimerson and Carothers 2002; Swiecki and Bernhardt 2002).

After fire, protection against grazing pressure from deer and cattle increased oak regrowth (Bartolome et al. 2002).



6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: None
 - i. Participant confidence: Moderate
-

7. Overall user ranking.

- a. Overall adaptive capacity of the system: Moderate-High
 - i. Participant confidence: Moderate

Additional comments: In general, oak woodlands have high adaptive capacity to a changing climate compared to other communities in the Sierra Nevada, but their limited recruitment of some oak species is a big problem that may be exacerbated by a drier climate, potentially causing adaptive capacity in the long-term to be low. In the short term, trees are adapted to fires and can tolerate droughts.

References: Poor natural regeneration has been noted in portions of the blue oak range (Bartolome et al. 1987; Bolsinger 1988; Tyler et al. 2006). Blue oak seedlings and saplings are present but relatively rare in many stands, and absent from others, with some stands showing no evidence of tree recruitment within the past 50 years. Although Tyler et al. (2006) caution that insufficient quantitative data exist to indicate a regeneration problem currently exists in California oak woodlands, they note that, because oaks are slow-growing and 50-100 years may be required to functionally replace lost individuals, managing for oak persistence in foothill woodlands may be warranted before mortality is demonstrated to exceed recruitment.



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the system: Precipitation, climatic water deficit, wildfire, runoff
 - i. Participant confidence: Moderate (precipitation); High (climatic water deficit); High (wildfire); Moderate-High (runoff)

2. Exposure region.

- a. Exposure by region: North – Low; Central – Low; South – Moderate
 - i. Participant confidence: North – Low; Central – more certainty in impacts due to land use and urbanization in this region; South – Low
-

3. Overall user ranking.

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

References:

Vegetation shifts: Principal trends in vegetative changes during the last 80 years in the Sierra Nevada include the loss of blue oak (*Quercus douglasii*), attributed to management choices, and the loss of hardwood-dominated forests, with a strong connection to climate warming (Safford et al. 2012). Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands is also be projected to increase in California (Gardali et al. 2012). Broadleaf species whose potential distributions are simulated to expand to the area west of the northern Sierra Nevada include the California white oak/valley oak (*Quercus lobata*), which can tolerate relatively warm and dry conditions. Conversely, red alder (*Alnus rubra*) and Oregon white oak (*Q. garryana*) are expected to shift potential ranges from the west to the east of the northern Sierras (Shafer et al. 2001). As CO₂ increases in the future, aspen (*Populus tremuloides*) productivity should increase as longer roots and thus better nutrient uptake increases (Morelli and Carr 2011).

See Kueppers et al. (2005) for modeled ranges of California endemic oaks under regional climate changes.

Wildlife - According to a vulnerability assessment by Gardali et al. (2012), along with grassland taxa, bird taxa of oak woodlands are least vulnerable to climate change in California. This may be due in part because oak woodlands are expected to increase in California (Gardali et al. 2012).

Valley oak woodlands (*Valley oak*, *California walnut*, *California sycamore*) - Future displacement of valley oaks will be a factor of both regional differences in the magnitude of climate changes, and the steepness of local topographically induced temperature and precipitation gradients (Sork et al. 2010). Rather than simply shifting northward and upward in elevation, valley oak may shift its range in all directions, including to the south of existing ranges. This is due to the topographic complexity and steep environmental gradients of western North American mountain ranges, which provide a high diversity of bioclimatic habitat under future climatic scenarios (Shafer et al. 2001).

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)

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.



while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5°C warming (Dettinger et al. 2004b). 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).



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). The area of oak woodland burned by contained fires is also projected to increase by 65% in Northern California in response to climate change (Fried et al. 2004). The area of oak woodland burned by contained fires is expected to increase by 65% in Northern California in response to climate change (Fried et al. 2004). However, long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

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/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **RED FIR**

CWHR Types: RFR¹: Red fir (*Abies magnifica*), white fir (*Abies concolor*), lodgepole pine (*Pinus contorta*)

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 workshop². The following document represents the vulnerability assessment results for the **RED FIR 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 disruption³.

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

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

¹ From California Wildlife Habitat Relationship (CWHR) habitat classification scheme see:

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.



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 evaluation⁴. 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.

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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	3 High	2 Moderate
Direct Sensitivities – Precipitation	3 High	3 High
Component Species	3 High	2 Moderate
Disturbance Regimes	3 High	2 Moderate
Climate-Driven Changes	3 High	2 Moderate
Non-Climatic Stressors – Current Impact	1 Low	2 Moderate
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	2 Moderate	2 Moderate
Other Sensitivities	2 Moderate	2 Moderate

Overall Averaged Confidence (Sensitivity)⁶: Moderate

Overall Averaged Ranking (Sensitivity)⁷: Moderate – High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	2 Moderate	3 High
Extent and Integrity – Fragmentation	2 Moderate	2 Moderate
Resistance and Recovery	2 Moderate	2 Moderate
Landscape Permeability	1 Low	2 Moderate
System Diversity – Physical/Topographical	3 High	2 Moderate
System Diversity – Component Species/Functional Groups	1 Low	2 Moderate
System Value	3 High	3 High
Specificity of Management Rules	3 High	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	2.5 Moderate-High
Precipitation	1.5 Low-Moderate
Shifts in vegetation type	3 High
Climatic water deficit	1.5 Low-Moderate
Wildfire	2 Moderate
Snowpack	3 High

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.



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)⁶: Moderate

Overall Averaged Ranking (Exposure)⁷: Moderate



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): High
 - i. Participant confidence: Moderate
- b. Sensitivity to precipitation (means & extremes): High
 - i. Participant confidence: High

Additional comments: The red fir system may have limited ability to move upslope. Red fir prefers areas with 30-49 in (762-1245 mm) of precipitation per year. It is vulnerable to declining snowpack even if overall precipitation increases.

References:

Temperature: In general, the climate of the red fir forest can be classified as cool with summer temperatures rarely exceeding 29° C and winter temperatures rarely below -29° C (Laacke 1990). However, red fir commonly grows in a buffered, riparian zone that reduces its sensitivity to annual climate fluctuations (Hurteau et al. 2007). Hurteau et al. (2007) suggest that the poor climate-growth relationship of red fir in the Teakettle Experimental Forest in the southern Sierra Nevada could be a result of buffering by microclimate at locations within the riparian zone.

Climate change, as indicated by warmer mean annual temperatures, may partially explain reduction of the red fir at a high elevation stand between 1948-2004 in the Sierra Nevada (Gonzalez et al. 2009).

Precipitation: Red fir is confined to cool/moist areas, typically in the upper montane zone at elevations above 1829 m and 2286 m (6000 ft and 7500 ft) in the northern and southern Sierra Nevada respectively (Laacke 1990; Long et al. 2013).

Red fir recruitment is associated with El Niño events perhaps due to enhanced winter snowpack and soil moisture levels (Barbour et al. 1991; North et al. 2005).

Snowpack: The upper montane red fir forests of northern California experience the highest snowpack of any vegetation type in the state and are strongly correlated with long-term mean April 1 snow water equivalence (SWE) rather than elevation (Barbour et al. 1991). The red fir is considered a climax species, and shares climax status with white fir at the upper limit of the white fir distribution (Laacke 1990). The shift in 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 red fir saplings to snowpack (Kunz 1988 cited in Barbour et al. 1990; Barbour et al. 1991), which are well adapted to heavy snows and ice (Gordon 1978).

2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: High
 - i. Participant confidence: Moderate

Additional comments: Hemlock and white fir are likely better suited to future climate changes as the density of large red fir has decreased by 50%. Higher mortality in smaller diameter red fir likely reflects warming and drying conditions. Red fir does best in well-developed, well-drained gravelly-loam soils, but also tolerates shallow soils. Red fir is sensitive to competition with lodgepole pine and white fir, which may be relatively less sensitive to climatic changes.

References: The component species display distinct associations with soil moisture gradients. For example, within red fir forests throughout the Sierra Nevada, lodgepole pine occupies wet sites, whereas dry sites in the south may be shared with sugar pine (*P. lambertiana*), mountain hemlock (*Tsuga mertensiana*) and incense cedar (*Calocedrus*) (Laacke 1990; North et al. 2002). The association between



El Niño events and red fir recruitment may be related to enhanced winter snowpack increasing soil moisture levels (Barbour et al. 1991; North et al. 2005). For example, Barbour et al. (1990) found that red fir and white fir seedlings established differentially in response to soil moisture. White fir were favored in open/xeric microhabitats, whereas red fir were favored in open/mesic microhabitats (Barbour et al. 1990). The soil 20 cm below the surface of a red fir site in Stanislaus National Forest contained 50% moisture (percent dry weight) 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, on steep slopes where soils are shallowest, red fir growth is poor and stands are open (Laacke 1990). At lower elevations, red fir is associated with riparian areas (North et al. 2002).

White fir may be better suited to adapt to the impacts of climate change relative to the red fir (Laacke and Tappeiner 1996), and white fir growth more closely follows trends in climate (Hurteau et al. 2007). In the Pacific Northwest, lodgepole pine grow best at sites with significant spring frost, summer temperatures averaging <15°C, and soils that fully recharge from snowmelt (Coops and Waring 2011).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, insects, disease
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: Moderate

Additional comments: Insect and disease issues include dwarf mistletoe (infects 40% of trees) and annosus root rot (a problem in dense stands). Drought may be an important, negative controlling agent of red fir regeneration after fire.

References:

Wildfire: Fire effects on red fir forests are generally poorly understood (Caprio 2000; see Long et al. 2013 for a discussion of relevant fire research). See Long et al. 2013 for a discussion of relevant research. It has both been suggested that upper montane red fir forests are not fire dependent (Barbour et al. 1990) and that fire was a major historic element in creating small openings in dense forests and preparing seedbeds for regeneration (Chappell and Agee 1996; Laacke and Tappeiner 1996). Historically, fire frequency in the red fir forest occurred at >50-year intervals (Pitcher 1987). Red fir forests were dominated by low- and moderate-intensity fires, resulting in small, scattered groups of regeneration (Kilgore 1971, Kilgore 1973, Agee 1990, and Taylor 1993 cited in Laacke and Tappeiner 1996; Taylor and Halpern 1991) and a patchwork of ages in trees (Kane et al. 2013), as red fir seedlings often take 3 to 4 years to establish after fire (Chappell and Agee 1996). 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). Intense fires, however, result in high mortality of red firs (Kane et al. 2013). Fire suppression policy instated in the early 1900s has reduced the fire frequency in these forests (Van de Water and Safford 2011). Reduced fire frequency can increase forest density and shift the forest composition to less fire tolerant species and more shade tolerant species (Bouldin 1999; Safford 2010)

Pathogens: Pathogens and pests, including dwarf mistletoe (*Arceuthobium abietinum* f. *sp. magnificae*), bark beetle (*Scolytus ventralis*), and root disease (*Heterobasidion annosum*) are major causes of fir mortality, while others, including broom rust (*Melampsorella caryophyllacearum*), trunk rot (*Echinodontium tinctorium*), and Douglas fir-tussock moth (*Orygia pseudotsugata*) have been shown to cause growth loss in the Teakettle Experimental Forest in the Sierra Nevada (Laacke 1990; North et al. 2002). Dwarf mistletoe infection and decay of red fir stands, however, may be important for wildlife (Laacke and Tappeiner 1996). The fir engraver, a bark beetle, is found throughout the range of red fir



and usually preys upon trees in conjunction with a disease or fire damage (Laacke 1990). Red and white fir can be infested by the fir engraver beetle while lodgepole and ponderosa pine can be infested by the mountain pine beetle (Living Assessment 2013).

A 2006 model estimated that 1.4 million acres (566,560 ha) of Sierra Nevada forest is susceptible to high levels of mortality due to insects and disease, where 'susceptible' is defined as the expectation that 25% or more of the standing tree volume would die over the next 15 years (Living Assessment 2013). In contrast, others have reported that insect infestations are relatively rare in the red fir forest (Laacke and Tappeiner 1996).

Drought: Red fir appears to be more sensitive to drought than white fir, but red fir also exhibits poor growth in water-logged soils (Laacke 1990). Pest pressure can increase tree sensitivity to drought (Waring et al. 1987).

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

- a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, evapotranspiration and soil moisture, altered hydrology
- b. Sensitivity to these climate and climate-driven changes: High
 - i. Participant confidence: Moderate

Additional comments: Red fir is sensitive to snowpack boundary, so as snow retreats, red fir stands will likely shift to cooler north slopes and move upward. However, soil constraints (e.g., moisture, nutrients) may limit movement in both (north and upslope) directions.

References:

Altered snowpack and hydrology: Red fir is considered to be a climax species, which dominates in areas with high average snowpack on April 1 (Barbour et al. 1991), and whose recruitment is associated with occurrence of El Niño events (North et al. 2005). In general, the southern portion of the Sierra Nevada forest has seen an increase in April 1 snowpack while the northern portion has seen a general decrease in snowpack from 1950-1997; however, there is a high degree of spatial heterogeneity (Moser et al. 2009).

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

- a. Sensitivity to other non-climate stressors including: Other – Altered interspecific interactions
- b. Current effects of these identified stressors on system: Low
 - i. Participant confidence: Moderate
- c. Degree stressors increase sensitivity to climate change: Moderate
 - i. Participant confidence: Moderate

Additional comments: Red fir is sensitive to non-climatic stressors that may increase its sensitivity to climate change, including recreation and water diversion, which alter soil moisture and the sediment regime. These non-climate stressors may exacerbate and/or accelerate climate impacts on red fir systems. Although red fir forests have not been historically logged, recently their harvest has become more common because their wood is very valuable. Some participants thought that increased timber extraction may accelerate sensitivity of the red fir system to climate change, however the literature is mixed. Pocket gophers (*Thomomys* sp.) reduce the establishment of red fir.

References: Red fir forests were historically not heavily logged in the Sierra Nevada because they were far from timber markets and located on inaccessible terrain (Laacke and Tappeiner 1996). Pocket gophers burrowing behavior has been shown to reduce the establishment of red firs in otherwise open



patches of land. This can cause a patchwork effect in forests, increasing heterogeneity (Laacke 1990; Laurent et al. 1994).

6. Other sensitivities.

- a. Other critical sensitivities not addressed: See additional comments
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase system sensitivity to climate change: Moderate

Additional comments: Other sensitivities include genetic bottlenecks and lack of appropriate soils in future climate space. Genetic bottlenecks may occur due to invasion of lodgepole and white fir, as well as fragmentation of habitat. Soils may not align with climate bands that could support red fir in the future, which could result in the red fir forest becoming more fragmented and persisting in discrete patches, making it vulnerable to disturbances other than climate (e.g. wildfire, road building, etc.).

7. Overall user ranking.

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

Additional comments: High sensitivity due to increased temperature, decreased snowpack, longer drought-affected soils, invasion by white fir and lodgepole pine, and non-climate stressors such as pocket gophers, insects, and mistletoe.



Adaptive Capacity

1. System extent and integrity.

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

Additional comments: Range of the red fir ecosystem is restricted to elevations between 1676-2134 m (5500-7000 feet). Red fir system exists in fragmented patches generally at elevations above 1829 m (6000 ft), and fragmentation is influenced by white fir and lodgepole pine. The system has limited ability to shift upslope.

References:

Geographic extent: Red fir forests occupy roughly 838,905 acres (339,492 ha) in the Sierra Nevada, 11% of the region's 7.8 million acres (3.1 million ha) (Long et al. 2013). 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). Red fir can also be found at lower elevations in canyons and cool riparian zones (Laacke 1990). From 1935 to 1992, the red fir forest subtype and the red fir-white fir forest subtype increased in landscape percent across the northern half of the Sierra Nevada by 8.9% and 2.5%, respectively. In contrast, the red fir-Jeffrey pine and red fir-western white pine forest subtypes have decreased in landscape percent by 6.3% and 5.1%, respectively. It is hypothesized that the Jeffrey pine and western white pine populations were replaced by more shade tolerant species such as mountain hemlock (Bouldin 1999). From 1935 to 1992, white fir-mixed conifer forests increased by 19.1% in the northern half of the Sierra Nevada (Bouldin 1999).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Moderate
 - i. Participant confidence: Moderate
- b. Suitable microclimates within the system that could support refugial communities: While red fir is susceptible to change at the landscape scale, examples of red fir receding and recovering under oscillating cold/dry and cool/wet periods support that it has persisted under past changing climate conditions.

3. Landscape permeability.

- a. Degree of landscape permeability: Low
 - i. Participant confidence: Moderate
- b. Potential types of barriers to dispersal that apply: Geologic features, arid lands

Additional comments: Red fir is restricted to cool/moist climates with significant snowpack. Adequate soils may be limited in the new elevations that will support the appropriate temperature bands and moisture for the red fir system.

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); more mature trees tend to produce more seeds. Seeds are distributed by wind as cones disintegrate, usually in late September and mid-October. Dispersal distance of California red fir seeds is usually 1.5 to 2 times the tree's height (Laacke 1990).



4. System diversity.

- a. Level of physical and topographic diversity: High
 - i. Participant confidence: Moderate
- b. Level of component species/functional group diversity: Low
 - i. Participant confidence: Moderate
- c. Description of diversity: System includes lodgepole pine, mountain hemlock, white fir, noble fir, and red fir. It appears that lodgepole pine, hemlock, white fir, and noble fir are better able to adjust to climatic changes than red fir, although red fir has been able to persist for thousands of years under changing climate conditions.

References:

Community structure: Red fir forests may be able to extend their range to higher elevations as temperatures warm and the growing season at elevation lengthens. "Pollen of white and red fir (*Abies concolor* and *A. magnifica*) and mountain hemlock suggests that during the early Holocene these species were only minor components of the Sierra Nevada forests. However, by approximately 6,000 years ago, each of these species increased in abundance, perhaps largely in response to changing climate and higher soil moisture levels. Because each of the tree species that increased during the late Holocene depends upon readily available soil moisture during the summer growing season, it has been suggested elsewhere (Anderson 1990) that either a reduction in the length of the summer dry season, an increase in precipitation during the winter months (as snow, lasting longer into the spring), a reduction in temperature causing reduced evaporation, or some combination of these processes would have favored the above-mentioned conifers" (Anderson 2004).

5. Management potential.

- a. Value level people ascribe to this system: High
 - i. Participant confidence: High
- b. Specificity of rules governing management of the system: High
 - i. Participant confidence: High
- c. Description of use conflicts: There is not strong development pressure though there is potential of increased human activity with warming climate.
- d. Potential for managing or alleviating climate impacts: Potential strategies include thinning of early seral stands to improve health and reduce mortality, managing for a variety of seral stages using the healthiest stands, and avoiding water diversions and other infrastructure that could modify groundwater patterns and flows.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: See comments below
 - i. Participant confidence: High
- b. Collective degree these factors affect the adaptive capacity of the system: High

Additional comments: It may be difficult to implement some management strategies (e.g., those related to fire) due to low social and/or political feasibility.

7. Overall user ranking.

- a. Overall adaptive capacity of the system: Low
 - i. Participant confidence: Moderate



Additional comments: Red fir will likely persist but warming, drying, longer summers, and more wildfire are all potential stressors to the detriment of the red fir system.



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, climatic water deficit, wildfire, snowpack, shifts in vegetation structure
 - i. Participant confidence: Moderate-High (temperature); Low-Moderate (precipitation); Low-Moderate (climatic water deficit); Moderate (wildfire); High (snowpack); High (vegetation)

2. Exposure by region.

- a. Overall exposure for different Sierra Nevada regions: North – Moderate-High; Central – Moderate-High; South – Moderate
 - i. Participant confidence: Moderate (all)
-

3. Overall user ranking.

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

References:

Distribution: A predominant effect of climate change in the Sierra Nevada regions will likely result in loss of red fir/lodgepole pine communities, especially at higher elevations (PRBO Conservation Science 2011). Based on other climate scenarios, lodgepole pine distributions in California are predicted to increase slightly to 2020 then decrease significantly by the end of the century (Miller 2003).

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 (GDFL⁹ and PCM¹⁰) 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

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.

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.



projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5°C warming (Dettinger et al. 2004b). Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to advance the runoff center of mass by 1-7 weeks by 2100 (Maurer 2007), although advances will likely be non-uniformly distributed in the Sierra Nevada (Young et al. 2009). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds, decreasing mean 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). 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). The change in modeled water deficit from present climate to future climate scenarios for Yosemite National Park is much greater than the change from the Little Ice Age to present (Lutz et al. 2010). The forecasted increase in deficit may be partially offset by increases in actual evapotranspiration in spring and autumn. Individual trees that established c. 1700 may be at risk of deficit related mortality if they are located near the North American range limit for the species; some plots in Yosemite National Park occupied by white fir and red fir may fall into this category (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) 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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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).



Pests: Increases in temperature regimes and shift in precipitation events may increase the susceptibility of lodgepole pine to pests. The mountain pine bark beetle (*Dendroctonus ponderosae*) is a recognized threat to pine species, primarily lodgepole pine, in western North America (Coops et al. 2012; Murdock et al. 2013). Studies in western Canada indicate that increased size and severity of mountain pine beetle outbreaks have been attributed to the reduced severity of winter temperatures, and to the increased abundance of its principal host, lodgepole pine (Coops et al. 2012; Murdock et al. 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>).

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Focal Resource: **SAGEBRUSH**

CWHR Types¹: **SGB:** Sagebrush species (*Artemisia* spp.), **BBR:** Rabbitbrush species (*Chrysothamnus* spp., *Ericameria* spp., *Lorandersonia* spp.), **LSG:** Horsebrush (*Tetradymia* 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 workshop². The following document represents the vulnerability assessment results for the **SAGEBRUSH 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 disruption³.

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/cw/hr/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 evaluation⁴. 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

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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	2 Moderate	3 High
Direct Sensitivities – Precipitation	2 Moderate	3 High
Component Species	No answer provided by participants	2 Moderate
Disturbance Regimes	3 High	3 High
Climate-Driven Changes	2.5 Moderate-High	2.5 Moderate-High
Non-Climatic Stressors – Current Impact	2.5 Moderate-High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	1 Low	3 High
Other Sensitivities	None	No answer provided by participants

Overall Averaged Confidence (Sensitivity)⁶: High

Overall Averaged Ranking (Sensitivity)⁷: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	2.5 Moderate-High	3 High
Extent and Integrity – Fragmentation	2 Moderate	2 Moderate
Resistance and Recovery	1.5 Low-Moderate	2.5 Moderate-High
Landscape Permeability	2.5 Moderate-High	1-3 Low to High
System Diversity – Physical/Topographical	Variable	3 High
System Diversity – Component Species/Functional Groups	2.5 Moderate-High	3 High
System Value	1.5 Low-Moderate	2 Moderate
Specificity of Management Rules	2 Moderate	3 High
Other Adaptive Capacities	No answer provided by participants	No answer provided by participants

Overall Averaged Confidence (Adaptive Capacity)⁶: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁷: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	3 High
Precipitation	3 High
Dominant vegetation type	3 High

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 columns.



Relevant Exposure Factor	Confidence
Climatic water deficit	3 High
Wildfire	3 High
Snowpack	2 Moderate
Runoff	2 Moderate
Timing of flows	2 Moderate
Low flows	2 Moderate
High flows	2 Moderate

Exposure Region	Exposure Evaluation	Confidence
Northern Sierra Nevada	2 Moderate	1.5 Low-Moderate
Central Sierra Nevada	2 Moderate	1.5 Low-Moderate
Southern Sierra Nevada	3 High	1.5 Low-Moderate
East	3 High	1.5 Low-Moderate

Overall Averaged Confidence (Exposure)⁶: Low-Moderate

Overall Averaged Ranking (Exposure)⁷: Moderate-High



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): Moderate
 - i. Participant confidence: High
- b. Sensitivity to precipitation (means & extremes): Moderate
 - i. Participant confidence: High

Additional comments: Many attributes of sagebrush ecosystem structure are sensitive to temperature and precipitation. For example, the transition from sagebrush to desert shrublands is driven by a combination of temperature and seasonality of precipitation. The proportion of herbaceous species in the understory has been correlated to precipitation, and tree invasion has been correlated to cooler temperatures and greater precipitation.

References identified by participants: Slaton and Stone 2013.

References:

Precipitation: *Artemisia* species are largely drought tolerant (Lenihan et al. 2008). However, big sagebrush is limited by summer moisture stress, and aridity defines its southern range limit (Shafer et al. 2001). Implications for big sagebrush ecosystems in the semiarid western United States under declining snow conditions depend on area-specific climatic conditions determined by the snow:precipitation ratio (Schlaepfer et al. 2012b). However, the influence of timing and amount of precipitation on the ability of water to percolate into deeper soil layers plays a greater role than whether precipitation falls as rain or snow (Schlaepfer et al. 2012c). Drought negatively affects seedling survival in sagebrush systems, and seedling establishment occurs intermittently in pulses during years with favorable conditions (Maier et al. 2001). The proportion of herbaceous species in the sagebrush understory has also been positively correlated with precipitation. However, greater precipitation and cooler temperatures are also correlated with areas experiencing tree invasion (Slaton and Stone 2013).

2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: no answer provided by participants
 - i. Participant confidence: Moderate

Additional comments: Differences exist among sagebrush taxa, and vulnerability varies across the landscape. Sensitivity of cheatgrass was ranked as High. Sensitivity of bitterbrush was ranked as Moderate or High (participant opinions differed). Sensitivity of pinyon and juniper were ranked as High. Component species distribution is driven more by precipitation than temperature, although animal interactions (e.g. deer) are also important.

References identified by participants: Flint suggests cold air pooling may provide habitat in the future (L. Flint, pers. comm.; http://ecoadapt.org/data/documents/Flint_CAHydrology.pdf). The Nature Conservancy has Sierra Nevada wide projections on sagebrush distributions (e.g., see maps available on Data Basin: <http://databasin.org/galleries/8c5db744f9fe4d3e9375b100dc695c4d>).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire (high), drought (moderate), flooding (moderate or low), other – cattle grazing (moderate or high)
- b. Sensitivity to these disturbance regimes: High
 - i. Participant confidence: High



Additional comments: Participants ranked wildfire sensitivity as High because wildfire may lead to cheatgrass invasion. Participants ranked drought sensitivity as Moderate because drought affects seedling survival and fire. Participants ranked flooding sensitivity as Moderate or Low (participant opinions differed) because flooding is localized, but could become more pervasive. Participants ranked grazing sensitivity as Moderate or High (participant opinions differed) because grazing controls the understory growth and affects soil surface stability.

The sagebrush species *Artemisia californica* from coastal scrub systems resprouts, but the sagebrush species from the intermountain sagebrush systems does not.

References identified by participants: Slaton and Stone 2013.

References:

Wildfire: Although lightning-ignited fires historically created disturbances necessary to maintain the sagebrush grassland community (Bates et al. 2009; Hanna 2012), sagebrush steppe plant communities can vary in their post-fire succession (Hanna 2012). Big sagebrush shrubs do not resprout after fire or other disturbance, and the shrubs are killed by most fires (Tirmenstein 1999). Frequent fire may limit recovery in Wyoming big sagebrush communities, while low frequency fire in mountain big sagebrush communities may result in conifer encroachment (Davies et al. 2011). Fire may also reduce suitable habitat for sage-grouse (Hanna 2012), and fire and drought lead to annual grassland invasion (Lenihan et al. 2008).

Drought: *Artemisia* spp. is drought tolerant. During the summer dry period, moisture extraction is facilitated by concentration of fine roots and water use near the main axis of the tap root, in addition to a broadly spreading superficial root system found in older sagebrush plants (Sturgis 1977; Welch and Jacobson 1988; Welch 1997; Schlaepfer et al. 2012c). In addition, *A. tridentata* roots appear to maintain nutrient uptake even in dry soil layers, contributing to growth and reproduction during moisture-limiting summer and fall (Matzner and Richards 1996).

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

- a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, altered hydrology, evapotranspiration and soil moisture, extreme temperature and precipitation events, storms
- b. Sensitivity to these climate and climate-driven changes: Moderate-High
 - i. Participant confidence: Moderate-High

Additional comments: Invasion by exotic annual grasses that change the fire regime and are very difficult to exclude from burned areas are becoming a major threat to sagebrush systems as fire frequencies increase. As fire frequency and intensity increases, many sagebrush species (e.g. big sagebrush) might be killed and may not have the ability to re-sprout.

References:

Altered hydrology: Sagebrush is sensitive to the presence and timing of winter precipitation (Schlaepfer et al. 2012a).

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

- a. Sensitivity to other non-climate stressors including: Residential and commercial development, agriculture, energy production and mining, transportation and service corridors, biological resource use, human intrusions and disturbance, invasive and other problematic species



- b. Current effects of these identified stressors on system: Moderate-High
 - i. Participant confidence: High
- c. Degree stressors increase sensitivity to climate change: Low
 - i. Participant confidence: High

Additional comments: Participants rank the system sensitivity to non-climate stressors as follows: Grazing: Moderate; Energy production: Moderate; Transportation: Moderate (because of the risk of introducing cheatgrass); Human intrusion: Moderate (because of the risk of introducing cheatgrass); Invasive species: High (principally cheatgrass); Juniper expansion: High (altered fire regime and change in wildlife habitat). Additional non-climate disturbances affecting recruitment and dispersal of sagebrush vegetation include agriculture, land development, geologic features such as mountain ranges, and extremely arid lands. Off-highway vehicle use, mining, and energy production represent additional use conflicts.

References: Changes in historic fire regimes, poor grazing management, and other factors may also contribute to woody encroachment in semiarid systems in the Interior West, for example, the invasion of juniper (*Juniperus spp.*) species into sagebrush steppe (Meyer 2012). Fire suppression policies, which increased the mean fire return interval, have resulted in sagebrush stands becoming more dense thereby reducing the productivity of annual grasses and forbs (Hanna 2012).

Residential and commercial development: The sagebrush steppe landscape has been fragmented by urban expansion, agriculture and energy and mining operations in the Intermountain West (Hanna 2012).

Invasive and other problem species: A bioclimate envelope model for invasive cheatgrass suggests that decreases in precipitation, particularly in summer, may facilitate expansion of cheatgrass and elevate the risk of invasion in the intermountain west and California (Bradley 2009). Spread of invasive species and overgrazing has led to degradation of sagebrush communities (Hanna 2012). Cheatgrass expansion contributes to increase fire frequency in sagebrush communities (Knick et al. 2003; Baker 2006; USFWS 2013), and can change the fire return interval from the natural 20 to 100 years for sagebrush grassland ecosystems to 3 to 5 years (Ypsilantis 2003). A combination of cheatgrass fuels and dry winters and springs has already resulted in the fire season shifting from late summer to early spring in some parts of the eastern Sierra Nevada (Slaton and Stone 2013).

6. Other sensitivities.

- a. Other critical sensitivities not addressed: No
 - i. Participant confidence: no answer provided by participants
- b. Collective degree these factors increase system sensitivity to climate change: N/A

References:

Soil: The ability of cold desert soils in the Interior West to retain soil organic carbon could be reduced by the effects of ongoing climate change. Aanderud et al. (2010) showed in an 11-year rain manipulation study that near-surface (0-300 mm or 0-12 in) soil organic carbon stocks in a sagebrush steppe (*A. tridentata*) community were significantly reduced when precipitation was shifted from a winter pattern to a spring-summer pattern. They credited this loss to increased microbial activity in wet surface soil at warm temperatures. Shifts from winter to spring-summer rainfall patterns are predicted for many parts of the Interior West as climate continues to warm. Rainfall timing impacts on deep soil organic carbon would be expected to be lower, however, because deep soil organic carbon is more buffered from seasonal temperature changes. This would tend to mitigate the effects of increased warm-season precipitation on soil C storage (Meyer 2012).



The presence of fungi (e.g. genus *Glomus*) may be required for the successful establishment of some big sagebrush (e.g. *A. tridentata* subsp. *tridentata*) seedlings (Rosentreter and Jorgensen 1986 cited in Tirmenstein 1999). Areas that experience frequent fire and are subsequently dominated by non-mycorrhizal cheatgrass may no longer maintain soil fungi. These sites may experience inhibited sagebrush reestablishment (Rosentreter and Jorgensen 1986 cited in Tirmenstein 1999).

7. Overall user ranking.

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

Additional comments: Sagebrush systems are not as sensitive as alpine or riparian systems, although an altered fire regime, invasive species (cheatgrass), and grazing make the sensitivity fairly high.



Adaptive Capacity

1. System extent and integrity.

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

Additional comments: Sagebrush occurs across a large area in the eastern Sierra Nevada and in the Great Basin to the east and north. Its extent is moderately fragmented by transportation corridors, fire and invasive cheatgrass. It is also fragmented by desert shrubland in the southern Sierra Nevada, and by pinyon juniper and yellow pine throughout the Sierra Nevada.

References:

Geographic extent: The sagebrush biome is the largest semi-arid ecosystem in the western United States, comprised of 62.7 x 106 ha (155 x 262 ac) (West 1983) and two ecosystem types: sagebrush steppe and Great Basin sagebrush (Miller and Eddleman 2000). Sagebrush (*Artemisia* spp.) occurs in the eastern Sierra Nevada and the Great Basin to about 1200 m (3937 ft) (Schlaepfer et al. 2012b) and big sagebrush (*A. tridentata*), a dominant species in sagebrush systems, is one of the most widespread shrubs in the western U.S (Freeman et al. 1991).

Shrublands (including sagebrush steppe, southern coastal scrub and chamise chaparral) currently cover approximately 21% of the Sierra Nevada landscape and about 3 % of Sierra Nevada Foothills, and grasslands currently cover approximately 10% of the Sierra Nevada landscape and 50% of the Sierra Nevada foothills. Subtropical arid lands (creosote brush scrub, saltbrush scrub, Joshua tree woodland) currently make up only about 2% of current Sierra Nevada Foothills landscape (Lenihan et al. 2008; North 2012).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Low-Moderate
 - i. Participant confidence: Moderate-High
- b. Suitable microclimates within the system that could support refugial communities: Some of the high-elevation desert mountains to the south may serve as refugial communities because they have been protected. At higher elevations and in the northern Sierra Nevada, refugial communities may exist on slopes or soils that do not have the potential to support trees, and, thus, may persist as sagebrush shrublands. Sagebrush restoration time is variable. In some cases it may recover in less than 50 years from disturbance, so recovery may be faster than in forests that require more time, but the presence of grazing and invasive cheatgrass create new steady states, which can slow sagebrush recovery.

Additional comments: Sagebrush reproduction is highly dependent upon distance from parent plant. Patchy fires that leave seed sources intact may recover more quickly than ones that remove seed sources.

References:

Seed dispersal: Although big sagebrush shrubs do not resprout after fire or other disturbance, and the shrubs are killed by most fires, abundant seed production from nearby unburned plants, coupled with high germination rates, enables rapid sagebrush establishment following fire (Goodwin 1956, and Sheehy and Winward 1991 cited in Tirmenstein 1999). However, approximately 90% of big sagebrush



seed disperses within 9 m (30 ft) of the parent plant, and few seeds are dispersed more than 30 m (100 ft) (Goodrich et al. 1985, and Shuman and Anderson 1986 cited in Tirmenstein 1999).

Recovery: The restoration potential of sagebrush communities is uncertain (Hemstrom et al. 2002), and once impacted, alteration of vegetation, nutrient cycles, and living (cryptobiotic) soil crusts may exceed recovery thresholds, impeding the restoration of suitable sagebrush habitat (Knick et al. 2003).

Processes to restore healthy native sagebrush systems are largely unknown and may require decades or centuries (Hemstrom et al. 2002; Knick et al. 2003).

3. Landscape permeability.

- a. Degree of landscape permeability: Moderate-High
 - i. Participant confidence: Low-High
- b. Potential types of barriers to dispersal that apply: Agriculture, industrial or urban development, suburban or residential development, geologic features, arid lands, mountains

Additional comments: Sagebrush is widespread, wind pollinated and dispersed. Mountain ranges and valleys can block dispersal. Some sagebrush regions exhibit high permeability, others exhibit moderate permeability.

References: Seedling survival and establishment occurs intermittently, in pulses each year, during favorable conditions (Maier et al. 2001).

4. System diversity.

- a. Level of physical and topographic diversity: Variable
 - i. Participant confidence: High
- b. Level of component species/functional group diversity: Moderate-High
 - i. Participant confidence: High
- c. Description of diversity: Sagebrush systems exhibit high evolutionary diversity, including bitterbrush, snowberry, ceanothus, rabbitbrush, as well as diverse forbs and graminoids found in the understory. The sagebrush genus contains multiple taxa and hybrids, and different species and subspecies occupy different areas. Higher diversity occurs at the lower and upper elevational boundaries of the system.

References identified by participants: Dave Tart (USFS, Regional Vegetation Ecologist), Dr. Robin Tausch (USFS, Research Range Scientist), and Jeanne C. Chambers (USFS, Research Ecologist).

References:

Component species: Thirty native taxa of sagebrush (*Artemisia* spp.) exist in California (Goodrich 2005; Hanna 2012), with southern taxa differing from northern taxa in habitat affinity, structure, or both (Montalvo et al. 2010). Varying edaphic, climatic and topographic conditions help to diversify the sagebrush landscape (West 1983 cited in Hanna 2012). Sagebrush landscape provides habitat for approximately 100 bird species and 70 mammal species (Hanna 2012).

5. Management potential.

- a. Value level people ascribe to this system: Low-Moderate
 - i. Participant confidence: Moderate
- b. Specificity of rules governing management of the system: Moderate
 - i. Participant confidence: High



- c. Description of use conflicts: Multiple use conflicts include grazing, hunting, recreation and off-highway vehicle (OHV) use, mining and energy production, and transportation.
- d. Potential for managing or alleviating climate impacts: There is a high potential to manage grazing. Improved management over last decade has resulted in much restoration.

Additional comments: There is a moderate level of regulation for sagebrush, primarily on federal lands with general regulation. In contrast, there is very high degree of regulation concerning sage-grouse.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: no answer provided by participants
 - i. Participant confidence: no answer provided by participants
- b. Collective degree these factors affect the adaptive capacity of the system: no answer provided by participants

7. Overall user ranking.

- a. Overall adaptive capacity of the system: Variable
 - i. Participant confidence: Variable

Additional comments: The participants have very diverse views and consensus was not reached. Adaptive capacity is variable, and depends on several factors, including elevation and geographic region (i.e. whether it is in the northern or southern Sierra Nevada). Some participants believe sagebrush displays very high adaptive capacity and that the system will move north and west, while others believe it displays low capacity, which will be exacerbated with pinyon-juniper encroachment.

References:

Vegetation changes: MC1 simulations are consistent with results from other scenario models (e.g., Lenihan et al. 2003; Hayhoe et al. 2004), projecting a decline in shrubland cover in California (Lenihan et al. 2008). Of 146 evergreen species in the southwest US modeled by Notaro et al. (2012), the two evergreen species with the largest projected range contractions are limber pine (*Pinus flexilis*) and big sagebrush (*A. tridentata*). Bioclimate modeling predicts that big sagebrush in the interior American West will shift northward, in response to increases in the mean temperature of the coldest month, and exhibit substantial range contraction due to increased summer moisture stress (Shafer et al. 2001). These results support the Neilson et al. (2005) bioclimate model prediction that sagebrush habitat in the Great Basin will decline due to synergistic effects of temperature increases, fire and disease, and to displacement by species moving north from the Mojave Desert in response to the northward shift in frost lines (Friggens et al. 2012). Areas currently occupied by big sagebrush are expected to become occupied by the northward expansion of the creosote bush (*Larrea tridentata*) (Shafer et al. 2001; Friggens et al. 2012). As the frequency of extreme drought increases, plant mortality is likely to occur in rapid pulses rather than gradual declines. This may result in isolated relict patches, which may inhibit the ability of the plant to recover and expand into more hospitable environments in northwestern Arizona (Gitlin et al. 2006).



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, dominant vegetation type, climatic water deficit, wildfire, snowpack, runoff, timing of flows, low flows, high flows
 - i. Participant confidence: High (temperature), High (precipitation), High (dominant vegetation type), High (climatic water deficit), High (wildfire), Moderate (snowpack), Moderate (runoff), Moderate (timing of flows), Moderate (low flows), Moderate (High flows)

2. Exposure region.

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

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: Moderate
 - i. Participant confidence: Moderate

Additional comments: Geographic area of interest makes difference in interpretation. Consistent maps are needed.

References: Using applied ecohydrology variables, Schlaepfer et al. (2012a) also project substantial decreases in big sagebrush in the southern part of the range and increases in the northern parts, with small increases at higher elevations (e.g. at the interface with coniferous forests). Increases in habitat-suitability for big sagebrush ecosystems at high elevations may be a result of earlier and longer growing season (Schlaepfer et al. 2012a). While both the climatic and ecohydrological species distribution models run by Schlaepfer et al. (2012a, 2012c) suggest large scale splitting of sagebrush ecosystem into disjunct areas, the ecohydrologic model predicts many smaller regions (i.e. Sierra Nevada, Washington, areas in Oregon and northern Nevada, central Idaho, and an area in eastern Utah, Wyoming, Colorado, and eastern Montana), while the climatic model predicts fewer, larger areas.

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 (GDFL⁹ and PCM¹⁰) 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

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.

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.



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

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

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

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



meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

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

Wildfire: 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 (Miller et al. 2009).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the 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/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **YELLOW PINE/MIXED CONIFER**

CWHR Types¹: **PPN**-Ponderosa pine, Jeffrey pine, Douglas fir, black oak; **JPN**-Jeffrey pine, ponderosa pine, sugar pine; **EPN**-Ponderosa pine, Jeffrey pine, white fir; **SMC**-Douglas fir, ponderosa pine, white fir, black oak and canyon live oak; **DFR**-Douglas fir, tanoak, ponderosa pine, canyon live oak; **WFR**-White fir, Douglas fir, sugar pine

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 workshop². The following document represents the vulnerability assessment results for the **YELLOW PINE/MIXED CONIFER 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 disruption³.

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.



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.

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 evaluation⁴. 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

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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>.



Overview of Vulnerability Component Evaluations

NOTE Content reflects both group participant elicitation and additional input by an external system expert. Where rankings differed between group and system expert, rankings in the tables below reflect input of system expert. Both rankings (group and system expert) are captured in the ‘Additional comments’ sections on sensitivity, adaptive capacity, and exposure, below.

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	2 Moderate	2 Moderate
Direct Sensitivities – Precipitation	2 Moderate	3 High
Component Species	1 Low to 3 High	3 High
Disturbance Regimes	2.5 Moderate–High	3 High
Climate-Driven Changes	2.5 Moderate–High	3 High
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	3 High
Other Sensitivities	None identified	1.5 Low-Moderate

Overall Averaged Confidence (Sensitivity)⁶: Moderate-High

Overall Averaged Ranking (Sensitivity)⁷: Moderate–High

ADAPTIVE CAPACITY

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

Overall Averaged Confidence (Adaptive Capacity)⁶: High

Overall Averaged Ranking (Adaptive Capacity)⁷: Moderate-High

EXPOSURE

Relevant Exposure Factor	Confidence
Climatic water deficit	3 High
Wildfire	3 High

⁶ ‘Overall user perceived ranking’ is participant group’s estimation of the overall sensitivity, adaptive capacity or exposure, given their knowledge and expertise in the subject area.

⁷ ‘Overall averaged ranking’ is the mean of the perceived rank entries provided in the respective evaluation columns.



Relevant Exposure Factor	Confidence
Snowpack	3 High

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

Overall Averaged Confidence (Exposure)⁶: Moderate

Overall Averaged Ranking (Exposure)⁷: Moderate / Moderate–High



Sensitivity

1. Direct sensitivities to changes in temperature and precipitation.

- a. Sensitivity to temperature (means & extremes): Low (group); Moderate (external system expert)
 - i. Participant confidence: High (group); Moderate (external system expert)
- b. Sensitivity to precipitation (means & extremes): Low (group); Moderate (external system expert)
 - i. Participant confidence: High (both)

Additional comments: The yellow pine/mixed conifer system is well studied, and persists under wide elevational range and/or climatic change. Changes in water balance and fire regimes are by far the greatest threats to the system. Long-term trends in yellow pine/mixed conifer forests are mostly driven by changes in available water (i.e. temperature x precipitation), as water availability drives forest health and vigor, and reduces fire activity, among other things.

References: There is substantial heterogeneity in species' sensitivity to climate (Battles et al. 2008; Scholl and Taylor 2010), however, growth and establishment of component species within the mixed conifer system are often positively associated with precipitation. For example, annual diameter increment for white fir, sugar pine and giant sequoia is positively correlated to winter precipitation on the western slope of the southern Sierra Nevada (York et al. 2010). Similarly, establishment of Jeffrey pine, sugar pine, and red fir are significantly associated with El Niño events, which cause wetter and warmer average conditions and a deep snowpack in the winter (North et al. 2005). Mixed conifer forest mortality was related to multiyear episodes of high spring and summer temperatures and low annual and seasonal precipitation in Yosemite National Park (Guarín and Taylor 2005), and conifer tree growth in the mixed forest has been shown to decline with decreases in winter precipitation and increases in summer temperature (Yeh and Wensel 2000).

Temperature: Of four variables tested, conifer tree growth in mixed forest was most sensitive to summer temperature (Yeh and Wensel 2000). A regional model for the southwestern U.S. indicated that ponderosa pine seedling densities were highest where average minimum May temperatures were highest (Puhlick et al. 2012).

2. Sensitivity of component species.

- a. Sensitivity of component species to climate change: Low (group); Low, Moderate, and High [*i.e. variable*] (external system expert)
 - i. Participant confidence: No answer provided by workshop participants; High (external system expert)

Additional comments: The ranking provided does not consider disturbance effects on species/ habitats, for instance, the risk of fire destroying fisher and/or owl habitat.

Much of the mixed conifer forest was yellow pine forest before logging and fire suppression. Successional processes have lead to dominance by shade-tolerant species that are less drought and fire tolerant than the pine species they are supplanting. The conifer species that are better set up to survive climate warming and drought are now those that are less dominant, but beetle outbreaks will likely seriously thin their ranks.

References:

Beetles and disease: Dwarf mistletoe (*Arceuthobium abietinum* f. *sp. magnificae*), bark beetle (*Scolytus ventralis*), and annosus root disease (*Heterobasidion annosum*) are major causes of white fir mortality,



while infestations of broom rust (*Melampsorella caryophyllacearum*), trunk rot (*Echinodontium tinctorium*), and the Douglas fir-tussock moth (*Orygia pseudotsugata*) have been shown to cause growth-loss in white fir (Laacke 1990; North et al. 2002). Exposure to pests can reduce tree vigor and increase tree susceptibility to additional pathogens and pests, potentially exacerbating the impacts of climate change. For instance, annosus root rot can increase the likelihood a tree will become infested by insects (Laacke 1990), and pest pressure can increase tree sensitivity to drought (Waring et al. 1987) and conversely, drought combined with increasing minimum temperatures, may enhance infestation of pine beetles in whitebark and limber pines (Millar et al. 2010). Attacks of bark beetle and pine beetle on Jeffrey pine and ponderosa pine have been associated with years of water shortage in the western U.S. (Gulke et al. 2009; Gulke 2010). The risk of widespread beetle-related mortality may also increase as winter temperatures warm, since prolonged periods of low temperatures result in significant overwintering mortality in some bark beetle species, but not others (Amman 1973, and Safranyik and Linton 1991 cited in Fettig et al. 2007). Moreover, pest pressure may indirectly reduce the capacity of conifers to adapt to climate change. For instance, Gulke (2010) suggests that the low ecophysiological trait variability displayed by sugar pine populations may be a result of pine blister rust experienced California-wide in the mid-1970s and 1980s.

Ponderosa pine: Warmer, drier sites are preferred by ponderosa pine (Scholl and Taylor 2010). Ponderosa pine growth is strongly limited by summer soil moisture in drier eastside Cascade and westside Rockies locations (Fagre et al. 2003), and earlier springtime drying of soils could result in reduced or delayed germination and increased seed mortality (Puhlick et al. 2012). In addition, changes in fire regimes may threaten old ponderosa pine forests, already rare (Strom and Fule 2007). In the Placerville quadrangle of the Sierra Nevada, the western edge of the ponderosa pine forest moved an average of 7.1 km (4.4 mi) eastward and shifted about 193 m (633 ft) upward between 1934 and 1996, with the previously ponderosa-dominated areas being replaced by non-conifer species (e.g. oaks), and climate change was likely at least partially responsible for the changes (Moser et al. 2009).

Jeffrey pine: Shade intolerant Jeffrey pine lagged in response to annual climatic fluctuations, possibly because its roots tap water reserves in bedrock fissures (Hurteau et al. 2007). Despite its restricted geographic range relative to white fir and ponderosa pine in the western U.S., Jeffrey pine exhibit high variability in key ecophysiological traits, and exhibited the greatest needle and branch elongation growth in the driest site (Gulke 2010).

Sugar pine: Sugar pine populations are likely vulnerable to climate changes due to the apparent low variability of key ecophysiological traits. Sugar pine had the least variability in ecophysiological traits of four pine species (i.e. sugar pine, white fir, ponderosa pine and Jeffrey pine) studied in the western U.S. (Gulke 2010).

Giant sequoia groves: A significant and positive correlation between winter precipitation and diameter growth was documented for all subsets of giant sequoia, regardless of canopy status or location (i.e. gap adjacent or reference). Conversely, no correlation was found between growth and summer temperature (York et al. 2010). Extreme positive growth anomaly years in mid-elevation giant sequoias in the central and southern Sierra Nevada are characterized by wet winters with temperatures near the mean and average or somewhat cool summers, while negative growth anomaly years are characterized by warm dry winters and somewhat warm summers (Garfin 1998). Soil moisture is a primary factor in the restriction of grove boundaries to their present locations (York et al. 2010), and future climate scenarios forecast increased water deficit for giant sequoia (Lutz et al. 2010).

Douglas fir: Daily maximum temperature optimum for Douglas fir in western Oregon decreased with available soil water at drier sites (Beedlow et al. 2013), suggesting that vulnerability to warmer predicted summers, particularly at drier sites, could become increasingly limiting (Beedlow et al. 2013).



Modeled responses of more southern and outlying populations responded less negatively to drought conditions, which may indicate genetic adaptation to local climate (Chen et al. 2010).

White fir: White fir, red fir and mountain hemlock depends on readily available moisture during the summer growing season (Anderson 2004). White fir is found on cool, mesic slopes (Scholl and Taylor 2010). In the western Sierra Nevada, white fir often grows in clusters, in mid-slope stands, and is a strong shade-tolerant competitor, which may allow it to capitalize on available moisture, resulting in increased responsiveness to inter-annual fluctuations in precipitation (Hurteau et al. 2007).

3. Sensitivity to changes in disturbance regimes.

- a. Sensitivity to disturbance regimes including: Wildfire, drought, insects, disease
- b. Sensitivity to these disturbance regimes: Low – all disturbances (group); Moderate-High (external system expert)
 - i. Participant confidence: Moderate (group); High (external system expert)

Additional comments: Yellow pine/mixed conifer forests are fairly sensitive to changes in fire regime, increased incidence of insects and disease, and increased drought, although not as sensitive as wet meadows to disturbances such as drought. Positive feedback cycles between these increasing disturbance regimes and the changes to the system they facilitate will exacerbate similar effects and trends.

References:

Wildfire: Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in Yosemite National Park (YNP) (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 2012). 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). Increases in fire will likely benefit comparatively fire-tolerant broadleaf trees on historically mixed conifer landscapes (Lenihan et al. 2008).

Since the 1980s, the Sierra Nevada has experienced an increase in large fires (>1000 acres) (>404 ha). This increase correlates to increasing temperatures and earlier snowmelt (Westerling and Bryant 2006). Fire severity has also risen from 1984-2007, especially in the middle-elevation conifer forests. In 1984, fires burned an average of 17% high (stand replacing) severity, compared to 30% in 1997-2007 (Miller et al. 2009). In parts of the southern Cascades (Taylor et al. 2008 cited in Taylor and Scholl 2012) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), higher fire activity is weakly associated with El Niño (warm), while in Yosemite National Park, large fires were associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). Fire frequency is usually higher on south-facing relative to north-facing slopes (Taylor 2000) and at mid- to upper-slope positions, due to higher winds, lower canopy cover, and fuel characteristics (Rothermel 1983). However, in Yosemite mixed conifer forests no spatial trend in fire frequency was found (Scholl and Taylor 2010).

Drought: Although mixed conifer forests in the Sierra Nevada have persisted through more severe



droughts (Cook and Krusic 2004 cited in North et al. 2009) than those experienced today, the long-term effects of warming and drying are largely unknown (North et al. 2009).

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

- a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, air pollution, altered hydrology (both)
- b. Sensitivity to these climate and climate-driven changes: High (group); Moderate-High (external system expert)
 - i. Participant confidence: No answer provided by workshop participants; High (external system expert)

Additional comments: Although mixed conifer forests are adapted to frequent low and moderate severity fire, changes in the fire regime can lead to type conversion, resulting in the loss of flagship and keystone species. Such changes in the fire regime, combined with logging of the pine species, have already converted millions of acres of yellow pine forest to mixed conifer forest.

Decreases in precipitation will likely lead to decreased groundwater recharge, which may lead to loss of flagship giant sequoia. Snowpack changes are having major effects on trends in fire and conifer mortality. In addition, air pollution is a major stressor in the southern Sierra Nevada and effects are moving north.

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

- a. Sensitivity to other non-climate stressors including: Transportation and service corridors, other – fire suppression
- b. Current effects of these identified stressors on system: High (both)
 - i. Participant confidence: High (both)
- c. Degree stressors increase sensitivity to climate change: High (both)
 - i. Participant confidence: High (both)

Additional comments: Fire suppression and fuel loading practices lead to changes in species composition. Transportation corridors affect connectivity, potentially leading to type conversion and establishment of invasive species. Establishment of exotic grasses may subsequently facilitate changes in fire regimes. Historical livestock grazing occurred throughout the mixed conifer forest.

External system expert: The key non-climate stressor is fire suppression. Its long term and ironic implications are going to be the loss of much of the yellow pine/mixed conifer belt as climates continue to warm.

References:

Fire suppression: Fire suppression has lead to structural homogenization and changes in species composition, facilitating increased tree densities and occupation by shade-tolerant species at the expense of species like Jeffrey pine, sugar pine and western white pine (Bouldin 1999; Beaty and Taylor 2008; Scholl and Taylor 2010; Safford et al. 2012b). Fire suppression could alter species and individual growth response to climate in Sierran forests (Hurteau et al. 2007), and increase the probability of catastrophic burns by “laddering” fire into the canopy crown (Miller and Urban 2000; North et al. 2002). In Yosemite, fire suppression has reduced fire frequency from every ten years to every 378 years, causing tree densities to increase. In the early 1900s, Yosemite had an average of 160 trees/ha (~395 trees/ac) composed mostly of pine and oak; in 2003 threefold more trees were present, and were on average 20% smaller, ¼ of which were pine and oak with a ten-fold increase in white fir (Scholl and Taylor 2010).



In the Lake Tahoe Basin the greatest compositional changes during the 115-year fire-free period prior to 2008 occurred in pine-dominated stands in valley bottoms and on south aspects, shifting composition from fire-tolerant species to fire-intolerant white fir (Beaty and Taylor 2008). North et al. (2005) found that mixed-conifer species in the Teakettle forest in Sierra Nevada had distinct responses to fire, suggesting that seedling requirements and microsite preference is different between species. For instance, in the Teakettle Experimental Forest, sugar pine was found to establish 1-4 years after fire, preferentially during wet years, while white fir and incense cedar began to recruit into burned areas 13 years after fire (North et al. 2005).

[Please refer to *Question 3: Disturbance Regimes* above for further references on altered fire regimes].

Biological resource use: Since the mid-19th century, management practices have fundamentally changed the structure, biota, and ecological processes in mixed conifer and yellow pine forest (Sugihara et al. 2006, Barbour et al. 2007 cited in Safford et al. 2012b). Historical logging partially explains the loss and homogenization of yellow pine-dominated forests (Safford et al. 2012b).

Pollution and poisons: Excess nitrogen and ozone cause physiological disturbances to trees in highly polluted areas such as stands in the San Bernadino Mountains. Air pollution effects in the Sierra Nevada appear to be reduced but ozone injury has been seen in the southern and western edge (Fenn et al. 2003). However, another study found that from Tahoe south to Sequoia, nitrogen loads that could cause impaired function were present. Nitrogen loads can cause increased invasive species, altered lichen communities and altered lake chemistry (Living Assessment 2013).

6. Other sensitivities.

- a. Other critical sensitivities not addressed: No answer provided by workshop participants; no answer provided by external system expert
 - i. Participant confidence: Low-Moderate (group); no answer provided by external system expert
- 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: Moderate (both)
 - i. Participant confidence: Moderate (both)

Additional comments: Sensitivity of the yellow pine/mixed conifer system to climate change may vary by sub-region. The northern Sierra Nevada might be ranked as High rather than Moderate, due to greater anticipated effects of altered fire regime, less snow, and longer fire season.



Adaptive Capacity

1. System extent and integrity.

- a. System extent throughout the Sierra Nevada (e.g., widespread to narrow distribution): High (both)
 - i. Participant confidence: High (both)
- b. Level of fragmentation across the Sierra Nevada: Low (group); Moderate (external system expert)
 - i. Participant confidence: High (both)

References identified by participants: Franklin and Fites-Kaufman 1996; Scholl and Taylor 2010; Collins et al. 2011. See Southern Sierra Adaptation Workshop handouts and materials⁸.

External system expert: The adaptive capacity of the mixed conifer forest may be reduced through fragmentation by roads, transmission corridors, land use, resource extraction, and severe fires, which are influenced by fire suppression.

References:

Geographic extent: The mixed conifer forest covers an estimated 10% of the vegetated area in the Sierra Nevada and is the dominant community in the lower montane zone (Sierra Nevada Ecosystem Project 1996 cited in Ansley and Battles 1998). The mixed conifer forest generally occupies elevations ranging from 1300-1800 m (4265-5905 ft) but can be found at lower elevations in moist sites, and at higher elevations in the southern Sierra Nevada. However, as of 1998, less than 15% of the mixed conifer forest in the Sierra Nevada had old-growth or late-successional features, much of which is found in national parks in the southern Sierra Nevada (Franklin and Fites-Kaufmann 1996 cited in Ansley and Battles 1998).

2. Resistance, recovery, and refugia.

- a. Ability of system to resist or recover from impacts: Moderate (both)
 - i. Participant confidence: Moderate (group); High (external system expert)
- b. Suitable microclimates within the system that could support refugial communities: These tend to occur more frequently in the southern Sierra and on north facing slopes.
External system expert: Cool and moist canyons may be climatic refuges in the future. Higher elevation sites as well. Southern Sierra could be a major refuge, as it is much higher and snowpack will not be as affected and much of the landscape is in wilderness.

Additional comments: Logged areas have not recovered to old growth. Yellow pine/mixed conifer forests within fire suppression management areas have changed species composition. After fire or other stress, yellow pine/mixed conifer forest types have experienced type conversion to grassland or chaparral.

3. Landscape permeability.

- a. Degree of landscape permeability: High (group); Moderate (external system expert)
 - i. Participant confidence: High (both)
- b. Potential types of barriers to dispersal that apply: Roads (highway, arterial, low volume), clear cut/logging, other – transmission corridors, land jurisdiction changes (both)

Additional comments: Potential barriers to dispersal vary depending on the time frame considered.

⁸ Southern Sierra Adaptation Workshop Information: <http://climate.calcommons.org/aux/sscaw/index.htm>



External system expert: Forest cover is patchy due to land use, crossed by many roads, transmission corridors, land jurisdiction changes, private logging, etc. Landscape is more or less permeable for many species but forest carnivores are having trouble dispersing/migrating.

4. System diversity.

- a. Level of physical and topographic diversity: High (both)
 - i. Participant confidence: High (both)
- b. Level of component species/functional group diversity: High (both)
 - i. Participant confidence: High (both)
- c. Description of diversity: No answer provided by workshop participants or external system expert.

External system expert: High diversity in all categories.

Additional comments: Some species within the system exhibit lower genetic diversity (e.g. fisher and perhaps giant sequoia), but in general the system displays high levels of diversity. Structural heterogeneity fosters resilience, and forests that experience periodic low intensity disturbance such as wind throw or low intensity fire may be better able to recover from climate-related stresses such as drought, fire and insects.

References:

Component species diversity: Grulke (2010) found that co-occurring populations of montane conifers in California varied in their potential to respond to climate change, as indicated by variability of key ecophysiological traits. Of the four species studied, white fir exhibited the highest variability, sugar pine exhibited the least, and ponderosa pine and Jeffrey pine had intermediate variability. Uphill redistribution of white fir in the Peninsular Range of southern California lends support that this species has the capacity to respond to environmental change (Grulke 2010).

Community structure: In mixed-conifer old-growth forests in the Sierra Nevada with restored fire regimes, topography and fire interact to influence forest productivity and burn intensity, creating structurally heterogeneous forests. Topography can be a strong influence on tree density and species composition (Lydersen and North 2012). "Topography can affect forest vegetation both directly, with contributing factors such as soil moisture (Scholl and Taylor 2010), soil thickness (Meyer et al. 2007), and microclimate (Abella and Denton 2009), and indirectly by differences in fire intensity (Beaty and Taylor 2001) and frequency (Taylor and Skinner 2003)" (Lydersen and North 2012).

5. Management potential.

- a. Value level people ascribe to this system: High (both)
 - i. Participant confidence: High (both)
- b. Specificity of rules governing management of the system: High (group); Moderate (external system expert)
 - i. Participant confidence: High (both)
- c. Description of use conflicts: There are conflicts regarding restoring the overall system for resilience. For example, managing for sensitive, listed, and/or species of concern can hinder restoration actions that could reduce the system's vulnerability to climate changes. A conflict also exists between managing to allow restoration of natural fire regimes, and managing for the protection of human life and property, and other infrastructure. The removal of materials to support restoration to the system is complicated by economic constraints and the constraints of public opinion and acceptance.



External system expert: There are huge conflicts including tradeoffs among resource extraction, recreation, livestock, aesthetics, watershed protection, exurban housing expansion, and wilderness.

- d. Potential for managing or alleviating climate impacts: Seed banks of tree species from different elevations could be utilized to facilitate assisted migration. Natural fire regimes could be reintroduced. Thinning of stands (especially of fire intolerant species) could reduce pressure on groundwater. However, management capacity and public opinion generally do not keep stride with changing fire regimes and fuel loading, thus the potential for managing the system in these ways to alleviate climate impacts is low.

External system expert: Theoretically, the potential for managing to alleviate climate impacts exists, especially through the use of fire and fire surrogates to reduce fire density and increase forest resilience to future drought and fire. However, political and economic realities make this very challenging. Increased planting of drought and fire tolerant species is another strategy.

Additional comments: Institutions have a low capacity to take advantage of flexibility in rules governing management, when they exist, due partially to resource constraints. In addition, although some rules include some degree of flexibility, management is also constricted by public opinion, as well as court decisions, among other factors.

References: The structural, ecological, and biological changes seen in yellow pine and mixed conifer dominated forest in the western U.S. including an increase in the area of forest dominated by shade-tolerant conifers, especially fir species (*Abies spp.*), are a product of management choices (e.g. fire suppression, logging, and grazing) since the mid-19th century (Safford et al. 2012b). To reduce catastrophic fire, retaining heterogeneity, including a mixture of species and age classes, would reduce fuel loads (Battles et al. 2008), while simultaneously increasing resilience to drought and wildfire, and providing habitat for sensitive species associated with high canopy closure and stem density (Lydersen and North 2012).

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: Invasive species; endangered species management (group); no answer provided by external system expert
 - i. Participant confidence: Moderate (group); no answer provided by external system expert
- b. Collective degree these factors affect the adaptive capacity of the system: Low (group); no answer provided by external system expert

Additional comments: Past practices (e.g. logging, hydraulic mining) may have negatively affected the adaptive capacity of the system. The spread of invasive species may facilitate changes in fire regimes and/or lead to type conversion, thereby decreasing adaptive capacity. As mentioned in question 5, managing for endangered species can reduce adaptive capacity, and managing forests for water quantity can influence tree species composition.

7. Overall user ranking.

- a. Overall adaptive capacity of the system: Moderate (both)
 - i. Participant confidence: Moderate (group); High (external system expert)



Additional comments: The yellow pine/mixed conifer system has generally high adaptive capacity, unless it becomes exposed to a significant increase in the frequency and severity of fire, resulting in potential type conversion or significant changes in structure and landscape patterns of seral stages.

External system expert: The diversity and large land base of the system make it able to absorb a great deal of change. It is the most widely distributed forest type in the Sierra Nevada, so its resilience is key to many species in the range. Although the system does not support many locally rare species, the implications of major change would be huge.



Exposure

1. Exposure factors⁹.

- a. Factors likely to be most relevant or important to consider for the system: Climatic water deficit, wildfire, snowpack
 - i. Participant confidence: High (climatic water deficit); High (wildfire); High (snowpack)

2. Exposure region.

- a. Exposure by region: North – Moderate/Moderate-High; Central – Moderate/Moderate-High; 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:

Distribution shifts of yellow pine/mixed conifer forests: The greatest change predicted for the forested landscape in the 21st century is the reduction of conifer-dominated forest area, which is forecast to be replaced by mixed woodland and hardwood-dominated forests (Lenihan et al. 2003; Lawler et al. *in press* cited in Purcell et al. 2012).

Please see PRBO Conservation Science (2011) for ecoregional summaries of vegetation change projected in California.

In the Sierra Nevada, deciduous forests are predicted to replace conifer dominated forests at low and middle elevations (Lenihan et al. 2008). Future increases in temperature and fire are projected to result in higher importance of broadleaf trees (especially oak species) (Lenihan et al. 2008). A drier future may present an increase in grasslands and shrublands in areas historically habited by mixed conifer forest (Lenihan et al. 2008). Results from Notaro et al.'s (2012) model indicate that potential range of white fir in the southwest U.S. will increase.

Battles et al. (2008) evaluated the impacts of climate change on the future productivity and health of a forest in the mixed-conifer region in California. Conifer tree growth declined under all climate scenarios and management regimes, with greatest reductions in white fir, incense cedar and Douglas fir relative to ponderosa pine and sugar pine (Battles et al. 2008).

Ponderosa pine, one of the two most abundant species in the southwestern U.S., is projected to decline on average by 47% in response to climate warming (Notaro et al. 2012). Warmer temperatures predicted by climate models may promote seedling germination earlier in the season and result in longer growth periods for shoot and root development, reducing the susceptibility of young seedlings to frost heaving and drought conditions (Puhlick et al. 2012).

Projected earlier snowmelt and runoff, and longer, drier summers in the Sierra Nevada may lead to low seedling survival, contraction of the regional distribution of Jeffrey pine, and an upslope migration of the forest-shrubland (Alpert and Loik 2013). However, a study by Hubbert et al. (2001) suggests Jeffrey pine in the Sierra Nevada might be buffered from variation in annual precipitation abundance by roots that

⁹ 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.



can access deep-water reservoirs. The bedrock fissure water-holding capacity in the shallow soils may afford the Jeffrey pine some protection from annual climate variation.

Soil moisture is a primary factor in the restriction of grove boundaries to their present locations (York et al. 2010), and future climate scenarios forecast increased water deficit for giant sequoia (Lutz et al. 2010).

Under future climate scenarios Douglas fir in the northern Sierras is projected to move from the west to the east of the mountains (Shafer et al. 2001).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012a). 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. 2012a), 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). Further, decreases in winter precipitation combined with increases in summer temperature may produce declines in conifer tree growth in mixed conifer forest of northern California (Yeh and Wensel 2000).

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 projected change in water deficit from present to future climate for Yosemite National Park is greater than that from the Little Ice Age to present, exceeding 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). In Yosemite mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010).

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 system may be found through the TACCIMO website (<http://www.sgccp.ncsu.edu:8090/>). Downscaled climate projections available through the Data Basin website (<http://databasin.org/galleries/602b58f9bbd44dff487a04a1c5c0f52>).

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Species



Focal Resource: SIERRA NEVADA BIGHORN SHEEP

Taxonomy and Related Information

Sierra Nevada bighorn sheep (*Ovis canadensis*); occur in southern Sierra, White and Inyo Mountains.

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop¹. The following document represents the vulnerability assessment results for the **SIERRA NEVADA BIGHORN SHEEP**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, <http://www.taccimo.sgcp.ncsu.edu/>) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

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

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption².

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

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

¹ For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at:

<http://ecoadapt.org/programs/adaptation-consultations/calcc>.

² Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. National Wildlife Federation, Washington, D.C.



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

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

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

Overall Averaged Confidence (Sensitivity)⁵: High

Overall Averaged Ranking (Sensitivity)⁶: Moderate – High

ADAPTIVE CAPACITY

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

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

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

EXPOSURE

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

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

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

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Sierra Nevada Bighorn Sheep



Relevant Exposure Factor	Confidence
Runoff	2 Moderate
Timing of flows	2 Moderate
Low flows	2 Moderate
High flows	2 Moderate

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

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

Overall Averaged Ranking (Exposure)⁶: High



Sensitivity

1. Generalist/Specialist.

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

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

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

2. Physiology.

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

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

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

3. Sensitive habitats.

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

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

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

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

4. Life history.

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



5. Ecological relationships.

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

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

6. Disturbance regimes.

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

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

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

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Agriculture, transportation and service corridors, altered interspecific interactions, human intrusions and disturbance, natural system modifications, invasive and other problematic species, other – possibly hunting
- b. Current degree to which stressors affect the species: High
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: High
 - i. Participant confidence: High

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

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



8. Other sensitivities.

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

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

9. Overall user ranking.

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

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



Adaptive Capacity

1. Dispersal ability.

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

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

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

2. Plasticity.

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

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

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

3. Evolutionary potential.

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

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

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

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
-

5. Management potential.

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

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

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

6. Other adaptive capacity factors.

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

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Low-Moderate
 - i. Participant confidence: High
-



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, Precipitation, Dominant vegetation type, Climatic water deficit, Snowpack, Runoff, Timing of flows, Low flows, High flows
 - i. Participant confidence: Moderate (for all)

2. Exposure region.

- a. Exposure by region: North – Not Applicable; Central – Not Applicable; South – High
 - i. Participant confidence: No answer provided by participants

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: High
 - i. Participant confidence: High

References:

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

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004; Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL⁸ and PCM⁹) 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)

⁷ Participants were asked to identify exposure factors most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

⁸ Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. *Journal of Climate*, 19:643-674.

⁹ Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. *Climate Dynamics* 16:755-744.



while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

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

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



(Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (Geos Institute 2013).

Wildfire: Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011; Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites -Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 2013) and other high elevation vegetation. Occurrence of large fire and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing by up to 74% by 2085 (Westerling et al. 2011). The area burned by wildfire in the Sierra Nevada is projected to increase between 35-169% by the end of the century, varying by bioregion, with the greatest increases projected at mid-elevation sites along the west side of the range (Westerling et al. 2011; Geos Institute 2013).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the species may be found through the TACCIMO website (<http://www.sgcp.ncsu.edu:8090/>). Downscaled climate projections available through the Data Basin website (<http://databasin.org/galleries/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: CALIFORNIA BLACK OAK

Taxonomy and Related Information

Black oak (*Quercus kelloggii*); Sierra Nevada-wide distribution between approximately 609-2134 m (2000-7000 ft). Rarely forms woodlands; usually subdominant component of lower to mid-elevation mixed conifer forests.

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 workshop¹. The following document represents the vulnerability assessment results for the **CALIFORNIA BLACK OAK**, 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 disruption².

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.



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.

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 evaluation³. 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.

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	Not applicable	No answer provided by participants
Physiology	2 Moderate	2 Moderate
Habitat	Not applicable	Not applicable
Life History	1 Low	No answer provided by participants
Ecological Relationships	2 Moderate	2 Moderate
Disturbance Regimes	No answer provided by participants	No answer provided by participants
Non-Climatic Stressors – Current Impact	3 High	2 Moderate
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	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	3 High	3 High
Barriers Affect Dispersal Ability	3 High	3 High
Plasticity	2.5 Moderate–High	2 Moderate
Evolutionary Potential	2 Moderate	2 Moderate
Intraspecific Diversity/Life History	1 Low	1 Low
Species Value	2 Moderate	3 High
Specificity of Management Rules	2 Moderate	3 High
Other Adaptive Capacities	None	No answer provided by participants

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

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	2 Moderate

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

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

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
California Black Oak



Precipitation	2 Moderate
Climatic water deficit	2 Moderate
Wildfire	2 Moderate
Snowpack	2 Moderate

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	1.5 Low-Moderate	2 Moderate
Central Sierra Nevada	1.5 Low-Moderate	2 Moderate
Southern Sierra Nevada	1.5 Low-Moderate	2 Moderate

Overall Averaged Confidence (Exposure)⁵: Moderate

Overall Averaged Ranking (Exposure)⁶: Low-Moderate



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: Not applicable
 - i. Participant confidence: No answer provided by participants
- b. Factors that make the species more of a specialist: Seed dispersal dependency

Additional comments: California black oak is dependent on birds and rodents for longer distance seed dispersal.

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: Temperature and precipitation were marked to indicate soil water deficit.

References: Precipitation is a key discriminant variable determining oak woodland type, with higher rainfall on western slopes in northwest California associated with black oaks (Jimerson and Carothers 2002). Black oak (*Q. kelloggii*) was found more often on more westerly sites in the northern portion of sites in northwest California, where rainfall was typically greatest (Jimerson and Carothers 2002). Acorn crop size is influenced by rainfall and temperature (Koenig et al. 1999). In addition, individual large California black oak trees established circa 1700, and located near the species range limit, may be at risk of water deficit related mortality (Lutz et al. 2010). However, California black oaks have the capacity to modify physiology in response to environmental conditions, and control stomata in response to water stress (Grulke et al. 2005).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: None
 - b. Species dependence on one or more sensitive habitat types: Not applicable
 - i. Participant confidence: No answer provided by participants
-

4. Life history.

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

Additional comments: California black oaks reproduce every year, producing lots of acorns although few survive to adulthood. Acorn production is dependent on climatic and weather conditions, such as spring-time weather and previous year's precipitation.

References: California black oaks are long-lived species, and age of maturity varies usually between 20 and 30 years old. They are capable of producing more than 6,000 acorns per oak (Bowyer and Bleich 1980 cited in Waddell and Barrett 2005), which take two years to develop and ripen (Tyler et al. 2006). The annual acorn crop for oaks varies widely in quantity from tree to tree and from year to year (Griffin 1971 cited in Tyler et al. 2006; Koenig et al. 1994), influenced by weather, tree age, size, and health, the size of the tree's previous year's crop, and perhaps the distance to and density of neighboring trees (Koenig et al. 1999, Knapp et al. 2001, and Sork et al. 2002 cited in Tyler et al. 2006).



5. Ecological relationships.

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

Additional comments: Competition for water with non-native grasses is sensitive to climate change. Likewise, changes in temperature and precipitation will affect water availability.

6. Disturbance regimes.

- a. Disturbance regimes to which the species is sensitive include: Wildfire, insects, 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:

Fire: Adults can usually survive fire and resprout from root crown, but seedlings and saplings are usually killed by fire. Increased frequency of fire would benefit California black oak in the short term by reducing the abundance of conifers.

Drought: California black oaks are drought tolerant, but mortality will occur if the threshold is reached.

Insects: If trees are stressed by other factors, it leaves them susceptible to attack by beetles or other insects.

References: Reports of black oak fire tolerance are mixed in the literature. McDonald (Silvics of North America, 1957) suggests that crown fires kill trees of all ages, and ground fires are often fatal, while other studies report high survival of larger trees after low-moderate intensity fires (Kauffman and Martin 1987; Jimerson and Carothers 2002) and vigorous re-sprouting or seedling recruitment after fire (Kaufmann and Martin 1987; McDonald 1990 cited in Bouldin 1999). Several authors have also suggested that, at least in the short term, frequent low-intensity fire benefits oak, including California black oak, by inhibiting conifer encroachment (Fritzke 1997; Jimerson and Carothers 2002; Swiecki and Bernhardt 2002) and by preparing adequate seedbed conditions (Kauffman and Martin 1987). Fire exclusion may benefit conifers, reduce the relative abundance of black oaks, and may promote increased severity fires when they do occur, with negative consequences for oak survival (Miller et al. 2009).

7. Interacting non-climatic stressors.

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

Additional comments: Other stressors include cattle grazing (included under 'biological resource use'), reduction of top predators (under 'altered interspecific interactions'), and fire exclusion and suppression (under 'natural system modification'). Cattle grazing and high deer densities are thought to limit new tree recruitment because, for example, deer preferentially eat acorns and seedlings. Reductions in top predators may result in higher deer densities. Fire exclusion benefits conifers and reduces relative



abundance of black oaks. Suburban development fragments habitat and reduces sites for potential expansion or climate refugia.

References: California black oaks are also impacted by a number of non-climate stressors, including fire exclusion (Miller et al. 2009), disease (Davidson et al. 2002), land conversion (Jimerson and Carothers 2002), and grazing (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002). Fire exclusion may benefit conifers while reducing the relative abundance of black oaks, and may promote higher severity fires when they do occur, with negative consequences for oak survival (Miller et al. 2009). Climate changes are anticipated to increase the incidence of large fires, which may compound the effects of fire suppression and augment the incidence of stand replacing fire (Jimerson and Carothers 2002). Conversion of forest for agriculture and development and intense grazing (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002) restrict dispersal and recruitment. For example, residential development fragments habitat and reduces sites for potential expansion. New tree recruitment may be limited by grazing by cattle and wild deer (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002), which are thought to preferentially consume acorns and seedlings, and which may be exacerbated by the removal of top predators.

Conversely, increased moisture is important in the spread of the introduced pathogen *Phytophthora ramorum*, the cause of sudden oak death, which affects black oaks in coastal and montane forests of California (Rizzo et al. 2002). 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, and heavy late-spring rain associated with El Niño events (e.g., 1998) may have played a role in the current distribution of *P. ramorum* in California (Meentemeyer 2004). Increases in winter rain may produce optimal conditions for the pathogen in some areas, and modeling projects future oak infection risk to be moderate and high in scattered areas of the Sierra Nevada foothills in Butte and Yuba counties (Meentemeyer et al. 2004).

8. Other sensitivities.

- a. Other critical sensitivities not addressed: None
 - i. Participant confidence: No answer provided by participants
- b. Collective degree these factors increase species' sensitivity to climate change: No answer provided by participants

9. Overall user ranking.

- a. Overall sensitivity of this species to climate change: Moderate
 - i. Participant confidence: No answer provided by participants

Additional comments: In the short-term California black oaks will likely benefit, as conifer cover is reduced due to increased fire. In the long term, California black oaks may contract their distribution to the wetter / cooler microsites. A warming climate will likely reduce recruitment, because recruitment (within existing distribution and into new areas) will be dependent on sufficient moisture.



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: High
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Road (highway), agriculture, industrial or urban development, suburban or residential development, other – low recruitment linked to over-browsing by cattle and deer
- d. Degree barriers affect dispersal for the species: High
 - i. Participant confidence: High
- e. Possibility for individuals to seek out refugia: California black oak will likely contract into wetter / cooler sites. Cattle grazing, deer browsing, and suburban development may greatly impact suitability of potential climate refugia.

References: The California black oak is one of the most common hardwood forest types in California, evenly divided between public and private ownership (Waddell and Barrett 2005). Surveys by Waddell and Barrett (2005) found California black oak forests along the length of the Sierra Nevada, with two-thirds occurring between 1890 ft - 5050 ft (576 m – 1539 m). However, California black oak distribution is greater than that of its woodland type, because individual California black oak typically occur outside of California black oak woodlands as a subdominant component of lower- to mid-elevation mixed conifer forests and hardwood forests (Waddell and Barrett 2005). Intense grazing and conversion of forest for agriculture and development (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002) may restrict dispersal and recruitment.

2. Plasticity.

- a. Ability of species to modify physiology or behavior: Moderate-High
 - i. Participant confidence: Moderate
- b. Description of species' ability to modify physiology or behavior: California black oak shut their stomata and display retarded growth in response to water stress. California black oak can alter the timing of flowering and leaf-out, and can adjust acorn production in response to climate changes.

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Moderate
 - i. Participant confidence: Moderate
- b. Description of characteristics that allow species to adapt evolutionarily: California black oak have a large population size and are genetically adapted to local / regional environmental conditions. On the other hand, they are a long-lived species that does not become reproductive until 20-30 years of age.

References: California black oaks are long-lived species, and age of maturity varies usually between 20 and 30 years old. The annual acorn crop for oaks varies widely in quantity from tree to tree and from year to year (Griffin 1971 cited in Tyler et al. 2006; Koenig et al. 1994), influenced by the tree's age, size, and health, the size of the tree's previous year's crop, and perhaps the distance to and density of neighboring trees (Koenig et al. 1999, Knapp et al. 2001, and Sork et al. 2002 cited in Tyler et al. 2006). California black oaks are capable of producing more than 6,000 acorns per oak (Bowyer and Bleich 1980 cited in Waddell and Barrett 2005), which take two years to develop and ripen (Tyler et al. 2006).



4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Low
 - i. Participant confidence: Low
- b. Description of diversity of life history strategies: No answer provided by participants

Additional comments: Age at maturity varies, as does crop size of flowers and acorn production each year. Age at maturity may be 20-30 years.

5. Management potential.

- a. Value level people ascribe to this species: Moderate
 - i. Participant confidence: High
- b. Specificity of rules governing management of the species: Moderate
 - i. Participant confidence: High
- c. Description of use conflicts: Much of California black oak distribution is on Forest Service lands that support cattle grazing. Lower elevations outside public lands are being developed and are expected to have lots of future development pressure.
- d. Potential for managing or alleviating climate impacts: Cooler / wetter sites could be identified and prioritized for conservation and/or restoration.

Additional comments: California black oaks are not valued as a timber species but are culturally highly valued by Native Americans, and for their aesthetic beauty. On the other hand, they are usually omitted as a component of the mixed conifer community.

6. Other adaptive capacity factors.

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
 - i. Participant confidence: Moderate

Additional comments: Adaptive capacity varies depending on life stage and existence of other stressors (e.g., cattle, deer, and development).



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, climatic water deficit, wildfire, snowpack
 - i. Participant confidence: Moderate (all)
-

2. Exposure region.

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

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: Moderate
 - i. Participant confidence: Moderate

Additional comments: In the short-term, California black oaks are likely to do okay or even expand, if they can recruit to new locations. In the longer term, fire and water deficits could reduce distributions to wet and cool micro-sites.

References: Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands are projected to increase in California (PRBO Conservation Science⁸ 2011). However, the area of oak woodland burned by contained fires is also projected to increase by 65% in Northern California in response to climate change (Fried et al. 2004), and the long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

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 (GFDL⁹ and PCM¹⁰) 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).

⁷ Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

⁸ PRBO Conservation Science now called 'Point Blue'

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.



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).

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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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).

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, decreasing mean annual flow (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.sgccp.ncsu.edu:8090/>). Downscaled climate projections available through the Data Basin website (<http://databasin.org/galleries/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **BLUE OAK**

Taxonomy and Related Information

Blue oak (*Quercus douglasii*); widespread across Sierra Nevada foothills between 152-762 m (500-2500 ft) elevation.

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 workshop¹. The following document represents the vulnerability assessment results for the **BLUE OAK**, 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.sgccp.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 disruption².

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 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.



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: 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 evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	Not applicable	No answer provided by participants
Physiology	1.5 Low-Moderate	2.5 Moderate-High
Habitat	1 Low	3 High
Life History	3 K-Selection	3 High
Ecological Relationships	1.5 Low-Moderate	2 Moderate
Disturbance Regimes	2 Moderate	2 Moderate
Non-Climatic Stressors – Current Impact	2 Moderate	2 Moderate
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	2.5 Moderate – High	2.5 Moderate-High
Other Sensitivities	None	2.5 Moderate-High

Overall Averaged Confidence (Sensitivity)⁵: Moderate-High

Overall Averaged Ranking (Sensitivity)⁶: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	2.5 Moderate-High	3 High
Barriers Affect Dispersal Ability	3 High	No answer provided by participants
Plasticity	3 High	3 High
Evolutionary Potential	2 Moderate	1 Low
Intraspecific Diversity/Life History	1 Low	1 Low
Species Value	1.5 Low-Moderate	2 Moderate
Specificity of Management Rules	1.5 Low-Moderate	2 Moderate
Other Adaptive Capacities	None	No answer provided by participants

Overall Averaged Confidence (Adaptive Capacity)⁵: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Precipitation	3 High
Climatic water deficit	3 High
Wildfire (biomass consumed)	3 High

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.

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
Blue Oak



Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	1.5 Low-Moderate	2.5 Moderate-High
Central Sierra Nevada	1.5 Low-Moderate	2.5 Moderate-High
Southern Sierra Nevada	1.5 Low-Moderate	2.5 Moderate-High

Overall Averaged Confidence (Exposure)⁵: Moderate-High

Overall Averaged Ranking (Exposure)⁶: Low-Moderate



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: Not applicable
 - i. Participant confidence: No answer provided by participants
- b. Factors that make the species more of a specialist: Seed dispersal dependency

Additional comments: Participants indicated that the Blue Oak species was generally captured by the coarse filter ecosystem vulnerability assessment for Oak Woodlands.

References identified by participants: Southern Sierra Nevada Adaptation Workshop (2013)⁷.

2. Physiology.

- a. Species physiologically sensitive to one or more factors including: None identified
- b. Sensitivity of species' physiology to one or more factors: Low-Moderate
 - i. Participant confidence: Moderate-High

Additional comments: Adult blue oaks are deep rooted and tolerant to drought; they are not very sensitive to temperature. Seedlings are more sensitive to water availability.

Several shrub and arborescent species of oaks (e.g., *Q. turbinella*, *Q. agrifolia* and *Q. engelmannii*) occupy drier and warmer sites on average, than *Q. douglasii*. Sustained and repeated droughts could adversely affect trees and make them more vulnerable to other stressors (e.g., insects and disease).

References: Periodic droughts appear to have little impact on mature trees (McCreary 1991). Wet years can produce nearly double the seedling emergence of dry years (Borchert et al. 1989 cited in Tyler et al. 2006), and all published studies on the regeneration of blue oak woodlands reviewed by Tyler et al. (2006) found saplings to be more common on mesic sites. Acorn crop size in blue oaks is also influenced by rainfall and temperature (Koenig et al. 1999 cited in Waddell and Barrett 2005).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Grasslands, seeps/springs
- b. Species dependence on one or more sensitive habitat types: Low
 - i. Participant confidence: High

Additional comments: Blue oaks are intermixed in grasslands.

4. Life history.

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

Additional comments: Blue oak reproduce annually through seedling production.

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Competition, other – seed dispersal, disease susceptibility
- b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation

⁷ Southern Sierra Nevada Adaptation Workshop Information: <http://climate.calcommons.org/aux/sscaw/index.htm>



- c. Sensitivity of species to other effects of climate change on its ecology: Low-Moderate
 - i. Participant confidence: Moderate

Additional comments: Competition with other plants for water.

References: Exotic annual grasses compete more effectively with oak seedlings for water than native perennials (Gordon et al. 1989), and have been shown to significantly reduce oak seedling emergence, growth and survival (Gordon et. al 1989, Danielsen 1990, and Gordon and Rice 1993 cited in Tyler et al. 2006).

6. Disturbance regimes.

- a. Disturbance regimes to which the species is sensitive include: Wildfire, insects, disease
- b. Sensitivity of species to one or more disturbance regimes: Moderate
 - i. Participant confidence: Moderate

Additional comments: The greatest impact of wildfire is on seedlings as their bark is thin and even low intensity ground fires can girdle them. However, the vast majority of top-killed seedlings will re-sprout the following year. Adults are able to survive fire.

References:

Wildfire: Relatively few studies have rigorously established the effects of fire on blue oak persistence (Allen-Diaz and Bartolome 1992; Swiecki and Bernhardt 1999). Some studies have linked fire with positive recruitment of blue oak woodlands (e.g., McClaran and Bartolome 1989, Bartolome 1991 cited in Tyler et al. 2006), however, the apparent correlation between fire and blue oak regeneration may be the result of removal of older stems by fire and establishment of even-aged stems from resprouting (McClaran and Bartolome 1989, Bartolome 1991 cited in Tyler et al. 2006). Other studies found no positive effect of fire treatments on recruitment, survival, and/or growth of blue oak seedlings (Bartolome and McClaran 1988, Bartolome 1991, and Allen-Diaz and Bartolome 1992, cited in Tyler et al. 2006; Swiecki and Bernhardt 2002). Despite high rates of growth of top-killed saplings immediately following fire, these rates slowed over time, resulting in retarded advancement of small saplings to the overstory (Swiecki and Bernhardt 2002). Moreover, moderate-intensity fire resulting in partial or complete top-kill were found to prolong the period that blue oak saplings were susceptible to subsequent fire and other damaging agents (Spero 2002). Frequent fire is negatively associated with blue oak sapling recruitment in California, whereas infrequent fire was not correlated or only slightly positively correlated with sapling recruitment (Swiecki et al. 1997b cited in Tyler et al. 2006). The long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

Disease: California blue oaks are threatened by the introduced pathogen *Phytophthora ramorum* in coastal and montane forests (Rizzo et al. 2002). 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, and heavy late-spring rain associated with El Niño events (e.g., 1998) may have played a role in the current distribution of *P. ramorum* in California (Meentemeyer et al. 2004). Increases in winter rain may produce optimal conditions for the pathogen in some areas, and modeling projects future oak infection risk to be moderate and high in scattered areas of the Sierra Nevada foothills in Butte and Yuba counties (Meentemeyer et al. 2004).

7. Interacting non-climatic stressors.



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

Additional comments: Although not marked, transportation corridors, biological resource use, and human intrusions and disturbance have minor impacts on the species' sensitivity to climate change. Altered interspecific interactions include reduction in predators and an abundance of deer. Invasive Eurasian grasses compete with seedlings for water.

Climate change could increase the abundance of invasive grasses in relation to native annuals and perennials.

References: While still on the tree, acorns are susceptible to mortality due to fungus, insects (predominantly weevils and moth larvae), birds (including jays, magpies, and acorn woodpeckers), mammals (including mice, squirrels, deer, pigs, and cattle), as well as heat (Griffin 1980b, Koenig et al. 2002 cited in Tyler et al. 2006).

Grazing has also been implicated in recruitment failure, although studies have yielded conflicting results (Tyler et al. 2006). Some studies identify predation of blue oak acorns, seedlings and saplings by rodents and deer as a major source of mortality (Borchert et al. 1989, Callaway 1992, and Swiecki et al. 1997b cited in Tyler et al. 2006; Adams and McDougald 1995), while Hall et al. (1992) suggest that grazing intensity plays a smaller role in seedling survival than seasonality of grazing. Spring and summer grazing of seedlings by livestock and wildlife alike is associated with significantly lower survivorship than areas in which seedlings were exposed only to winter grazing (Hall et al. 1992).

Loss of blue oak woodland is largely a product of urban expansion since the 1930s (Safford et al. 2012). Blue oak occurs predominantly on private lands in California where habitat conversion to agriculture and residential development reduce blue oak extent and abundance (Bolsinger 1988; Pavlik et al. 1991).

Exotic annual grasses compete more effectively with oak seedlings for water than native perennials and have been shown to significantly reduce oak seedling emergence, growth and survival (Gordon et. al 1989, Danielsen 1990, and Gordon and Rice 1993 cited in Tyler et al. 2006).

8. Other sensitivities.

- a. Other critical sensitivities not addressed: None
 - i. Participant confidence: Moderate-High
- b. Collective degree these factors increase species' sensitivity to climate change: Not applicable

9. Overall user ranking.

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

Additional comments: Blue oaks are widely distributed across a broad elevation range within the Sierra Nevada. This broad distribution and apparent broad tolerance for differences in soil types and depth, precipitation, water deficit, and fire regimes would offer them a substantial degree of resilience as a species to future climate changes. Range contractions and shifts (assuming dispersal and recruitment is



possible) to the most suitable habitats is a likely outcome in the long term. In the short term, likely increases in fire frequency and severity would reduce conifer densities, leaving blue oaks relatively more abundant.



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: <0.2 km (<0.12 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: Moderate-High
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Road – highway, agriculture, industrial or urban development, suburban or residential development
- d. Degree barriers affect dispersal for the species: High
 - i. Participant confidence: No answer provided by participants
- e. Possibility for individuals to seek out refugia: Dependent on access to refugia.

Additional comments: The problem lies with seedlings becoming established, not with dispersal occurring. Sapling recruitment may be more limiting than seedling recruitment. Seedlings tend to be abundant following very wet years but most do not survive into sapling stage. Range contractions and shifts for this species are likely in the long term.

References: Poor natural regeneration of blue oak has been noted in portions of its range (Bartolome et al. 1987; Bolsinger 1988; Tyler et al. 2006). Blue oak seedlings and saplings are present but relatively rare in many stands, and absent from others. Some stands show no evidence of tree recruitment within the past 50 years, however, low mortality rates of adults, estimated between 2 to 4% per decade (Swiecki et al. 1993), may be sufficient to allow replacement even at low sapling survival rates.

2. Plasticity.

- a. Ability of species to modify physiology or behavior: High
 - i. Participant confidence: High
- b. Description of species' ability to modify physiology or behavior: Plasticity is high; for example, oaks can reduce water use during times of drought.

References: Periodic droughts appear to have little impact on mature trees (McCreary 1991), in part because blue oaks lose leaves early during dry years (McCreary 1990) to reduce water loss.

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Moderate
 - i. Participant confidence: Low
- b. Description of characteristics that allow species to adapt evolutionarily: Blue oak has adapted well to drier climates. The population base is large and well-connected, and genetic diversity seems high.

Additional comments: Blue oaks are distributed across a broad elevational and latitudinal range.

References: The blue oak woodland type, ranging from open savannas to dense woodlands, ranks first in terms of total land area among California oaks (Davies et al. 1998 cited in Tyler et al. 2006).

4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Low
 - i. Participant confidence: Low
- b. Description of diversity of life history strategies: Blue oak reproductive strategy is mostly static.



References: Although not well documented, age of first reproduction is at least several decades old (Olson 1974 cited in Tyler et al. 2006), with maximum production occurring decades later. The acorn crop varies widely in quantity from tree to tree and from year to year (Griffin 1971, Koenig et al. 1994 cited in Tyler et al. 2006), and may be influenced by weather, tree age, size, and health, the size of the tree's previous year's crop, and perhaps the distance to and density of neighboring trees (Koenig et al. 1994, Koenig et al. 1999, Knapp et al. 2001, and Sork et al. 2002 cited in Tyler et al. 2006).

5. Management potential.

- a. Value level people ascribe to this species: Low-Moderate
 - i. Participant confidence: Moderate
- b. Specificity of rules governing management of the species: Varies but overall Low-Moderate
 - i. Participant confidence: Moderate
- c. Description of use conflicts: Heavy development pressure and grazing pressure on this species in the central Sierra Nevada.
- d. Potential for managing or alleviating climate impacts: Potential actions include identifying cooler and wetter sites that might serve as refugia. However, it is difficult to manage for this species, given that much of it occurs on private lands.

Additional comments: The specificity of rules governing management depends on county ordinances.

6. Other adaptive capacity factors.

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate-High
 - i. Participant confidence: Moderate
-



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the species: Precipitation, climatic water deficit, wildfire
 - i. Participant confidence: High (for all)
-

2. Exposure region.

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

3. Overall user ranking.

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

Additional comments: Blue oaks currently occupy the driest sites of all oak species in California and are the most drought-tolerant. This may provide an increased level of resistance to a future warmer and drier climate. However, water deficit thresholds could be reached, leading to high tree mortality and a further reduction in new tree recruitment. Associated increases in fire frequency and severity could further reduce numbers, densities, and recruitment.

References: The effects of climate change projected to 2070 forecast increases of blue oak/foothill pine (*Pinus sabiniana*) in the Sierra Nevada ecoregion (23 to 97%) and the California Cascades (94 to 108%) (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).

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.



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).

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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Focal Resource: **BRISTLECONE PINE**

Taxonomy and Related Information

Great Basin bristlecone pine (*Pinus longaeva* also known as *Pinus aristata* Engelm. var. *longaeva* (D.K. Bailey); White and Inyo Mountains.

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop¹. The following document represents the vulnerability assessment results for the **BRISTLECONE PINE**, 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 disruption².

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 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.



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: 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 evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	2 Between generalist & specialist	2 Moderate
Physiology	3 High	3 High
Habitat	3 High	3 High
Life History	3 K-selection	3 High
Ecological Relationships	2 Moderate	2 Moderate
Disturbance Regimes	Varied	1 Low
Non-Climatic Stressors – Current Impact	1 Low	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	1 Low	2 Moderate
Other Sensitivities	2 Moderate	2 Moderate

Overall Averaged Confidence (Sensitivity)⁵: Moderate-High

Overall Averaged Ranking (Sensitivity)⁶: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	3 High	3 High
Barriers Affect Dispersal Ability	1 High	3 High
Plasticity	1 Low	3 High
Evolutionary Potential	1 Low	2.5 Moderate-High
Intraspecific Diversity/Life History	1 Low	3 High
Species Value	3 High	3 High
Specificity of Management Rules	3 High	3 High
Other Adaptive Capacities	2 Moderate	2 Moderate

Overall Averaged Confidence (Adaptive Capacity)⁵: High

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	3 High
Precipitation	3 High
Shifts in vegetation type	3 High
Climatic water deficit	1 Low
Snowpack	1 Low
Runoff	3 High

⁵ Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

⁶ Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.



Bristlecone Pine

Relevant Exposure Factor	Confidence
Timing of flows	3 High
Other: Competition; Soils – White and Inyo Mountains	3 High

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	Not applicable	Not applicable
Central Sierra Nevada	Not applicable	Not applicable
Southern Sierra Nevada	Low-Moderate	3 High

Overall Averaged Confidence (Exposure)⁵: Moderate

Overall Averaged Ranking (Exposure)⁶: Low-Moderate



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: In between with some specialist tendencies
 - i. Participant confidence: Moderate
- b. Factors that make the species more of a specialist: Seed dispersal dependency, other – soils.

Additional comments: Bristlecone may be closer to a specialist because it prefers a specific climate. It also prefers dolomitic soils, but is not dependent on them. It can handle granitic soils but gets outcompeted on them, by sagebrush, for example. It is primarily dependent on the Clark's nutcracker (*Nucifraga columbiana*) for seed dispersal.

References: Great Basin bristlecone pine is most common on thin, rocky substrates. Soils are usually derived from limestone or dolomite (Lanner 1985, Welsh et al. 1987, Kartesz 1988, Hickman 1993 cited in Fryer 2004), although some populations grow on sandstone or quartzite (Lanner 1999 cited in Fryer 2004). In the White Mountains, Great Basin bristlecone pine communities occur on dolomite soils with a rock content of 50% or more. Dolomite soils are alkaline, high in calcium and magnesium, and low in phosphorus. Those factors tend to exclude other plant species. For example, limber pine co-dominates or associates with Great Basin bristlecone pine on dolomite soils in the White Mountains, but becomes the dominant species on granitic soils (Fritts 1969 cited in Fryer 2004). Moreover, dolomite soils are light-colored, reflect more light, are cooler, and have a higher total water storage capacity (~20%) than surrounding soils, and those factors favor Great Basin bristlecone pine establishment (Wright 1965 cited in Fryer 2004). Some Great Basin bristlecone pine populations on Wheeler Peak occur on quartzite and monzonite soils, although most are on limestone (Bare 1982, Hiebert and Hamrick 1983, Hiebert 1977, Lanner 1985 cited in Fryer 2004).

Bristlecone pine only grows where *Artemisia* is sparse or absent. If *Artemisia* becomes established where bristlecone pine is expected to shift, *Artemisia* would likely reduce seedling establishment and growth (Wright and Mooney 1965, LaMarche 1973 cited in Van de Ven 2007).

2. Physiology.

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

Additional comments: There is uncertainty related with soils. Dolomitic soils may not be available at higher elevations. In terms of precipitation, some studies say it is sensitive, some say it is not.

References: High elevation forest responses appear to be largely dictated by water supply (Lloyd and Graumlich 1997; Fites-Kaufman et al. 2007).

A strong positive relationship exists between temperature and treeline growth (i.e. ring width) of bristlecone pine. No clear decadal-scale relationship between precipitation and growth was found however, weaker positive associations at sites in Sheep Mountain, California, Mt. Washington, Nevada, and Pearl Creek, Nevada may indicate precipitation contributed to growth (Salzer et al. 2009).

Habitat availability at higher elevations in the White and Inyo Mountains is limited by its aversion to granitic substrates. With an increase in temperature of 5°C, carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007). However, surveys of remnant bristlecone snags and logs show that the bristlecone pine occurred higher in the White Mountains, when temperatures



were approximately 3.5°C warmer about 6000 years ago (LaMarche and Mooney 1967, LaMarche 1973 cited in Van de Ven 2007).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Alpine/subalpine, other – soils
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: High

Additional comments: See soils comment above.

References: In California, Great Basin bristlecone pine occurs in montane, subalpine, and timberline communities. In California, it occurs between 2200-3700 m (7200–12000 ft) (Hickman 1993 cited in Fryer 2004). Schulman (1954, cited in Fryer 2004) suggested that longevity of bristlecone pines is directly related to site adversity.

4. Life history.

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

Additional comments: Although the population produces cones each year, individual trees do not. Trees may produce cones every few years. Dispersal, and especially recruitment are the limiting factors. Recruitment can be decadal.

References: Great Basin bristlecone pine does not mast, but is a steady cone and seed producer (Lanner 1988). Great Basin bristlecone pine has the longest life span of any non-clonal species, and can produce viable seed for thousands of years (Lanner 1985, Lanner 1988 cited in Fryer 2004). In the White Mountains, the Alpha tree continues to produce viable seed at 4,300+ years of age (Lanner 1985 cited in Fryer 2004). Although conditions required for seedling establishment are rarely met, endurance of seed production, together with the capacity to produce seeds yearly, allow bristlecone pines to take advantage of infrequent favorable conditions to germinate and grow (Billings and Thompson 1957, Keeley and Zedler 1998 cited in Fryer 2004).

Seedling establishment is a rare event for Great Basin bristlecone pine. Since Great Basin bristlecone pine primarily grows on dry, nutrient-poor soils, conditions favorable to Great Basin bristlecone pine germination and growth are infrequent (Billings 1957, Keeley and Zedler 1998 cited in Fryer 2004).

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Habitat, hydrology, competition, other – fire at lower elevation edge of range
- 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: Moderate
 - i. Participant confidence: Moderate

Additional comments: Currently outcompetes in dolomitic soils but gets outcompeted in higher elevation granitic soils. Maybe with climate change and bristlecone moving upslope, it will be able to outcompete.

References:



As temperatures increase, bristlecone pine migrates to higher elevations in the White and Inyo mountains where its habitat availability is limited by its aversion to granitic substrates. With an increase in temperature of 5°C, carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007).

Great basin bristlecone pine may outcompete other plant species on dolomite soils, on which the high calcium and magnesium and low phosphorus tend to exclude other plants, but appears to be a poor competitor elsewhere, resulting in limber pine becoming the dominant species on granitic soils (Fritts 1969 cited in Fryer 2004).

Throughout its range, Great Basin bristlecone pine grows in pure stands in timberline and upper subalpine zones and co-dominates or associates with limber pine (*Pinus flexilis*) at lower elevations (Critchfield and Allenbaugh 1969, Vasek and Thorne 1977 cited in Fryer 2004). Great Basin bristlecone pine communities are surrounded by sagebrush (*Artemisia* spp.) and salt-desert communities at low elevations. Cushion plant communities and bare rock occur above Great Basin bristlecone pine communities (Hiebert 1977, Bare 1982 cited in Fryer 2004). Great Basin bristlecone pine communities usually merge with low sagebrush or limber pine communities at about 2900 m (9500 ft) elevation, but sometimes merge with singleleaf pinyon-western juniper (*Juniperus occidentalis*) woodlands, particularly on Nevada's eastern slope (Thorne 1976, Holland 1986 cited in Fryer 2004). Mooney et al. (1966, cited in Fryer 2004) concluded that Great Basin bristlecone pine was better adapted to colder, high-elevation sites, while big sagebrush was better adapted to the warmer temperatures typical of lower elevations.

Despite temperature increases, individual bristlecone pine may survive hundreds of years at low-elevations due to slow dieback and local refugia, while species like *Pinus monophylla* and *Juniperus osteosperma* rapidly migrate upslope, resulting in rare, transitory forest associations. The combination of bristlecone–pinyon–juniper forest is currently very rare in the White Mountains but could become more commonplace as temperatures increase (Van de Ven et al. 2007).

6. Disturbance regimes.

- a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, insects, disease
- b. Sensitivity of species to one or more disturbance regimes: Varied
 - i. Participant confidence: Low

Additional comments: Sensitivity to disturbance regimes is categorized as varied overall, including low sensitivity to drought, moderate sensitivity to fire, and high sensitivity to disease and insects. Fire potential generally occurs at lower elevation edge of range. No known current insect or disease outbreaks (except black root), although uncertain if species is highly resistant or simply not exposed (likely susceptible to pine beetle). Drought leads to high sensitivity. Uncertainty in terms of sensitivity to disturbance regimes is high.

References:

Wildfire: Bristlecone is a thin-barked pine and not well-suited to survive fire (Zavarin and Snajberk 1973 cited in Fryer 2004). Methods of Great Basin bristlecone pine post-fire seedling establishment are undocumented (Fryer 2004). Stand dynamics in high-elevation Great Basin bristlecone pine communities are more influenced by climate and seed dispersal patterns than by fire (Lanner 1980, Lanner 1985, Lanner 1988, Bradley et al. 1991 cited in Fryer 2004). In the White Mountains, however, the low density of bristlecone trees and the general lack of flammable groundcover and litter between them generally



precludes widespread burning, at least under current conditions (LaMarche and Mooney 1967 cited in Fryer 2004).

Drought: Great Basin bristlecone pine is highly drought tolerant (Tang et al. 1999; Bare 1982 cited in Fryer 2004). In the White Mountains, average rainfall during the growing season is about 2.5 in (64 mm) (LaMarche and Mooney 1972 cited in Fryer 2004). Branched, shallow roots maximize water absorption, and waxy needles and thick needle cuticles increase water retention (Conner and Lanner 1991 cited in Fryer 2004). A high proportion of dead:live wood reduces respiration and water loss, potentially extending bristlecone life span by allowing the tree to maintain a constant ratio of photosynthesizing to non-photosynthesizing live tissue (Wright and Mooney 1965, Keeley and Zedler 1998 cited in Fryer 2004). Further, Great Basin bristlecone pines exhibit a high proportion of dead trunk- and branchwood on harsh sites (Lanner 1990 cited in Fryer 2004), indicating a diversity of morphologies that may support adaptive capacity. Factors slowing growth include high elevation; extreme temperatures; dry, nutrient-poor soils; strong winds; south and west aspects; and high amounts of solar radiation (Beasley and Klemmedson 1973 cited in Fryer 2004).

Insects and disease: Surveys have not found rust infections in Great Basin bristlecone pine in California (Maloney 2011), although populations in the White and Inyo Mountains lie close to moderately high white pine blister rust (*Cronartium ribicola*) infection centers in the Sierra Nevada, and may be at risk for infection and spread (Smith and Hoffman 2000 cited in Fryer 2004). Blister rust-infected white pines such as Great Basin bristlecone pine may take 2 years to decades to succumb, but infection is always fatal (Hoff 1992, Hoff et al. 1994 cited in Fryer 2004). The Great Basin bristlecone pine is also susceptible to mountain pine beetle (*Dendroctonus ponderosae* Hopkins) infestations throughout its range (Lanner 1985 cited in Fryer 2004), and rising minimum temperatures, combined with drought, may increase bark beetle infestations in the Sierra Nevada (Millar et al. 2007 cited in Millar et al. 2012).

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Altered interspecific interactions, invasive and other problematic species
- b. Current degree to which stressors affect the species: Low
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: Low
 - i. Participant confidence: Moderate

Additional comments: Invasive species (e.g., cheatgrass) may increase fires however, drier temperatures with climate change could buffer cheatgrass invasions. Interspecific interactions were identified as a stressor due to the Clark's nutcracker likely moderate sensitivity to climate change, as it serves as a main dispersal mechanism for bristlecone pine. Interspecific interactions also include removal of competitors.

8. Other sensitivities.

- a. Other critical sensitivities not addressed: Dispersal
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase species' sensitivity to climate change: Moderate

Additional comments: Dispersal is potentially dependent on Clark's nutcracker (and maybe chipmunks). Clark's nutcracker is likely moderately sensitive to climate change.

References: It has been suggested that Clark's nutcrackers disperse Great Basin bristlecone pine seeds (Lanner et al. 1984, Lanner 1988, Lanner 1996 cited in Fryer 2004).



9. Overall user ranking.

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

Additional comments: In an absolute sense, user ranking is high, but relative to other alpine/subalpine species, bristlecone pine may be considered moderate. Existing bristlecone pine might survive, but it may be very difficult or impossible to get new generations if recruitment and dispersal do not occur due to climate change.



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 5-50 km (3-31 mi)
 - i. Participant confidence: Moderate
- b. Ability of species to disperse: High
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Other – requires a disperser (Clark's nutcracker)
- d. Degree barriers affect dispersal for the species: High
 - i. Participant confidence: High
- e. Possibility for individuals to seek out refugia: It may be possible for adult trees, but it is unlikely for seed dispersal and recruitment due to soil, climate conditions, and dispersal agent.

Additional comments: Maximum annual dispersal distance based on Clark's nutcracker. The ability to disperse is high, but it needs an animal species to disperse.

References: Great Basin bristlecone pine occurs in a relatively narrow latitudinal range in California, Nevada, and Utah (Little 1971, Lanner 1999 cited in Fryer 2004). In California, it occurs on the summits of the Panamint, Inyo, and White mountains of Mono and Inyo counties (Hickman 1993 cited in Fryer 2004).

Great Basin bristlecone pine is pollinated by wind (Lanner 1990, Lanner 1996 cited in Fryer 2004). 'Germinability' of Great Basin bristlecone pine pollen may be low. Great Basin bristlecone pine reproduces from seed (Lanner 1985 cited in Fryer 2004), and it has been suggested that Clark's nutcrackers disperse Great Basin bristlecone pine seeds (Lanner et al. 1984, Lanner 1988, Lanner 1996 cited in Fryer 2004).

2. Plasticity.

- a. Ability of species to modify physiology or behavior: Low
 - i. Participant confidence: High
- b. Description of species' ability to modify physiology or behavior: Not really able to modify physiology or behavior.

Additional comments: Bristlecone are very tough and able to persist in marginal habitats and drought conditions. Bristlecone pines are long-lived and not designed to change during their life.

References:

In the White Mountains, Johnson and Critchfield (1974, cited in Fryer 2004) noted a high degree of polymorphism in pollen and female cone characteristics of trees in the Sherman Grove. In addition, Great Basin bristlecone pine is a native conifer of highly variable growth form. Great Basin bristlecone pine bark is thin (Zavarin and Snajberk 1973 cited in Fryer 2004), however, Great Basin bristlecone pines on harsh sites have a high proportion of dead trunk- and branchwood. Old trunks and exposed roots have thick, vertical ribbons of dead wood. Between the dead ribbonwood, thin strips of living root and stem tissue support living branches (Lanner 1990 cited in Fryer 2004). In younger trees, branches are long and pendulous, forming an irregular crown (Tang et al. 1999).

Physiological and morphological adjustments made in the needles in response to summer drought in the White Mountains also protect trees from winter desiccation, which is largely responsible for inducing krummholz growth (LaMarche and Mooney 1972 cited in Fryer 2004). In addition, during the past 200



years, increased water use efficiency by bristlecone pine is attributed to increased atmospheric CO₂ (Tang et al. 1999).

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Low
 - i. Participant confidence: Moderate-High
- b. Description of characteristics that allow species to adapt evolutionarily: Bristlecone pine has genetic diversity within the population in White Mountains (small area), but generation time is slow that it is unlikely to keep up with climate change.

References: Few studies have been conducted on Great Basin bristlecone pine population genetics. In the White Mountains, Johnson and Critchfield (1974, cited in Fryer 2004) noted a high degree of polymorphism in pollen and female cone characteristics of trees in the Sherman Grove. Hiebert and Hamrick (1983, cited in Fryer 2004) conducted allozyme tests on 5 Great Basin bristlecone pine populations across eastern Nevada and western Utah. They found normal to high levels of genetic variation in Great Basin bristlecone pine compared to other pine species. Most variation occurred within, rather than among, populations. Polymorphic loci and number of alleles per loci were average for pines; level of heterozygosity was above average. The authors attributed high levels of heterozygosity to wind pollination, Great Basin bristlecone pine's multiple-age class structure, and its wide geographic distribution in the Pleistocene.

Populations in the White Mountains may be less genetically diverse than eastern Great Basin bristlecone pine populations. In the Ancient Bristlecone Pine Botanical Area, allozyme and DNA tests showed slightly lower than average genetic variation for Great Basin bristlecone pine compared to most pine species. Genetic variation at the population level was about average for pine species (Lee et al. 2002 cited in Fryer 2004).

Great Basin bristlecone pines on desert "sky islands" may be susceptible to inbreeding due to poor pollen and seed dispersal (Lanner et al. 1984 cited in Fryer 2004).

4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Low
 - i. Participant confidence: High
- b. Description of diversity of life history strategies: Bristlecone pine exhibits one life history strategy without much variation.

References: There is no evidence of vegetative reproduction (Lanner et al. 1984).

Also refer to the references in *Question 3 'Evolutionary Potential'*.

5. Management potential.

- a. Value level people ascribe to this species: High
 - i. Participant confidence: High
- b. Specificity of rules governing management of the species: High
 - i. Participant confidence: High
- c. Description of use conflicts: None. All federal and wilderness lands in which bristlecone pine occurs are almost all protected.
- d. Potential for managing or alleviating climate impacts: Some groves are in areas that have management potential, but how to manage is uncertain (e.g., fire and weeds can be



managed, but mechanical equipment is unlikely). Possible actions include seed dispersal or other planting projects.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: Ectomycorrhizal fungus
 - i. Participant confidence: Moderate
- b. Collective degree these factors affect the adaptive capacity of the species: Moderate

Additional comments: Very low diversity associated with bristlecone stands, which could predispose it to climate impacts. Bristlecone pine is dependent on fungi for water uptake. More research is needed to better understand adaptive capacity of the species.

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate-High
 - i. Participant confidence: No answer provided by participants

Additional comments: Bristlecone have long generation times. They are hardy but rely on species for dispersal, water uptake, and competition; those species are also likely sensitive to climate change.



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, snowpack, shifts in vegetation type, climatic water deficit, wildfire, other – competition, soils.

- i. Participant confidence: Low (climatic water deficit & wildfire); High (all others)

2. Exposure region.

- a. Exposure by region: North – Not applicable; Central – Not applicable; South – Low-Moderate

- i. Participant confidence: High

3. Overall user ranking.

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

- i. Participant confidence: Moderate-High

Additional comments: Exposure is largely dependent on species that bristlecone relies on (e.g., for dispersal, water uptake, etc.). MC1 dynamic vegetation modeling demonstrates fewer climate impacts on White Mountains. However, uncertainty is high and more climate modeling is needed for White and Inyo Mountains.

References: Van de Ven et al. (2007) assert that despite temperature increases, individual bristlecone pine may survive hundreds of years at low-elevations due to slow dieback and local refugia, while species like *Pinus monophylla* and *Juniperus osteosperma* rapidly migrate upslope, resulting in rare, transitory forest associations. The combination of bristlecone–pinyon–juniper forest is currently very rare in the White Mountains but could become more commonplace as temperatures increase (Van de Ven et al. 2007).

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 (GDFL⁸ and PCM⁹) 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).

⁷ Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) 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.



Vegetation shifts: Many models of climate change in the Sierra Nevada predict uphill migration and restricted distribution of alpine/subalpine plant communities (Hayhoe et al. 2004; Lenihan et al. 2006; Van de Ven et al. 2007). However, habitat availability at higher elevations in the White and Inyo Mountains may be limited by bristlecone pine's aversion to granitic substrates. With an increase in temperature of 5°C (9°F), carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007).

Precipitation: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, annual temperatures in the Sierra Nevada are expected to rise between 2.4-3.4°C varying by season, geographic region, and elevation (Das et al. 2011; Geos Institute 2013). 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), with changes of least magnitude during both seasons anticipated 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 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 mean annual flow (Null et al. 2010).

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

Wildfire: 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).

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

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). Wildfire would be expected to have greatest impact in denser stands and at lower elevations adjacent to relatively productive upper montane forests, where fuel loading is higher and spatially contiguous.

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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Focal Resource: AMERICAN MARTEN

Taxonomy and Related Information

Marten (*Martes americana*); occurs across the Sierra Nevada but more common in the central and southern 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 workshop¹. The following document represents the vulnerability assessment results for the **AMERICAN MARTEN**, 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 disruption².

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 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.



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: 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 evaluation³. 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.

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	2 Between generalist & specialist	3 High
Physiology	2 Moderate	1 Low
Habitat	3 High	2.5 Moderate-High
Life History	3 High	3 High
Ecological Relationships	3 High	2 Moderate
Disturbance Regimes	3 High	2.5 Moderate-High
Non-Climatic Stressors – Current Impact	2 Moderate	2.5 Moderate-High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	2.5 Moderate-High
Other Sensitivities	2 Moderate	2 Moderate

Overall Averaged Confidence (Sensitivity)⁵: Moderate

Overall Averaged Ranking (Sensitivity)⁶: Moderate–High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	2 Moderate	2 Moderate
Barriers Affect Dispersal Ability	2.5 Moderate-High	2.5 Moderate-High
Plasticity	2 Moderate	1.5 Low-Moderate
Evolutionary Potential	2 Moderate	2 Moderate
Intraspecific Diversity/Life History	2 Moderate	2 Moderate
Species Value	3 High	3 High
Specificity of Management Rules	1.5 Low-Moderate	2.5 Moderate-High
Other Adaptive Capacities	No answer provided by participants	No answer provided by participants

Overall Averaged Confidence (Adaptive Capacity)⁵: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	2 Moderate
Precipitation	2 Moderate
Shifts in vegetation structure	1.5 Low-Moderate
Wildfire	2 Moderate
Snowpack	3 High

⁵ Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

⁶ Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.



Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	3 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: In between
 - i. Participant confidence: High
- b. Factors that make the species more of a specialist: Predator/prey relationship, foraging dependency, other – snowpack

Additional comments: Marten range is restricted by snow conditions, prey availability, and competition with the fisher and great grey owl.

The marten is a diet generalist when considered year-round, but winter diet can be much more specific (e.g., snowshoe hares, flying squirrels, and voles). Two of the three prey species are very dependent on snow conditions and the maintenance of subnivean foraging opportunities or deep snow. Thus, the diet in the most vulnerable season – from a climate change perspective – is rather specialized and several of the species used as prey resources are dependent on snow conditions.

References: Marten prefer high-elevation (approximately 1400 m to 3000 m) (4593 ft to 9843 ft) (Purcell et al. 2012), late-successional mixed-conifer, and red fir forests for resting and denning (Verner and Boss 1980, Meslow et al. 1981 cited in Spencer et al. 1983). Marten are highly selective of microhabitats, preferring complex structures near the ground, closed canopy (Slauson et al. 2007; Kirk and Zielinski 2009) and large diameter trees (Martin and Barrett 1991; Buskirk and Powell 1994; Slauson et al. 2007; Kirk and Zielinski 2009). For example, snags, stumps, and logs made up 61% of resting sites found near Sagehen Creek in Tahoe National Forest, and tree canopy accounted for another 13% of resting sites (Martin and Barrett 1991). Snag diameters averaged 43.9 cm (17.3 in), stump diameters averaged 83 cm (32.7 in), and log diameters averaged 69.4 cm (27.3 in) (Martin and Barrett 1991). Martens do not persist in forest systems where >30% of the original forest cover has been removed (Bissonette et al. 1997; Chapin et al. 1998; Hargis et al. 1999; Potvin et al. 2000).

Overall marten exhibit a generalist annual diet (Zielinski and Duncan 2004), however, winter diet of marten is specialized to a few accessible or abundant prey items, many of which rely on deep snow for subnivean foraging and caching opportunities (Grinnell et al. 1937, Marshall 1946, Cowan and Mackay 1950, Weckwerth and Hawley 1962, Francis and Stephenson 1972, and Soutiere 1979 cited in Zielinski et al. 1983; Zielinski and Duncan 2004). In winter, as subnivean dens and cone caches begin to be used by larger animals, martens appears to switch to larger prey, which likely representing a greater energy gain per capture (Zielinski et al. 1983). Winter prey includes voles (*Microtus spp.*), Douglas squirrels (*Tamiasciurus douglasii*), snowshoe hares (*Lepus americanus*), and flying squirrels (*Glaucomys sabrinus*) (Zielinski et al. 1983). Because marten requires thermal cover provided by snow in subalpine and montane habitats during winter (Buskirk et al. 1989, Taylor and Buskirk 1994 cited in Halofsky et al. 2011), changes in the structure and quality of the subnivean environment due to reduced snowpack (Pauli et al. 2013) could expose the marten to lethally cold temperatures (Halofsky et al. 2011).

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: Moderate
 - i. Participant confidence: Low

Additional comments: Species is reproductively sensitive to the factors listed above, not physiologically sensitive.



3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Other – snowpack, limited number of competitors
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: Moderate-High

Additional comments: The marten requires winter snowpack for reproductive success.

References: Martens rely on thick snowpack to exclude predators, provide high-quality hunting conditions, and provide winter resting and denning sites (Martin and Barrett 1991; Buskirk and Powell 1994; Bull and Heater 2000). Winter diet includes a few dominant species, most of which rely on subnivean conditions or deep snow to prosper, thus winter diet may be considered rather specialized (Zielinski et al. 1983). Furthermore, because the marten requires thermal cover provided by snow in subalpine and montane habitats during winter, reduced snowpack could expose the marten to lethally cold temperatures (Halofsky et al. 2011).

4. Life history.

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

Additional comments: Marten bears kits each year.

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Predator/prey relationship, competition
- 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: Moderate

Additional comments: Climate change may intensify interspecific competition and prey availability might no longer be sufficient.

Deep snow gives marten a competitive advantage over fishers due to higher foot loading of martens (i.e., better “snowshoes”). Thus, decreasing snow – or snow period – will give an edge to fishers, as will the habitat changes expected in the Sierra.

References: The subnivean environment provides stable temperatures, and decreased snowpack is expected to result in colder and more thermally variable subnivean space, despite warming winter temperatures (Pauli et al. 2013), potentially affecting both marten and prey species. Colder and more variable temperatures within the subnivean space may have major impacts on mammal communities that have evolved under these mild and stable subnivean conditions (Pauli et al. 2013). Marten have a competitive advantage over fisher in deep snow, due to higher foot loading in marten; decreasing snowpack may remove this advantage and benefit fishers, potentially altering marten and fisher spatial distributions (Krohn et al. 1997).

6. Disturbance regimes.



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

Additional comments: Severe wildfire is negative in the short-term because marten require logs, large woody debris, shrubs, and downed snags as habitat for foraging, resting, and denning. In the long term, wind and the other disturbance factors may provide additional habitat by providing more downed trees.

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Altered interspecific interactions, pollution and poisons, other – large openings
- b. Current degree to which stressors affect the species: Moderate
 - i. Participant confidence: Moderate-High
- c. Degree to which non-climate stressors make species more sensitive: High
 - i. Participant confidence: Moderate-High

Additional comments: Marten may be susceptible to poisons such as rodenticides if they are used at the elevations that marten occupy. Zielinski et al. 2008 suggest that martens tolerate snowmobile use and noise.

References: Martens are sensitive to disturbances that may limit habitat availability and quality (Kirk and Zielinski 2009; Slauson et al. 2007), including grazing pressure (Spencer et al. 1983), road density (Wasserman et al. 2010), timber harvest, and forest management practices (Zielinski et al. 2005). The distribution of mature forests may be the primary determinant of marten distribution (Kirk and Zielinski 2009).

Pesticides employed in illegal marijuana cultivations are known to cause mortality and decreased fitness in Pacific fishers, and may pose a risk to martens in the Sierra Nevada (Gabriel et al. 2012). Sublethal exposure to pesticides has been associated with reduced thermoregulatory capacity in birds and mice (Grue et al. 1991, Gordon 1994 cited in Thompson et al. 2013).

Martens appear to tolerate snowmobile noise (Zielinski et al. 2008).

8. Other sensitivities.

- a. Other critical sensitivities not addressed: Large scale-high intensity fires
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase species' sensitivity to climate change: Moderate

References: Zielinski et al. 2008 suggest that martens tolerate snowmobile use and noise.

9. Overall user ranking.

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

References: Please also refer to the following references on marten in California: Simon (1980), Spencer et al. (1983), Zielinski et al. (1983), Hargis and McCullough (1984), and Ellis (1998).



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: >100 km (>62 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: Moderate
 - i. Participant confidence: Moderate
- c. General types of barriers to dispersal include: Road-highway, industrial or urban development, suburban or residential development, clear cut, arid lands
- d. Degree barriers affect dispersal for the species: Moderate-High
 - i. Participant confidence: Moderate-High
- e. Possibility for individuals to seek out refugia: No answer provided by participants

Additional comments: The marten is a very mobile species. Potential impediments to dispersal include highways, residential developments, and clear-cut areas.

References: Distribution of martens has decreased since the early 1900s, and is fragmented in the southern Cascades and northern Sierra Nevada (Zielinski et al. 2005). The distribution of mature forests may be the primary determinant of marten distribution (Kirk and Zielinski 2009). Forest fragmentation may reduce marten numbers, and may influence fragmentation of population distribution (Phillips 1994; Zielinski et al. 2005; Kirk and Zielinski 2009). Martens do not persist in forest systems where >30% of the original forest cover has been removed (Bissonette et al. 1997; Chapin et al. 1998; Hargis et al. 1999; Potvin et al. 2000).

2. Plasticity.

- a. Ability of species to modify physiology or behavior: Moderate
 - i. Participant confidence: Low-Moderate
- b. Description of species' ability to modify physiology or behavior: The marten is very mobile and has a generalist annual diet, but has strict requirements of snow for reproduction.

References: In serpentine habitats in California, where large diameter trees and logs are largely absent, marten have been located in large rock structures with interstitial spaces, which may provide for the life-history needs that woody structures typically provide (Slauson et al. 2007). While martens have been documented using boulder fields, talus slopes, and rockslides in areas with reduced forest cover, those habitats may not provide for year-round habitat needs (Slauson et al. 2007; Green 2007 cited in Purcell et al. 2012).

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Moderate
 - i. Participant confidence: Moderate
- b. Description of characteristics that allow species to adapt evolutionarily: Lack of habitat connectivity may inhibit gene flow.

References: Distribution of martens has decreased since the early 1900s and is fragmented in the southern Cascades and northern Sierra Nevada (Zielinski et al. 2005). Moreover, dramatic reduction of habitat area will likely be accompanied by large decreases in local population size, increasing likelihood of local extinction (Wasserman et al. 2012). Climate change may shift suitable bioclimate conditions up the elevational gradient, reducing connectivity of important habitat for high elevation species (Wasserman et al. 2010), such as martens. Habitat patchiness and population isolation is predicted to genetically isolate the marten, reducing genetic allelic richness and expected heterozygosity (Wasserman et al. 2012). Inbreeding depression has been strongly linked to extinction risk and the loss



of allelic diversity reduces evolutionary potential. In addition, dramatic reduction of habitat area will likely be accompanied by large decreases in local population size, increasing likelihood of local extinction (Wasserman et al. 2012).

4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Moderate
 - i. Participant confidence: Moderate
- b. Description of diversity of life history strategies: The marten is mobile but has limited reproductive potential and ability to change reproduction.

5. Management potential.

- a. Value level people ascribe to this species: High
 - i. Participant confidence: High
- b. Specificity of rules governing management of the species: Low-Moderate
 - i. Participant confidence: Low-Moderate
- c. Description of use conflicts: Recreation and water diversions.
- d. Potential for managing or alleviating climate impacts: The potential for managing or alleviating climate impacts is low. Focusing on habitat connectivity and water diversion considerations, such as those that allow wet meadows to be maintained, could improve adaptive capacity. Management actions could maintain or increase cover, naturally or artificially, in open areas.

References: The potential for management to alleviate climate impacts is low, and should focus on maintaining habitat connectivity, including dense shrub cover (Slauson et al. 2007).

6. Other adaptive capacity factors.

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
 - i. Participant confidence: Moderate
-



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, shifts in vegetation, wildfire, snowpack
 - i. Participant confidence: Moderate (temperature), Moderate (precipitation), Low-Moderate (shifts in vegetation), Moderate (wildfire), High (snowpack)

2. Exposure region.

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

3. Overall user ranking.

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

Additional comments: Participants are unsure how flexible the species will be in the future.

References: Please see the book Martens and fishers in a changing climate by Lawler et al. (2012) for climate impacts on marten.

Vegetation and habitat changes: In the Sierra Nevada, a shift in distribution to higher elevations could drive martens toward the limit of forested habitats, potentially limiting their distribution and leading to decreases in population size. Models suggest that increased temperature as a result of climate change and an increase in plant fuel could augment both the severity and frequency of fire, potentially leading to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008) important for marten habitat. Loss of red fir/lodgepole communities in the Sierra Nevada may be accelerated by changes in the severity and frequency of fire (PRBO Conservation Science⁸ 2011), although increased fire may create opportunities to expand for some component species, such as lodgepole pine (Bartlein et al. 1997). Climate change may also reduce the connectivity of dispersal habitat for the marten and fisher (Wasserman et al. 2010), resulting in predicted genetic isolation, reduced genetic allelic richness and expected heterozygosity, and increased risk of local extinction (Wasserman et al. 2012).

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 (GDFL⁹ and PCM¹⁰) 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).

⁷ Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

⁸ PRBO Conservation Science is now 'Point Blue'

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.



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 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). Decreases in winter precipitation combined with increases in summer temperature may produce declines in conifer tree growth in mixed conifer forest of northern California (Yeh and Wensel 2000).



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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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). Models suggest that the increase in fuel and temperature could increase both the severity and frequency of fire, potentially leading to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008).

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/602b58f9bbd44dff487a04a1c5c0f52>).

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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 workshop¹. 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.sgccp.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 disruption².

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

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

¹ For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at:

<http://ecoadapt.org/programs/adaptation-consultations/calcc>.

² Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. National Wildlife Federation, Washington, D.C.



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

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation³. 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.

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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>.



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

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.

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
Mountain Quail



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).

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.

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)

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.

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).

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

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).

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).

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.

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).

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

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
 - i. Participant confidence: Moderate
-



Exposure

1. Exposure factors⁷.

- 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).

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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Focal Resource: **MOUNTAIN & SIERRA NEVADA YELLOW-LEGGED FROGS**

Taxonomy and Related Information

Mountain yellow-legged frog (*Rana muscosa*); Sierra Nevada yellow-legged frog (*Rana sierra*); occur across Sierra Nevada mountains.

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop¹. The following document represents the vulnerability assessment results for **MOUNTAIN & SIERRA NEVADA YELLOW-LEGGED FROGS**, 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 disruption².

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.



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.

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 evaluation³. 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.

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	2 Moderate
Physiology	3 High	3 High
Habitat	3 High	3 High
Life History	1 R-selection	3 High
Ecological Relationships	3 High	2 Moderate
Disturbance Regimes	3 High	3 High
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	2 Moderate	1 Low
Other Sensitivities	No answer provided by participants	No answer provided by participants

Overall Averaged Confidence (Sensitivity)⁵: Moderate–High

Overall Averaged Ranking (Sensitivity)⁶: Moderate–High

ADAPTIVE CAPACITY & EXPOSURE

These sections were not completed by participants in the time allotted.

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 columns.



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: Specialist
 - i. Participant confidence: Moderate
- b. Factors that make the species more of a specialist: Phenology dependency

Additional comments: Factors that make the species more of a specialist include dependence on water availability for breeding. Overall, these species are considered specialists because of habitat needs, not because of diet needs.

References: The Sierra Nevada and mountain yellow-legged frogs occupy high-elevation (i.e. 1370 m to 3660 m) (4495 ft to 12008 ft) lakes, seeps and springs, slow-moving streams (Lacan et al. 2008), and meadows. Both species of mountain yellow-legged frog are dependent on perennial water for breeding and prolonged larval development (Lacan et al. 2008).

2. Physiology.

- a. Species physiologically sensitive to one or more factors including: Temperature, precipitation, salinity, pH, dissolved O₂, other – disease
- b. Sensitivity of species' physiology to one or more factors:
 - i. Participant confidence:

Additional comments: The egg and larval stages are extremely sensitive to water quality. Currently there are studies examining the impacts of pollution on frog declines to determine if there is a correlation. Although not a direct impact on frog physiology, the main disease threat (Chytrid fungus) cannot survive in hot temperatures but does well in cold, upper elevations.

References: In addition, warming water temperatures may exert both positive and negative influence on mountain yellow-legged frogs. Stream temperatures have increased in recent decades as air temperatures have increased (Hari et al. 2006, Webb and Nobilis 2007, and Kaushal et al. 2010 cited in Null et al. 2012). Water temperatures influence the biological, physical, and chemical properties of aquatic ecosystems, including dissolved oxygen levels, nutrient cycling, productivity, metabolic rates and life histories (Vannote and Sweeney 1980; Poole and Berman 2001). Warming may benefit mountain yellow-legged frogs if it results in decreased time to metamorphosis, as occurs with some species (e.g. Pacific tree frog) (Paull et al. 2012). Warming may also alter susceptibility to infection and infection rates, although the relationship in North American amphibians is often nonlinear. Warming may increase the ability of a pathogen to penetrate the host, but also decrease a tadpole's period of sensitivity (Paull et al. 2012). Furthermore, pathogen outbreaks in foothill yellow-legged frogs in Northern California associated with warm temperatures (e.g. *Lernaea cyprinacea*) may be aided by reduced water levels, resulting in higher densities of larvae and easier transmission of the pathogen (Kupferberg et al. 2009).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Seasonal streams, seeps/springs, alpine/subalpine, other – perennial water
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: High

Additional comments: There is high dependence on perennial water; for example, successful breeding requires perennial water because egg to metamorphosis is 2-3 years.



References: Breeding occurs primarily in smaller lakes, which are more susceptible to drying (Lacan et al. 2008). Highest egg mass counts have been recorded in summers following high snowpack, and snowpack reductions predicted in the northern Sierra Nevada (Safford et al. 2012) may reduce Sierra Nevada yellow-legged frog recruitment success as the frequency of summer drying of small lakes increases (Lacan et al. 2008). Full metamorphosis for the Sierra Nevada population segments requires two to four years (Knapp and Matthews 2000; Lacan et al. 2008), and drying even once in 10 years yielded a significantly lower abundance of metamorphs than lakes and ponds that remained wet (Lacan et al. 2008).

4. Life history.

- a. Species reproductive strategy: R-strategy
 - i. Participant confidence: High
- b. Species polycyclic, iteroparous, or semelparous: Iteroparous

Additional comments: There is a very low survival rate overall (many different life stages that may not survive).

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, pH (changes in water chemistry from runoff and wildfires)
- c. Sensitivity of species to other effects of climate change on its ecology: High
 - i. Participant confidence: High

Additional comments: Forage may also be sensitive if macroinvertebrate abundance changes.

6. Disturbance regimes.

- a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, flooding, other – long winter, extreme cold
- b. Sensitivity of species to one or more disturbance regimes: High
 - i. Participant confidence: High

Additional comments: Disturbance regimes include wind (could be an issue for dispersion from water body to water body and/or an issue of desiccation), wildfire (frequency and severity), flooding (severity and timing), drought (frequency, severity, duration), and extreme cold (frequency and severity).

References: In other areas, such as Colorado, extinctions of amphibian species in montane regions are attributed to drought conditions experienced during the mid 1970s (Finch et al. 2012). However, no clear pattern exists regarding effects of wildfire on amphibians, possibly because there are limited studies for most species. Response to fire varies according to life history strategy. According to a meta-analysis conducted by Hossack and Pilliod (2011), of 19 populations in the Western U.S., studied before and after fire, 7 displayed negative response to fire, 5 positive, and 6 displayed no response to fire. Fire effects were greater in forests where fire had been suppressed and in areas that burned with high severity. Species that breed in streams were also vulnerable to post-fire habitat changes, especially in the Southwest, as pools may dry or fill with sediment, and post-fire debris flows may greatly reduce rearing habitat. In contrast to fishes, amphibian re-colonization from adjacent areas is expected to occur slowly (Hossack and Pilliod 2011).



7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Residential and commercial development, agriculture and aquaculture (fish stocking, grazing), energy production and mining, transportation and service corridors, biological resource use (logging), human intrusions and disturbance, natural system modification, invasive and other problematic species, pollution and poisons
- b. Current degree to which stressors affect the species: High
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: Moderate
 - i. Participant confidence: Low

Additional comments: Both frogs are high elevation species and as such, responses above are based in that context.

References: Mountain yellow-legged frogs are sensitive to a number of non-climatic stressors, including high-elevation non-native fish stocking (Bradford 1989; Knapp and Matthews 2000; Null et al. 2012), agrochemical contamination (Davidson et al. 2002, Davidson and Knapp 2007), and fungal infections (Fellers et al. 2001; Wake and Vredenburg 2008), which may compound species sensitivity to climate-driven changes. Rivers on the western slope of the Sierra Nevada above about 2000 m (6562 ft) were mostly fishless prior to stocking, although they are now managed to sustain several native and non-native trout (Viers and Rheinheimer 2011). Studies have found that stocked non-native trout have contributed to the decline of mountain yellow-legged frogs (Bradford 1989; Bradford et al. 1994; Knapp and Matthews 2000) and may severely limit breeding habitat to smaller ponds prone to desiccation (Lacan et al. 2008), compounding possible mortality from desiccation and other climate-driven changes. In addition, it has been suggested that airborne pesticides have contributed to the decline of mountain yellow-legged frog populations (Davidson et al. 2002; Fellers et al. 2004). The long metamorphosis of tadpoles in the Sierra Nevada populations and the fact that adults spend nearly all their time in the water make them especially susceptible to pesticide poisoning (Fellers et al. 2004). Declines of mountain yellow-legged frog were found concentrated in lower elevation sites in California, and were associated with the amount of upwind agricultural land use, suggesting that mountain yellow-legged frogs may be particularly sensitive to agrochemicals (Davidson et al. 2002). Analysis of tissue from other Sierra Nevada frogs indicates that high-elevation frogs accumulate pesticides, and that tissue concentrations can be better indicators of exposure than water and soil concentrations (Smalling et al. 2013). Sub-lethal impacts resulting from pesticides, including reduced resistance to disease, are also likely (Sparling 1994 cited in Fellers et al. 2004; Smalling et al. 2013). In contrast, other studies suggest that pesticides may not contribute to the decline of mountain yellow-legged frogs in the alpine regions of the southern Sierra Nevada, but rather that declines are consistent with a pattern of spread of chytridiomycosis (Bradford et al. 2011). Chytridiomycosis, an emerging infectious disease caused by a fungal pathogen, *Batrachochytrium dendrobatidis*, is having a devastating impact on native frogs of the Sierra Nevada, already weakened by the effects of pollution and introduced predators (Fellers et al. 2001; Wake and Vredenburg 2008; Bradford et al. 2011).

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

9. Overall user perceived ranking.

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



Adaptive Capacity & Exposure

Workshop participants were unable to complete the Adaptive Capacity and Exposure sections of the Vulnerability Assessment for Sierra Nevada and Mountain Yellow-Legged Frogs. Please refer to the vulnerability briefing titled *Sierra Nevada Individual Species Vulnerability Assessment Briefing: Mountain Yellow-Legged Frogs* for an overview of vulnerability findings for these species.



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Focal Resource: PACIFIC FISHER

Taxonomy and Related Information

Pacific fisher (*Pekania pennanti*, formerly *Martes pennanti*)¹; southern Sierra population south of Merced River (small population: 100-400 adults); one introduced population north-western California; historic: two separate populations (separated over 1000 years).

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 workshop². The following document represents the vulnerability assessment results for the **PACIFIC FISHER**, 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.sgccp.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.

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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 disruption³.

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 Following Koepfli et al. 2008.

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: 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 evaluation⁴. 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.

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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	1 Generalist	3 High
Physiology	2 Moderate	2 Moderate
Habitat	3 High	2 Moderate
Life History	3 High	3 High
Ecological Relationships	No answer provided by participants	1 Low
Disturbance Regimes	3 High ⁵	3 High
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	1.5 Low-Moderate	2 Moderate
Other Sensitivities	None	2 Moderate

Overall Averaged Confidence (Sensitivity)⁶: Moderate-High

Overall Averaged Ranking (Sensitivity)⁷: Moderate-High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	2 Moderate	3 High
Barriers Affect Dispersal Ability	1 Low	1 Low
Plasticity	3 High	No answer provided by participants
Evolutionary Potential	1 Low	3 High
Intraspecific Diversity/Life History	1 Low	1 Low
Species Value	3 High	3 High
Specificity of Management Rules	2 Moderate	2 Moderate
Other Adaptive Capacities	None	2 Moderate

Overall Averaged Confidence (Adaptive Capacity)⁶: Moderate

Overall Averaged Ranking (Adaptive Capacity)⁷: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Wildfire	3 High
Snowpack	1 Low
Shifts in vegetation structure	3 High

⁶ 'Overall averaged confidence' is the mean of the entries provided in the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

⁷ '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 Moderate	No answer provided by participants
Central Sierra Nevada	Not applicable	No answer provided by participants
Southern Sierra Nevada	2 Moderate	No answer provided by participants

Overall Averaged Confidence (Exposure)⁶: Moderate

Overall Averaged Ranking (Exposure)⁷: Moderate



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: Generalist – overall; specialist in terms of resting/denning structures
 - i. Participant confidence: High
- b. Factors that make the species more of a specialist: Other dependencies – denning/resting

Additional comments: The species has multiple prey and habitat elements. Important structures for denning/resting include decadent structures and old growth habitats.

Black oaks do seem important in the southern Sierra Nevada, but oaks may not be critical in other regions.

References: Although the Pacific fisher utilizes multiple prey (Zielinski et al. 1999) and multiple habitat elements, the Pacific fisher is considered a habitat specialist, with resting and denning structures considered to be the most important habitat elements required for maintenance of fisher populations (Lofroth et al. 2010 cited in Zhao et al. 2012; Weir et al. 2012). Fishers prefer habitats with dense canopy cover and decadent structures for denning and resting (Purcell et al. 2009), such as large trees with visible signs of decay (Weir et al. 2012). Black oaks appear to contribute to fisher habitat quality by providing good cavities for denning and resting, and by providing mast that support fisher prey in the southern Sierra Nevada (Purcell et al. 2012, Spencer and Rustigian-Romsos 2012), but may be less critical in other regions. Sensitivity of Pacific fisher prey species to climate change is largely unknown (Purcell et al. 2012).

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: Fisher responds to warmer temperature by moving to riparian areas, canyon bottoms, dense canopies, and north facing slopes to avoid extremes (especially high temperatures and/or high daily temperature amplitudes). Snow limits movement ability; in general, fishers do not do well with deep, persistent, fluffy snows. Fishers are more sensitive to climate stress in denning season. More information is needed on physiological constraints of fishers.

References: Fisher are sensitive to deep snow, which limits movement ability (Krohn et al. 1997).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Other: Old growth/complex forest, riparian areas
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: Moderate

Additional comments: Old growth and complex forests are sensitive to indirect climate change effects such as drought and altered fire regimes. Fishers use riparian areas as travel corridors.

4. Life history.

- a. Species reproductive strategy: K-selection
 - i. Participant confidence: High



- b. Species polycyclic, iteroparous, or semelparous: Iteroparous

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Habitat
- 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: No answer provided by participants
 - i. Participant confidence: Low

Additional comments: Habitat components that are sensitive include old growth and complex components. Temperature and precipitation changes may result in drought and water deficit, potentially affecting important habitat components. Fisher may depend on other species, such as the pileated woodpecker, mistletoe, and witches broom to create habitat to rest in or on. The sensitivity of these other species to climate change is unknown. Prey species' sensitivities are also unknown and could be critical. While competition may be enhanced with American marten due to snowpack decreases at transitional elevations, fishers are actually likely to 'win' these competitive interactions.

References:

Vegetation structure and distribution: Fishers depend on the presence of water (Purcell et al. 2009), and habitat persistence is sensitive to water deficit and altered fire regimes (Zielinski et al. 2013). In the Sierra Nevada, conifer forests are predicted to be largely replaced by deciduous forests at low and middle elevations (Lenihan et al. 2008). Because California black oaks appear to enhance fisher habitat in the southern Sierra Nevada, predicted shifts of conifer-dominated forest types to mixed woodland and hardwood forest types may benefit fishers (Purcell et al. 2012). However, the expectation is for an overall decrease in the availability of fisher habitat as changes in fire regime are projected to result in loss of late seral habitat, and decreases in the density of large conifer and hardwood trees and canopy cover (Purcell et al. 2012). In the Sierra Nevada, the Sierra mixed conifer/white fir/Jeffrey pine vegetation type is projected to decrease (by 12-32%), while blue oak/foothill pine and ponderosa pine/Klamath mixed conifer are projected to increase by 2070 (PRBO Conservation Science 2011). An increase in both the severity and frequency of fire could lead to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008). These changes will likely increase the threat to species associated with closed-canopy forests (McKenzie et al. 2004), such as fishers. A drier future may also result in the mixed conifer forest inhabited by fishers being replaced by grasslands and shrublands (Lenihan et al. 2008), which are unsuitable for fishers.

Fishers are associated with areas of low or intermediate snowfall in which topographic breaks change snowfall amounts over small areas, since deep snow limits movement ability and mitigates competitive interaction between fisher and marten (Krohn et al. 1997). Future reductions in snowpack could alter competitive relationships between martens and fishers, providing fishers a competitive advantage (Krohn et al. 1997; Purcell et al. 2012). Fishers also uses cavities created by other species such as the pileated woodpecker, and clusters created by mistletoe and rust broom (Purcell et al. 2012), whose sensitivity to climate change is largely unknown. Sensitivity of prey species to climate change is also largely unknown (Purcell et al. 2012).

6. Disturbance regimes.

- a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, insects, wind, disease



- b. Sensitivity of species to one or more disturbance regimes: High
 - i. Participant confidence: High

Additional comments: Uncharacteristically severe wildfire and drought may negatively impact fisher by reducing canopy cover and killing larger trees. Fisher may be positively impacted by increased wind and tree disease over smaller scales, which may provide structure for denning and resting sites. Increased insects over smaller scales may also be a benefit to fisher, as they cause more cavities and decadence in forest structure. However, larger scale effects in any of these disturbances (wind, disease, insects, wildfire) could remove habitat value over large areas.

References: Large-scale or uncharacteristically severe wildfire and drought may reduce canopy cover and kill larger trees, removing habitat value over large areas and potentially impacting prey dynamics. Periods of water shortage are associated with tree susceptibility to infections and insects, such as dwarf mistletoe (*Arceuthobium abietinum* f. *sp. magnificae*), root disease (*Heterobasidion annosum*), and bark beetles (North et al. 2002; Grulke et al. 2009; Grulke 2010), whose impacts can be both beneficial and detrimental to fisher, depending on the scale of the impact. Diseases such as mistletoe and rust broom in trees of declining health may be beneficial to Pacific fishers by creating perches and cavities (Purcell et al. 2012) used for denning and resting, whereas major mortality events resulting from pest complexes (e.g. root diseases/dwarf mistletoe/bark beetles) (North et al. 2002) may reduce habitat available to fisher.

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Residential and commercial development, transportation and service corridors, altered interspecific interactions, poisons, other – fuel management
- b. Current degree to which stressors affect the species: High
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: Low-Moderate
 - i. Participant confidence: Moderate

Additional comments: Fishers are impacted by wildland-urban interface (WUI) fuel treatments related to residential development. Urban development is very minor in fisher range in California; exurban (e.g., cabins, summer homes) development increases risks due to increased likelihood of fire, increased need for forest thinning, increased exposure to pets, etc. Fishers are victim to road mortality and increased predation. Predation is the primary, ultimate cause of death for most fishers, with predation rates “unnaturally high” probably due to synergistic threats (e.g., rodenticides weaken fishers, making them more susceptible to predation) and the opening of forests by roads and management actions that increase access for predators (especially bobcats, coyotes, and pumas). Although it is poorly understood, altered availability of larger prey (e.g., porcupine, lagomorphs) in the southern Sierra Nevada may also increase fisher sensitivity to climate change. There is a lack of data on influence of recreation use, although it is likely a minor impact. Rodenticides, pesticides, and insecticides used at marijuana grow sites may reduce individual animals’ ability to respond to other stressors, or cause direct mortality. These stressors make the fisher more sensitive to climate change to a lesser degree, but they keep the fisher population size small, and small populations are less able to expand and recover from any perturbation. Not implementing fuel treatments /vegetation management because of its short-term negative effect on fisher habitat ultimately increases species’ sensitivity due to projected increases in fire (both frequency and severity) as a result of climate change. Therefore, fuel treatment stressors actually make the fisher less sensitive to the stress of increased fire (caused by climate change) in the long term. This highlights the trade-offs between short and long term sensitivities.



References: The Pacific fisher population is also stressed by numerous non-climate factors that increase mortality and may increase population sensitivity to climate change. Habitat alterations due to timber harvest (Zielinski et al. 2013); fire management (Scheller et al. 2011, Zielinski et al. 2013); exurban development (e.g., cabins, summer homes) and its influence on fuel treatments; exposure to domestic pet diseases (Spencer and Rustigian-Romsos 2012); road mortality (Spencer and Rustigian-Romsos 2012); reduced fitness or direct mortality associated with rodenticides and other pesticides used at marijuana grow-sites (Gabriel et al. 2012, Thompson et al. 2013); altered prey availability; and predation (Spencer and Rustigian-Romsos 2012). Pacific fishers in the southern Sierra Nevada lack the larger prey (e.g. porcupines, lagomorphs) that compose a large portion of fisher diet in other regions, but the effects of prey availability are poorly understood, and sensitivity of Pacific fisher prey species to climate change is largely unknown (Purcell et al. 2012). Prey consumed by fishers in the southern Sierra Nevada, including insects and plant material, small mammals, birds, and carrion (Zielinski et al. 1999; Zielinski and Duncan 2004), may expose them to direct and secondary toxicants (Thompson et al. 2013). Direct and secondary exposure to rodenticides and pesticides represent a significant risk to isolated California populations (Gabriel et al. 2012), and appear to cause both mortality and decreased fitness by increasing fisher susceptibility to hypothermia, parasites, pathogens and predation (Berny et al. 1997, Winters et al. 2010, and Lemus et al. 2011 cited in Thompson et al. 2013; Gabriel et al. 2012). Poisoning risk has the potential to shift a population from positive to negative growth rate (Thompson et al. 2013). Predation by bobcats (*Lynx rufus*) and cougars (*Puma concolor*) appears to be the leading cause of mortality, facilitated by road building and forest thinning, which likely provide access to fisher habitat by predators while reducing fisher cover and escape (Spencer and Rustigian-Romsos 2012).

8. Other sensitivities.

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

9. Overall user ranking.

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

Additional comments: General sensitivity was low, except for extreme risk of fire, so perhaps overall, the fisher gets a “high”, rather than the averaged rating of “moderate”, indicated here.



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 75-100 km (46-62 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: Moderate
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Road – highway, major river canyons, unforested areas
- d. Degree barriers affect dispersal for the species: Low
 - i. Participant confidence: Low
- e. Possibility for individuals to seek out refugia: Available

Additional comments: Dispersal distance is given in CDFG (2010⁸). Roads may affect dispersal if road mortality is high enough. Fishers readily cross roads in the region; occasional roadkill, especially during denning season, are a problem and road-crossing structures are needed. Additional barriers or strong filters to dispersal movements appear to include steep ravines, major river canyons, and unforested areas. Snow could also present a barrier. Other interacting stressors impacting the population include predation, roadkill, rodenticides, etc., and this may be contributing to the population's lack of dispersal.

References: Fishers have failed to expand into historically occupied habitat (Thompson et al. 2013) for unknown reasons. Elevated mortality rates may be limiting the population's potential for expansion (Spencer et al. 2011) despite long dispersal capacity. Installation of movement corridor structures may aid expansion (Spencer and Rustigian-Romsos 2012) and reduce mortality from road strikes.

2. Plasticity.

- a. Ability of species to modify physiology or behavior: High
 - i. Participant confidence: No answer provided by participants
- b. Description of species' ability to modify physiology or behavior: Fisher may move upslope, or into shade, riparian areas, or cavities to escape high temperatures. The fisher has long dispersal capabilities, and is able to move long distances in a short time. The fisher also has the ability to change prey focus seasonally / annually. It has no physiological change capacity.

References: Resting sites are used to regulate body temperatures (Powell and Zielinski 1994 cited in Zhao et al. 2012).

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Low
 - i. Participant confidence: High
- b. Description of characteristics that allow species to adapt evolutionarily: The fisher's low genetic diversity (Tucker et al. 2012), lack of connectivity with other populations (Tucker et al. 2012), and small population size (Zielinski et al. 2013, CDFG 2010⁹) limit its evolutionary potential.

⁸ <http://www.dfg.ca.gov/wildlife/nongame/publications/docs/FisherStatusReviewComplete.pdf>



References: The fisher is a candidate species for listing under Federal, Oregon, and California Endangered Species Acts (Zhao et al. 2012; Thompson et al. 2013). In California, fishers occur in two isolated populations (Davis et al. 2007, Knaus et al. 2011 cited in Zhao et al. 2012); the southern Sierra Nevada population is completely isolated and has an estimated 100 to 400 individuals (Lamberson et al. 2000 cited in Zielinski et al. 2013, Spencer et al. 2011). A second larger fisher occupancy area extends from the northern Sierra Nevada into the Klamath-Cascades region of Oregon, and populations are considered at high risk of local extinction from stochastic events such as disease or wildfire (Spencer et al. 2011; Thompson et al. 2013).

4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Low
 - i. Participant confidence: Low
- b. Description of diversity of life history strategies: None recorded

Additional comments: Participants know of no examples of life history diversity.

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: Conflicts between vegetation management and fisher protection, economic harvest and fisher protection, and marijuana gardens and fisher protection (due to the rodenticide used and the secrecy involved in law enforcement activities).
- d. Potential for managing or alleviating climate impacts: Possibilities for managing or alleviating climate impacts include vegetation management and fuel treatment to reduce the risk of altered fire regimes and catastrophic fire and reintroduction and assisted migration. However, source population may not have enough individuals to reintroduce from the southern Sierra population, but possibly different population in Northern California. Perhaps more kits of mothers killed by cars could be relocated.

Additional comments: Potential ESA listing may have huge impacts on specificity and flexibility of "rules" governing management.

References: Forest management can affect the fisher both positively and negatively (Spencer and Rustigian-Romsos 2012). Tree removal may reduce fisher habitat, while fuel treatments that reduce the risk of catastrophic fire may indirectly benefit fisher (Scheller et al. 2011).

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: None
 - i. Participant confidence: No answer provided by participants
- b. Collective degree these factors affect the adaptive capacity of the species: Not applicable

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Low
 - i. Participant confidence: Moderate



Additional comments: Adaptive capacity is influenced by their low population density, small population size, and low genetic diversity. The southern Sierra population is not growing for some reason, and may be impacted by an unidentified stressor. It is unknown why the fisher is not currently expanding into theoretically suitable habitat.

References: The Pacific fisher's capacity to accommodate climate changes is limited by its small population size, low reproductive rate, geographic and genetic isolation, and low genetic diversity (Purcell et al. 2009, Purcell et al. 2012, Spencer et al. 2011, Tucker et al. 2012, Zielinski et al. 2013).



Exposure

1. Exposure factors⁹.

- a. Factors likely to be most relevant or important to consider for the species: Snowpack, wildfire, shifts in vegetation structure
 - i. Participant confidence: High (wildfire), High (vegetation), Low (snowpack)

2. Exposure region.

- a. Exposure by region: North – High; Central – N/A; South – High
 - i. Participant confidence: No answer provided by participants

3. Overall user ranking.

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

Additional comments: Due to reliance on multi-structure and old growth and dense habitats, exposure risk is higher for catastrophic fire. Climate change effects models show major shifts in vegetation due in part to fire, but not entirely. Overall major reductions in fisher habitat are predicted over the next 50 years. Vegetation type, per se, is not as important as vegetation structure. Information on location of future refugia in relation to recreation and other uses would be helpful.

References:

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

⁹ 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.



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).

Wildfire: Large, severe wildfires may pose a potential risk to the remaining fisher populations in the southern Sierra Nevada. Fisher habitat in the Sierra Nevada occurs at elevations where fire risk is greatest (Miller et al. 2009; Scheller et al. 2011). Models by Scheller et al. (2011) projected that the ability of fuel treatments to preserve fisher habitat will vary by elevation, with the best results at higher elevations (Scheller et al. 2011). Treatments under more severe fire regimes, and in proximity to high-quality habitat (>0.5 fisher occurrence probability) provided the greatest benefit to fishers. Under a heightened fire regime simulation, fuel treatments in marginal fisher habitat also benefited fishers as fires spread more readily between high and low quality habitat (Scheller et al. 2011).

Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009).

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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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).

Changes in vegetation: Decreases in winter precipitation combined with increases in summer temperature may produce declines in conifer tree growth in mixed conifer forest of northern California (Yeh and Wensel 2000). Models suggest that the increase in fuel and temperature could increase both the severity and frequency of fire, potentially leading to vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008).

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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Focal Resource: RED FIR SPECIES

Taxonomy and Related Information

Red fir (*Abies magnifica*); 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 workshop¹. 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 disruption².

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

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

¹ For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at:

<http://ecoadapt.org/programs/adaptation-consultations/calcc>.

² Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.



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

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation³. 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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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>.



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

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).

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).

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.



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.

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).

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).



7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Biological resource use, altered interspecific interactions, human intrusions and disturbance, natural system modifications
- 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: 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 (*Melampsorella caryophyllacearum*), trunk rot (*Echinodontium tinctorium*), and the Douglas fir-tussock moth (*Orygia pseudotsugata*) have been shown to cause growth-loss in both red and white fir (Laacke 1990; North et al. 2002).

8. Other sensitivities.

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

9. Overall user ranking.

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



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 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)

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.

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).

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

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.



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.

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 factors⁷.

- 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)

2. Exposure region.

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

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 (GDFL⁸ and PCM⁹) 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

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/602b58f9bbd44dff487a04a1c5c0f52>).

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Focal Resource: **SAGE-GROUSE**

Taxonomy and Related Information

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

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop¹. The following document represents the vulnerability assessment results for the **SAGE-GROUSE**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, <http://www.taccimo.sgcp.ncsu.edu/>) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

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

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption².

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

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

¹ For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at:

<http://ecoadapt.org/programs/adaptation-consultations/calcc>.

² Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment*. National Wildlife Federation, Washington, D.C.



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

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

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

Overall Averaged Confidence (Sensitivity)⁵: Moderate

Overall Averaged Ranking (Sensitivity)⁶: Moderate-High

ADAPTIVE CAPACITY

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

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

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

EXPOSURE

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

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

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



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

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	2 Moderate	1.5 Low-Moderate
Central Sierra Nevada	2 Moderate	1.5 Low-Moderate
Southern Sierra Nevada	3 High	1.5 Low-Moderate
Eastern Sierra Nevada	3 High	1.5 Low-Moderate

Overall Averaged Confidence (Exposure)⁵: Low-Moderate

Overall Averaged Ranking (Exposure)⁶: Moderate – High



Sensitivity

1. Generalist/Specialist.

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

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

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

2. Physiology.

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

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

3. Sensitive habitats.

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

References: Once impacted, alteration of vegetation, nutrient cycles, and living (cryptobiotic) soil crusts in sagebrush communities may exceed recovery thresholds, impeding the restoration of suitable sagebrush habitat (Knick et al. 2003). Processes to restore healthy native sagebrush systems are largely unknown and may require decades or centuries (Hemstrom et al. 2002; Knick et al. 2003).

4. Life history.

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

5. Ecological relationships.

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



Additional comments: Big sagebrush distribution is limited by summer moisture stress, and aridity defines its southern range limit (Shafer et al. 2001). Drought negatively affects seedling survival in sagebrush systems (Maier et al. 2001), and contributes to fire events and conversion of sagebrush systems to grassland (Callaway and Davis 1993; Keeley 2002).

6. Disturbance regimes.

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

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

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

An increase in fire frequency in sagebrush communities is facilitated in part by cheatgrass (*Bromus tectorum*) expansion (Miller and Eddleman 2000; Knick et al. 2003; Baker 2006), which can change the fire return interval from the natural 20 to 100 years for sagebrush grassland ecosystems to 3 to 5 years (Ypsilantis 2003), and may reduce native grasses and forbs essential for sage-grouse food and cover (USFWS 2013). Cheatgrass grows rapidly and dies early in the season, producing a continuous layer of dry fuels in the late spring and early summer (Slaton and Stone 2013). A combination of cheatgrass fuels and dry winters and springs has already resulted in the fire season shifting from late summer to early spring in some parts of the eastern Sierra Nevada (Slaton and Stone 2013).

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Residential and commercial development, agriculture, energy production and mining, transportation and service corridors, altered interspecific interactions, human intrusions and disturbance, natural system modifications, invasive and other problematic species
- b. Current degree to which stressors affect the species: High
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: Moderate
 - i. Participant confidence: Low



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

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

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

9. Overall user ranking.

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



Adaptive Capacity

1. Dispersal ability.

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

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

2. Plasticity.

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

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

3. Evolutionary potential.

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

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

4. Intraspecific diversity/life history.

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

5. Management potential.

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



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

6. Other adaptive capacity factors.

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

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Low
 - i. Participant confidence: High
-



Exposure

1. Exposure factors⁷.

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

2. Exposure region.

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

3. Overall user ranking.

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

References:

Vegetation changes: Bioclimate modeling predicts that sagebrush habitat in the Great Basin will decline due to synergistic effects of temperature increases, fire, and disease, and to displacement by species encroaching from the Mojave Desert in response to the northward shift in frost lines (Friggens et al. 2012). Big sagebrush and other similar semiarid ecosystems could decrease in viability or disappear in dry areas and likely increase only in the areas with greatest snowfall (Schlaepfer et al. 2012a). The effects of climate change on water balance and vegetation activity across the climatic and elevational gradient of sagebrush systems, however, are often nonlinear (Schlaepfer et al. 2012a). MC1 simulations are consistent with results from other scenario models (e.g., Lenihan et al. 2003; Hayhoe et al. 2004) and project a decline in shrubland cover in California (Lenihan et al. 2008).

Temperature: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004; Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL⁸ and PCM⁹) 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

⁷ Participants were asked to identify exposure factors most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

⁸ Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. *Journal of Climate*, 19:643-674.

⁹ Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. *Climate Dynamics* 16:755-744.



bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

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

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

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

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

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



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

Wildfire: In the Californian Great Basin, changes in vegetation communities will be important for wildlife. These changes will include projected increases in the amount of pine and juniper forest and desert scrub and grasslands, and a loss of sagebrush and other shrub habitats. This shift may be hastened by changes in fire severity and frequency (PRBO Conservation Science 2011). Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the species may be found through the TACCIMO website (<http://www.sgccp.ncsu.edu:8090/>). Downscaled climate projections available through the Data Basin website (<http://databasin.org/galleries/602b58f9bbd44dfffb487a04a1c5c0f52>).

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Focal Resource: WHITEBARK PINE

Taxonomy and Related Information

Whitebark pine (*Pinus albicaulis*); Distribution Sierra Nevada-wide, although primarily in central and southern Sierra; patchy distribution in the north.

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 workshop¹. The following document represents the vulnerability assessment results for the WHITEBARK PINE, 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 disruption².

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 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.



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: 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 evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	2 Between generalist & 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	1 Low	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	2 Moderate	3 High
Other Sensitivities	3 High	2 Moderate

Overall Averaged Confidence (Sensitivity)⁵: High

Overall Averaged Ranking (Sensitivity)⁶: Moderate–High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	3 High	3 High
Barriers Affect Dispersal Ability	1 High	3 High
Plasticity	1 Low	3 High
Evolutionary Potential	2 Moderate	2 Moderate
Intraspecific Diversity/Life History	1 Low	3 High
Species Value	1.5 Low-Moderate	3 High
Specificity of Management Rules	3 High	3 High
Other Adaptive Capacities	2 Moderate	3 High

Overall Averaged Confidence (Adaptive Capacity)⁵: High

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	3 High
Precipitation	3 High
Climatic water deficit	2 Moderate
Wildfire	2 Moderate
Snowpack	3 High

⁵ Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

⁶ Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
Whitebark Pine



Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	2.5 Moderate–High	3 High
Central Sierra Nevada	2.5 Moderate–High	3 High
Southern Sierra Nevada	3 High	3 High

Overall Averaged Confidence (Exposure)⁵: High

Overall Averaged Ranking (Exposure)⁶: Moderate–High



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: In between
 - i. Participant confidence: High
- b. Factors that make the species more of a specialist: Seed dispersal dependency, other – temperature/precipitation.

Additional comments: Distribution of whitebark pine is climate-driven.

2. Physiology.

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

Additional comments: Very dependent on climate, including temperature, and particularly cold temperatures.

References: Whitebark pine responses to warming temperatures may vary. Warming throughout the 20th century in the southeastern Sierra Nevada was positively correlated with annual branch growth rates of whitebark pine (Millar et al. 2004). That warming period produced abundant vertical branches in latter-century krummholz whitebark pine thickets at the upper treeline, compared with the compact, flat-topped crowns displayed at the start of the century (Millar et al. 2004). In contrast, whitebark pines that experienced significant mortality from 2007-2010 at low-elevations in the subalpine zone also experienced warmer, albeit drier conditions relative to the regional species distribution (Millar et al. 2004). Dolanc et al. (2013a) studied whitebark pine growth responses to climate in the central Sierra Nevada and found that radial growth was positively correlated with higher winter precipitation and higher spring temperatures, however whitebark and other drier-site subalpine species were somewhat sensitive to climate drivers than species found in more mesic sites. Although whitebark pine has been described as abundant on drier inland slopes and largely absent from wetter areas throughout its native range (Arno and Hoff 1989), in some semiarid areas it is more common on comparatively cold and moist sites (Mathiasen 1998 cited in Fryer 2002). Precipitation in whitebark pine communities ranges from 24 to 63 inches per year (Weaver 2001 cited in Fryer 2002), the majority (~66%) of which falls as snow (Arno and Hoff 1989 cited in Fryer 2002). Temperature and water availability also influence reproduction. Studies report that reproduction is best when July day/night temperatures exceed 68°/39°F (20°/4°C), and there is no water stress (Weaver 2001 cited in Fryer 2002).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Alpine/subalpine
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: High

Additional comments: See comment above.

4. Life history.

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



Additional comments: Stand-wide and population-wide production of cones can be episodic in some areas.

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Hydrology, competition, other – dispersal agents
- b. Types of climate and climate-driven changes that affect these ecological relationships including: Precipitation
- c. Sensitivity of species to other effects of climate change on its ecology: High
 - i. Participant confidence: High

Additional comments: Competition with lodgepole pine, red fir, and mountain hemlock.

6. Disturbance regimes.

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

Additional comments: Whitebark pine is sensitivity to disturbance regimes including insects (e.g., very susceptible to the pine beetle), disease (e.g., white pine blister rust, particularly in the northern Sierra), and wildfire (i.e., in higher density stands at lower elevations).

References: Whitebark pine responses to fire are also complex, and little is known about the relationship between whitebark pine and fire in California, where stands tend to be much less dense than in the well-studied Rocky Mountain populations. Whitebark pine communities have a mixed-severity fire regime of widely ranging fire intensities and frequencies; fire-return intervals range from 30 to greater than 350 years (Arno and Hoff 1989; Agee 1994, Barrett 1994, Morgan et al. 1994 cited in Fryer 2002). Fire may support whitebark pine recruitment and establishment by preparing seedbeds (Vogl and Ryder 1969, McCaughey 1990 cited in Fryer 2002), reducing competition (McCaughey 1994 cited in Fryer 2002), and creating forest openings for Clark's nutcracker (*Nucifraga columbiana*) seed caching (Tomback 1982 cited in Fryer 2002). Higher-severity fires may actually better prepare seedbeds than low-severity fires (McCaughey 1990, Vogl and Ryder 1969 cited in Fryer 2002). Although survivorship is considered best on burned sites (McCaughey 1990 cited in Fryer 2002), very hot fires may retard seedling establishment for several decades (Arno 1980), and surface and crown fires of moderate intensity may kill large mature trees (Barmore et al. 1976, Keane and Arno 2001, Morgan and Bunting 1990 cited in Fryer 2002).

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Commercial development, invasive and other problematic species
- b. Current degree to which stressors affect the species: Low
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: Moderate
 - i. Participant confidence: High

Additional comments: Participants classified outdoor recreation (e.g., ski areas) as commercial development.



References: Whitebark pine is experiencing the most significant ongoing mortality episode in subalpine forests of western North America (Millar et al. 2012), in which mortality trends have increased since 1998 (Gibson et al. 2008 cited in Millar et al. 2012). The primary reason for these declines has been attributed to mountain pine beetles (*Dendroctonus ponderosae* Hopkins) and blister rust (*Cronartium ribicola*) (Tomback and Achuff 2010). In contrast to reported low-levels of mountain pine beetle mortality in California from 1998-2005 (Gibson et al. 2008 cited in Millar et al. 2012), a major mortality event occurred in eastern California from 2007-2010 (Millar et al. 2012), and expanding centers of pine beetle-caused mortality are currently found in the Warner Mountains and parts of the Inyo National Forest. Mountain pine beetle infestations often occur in conjunction with other pathogens, insects and environmental stressors, such as drought. Pest pressure can increase tree sensitivity to drought (Waring et al. 1987), and drought combined with increasing minimum temperatures, may enhance infestation of pine beetles in whitebark and limber pines (Millar et al. 2010). Warming temperatures may also facilitate an upward elevational shift of mountain pine beetle populations into whitebark pine habitats (Logan et al. 1995, Logan and Powell 2001 cited in Fryer 2002; Bentz et al. 2010).

Whitebark pines in the western U.S. are also sensitive to the exotic pathogen white pine blister rust (Tomback and Achuff 2010). Although infected trees may not die for several decades, white pine blister rust inhibits the trees' ability to produce seeds (Arno and Hoff 1989). White pine blister rust can also increase whitebark pine susceptibility to beetle-related mortality (Tomback and Achuff 2010). Field surveys in high-elevation forests in 2004-2006 found white pine blister rust in 24% of whitebark pine in the northern Sierra Nevada, and the pathogen is spreading southward in California (Maloney 2011). Currently, white pine blister rust does not appear to be advancing into upper subalpine zones (Millar et al. 2012). However, spread of white pine blister rust may have been limited by climate conditions (Dolanc et al. 2013b), and extended growing seasons may facilitate uphill expansion.

8. Other sensitivities.

- a. Other critical sensitivities not addressed: Relies on Clark's nutcracker for dispersal
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase species' sensitivity to climate change: High

Additional comments: The Clark's nutcracker is likely moderately sensitive to climate change.

References: Because whitebark pine cones do not split open when ripe, the species is heavily dependent on the caching habits of the Clark's nutcracker for seed dispersal (Hutchins and Lanner 1982 cited in Fryer 2002). Clark's nutcrackers break cones and bury the seeds in shallow caches (Tomback 1978, 1982 cited in Fryer 2002), where un-retrieved seeds may germinate into new trees (Hutchins and Lanner 1982, Lanner 1982, Lanner and Gilbert 1994 cited in Fryer 2002). However, when whitebark pines are impacted by blister rust or other disturbance that limits seed production, predation by Clark's nutcracker may leave very few seeds for regeneration (Tomback 2002 cited in Fryer 2002). Seed establishment is also aided by ectomycorrhizal fungi (Cripps and Antibus 2011).

9. Overall user ranking.

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

Additional comments: Overall sensitivity of this species to climate change is due to sensitivity to pine beetle, blister rust, temperature, and precipitation.



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 5-50 km (3.1-31 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: High
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Other – requires a disperser, geologic features (i.e., high elevations in the northern Sierra)
- d. Degree barriers affect dispersal for the species: High
 - i. Participant confidence: High
- e. Possibility for individuals to seek out refugia: Yes, at the highest elevations.

Additional comments: Dispersal ability depends on dispersal agents, particularly the Clark's nutcracker.

2. Plasticity.

- a. Ability of species to modify physiology or behavior: Low
 - i. Participant confidence: High
- b. Description of species' ability to modify physiology or behavior: Whitebark pine may demonstrate some variable seed morphology (i.e. wing vs. no-wing) if nutcracker or squirrel dispersal agents are absent.

Additional comments: Whitebark pine has long generation times.

References: Whitebark pines at high elevations also frequently experience near-hurricane-force winds (Biswell n.d. cited in Fryer 2002), and develop variations in trunk morphology (i.e. krummholz) that may provide protection against wind (Fites-Kaufman et al. 2007) and other disturbances.

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Moderate
 - i. Participant confidence: Moderate
- b. Description of characteristics that allow species to adapt evolutionarily: Whitebark pine can evolve seeds with wings if dispersal agent is lost, but may lose some genetic diversity as a result. Genetic diversity currently exists because of long-range dispersal (i.e., via nutcracker).

Additional comments: Whitebark pine exhibits different morphologies at higher elevations (i.e., krummholtz for wind, which also protects against beetles).

References: Whitebark pine is slow-growing and long-lived (Arno and Hoff 1989). Stands older than 600 years have been found in Wyoming and Alberta (Luckman et al. 1984, Steele et al. 1983 cited in Fryer 2002), and the oldest recorded specimen was over 1200 years old (Perkins and Swetnam 1996 cited in Fryer 2002). Seed cones are first produced at 20 to 30 years; peak production is achieved at approximately 60 to 100 years, and lasts several hundred years (Lewis 1971, McCaughey and Tomback 2001 cited in Fryer 2002). Stand-wide and population-wide production of cones can be episodic. Clark's nutcracker seed-caching habits may result in tree clusters composed of related individuals. On a larger scale, long-distance dispersal by Clark' nutcracker may contribute to low inter-population diversity (Bruederle et al. 2001, Bruederle et al. 1998 cited in Fryer 2002).

4. Intraspecific diversity/life history.



- a. Degree of diversity of species' life history strategies: Low
 - i. Participant confidence: High
- b. Description of diversity of life history strategies: Seed dispersal (e.g. wing vs. no-wing seeds)

Additional comments: Whitebark pines are 50-80 years old before they produce cones, and production increases after 100 years of age.

References: Differential responses to water deficit and maximum temperatures suggest that at least two genotypic groups of whitebark pines exist, with some trees better able to take advantage of warm conditions (Millar et al. 2012).

5. Management potential.

- a. Value level people ascribe to this species: Low-Moderate
 - i. Participant confidence: High
- b. Specificity of rules governing management of the species: High
 - i. Participant confidence: High
- c. Description of use conflicts: Ski resorts
- d. Potential for managing or alleviating climate impacts: A few areas do have management potential, for instance ski areas and USFS lands.

Additional comments: Currently a federal candidate species for ESA inclusion. Approximately 90% of whitebark pine range is in designated wilderness and protected areas.

References: Historically, whitebark pine was a major component of subalpine forests in the Sierra Nevada (Arno and Hoff 1989) and although the majority of whitebark pine range in California occurs within protected areas and designated wilderness, it has experienced significant declines in the western US and is now a candidate species for federal listing under the Endangered Species Act.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: Ectomycorrhizal fungus, other animal dispersers (i.e. chipmunk, squirrel)
 - i. Participant confidence: High
- b. Collective degree these factors affect the adaptive capacity of the species: Moderate

Additional comments: Whitebark pines are more diverse than bristlecone pines, but there still exists a lot of uncertainty, especially concerning responses to climatic change.

References: In seedlings, drought tolerance is conferred in part rapid growth of deep roots and thick, drought-resistant stems (Bruederle et al. 1998 cited in Fryer 2002). Moderate-thickness bark may support survival of mature trees during moderate- and low-intensity fires (Fryer 2002). In addition, whitebark pine forest growth patterns that form discontinuous canopies and sparse understories may further limit the spread and extent of fire (Botti 1979, Brown et al. 1994, and Steele et al. 1983 cited in Fryer 2002).

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Low-Moderate
 - i. Participant confidence: High

Additional comments: The whitebark pine is very sensitive to temperature, and dependent upon other species for seed dispersal and water uptake. It has long generations and not many life history strategies,



but can exhibit other growth structures (e.g., krummholtz) in response to different environmental conditions.



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, climatic water deficit, wildfire, snowpack
 - i. Participant confidence: High (temperature, precipitation, and snowpack); Moderate (climatic water deficit and wildfire)

2. Exposure region.

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

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: High
 - i. Participant confidence: High

Additional comments: Exposure factors considered especially important for whitebark pine include temperature and pine beetles.

References:

Vegetation shifts: In regions outside of the Sierra Nevada, models predict a decline in whitebark pine due to warming temperature and more frequent summer droughts (McCaughey 1994, Mattson and Reinhart 1997, McCaughey and Tomback 2001 cited in Fryer 2002).

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013b). 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 (GDFL⁸ and PCM⁹) 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)

⁷ Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

⁸ Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. *Journal of Climate*, 19: 643-674.

⁹ Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. *Climate Dynamics* 16:755-744.



while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation that falls as snow at the high elevations that characterize this part of the range (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 pattern 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).

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

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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990 cited in Strom and Fule 2007; McKenzie et al. 2004) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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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Focal Resource: WILLOW FLYCATCHER

Taxonomy and Related Information

Subspecies *Empidonax traillii brewsteri* and *E. t. adastus*, and *E. t. extimus*; occurs across Sierra Nevada. One of the rarest birds in the Sierra Nevada, with fewer than 400 breeding individuals range-wide (Mathewson et al. 2013). Willow flycatchers have been extirpated from the southern Sierra Nevada and the majority of the population occurs in the extreme northern Sierra Nevada and southern Cascade mountains (Bombay et al. 2003; Green et al. 2003; King and King 2003; Mathewson et al. 2013).

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 workshop¹. The following document represents the vulnerability assessment results for the **WILLOW FLYCATCHER**, 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 disruption².

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.



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.

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 evaluation³. 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.

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	1 Low	2 Moderate
Habitat	3 High	3 High
Life History	2 Moderate	3 High
Ecological Relationships	3 High	2 Moderate
Disturbance Regimes	3 High	3 High
Non-Climatic Stressors – Current Impact	3 High	3 High
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	3 High	2 Moderate
Other Sensitivities	2 Moderate	2 Moderate

Overall Averaged Confidence (Sensitivity)⁵: Moderate-High

Overall Averaged Ranking (Sensitivity)⁶: Moderate-High

ADAPTIVE CAPACITY

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

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

Overall Averaged Ranking (Adaptive Capacity)⁶: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Climatic water deficit	2 Moderate
Snowpack	2 Moderate
Shifts in vegetation type	2 Moderate
High flows	2 Moderate

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

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

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
Willow Flycatcher



Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	2.5 Moderate–High	No answer provided by participants
Central Sierra Nevada	2.5 Moderate–High	No answer provided by participants
Southern Sierra Nevada	3 High	No answer provided by participants

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: Predator/prey relationship, foraging dependency

Additional comments: Willow flycatcher is a habitat specialist; it needs willow and alder multi-structure, large open meadows with large shrub and tall herbaceous cover, and with soil saturation and moderate elevation, which determine snowpack and subsequent timing of the emergence of prey. The willow flycatcher also requires flying insects as prey.

References: The willow flycatcher is dependent on insects as prey (Durst et al. 2008), and earlier snowmelt, warmer stream water, and intermittent flows may reduce the abundance of aquatic insects (Perry et al. 2012). Events that influence the overall abundance of arthropods, such as regional droughts, may be critical drivers of productivity for generalists such as willow flycatchers (Durst et al. 2008).

2. Physiology.

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

Additional comments: Sensitive to climate-created habitat (i.e., wet meadows).

References: See "Question 3. Sensitive habitats" below.

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Wetlands, seeps/springs, ecotones, other – shrub cover to open meadow
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: High

Additional comments: The willow flycatcher needs meadows and surface water through July. It relies upon rare, water-dependent habitat experiencing extensive degradation due to alterations to hydrological cycles.

References: The willow flycatcher only occurs at elevations above the snowpack line, and requires wet meadows with willow stands (Harris et al. 1987 cited in Sanders and Flett 1989). Meadow desiccation appears to be the most important proximate factor in willow flycatcher decline in the Sierra Nevada (Green et al. 2003). Desiccation can result from reduced snowpack, as well as flashy runoff events that can increase incision and erosion in meadows (Viers et al. 2013). Drier meadows tend to be dominated by grasses rather than sedges, rushes and willow (Viers et al. 2013), and do not provide adequate habitat for willow flycatcher. Siegel et al. (2008) postulate that the extirpation of the willow flycatcher from meadows in Yosemite National Park may be in response to climate cycles leading to meadows drying out.

4. Life history.

- a. Species reproductive strategy: In between r- and k-selection
 - i. Participant confidence: High
- b. Species polycyclic, iteroparous, or semelparous: Iteroparous



Additional comments: The willow flycatcher has relatively low reproductive output due to its dependence on mid-elevation habitat, which limits the length of the nesting season and thus its nesting attempts during a season.

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Forage, habitat, hydrology, other – extreme events
- 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: High
 - i. Participant confidence: Moderate

Additional comments: 'Extreme events' include snowfall in summer and high winter and spring flows that result in stream channel incision and meadow desiccation.

References: The willow flycatcher is sensitive to extreme weather events, such as summer snowfall, as well as both droughts, and high winter and spring flows that can result in channel incision and meadow desiccation (Viers et al. 2013), which render the habitat unsuitable. As mentioned above, willow flycatchers are also sensitive to meadow desiccation, which results in a reduction of willow cover and standing water, leading to encroachment by conifers. Presence of conifers and lack of standing water may allow predators easier access to nests, leading to a principle cause in willow flycatcher population decline in the Sierra Nevada (Green et al. 2003).

6. Disturbance regimes.

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

Additional comments: Willow flycatcher requires saturated soils and, as stated above, any disturbance that results in stream isolation from floodplain (e.g., extreme flows) may render habitat unsuitable for this species. Drought that results in reduced soil moisture may kill water willows upon which flycatcher depend.

7. Interacting non-climatic stressors.

- a. Other stressors that make the species more sensitive include: Agriculture and aquaculture, human intrusions and disturbance, natural system modifications, invasive and other problematic species
- b. Current degree to which stressors affect the species: High
 - i. Participant confidence: High
- c. Degree to which non-climate stressors make species more sensitive: High
 - i. Participant confidence: Moderate

Additional comments: Non-climatic stressors include grazing, cowbird parasitism and predation, elevated predation risk (e.g., from small mammals) resulting from meadow desiccation and conifer encroachment, and direct human disturbances such as pack stations and development. This species appears extremely sensitive to even light grazing pressure, with ~90% of the Sierra population occurring in ungrazed meadows.



References: The willow flycatcher's sensitivity to non-climatic stressors may exacerbate its sensitivity to climate change (Mathewson et al. 2013). Flycatchers are sensitive to disturbances such as grazing during the breeding season from late June until mid-August (Taylor and Littlefield 1986; Sanders and Flett 1989). Cattle can upset nests in willow thickets directly, and adversely affect regeneration of woody vegetation (Crumpacker 1984 cited in Sanders and Flett 1989), compact soils, and accelerate streambank erosion and incision (Thomas et al. 1979, Platts 1984, and Ratliff 1984, cited in Sanders and Flett 1989), resulting in lowered water tables (Van Haveren and Jackson 1986 cited in Sanders and Flett 1989). Grazing may compound the incision and desiccation effects anticipated in Sierra Nevada meadows as a result of climate change, leading to habitat conversion to meadows dominated by grasses (Viers et al. 2013). Conversion may in turn facilitate predation (Cain et al. 2003; Green et al. 2003; Mathewson et al. 2013), and cowbird parasitism (Sanders and Flett 1989).

8. Other sensitivities.

- a. Other critical sensitivities not addressed: Wintering habitat; disturbance to corridors
 - i. Participant confidence: Moderate
- b. Collective degree these factors increase species' sensitivity to climate change: Moderate

Additional comments: It is not known to what extent loss or degradation of migration stopover or wintering habitat in Central America may affect this species.

References: Degradation and loss of wintering habitat in Central America may also play a role in species decline (Finch and Stoleson 2000).

9. Overall user ranking.

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



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 5-25 km (3.1-15.5 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: Moderate
 - i. Participant confidence: High
- c. General types of barriers to dispersal include: Other – distance from natal grounds
- d. Degree barriers affect dispersal for the species: Low
 - i. Participant confidence: High
- e. Possibility for individuals to seek out refugia: Willow flycatcher exhibit high site fidelity, and most return to their natal meadows or nearby. However, compared to other species (e.g., amphibians) their ability to disperse is high as they have re-colonized restored meadows within 30 km (18.6 mi) of source populations in the Lassen region.

References identified by participants: Mathewson et al. 2013

References: Dispersal is fairly low given the willow flycatcher's high site fidelity, returning to natal or nearby meadows (Mathewson et al. 2013). However, willow flycatchers have been recorded in restored meadows within 30 km (18.6 mi) of natal populations in the Lassen region (Mathewson et al. 2013).

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: Willow flycatchers may regulate temperature in the nest by either shading young, or sitting on the nest to incubate once young are hatched. Other ways the species is able to modify its physiology or behavior includes reducing heat stress feathers and early initiation breeding, among others.

References: Willow flycatchers may modify behavior to regulate nest temperature, and can initiate breeding early in response to brief climatic variation, but overall they lack the plasticity to nest in other habitat types (Green et al. 2003).

3. Evolutionary potential.

- a. Ability of species to adapt evolutionarily: Moderate
 - i. Participant confidence: Moderate
- b. Description of characteristics that allow species to adapt evolutionarily: Multiple subspecies of willow flycatcher exist, however, the overall population is small and subspecies are isolated.

Additional comments: Willow flycatcher has relatively low reproductive output for a passerine bird due to dependence on higher elevations, which limit nesting attempts within a season. Also, existing stressors may reduce nesting success (e.g., higher predation resulting from sub-optimal habitat).

References: The willow flycatcher is thought to be one of the rarest birds in the Sierra Nevada, with surveys estimating fewer than 400 breeding individuals range-wide (Serena 1982, Harris et al. 1987, and Bombay 1999 cited in Mathewson et al. 2013), divided between isolated subspecies (Bombay et al. 2003; Mathewson et al. 2013).

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: None recorded

Additional comments: The willow flycatcher has limited habitat used for breeding.

5. Management potential.

- a. Value level people ascribe to this species: Low
 - i. Participant confidence: High
- b. Specificity of rules governing management of the species: High
 - i. Participant confidence: High
- c. Description of use conflicts: Grazing reduces willow and herbaceous understory, both critical habitat components for this species. The species is also highly sensitive to meadow desiccation.
- d. Potential for managing or alleviating climate impacts: Restoration of meadow habitats is possible by improving floodplain function and thus increasing meadow wetness and density of willow and herbaceous cover. Alternative grazing management and cowbird management are also potential actions.

6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: None
 - i. Participant confidence: Moderate
- b. Collective degree these factors affect the adaptive capacity of the species: Not applicable

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Low
 - i. Participant confidence: Moderate

Additional comments: The ecological tolerance of willow flycatcher is low, as it is dependent on mid-elevation wet meadows with large area to edge ratios. These large meadows are rare at higher elevations and mid elevations may experience desiccation or convert to forb and grass dominated systems which are less suitable for this species.



Exposure

1. Exposure factors⁷.

- a. Factors likely to be most relevant or important to consider for the species: Climatic water deficit, snowpack, shifts in vegetation type, high flows
 - i. Participant confidence: Moderate (all)
-

2. Exposure region.

- a. Exposure by region: North – Moderate-High; Central – Moderate-High; South – High
 - i. Participant confidence: No answer provided by participants
-

3. Overall user ranking.

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

Additional comments: Willow flycatcher is one of the rarest birds in the Sierra Nevada with less than 400 breeding territories range-wide. They are also dependent on a rare habitat type that has been highly degraded. They are very sensitive to meadow desiccation and habitat suitability is incompatible with current livestock management practices employed in most meadows in the Sierra on public and private land. They have been extirpated from the southern Sierra and the majority of the population now occurs in the far northern Sierra and southern Cascades at elevations predicted to be below snowpack in 70 years. The most relevant elements of climate exposure to willow flycatcher are those that impact the distribution, structure, and function of wet meadows, including changes in dominant vegetation type, snowpack, climatic water deficit, and high flows.

References:

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010). An increase in flashy precipitation events may lead to erosion of moist peat and topsoil due to flooding (Weixelman et al. 2011, Viers et al. 2013), as well as drying of meadows caused by channel incision (Viers et al. 2013).

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,

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.



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 mean 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 species may be found through the TACCIMO website (<http://www.sgccp.ncsu.edu:8090/>). Downscaled climate projections available through the Data Basin website (<http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52>).

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Focal Resource: **WOODRATS**

Taxonomy and Related Information

Big-eared woodrat (*Neotoma macrotis*); Dusky-footed woodrat (*Neotoma fuscipes*) (following Matoqo 2002); Arboreal and semi-arboreal: Southern 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 workshop¹. The following document represents the vulnerability assessment results for **BIG-EARED & DUSKY-FOOTED WOODRATS**, 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 disruption².

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 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.



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 evaluation³. 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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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>.



Overview of Vulnerability Component Evaluations

SENSITIVITY

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

Overall Averaged Confidence (Sensitivity)⁵: Moderate

Overall Averaged Ranking (Sensitivity)⁶: Moderate-High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	No answer provided by participants	No answer provided by participants
Barriers Affect Dispersal Ability	No answer provided by participants	No answer provided by participants
Plasticity	No answer provided by participants	No answer provided by participants
Evolutionary Potential	No answer provided by participants	No answer provided by participants
Intraspecific Diversity/Life History	2 Moderate	2 Moderate
Species Value	1 Low	3 High
Specificity of Management Rules	1 Low	3 High
Other Adaptive Capacities	No answer provided by participants	No answer provided by participants

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

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

⁵ Overall averaged confidence is the mean of the entries for the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

⁶ Overall averaged sensitivity, adaptive capacity, and exposure are the mean of the ranks provided for the sensitivity, adaptive capacity, and exposure evaluation entries above, respectively.



EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	No answer provided by participants
Dominant vegetation type	No answer provided by participants
Wildfire (biomass consumed)	No answer provided by participants
Low flows	No answer provided by participants
High flows	No answer provided by participants

Participants were unable to assess Exposure by region in the time allotted. Consequently, no averaged ranking or confidence score for exposure are provided.



Sensitivity

1. Generalist/Specialist.

- a. Where does species fall on spectrum of generalist to specialist: In between
 - i. Participant confidence: Moderate
- b. Factors that make the species more of a specialist: Predator/prey relationship, foraging dependency, seed dispersal dependency

Additional comments: Requires relatively dense chaparral, streamside thicket, and mixed coniferous forest with well-developed undergrowth (Murray and Barnes 1969); understory canopy closure is more important than overstory. Woodrats can use fragmented landscapes but not with plots smaller than 1 acre (0.4 ha). Woodrat diet consists of sticks, seeds, and leaves of a variety of plants.

Dusky-footed and big-eared woodrats can reach high densities in communities without trees (e.g., see Vogl 1967).

References: *Neotoma* have a diet consisting of seeds, stems, and leaves of a variety of plants, and they occupy relatively dense chaparral, broad-leaf woodland, riparian thickets, or mixed-conifer forest (Carraway and Verts 1991; Innes et al. 2007). East of the Cascade divide *N. fuscipes* consistently utilize juniper trees for lodging and food (Murray and Barnes 1969), and in mixed-conifer forests, *N. fuscipes* displays strong associations with California black oak (Innes et al. 2007). The most important habitat features appear to be high shrub density and diversity regardless of habitat type. Densities of both *Neotoma* species are highest where shrub cover is high (Vestal 1938, Linsdale and Tevis 1956, Vogl 1967, and Biswell 1989 cited in Lee and Tietje 2005) and understories are well developed, and lowest in open areas (Murray and Barnes 1969; Carraway and Verts 1991; Haynie et al. 2007; Innes et al. 2007).

2. Physiology.

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

Additional comments: Upper thermal limit is 35°C and optimum temperature 20°C. Woodrats require water – a minimum 10% of body mass.

References: In the absence of a persisting blanket of snow, occasional severe weather such as a freeze in the wake of heavy rainfall, may cause large mortality events in *N. fuscipes* (Murray and Barnes 1969).

3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Seasonal streams, seeps/springs
- b. Species dependence on one or more sensitive habitat types: High
 - i. Participant confidence: High

Additional comments: Dense vegetative cover and drinking water are required (Carraway and Verts 1991).

References: Drinking water is required by big-eared woodrats (Lee 1963 cited in Carraway and Verts 1991) and probably dusky-footed woodrats, and as aridity increases big-eared (Spevak 1983 cited in Carraway and Verts 1991) and dusky-footed (Gillespie et al. 2008) population densities decrease significantly.

4. Life history.



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

Additional comments: Breeding season is from February to September, and woodrats have 2-6 offspring per year.

References: The preceding winter's low temperature has also been correlated with fecundity in *N. macrotis* (Lee and Tietje 2005).

5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Predator/prey relationship, 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: No answer provided by participants
 - i. Participant confidence: No answer provided by participants

Additional comments: Woodrats are susceptible to other species taking over their nests (e.g., king snakes), and nests support other animals (salamanders, arthropods), with woodrats thereby functioning as a keystone species (Carraway and Verts 1991).

References: Precipitation is thought to be important for small mammal population dynamics through its effect on food resources (Meserve et al. 2001 cited in Lawson 2011), although woodrats in southern coastal California did not show a response to extreme precipitation associated with El Niño-Southern Oscillation (ENSO) (Braswell 2007 cited in Lawson 2011).

6. Disturbance regimes.

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

Additional comments: Woodrats are susceptible to plague and grazing.

References: The species probably has a low sensitivity to fire overall, being common in communities that experienced frequent fire historically. However, changes in fire regimes due to climate change, human ignitions, invasive species, or a combination of factors could negatively affect the species. For example, very frequent fires in chaparral (<10 years; Keeley 1995) are likely to be detrimental to *Neotoma* because of the potential conversion of chaparral communities to nonnative annual grasslands (Bolger et al. 1997).

Low- to moderate-severity fire in oak woodland may reduce habitat suitability for *N. fuscipes* in the short term by reducing understory cover, destroying houses, removing woody debris used to build houses (Lee and Tietje 2005), and causing direct mortality. Carraway and Verts (1991) cited Tevis (1956) to support their statement that *N. fuscipes* prefers areas "undisturbed by fire", but Tevis states that *N. fuscipes* is most common in early-seral Douglas-fir forests and least common in mid- and late-successional Douglas-fir forests. In mixed conifer forests, they are common in early succession (30-40 years post-logging; Innes et al. 2007). In chaparral, *Neotomas* are likely to be at their lowest densities soon after fire when food and cover is sparse but they probably are common in both early and late succession habitats. *N. fuscipes* and *N. macrotis* occur in many communities that are fire-adapted and



experienced relatively frequent fire historically. California chaparral has a stand-replacement fire regime and a mean fire interval of 50 years. California mixed conifer forests (south slopes) experienced mostly low-severity fires about every 10 years⁷.

Conversely, long fire periods in mixed conifer forests may also result in understory habitat less suitable to *N. fuscipes* due to reduced understory shrub density and diversity, and less favorable conditions for California black oaks (Innes et al. 2007).

7. Interacting non-climatic stressors.

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

Additional comments: Non-climate stressors include grazing (categorized under agriculture), poop collection (categorized under biological resource use), rodenticide used in marijuana farms (categorized under pollution and poisons), and development (an issue due to the woodrats' low dispersal extent).

References: Loss and fragmentation of habitat, and introduction of invasive plant species pose non-climate threats to *Neotoma* populations, particularly in sage-scrub and chaparral systems (Bolger et al. 1997; Haynie et al. 2007). Both grazing and historic use of non-native annuals for post-fire rehabilitation in chaparral can introduce non-native invasive grasses, which contribute to greater fire frequency (Keeley 1995).

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

Additional comments: Woodrats are susceptible to plague, but the participants are unsure of the importance of diseases and parasites. The relationship between episodes of plague and increased temperature is unknown.

Murray and Barnes (1969) and Caraway and Verts (1991) also proposed that disease (e.g., bubonic plague) may affect *N. fuscipes* distribution.

References identified by participants: Holt et al. 2009 examined plague in California and the potential response to climate change.

9. Overall user ranking.

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

Additional comments: Overall sensitivity ranked low to moderate based on fire threat.

⁷ http://www.fs.fed.us/database/feis/fire_regime_table/PNVG_fire_regime_table.html#California



Adaptive Capacity

1. Dispersal ability.

- a. Maximum annual dispersal distance: 1-2 km (0.6-1.2 mi)
 - i. Participant confidence: High
- b. Ability of species to disperse: No answer provided by participants
 - i. Participant confidence: No answer provided by participants
- c. General types of barriers to dispersal include: Road – highway, rivers, waterfalls
- d. Degree barriers affect dispersal for the species: No answer provided by participants
 - i. Participant confidence: No answer provided by participants
- e. Possibility for individuals to seek out refugia: No answer provided by participants

References identified by participants: NatureServe (<http://www.natureserve.org/explorer/>)

References: Although home-range sizes for adult dusky-footed woodrat range widely (0.2-5.9 ha) (0.5-14.6 ac) (Innes et al. 2009) and previous studies indicate good dispersal ability (Smith 1965 cited in Lawson 2011), females are largely philopatric and do not disperse from natal areas (Innes et al. 2012). Although female big-eared woodrats do not appear to display high levels of philopatry (Matocq and Lacey 2004 cited in Lawson 2011; Haynie et al. 2007), essentially no elevational shift was recorded for this species during 100 years of climate warming in the Yosemite National Park (Moritz et al. 2008). Dispersal of both species may be limited by the presence of roads, water bodies, and open spaces (Carraway and Verts 1991; Bolger 1997).

2. Plasticity.

- a. Ability of species to modify physiology or behavior: No answer provided by participants
 - i. Participant confidence: No answer provided by participants
- b. Description of species' ability to modify physiology or behavior: Unknown

References: The capacity of *Neotoma* to adapt to climate changes may be high, based on prehistoric midden data for congeners (Smith and Betancourt 2003 cited in Lawson 2011).

3. Evolutionary potential.

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

References: *Neotoma* displays moderate to high genetic diversity in California (Haynie et al. 2007).

4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Moderate
 - i. Participant confidence: Moderate
- b. Description of diversity of life history strategies: Woodrats are fairly plastic in terms of food sources and shelter species.

References: *Neotoma* have a diet consisting of seeds, stems, and leaves of a variety of plants, and they occupy relatively dense chaparral, broad-leaf woodland, riparian thickets, or mixed conifer forest (Verts and Carraway 1991; Innes et al. 2007).

5. Management potential.

- a. Value level people ascribe to this species: Low
 - i. Participant confidence: High



- b. Specificity of rules governing management of the species: Low
 - i. Participant confidence: High
- c. Description of use conflicts: No answer provided by participants
- d. Potential for managing or alleviating climate impacts: No answer provided by participants

References: Management techniques that promote growth and retention of large California black oaks in mixed conifer systems may benefit *N. fuscipes* (Innes et al. 2007).

6. Other adaptive capacity factors.

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

7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
 - i. Participant confidence: Moderate
-



Exposure

1. Exposure factors⁸.

- a. Factors likely to be most relevant or important to consider for the species: Temperature, dominant vegetation type, wildfire, low flows, high flows
 - i. Participant confidence: No answer provided by participants

2. Exposure region.

- a. Exposure by region: No answer provided by participants
 - i. Participant confidence: No answer provided by participants

3. Overall user ranking.

- a. Overall exposure of the species to climate changes: Moderate
 - i. Participant confidence: Moderate

References:

Vegetation changes: Projections conflict on the distribution of suitable future habitats for woodrats. While some projections predict an increase in the distribution of chaparral, oak, and pine in northern California by 2070 (PRBO Conservation Science 2011), others predict the loss of virtually all suitable habitat for *N. macrotis*, with negligible amounts of emergent suitable habitat (Lawson 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 (GDFL⁹ and PCM¹⁰) 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).

High and Low Flows: 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

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.

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.



expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds, decreasing mean annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null 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).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in YNP (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales” (Taylor and Scholl 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/602b58f9bbd44dff8487a04a1c5c0f52>).

Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis:
Big-Eared & Dusky-Footed Woodrats



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5. Conclusions

The results of this vulnerability assessment are intended to help guide and support a manager or planner in identifying which resources are likely to be most affected by changing climate conditions and improving understanding as to why those resources are likely to be vulnerable. The results of this assessment are a new toolset among many that can be used in managing natural resources for climate change. The vulnerability assessment findings from this process are intended to be a living resource that new information can be added to as it becomes available. One way to keep apprised of new information for a particular focal resource is through the use of TACCIMO, a web-based tool that connects forest planning to current climate change science. Box 1 describes several ways to find information on a specific focal resource using TACCIMO.

Box 1. Using TACCIMO to find the most current climate change science for a focal resource

TACCIMO provides access to the most current climate change projections and science for forest resources, including dynamically linked peer-reviewed scientific statements described climate change effects on resources. To find current information on a focal resource (e.g., ecosystem, species), enter the TACCIMO site (<http://www.taccimo.sgcp.ncsu.edu/>) and click the tab “Generate a Report”. From the drop-down menu, select “Custom Reports-Beta Version”. There are two options for climate change effects on a focal resource: Effects By Source Report and Effects By Source Report – Keywords.

For coarse filter focal resources (e.g., ecosystems, habitats): select “Effects By Source Report” and, from the drop-down menu, select the relevant Factor (e.g., for aquatic systems, select Freshwater Ecosystems; for alpine ecosystems, select Plant Communities). Use the drop-down menu for Region to find literature for a specific region such as the Pacific Southwest. Use the Category drop-down menu to select more specific components within a factor (e.g., riparian areas within freshwater ecosystems). Click “Run Report” once the Factor, Region, and Category have been identified.

For fine filter focal resources (e.g., species): select “Effects By Source Report - Keywords”. Under Factor and Category drop-down menus click “<select all>”. Use the drop-down menu for Region to find literature on the focal resource for a specific place, such as the Pacific Southwest. Type the scientific name of the species into the Keywords in quotations (e.g., “Pinus ponderosa”). Click “Run Report” and click on the factors in the left column to see current literature on the species.

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7. Appendices

Appendix I. Vulnerability Assessment Workshop Participant List

Name	Organization
Susan Antenen	Conservation Biology Institute
Greg Aplet	The Wilderness Society
Steven Brink	California Forestry Association
Sue Britting	Sierra Forest Legacy
Emily Brown	Earthjustice
Ryan Burnett	Point Blue Conservation Science
Chris Dallas	Sierra Nevada Conservancy
Aimee Delach	Defenders of Wildlife
Gavin Feiger	Sierra Nevada Alliance
Jo Ann Fites-Kaufman	U.S. Forest Service Pacific Southwest Region
Rebecca Fris	U.S. Fish & Wildlife Service, California Landscape Conservation Cooperative
John Gallo	The Wilderness Society
Bruce Goines	U.S. Forest Service Pacific Southwest Region
Shana Gross	U.S. Forest Service, Lake Tahoe Basin Management Unit
Bruce Hamilton	Sierra Club
Chrissy Howell	U.S. Forest Service Pacific Southwest Region
Chris Keithley	California Department of Forestry & Fire Protection
Bill Kuhn	Yosemite National Park
Stefan Lorenzato	California Riparian Habitat Joint Venture
Marc Meyer	U.S. Forest Service Pacific Southwest Region
Tiffany Meyer	California Department of Forestry & Fire Protection
Laura Patterson	California Department of Fish & Wildlife
Sarah Sawyer	U.S. Forest Service Pacific Southwest Region
Deb Schlafmann	U.S. Fish & Wildlife Service, California Landscape Conservation Cooperative
Greg Schroer	U.S. Forest Service, Sierra National Forest
Terri Simon-Jackson	U.S. Forest Service, Plumas National Forest
Michele Slaton	U.S. Forest Service, Inyo National Forest
Tony Valdes	U.S. Forest Service, Eldorado National Forest
Angela White	U.S. Forest Service Pacific Southwest Research Station
Tricia York	California Tahoe Conservancy

Appendix II. Stakeholder Advisory Committee and Science Advisory Group Members

Science Advisory Group	
Name	Organization
Dominique Bachelet	Conservation Biology Institute
Ryan Burnett	Point Blue Conservation Science
Lorraine Flint	U.S. Geological Survey
John Gallo	The Wilderness Society
Connie Millar	U.S. Forest Service Pacific Southwest Research Station
Hugh Safford	U.S. Forest Service Pacific Southwest Region
Nate Stephenson	U.S. Geological Survey
Anthony Westerling	University of California Merced

Stakeholder Advisory Committee	
Name	Organization
Whitney Albright	California Department of Fish & Wildlife
Susan Antenen	Conservation Biology Institute
Greg Aplet	The Wilderness Society
Sue Britting	Sierra Forest Legacy
Aimee Delach	Defenders of Wildlife
Mark Drew	Cal Trout
Gavin Feiger	Sierra Nevada Alliance
Steve Frisch	Sierra Business Council
Bruce Goines	U.S. Forest Service Pacific Southwest Region
Bruce Hamilton	Sierra Club
Chrissy Howell	U.S. Forest Service Pacific Southwest Region
Chris Keithley	California Department of Forestry & Fire Protection
Bill Kuhn	Yosemite National Park
Marc Meyer	U.S. Forest Service Pacific Southwest Region
Koren Nydick	Sequoia and Kings Canyon National Parks
Michelle Selmon	California Department of Water Resources
Michele Slaton	U.S. Forest Service, Inyo National Forest
<i>Alternate: Susan Joyce</i>	U.S. Forest Service, Inyo National Forest

Appendix III. Expert Reviewers for Focal Resources

Name	Organization
David Ackerly	University of California, Berkeley
Frank Davis	University of California, Santa Barbara
David Delehanty	Idaho State University
Nina Hemphill	U.S. Forest Service
Robin Innes	U.S. Forest Service
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Laura Patterson	California Department of Fish & Wildlife
Paul Rogers	Utah State University
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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.

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