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Eco-cultural criteria for climate refugia mapping of resources of value to tribal communities

FINAL REPORT TO THE CALIFORNIA LANDSCAPE CONSERVATION PARTNERSHIP

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Table of Contents

EXECUTIVE SUMMARY

Climate change refugia can result from a variety of topographic and environmental characteristics, but in general they are places that are expected to generally retain their current temperature and/or precipitation profiles, and in the Sierra Nevada they additionally have lower risk of high severity fire. For Indigenous peoples, the current and future impacts of climate change represent yet another wave of significant socio-environmental change in recent history, and they hold knowledge and perspective that is more important than ever to inform, guide, and participate in land stewardship (Morishima and Mason 2017). The goal of this project was to develop socio-ecological resilience-based refugia criteria and where feasible link these to measurable, forecasted climate variables. Specifically, we seek to overlay our geographical understanding of climatic refugia with the issues of what natural resources are of the highest value and for whom. Our focal area was the 2.4 million acre Tahoe Central Sierra Initiative (TCSI) landscape, but many of the resource values identified and their climate vulnerabilities will be relevant throughout the Sierra Nevada.

We relied on the Framework for Resilience (Manley *et al.* 2020) to structure our assessment of resource vulnerabilities, which has been adopted by the Sierra Nevada Conservancy and the recently released Wildfire and Forest Resilience Action Plan (California Forest Management Task Force 2021). The Framework has 10 pillars that represent the full spectrum of socio-ecological outcomes and their resilient conditions: forest resilience, fire dynamics, fire adapted communities, carbon sequestration, biodiversity conservation, wetland integrity, water security, air quality, economic diversity, and social and cultural wellbeing.

We consulted published literature, tribal resource specialists, area experts, and stakeholders throughout the TCSI landscape to gather information on the climate vulnerability, potential impacts, and climate refugia parameters associated with each of the three main topic areas and their ecosystem linkages. We considered multiple attributes under each resilience pillar, and whether or not an attribute was of socio-ecological value, mappable, and vulnerable to climate change. Socio-ecological value was derived from relationships with the 10 pillars within the Framework for Resilience and through consultation. Resources were considered mappable if it was possible to identify spatially explicit locations or derive modeled estimates across all lands to represent current conditions. Vulnerability was evaluated as the degree to which climate change had the potential to impact the resource either directly or indirectly.

In this report we provide a template of metrics and values from which multiple criteria can be assembled and evaluated to create a management plan for any particular decisional jurisdiction. We identify numerous reasonable social and ecological values that are important to significant fractions of stakeholders and evaluate which ones can be mapped and projected into a future climate model. What we have not done, nor could we legitimately do, is to suggest how these multiple criteria might be relatively valued or prioritized. We argue that decisions will be more durable and socially acceptable if they are done using a transparent and structured decision process that includes multiple representatives of different social and cultural interests. A critical bearing on decision making is determining the fundamental objectives, their relative value to one another, and agreeing upon meaningful measures of success in a socially engaged process. Those whose values are being managed must also participate in determining the place of those objectives in the final decisions in order for decisions to be credible, legitimate and salient (Cash *et al.* 2003). We discuss several decision support tools that are suitable for refugia modeling using bioclimatic models of climate change that can inform a socially driven process of land management priorities and approaches.

INTRODUCTION

THE ROLE OF CLIMATE REFUGIA

There are a number of well developed and articulated references to consult on the subject of climate refugia (*e.g.* Morelli *et al.* 2016, Morelli and Millar 2018, McWethy *et al.* 2019, Morelli *et al.* 2020). Here, we provide a simple overview and suggest going directly to primary literature sources for more in-depth information. In short, climate adaptation strategies are generally categorized into three types: resistance (protection), resilience (adaptation), and transformation (facilitated change). Although these are categorical terms, in practice they represent a continuum of management intent and intervention based on a concomitant continuum of pace and magnitude of change. Climate refugia are defined as places on the landscape that have the greatest ability to contribute to resistance/protection objectives.

“Resistance” strategies seek to preserve, as much as possible, the existing and historical structure, composition, and function of the ecosystem for as long as possible as the landscape around them changes (Morelli *et al.* 2016). Climate change refugia are “areas that remain relatively buffered from contemporary climate change over time and enable persistence of valued physical, ecological, and socio-cultural resources” (Morelli *et al.* 2016). Thus, it is logical to assume that resistance strategies are principally deployed in areas defined as potential climate change refugia.

Climate refugia may be considered at a multitude of scales. Our focus is on the ecosystem scale where climatic refugia are places that are more likely to retain their general ecosystem characteristics. Within these systems, specific resources may be protected through focused management. However, we should also recognize that climate refugia can also be defined with respect to individual resources. In this sense, these are places where a specific resource is expected to persist. Climate change that results in strong ecosystem shifts in a specific area may, for species of high socio-cultural value and broad climatic tolerance (*e.g.* the bald eagle (*Haliaeetus leucocephalus*)), still function as refugia through ecosystem change if that ecosystem can support these values despite an ecosystem regime shift. Our focus lies in the more general sense of climatic refugia.

Climate change refugia can result from a variety of topographic and environmental characteristics (Figure 1), but in general they are places that for one reason or another are expected to generally retain their current temperature and/or precipitation profiles for longer than the landscape overall and, in the Sierra Nevada, they additionally need to have lower probabilities of the threat of high severity fire. Examples include wetlands, riparian zones, rock glaciers, talus slopes, and large bodies of water, which support micro-climatic conditions that temper larger scale changes.

Of course, the predicted longevity of amenable climate conditions in one place versus another is only one consideration, although an important one, in determining which places and things merit management investments to protect and preserve them as long as possible. Climate refugia are most typically defined by applying climate models to vegetation coverage projections to understand where on the landscape ecosystems are least likely to change. These refugia, defined by the physical environment, can then be evaluated in terms of what values they can and do support; however, important socio-cultural values that are vulnerable to climate change will exist outside of climate refugia, and resistance strategies will still be employed to protect them as long as possible. This suggests that there are two tracks to understanding where resistance strategies are warranted: 1) where climate refugia provide a more stable and amenable environment; and 2) where important socio-cultural values exist. Where these two tracks overlap, there is clearly a strong incentive to manage for the socio-cultural value, where they do not, management will likely still work to retain important socio-cultural values as long as possible.

We can use giant sequoia as a simple example. We could apply a bioclimatic envelope model to predict which groves are most likely to remain within the climatic tolerance zones of current groves by the end of the century. These would be then defined as natural refugia for the giant sequoia. In seeking to manage for resilience, we might be tempted to then prioritize the groves that had the highest climatic resilience as refugia and manage fire and climate risk to minimize the risk of extreme wildfire-driven mortality. In contrast, from a socio-cultural perspective, we have a strong incentive to treat the General Grant Grove as a place where we would like to retain the current ecosystem structure for as long as possible simply by virtue of the fact that we have built visitor facilities around this grove and are reluctant to let that go easily. Hence, we might reasonably decide to allocate resources to maintain this grove's security, as was done in the summer of 2021 during a wildfire event, despite the fact that the grove might not be found in a climatic zone that provides a natural buffering from climate change. Even in the case of place-based values, it is helpful to understand the magnitude of the challenge that climate will pose to maintaining socio-cultural values in a given location.

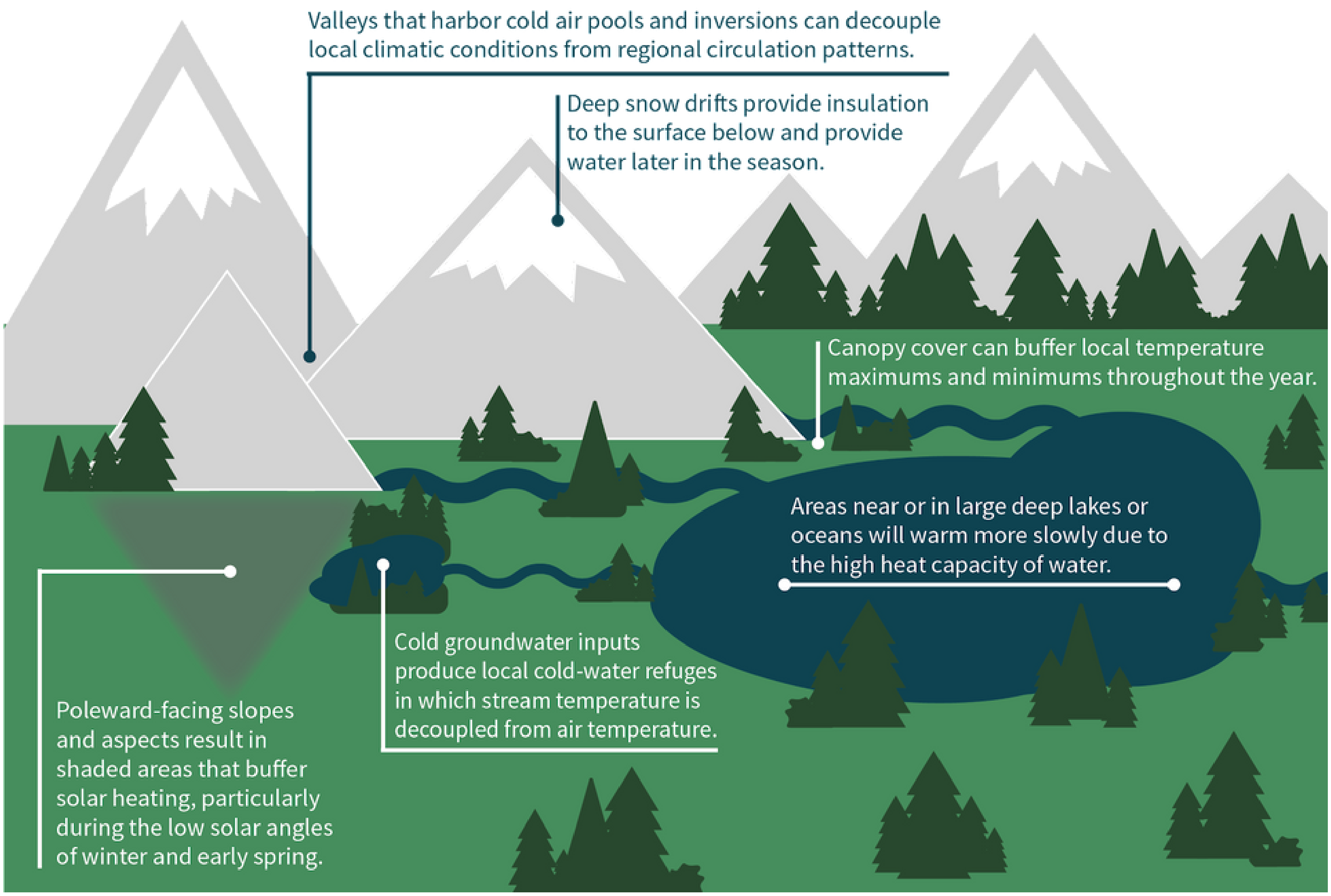


Figure 1. Environmental conditions commonly associated with climate refugia. From Morelli and Millar (2018), USDA Climate Change Resource Center (https://www.fs.usda.gov/ccrc/topics/climate-change-refugia).

INDIGENOUS NATIONS

Indigenous communities have lived within and stewarded the forested landscapes and ecosystems in California for millennia. California has approximately 60 different cultural regions, 10 of which have a footprint in the Sierra Nevada, and each with its associated tribal entities, according to the California Native American Heritage Commission (NAHC Digital Atlas). California has more tribes and Native Americans than any other state, but less land under tribal jurisdiction than most of the states in the west, so tribes in California require access to public lands for access to natural resources and to exercise their cultural practices (Long and Lake 2018). Many aspects of tribal cultural heritage values in forested ecosystems have declined under federal and state management due to exclusion of fire and Indigenous stewardship; and those declines are associated with declines in biodiversity, impacts to air quality, increased wildfire hazards, impacts to water quality and quantity, and other impacts to ecosystem services for society-at-large (Long *et al.* 2021). Increases in invasive species and climate change are additional drivers of decline (Alexander *et al.* 2017, Spies *et al.* 2018). It is incumbent upon efforts directed at improving ecosystem conditions and future resilience to include emphasis on natural resource conditions and values of importance to Indigenous peoples in California (Long *et al.* 2020). This report is intended to highlight some key resources of cultural and subsistence value that are vulnerable to future impacts from changing climate. Further, we explore how their values, and the values of stakeholders with shared interests in the fate of these same resources, can be accommodated and accomplished in the course of adapting to a changing environment that will affect all living beings.

The effects of climate change are already apparent across California's forested landscapes and future projections forecast more significant changes to come. To effectively cope with climate change, a critical first step is grounding our decisions in the fact that we are in a period of rapid change. Assessing what can be retained, where, for how long, and how management can guide change determines whether we can mitigate the loss. The concept of climate refugia is being increasingly applied to identify locations within landscapes that have the potential to support more climate vulnerable biota and functions, or if nothing else provide more time for species and processes to adjust to changing climatic conditions (Morelli *et al.* 2020).

For Indigenous peoples, the current and future impacts of climate change are adding to the legacy of Euro-American colonialism in inhibiting Indigenous communities from continuing traditional stewardship activities that support their well-being and maintain ecological integrity (Long and Lake 2018). Because of their long relationship with their aboriginal lands, Indigenous communities hold knowledge and perspective that can inform land stewardship (Morishima and Mason 2017). As Dockry and Hoagland (2017) stated, "Native American forests and tribal forest management practices have sustained indigenous communities, economies, and resources for millennia. These systems provide a wealth of knowledge and successful applications of long-term environmental stewardship and integrated, sustainable forest management." Every tribe has a different history and holds multiple and diverse cultural perspectives (Dockry and Hoagland 2017). Awareness and attention is needed to integrate cultural knowledge and values into management activities directed at mitigating and adapting to climate impacts, particularly for natural resources that have important cultural value and significance to tribal communities.

PROJECT GOALS

The goal of this project is to develop socio-ecological resilience-based refugia criteria and where feasible link these to measurable, forecasted climate variables. We used peer reviewed literature and expert opinion to evaluate concordance, or lack thereof, among several socio-ecological values (*e.g.* giant sequoia) and the capacity to identify biophysical climate refugia for each resource.

Our focal study area was the 2.4 million-acre Tahoe Central Sierra Initiative (TCSI) landscape, but many of the resource values identified and their climate vulnerabilities will be relevant throughout the Sierra Nevada. This project builds on substantial investments in the TCSI landscape by multiple stakeholders including NGOs, scientists, land managers, and tribal partners over the past three years.

Tribal values are associated with a wide array of ecological features that support tribal well-being, including continuation of cultural traditions and security. Although the TCSI has concerned itself with a variety of socio-ecological values (see Figure 3), here we placed a special emphasis on values that have been identified as important to tribal communities. Concerns for climate change impacts on California tribes have been documented in the tribal report for the Fourth California Climate Change Assessment (Goode *et al.* 2018). Previous work has highlighted impacts of climate change on food resources important to tribes (Lynn *et al.* 2014).

Three resource areas were considered focal in this report: 1) functional fire, 2) large trees / mature forests, and 3) focal tribal cultural elements including mature hardwoods (especially California black oak as a staple traditional food, but also considering other native hardwoods, shrubs, and understory plants that provide food, medicines, and materials), meadows (as locations for traditional foods and materials), and culturally important wildlife. We chose to examine these resources because they have value to Indigenous communities, as well as social and ecological significance to all communities. What and how natural resources are valued can vary substantially among communities, so we explored the degree to which desired conditions and management outcomes may be coincident or differ between tribal values and stakeholder values across landscapes in the Sierra Nevada and the TCSI landscape in particular (Figure 2). Of course, integration of tribal values into land management plans will depend on meaningful government-to-government consultation and engagement, most likely at a local level. Our exploratory work is intended to demonstrate opportunities to better incorporate tribal values into landscape decision support systems and forest planning efforts so that it will be easier for managers and tribes to communicate their interests and consider socio-cultural outcomes in the development of alternative strategies. Our efforts here can serve as a proof-of-concept by highlighting where there is likely to be congruence, as well as possible points of tension, among different values.

Figure 2. The Tahoe Central Sierra Initiative (TCSI) landscape. From https://sierranevada.ca.gov/what-we-do/tcsi/.

We categorized each aspect of climate vulnerability and potential impacts by direct effects (*e.g.* temperature and precipitation), indirect effects (*e.g.* pest presence, novel species combinations, change in bloom time, wind), characteristics (*e.g.* temporal or spatial distribution, extremes), and whether those aspects were mappable. Some highly valued natural resources and culturally important places are not mappable because they are not defined spatially or have not been publicly mapped, often to preserve their anonymity and integrity. In other cases certain high value tribal areas, such as places that were more recently burned by Indigenous practitioners, have not been identified, yet tribes can identify those areas and those would be important opportunities for forest plans. We began to suggest where these resources and places may occur. Finally, we explored "management activities" that can protect and enhance climate refugia as well as funding sources (*e.g.* government agencies, utilities, private companies) which could be leveraged to support needed work.

In the course of evaluating the three focal resource areas, we felt it would be valuable to put them in the context of the broader ecosystem. Therefore, we used the Framework for Resilience (Manley *et al.* 2020) pillars and elements as a context for evaluating the vulnerability of these resources to climate change, and the interdependence of these resources with other resource conditions. The result of this work is a first step toward building a tool kit of climate criteria associated with mappable tribal cultural heritage values within their associated pillar that can be used by practitioners and managers to guide the assessment of climate refugia across the central Sierra Nevada. This work is not exhaustive by any means, rather it is a contribution toward recognizing, mapping, quantifying, and integrating tribal and related stakeholder values, desired outcomes, and stewardship methods that are effective in preserving and adapting treasured socioecological systems in the Sierra Nevada.

METHODS

Framework for Resilience

We relied on the Framework for Resilience (Manley *et al.* 2020) to structure our assessment of resource vulnerabilities. The Framework has been adopted by the Sierra Nevada Conservancy and the recently released California Wildfire and Forest Resilience Action Plan (2021), which is an interagency product jointly developed over the previous 5 years in response to declining forest conditions and increases in large, destructive wildfires across the state. The Framework has 10 pillars that represent the full spectrum of socio-ecological outcomes and their resilient conditions (Figure 3). Each pillar has two to four elements that pertain to the primary facets of the pillar and associated conditions. We categorized the three original focal resource areas by pillar: functional fire is associated with the fire dynamics pillar; large trees and old forests are associated with the forest resilience pillar; and focal tribal resources are largely associated with the biodiversity conservation pillar. Resources that are linked to these primary areas of interest resulted in the addition of the fire-adapted community and air quality pillars (linked to fire), wetland integrity (linked to focal tribal resource and biodiversity), and water security (linked to everything).

Figure 3. The ten pillars of the Framework for Resilience for forested landscapes (Manley *et al.* 2020).

Literature and Consultations

We consulted published literature, tribal resource specialists, area experts, and stakeholders throughout the TCSI landscape to gather information on the climate vulnerability, potential impacts, and climate refugia parameters associated with each of the three main topic areas and their ecosystem linkages. We initially reviewed published climate and tribal values-focused literature, associating each value with the appropriate pillar of the Framework. Key word searches were combined with expert advice to identify relevant literature to be included in our review. Once the vulnerability of each value to climate change was initially evaluated (see below), tribal resource specialists framed the effect that potential changes to conditions precipitated by climate change would have on tribal cultural heritage resources and practices. To understand stakeholder perspective, we also conducted an expert solicitation survey to inquire as to the relative importance of each pillar of resilience as an initial step toward understanding how resource values might be prioritized across the landscape in situations where conflicts might arise (Appendix A). Tribal values and methods for achieving multiple objectives across important values are of high interest, but this project did not have sufficient time to have those important conversations in an appropriate manner. Nevertheless, this effort is intended to suggest how these focal tribal values could be incorporated into planning frameworks and support deeper engagement with land managers going forward.

Evaluation of Climate Vulnerability

We used expert elicitation to link mappable, climate-relevant attributes to each of the primary resource topic areas (old forests and large trees, fire, and culturally important plant and animal species) and their ecosystem linkages across the pillars of resilience. We considered multiple attributes under each pillar, and whether or not the attribute was both mappable and vulnerable to climate change. For resources that met both criteria, published literature was consulted to identify the specific attributes of climate change (*e.g.* min/mean/max temperature, phase and amount of precipitation) that would affect the condition or resilience of the resource condition.

Resources were considered mappable if it was possible to identify spatially explicit locations or derive modeled estimates across all lands to represent current conditions. Some entire classes of resources, such as risks associated with air quality, are too complex to readily map based upon current conditions. Other classes of resources, such as biodiversity, were mixed in their ability to be mappable. For example, researchers have mapped climate projections for shrubs of high cultural importance, including huckleberry (*Vaccinium membranaceum*), beaked hazelnut (*Corylus cornuta*), Oregon grape (*Mahonia aquifolium*), and salal (*Gaultheria shallon*) (Prevéy *et al.* 2020a, 2020b); however, amenable climate conditions for many other understory plants of high cultural value have not been modeled and mapped and there are important questions about how well model projections translate into management strategies to ensure sustainable harvest. For many wildlife species of special importance, habitat quality reflects a complex combination of denning/roosting/breeding habitat as well as food resources. Some habitat modeling has only considered one dimension of habitat, such as overstory forest structure (White *et al.* 2013), rather than effects on understory composition and fire effects. As another example, availability of band-tailed pigeon (*Patagioenas fasciata*) depends on roost structure, food (*e.g.* acorns), and mineral springs, so it is challenging to construct a model of how climate change would affect those multiple drivers. Finally, some resources may not be readily mappable because of data sensitivity. Tribes and agencies may be justifiably reluctant to identify locations on maps in order to protect these resources. Examples range from active tribal harvesting locations and sacred sites, to locations of endangered species that may be under poaching pressure (*e.g.* sensitive cacti, select reptiles).

Vulnerability was evaluated as the degree to which climate change had the potential to impact the resource either directly (*e.g.* limits on capacity to exist outside a defined temperature envelope) or indirectly (*e.g.* tree mortality from drought stress or increasing prevalence of large-scale high severity fire). The type and degree of vulnerability were described, typically in qualitative terms such that the results are broadly applicable across the Sierra Nevada. In some cases, modeling data from the TCSI landscape enabled more definitive data on vulnerabilities and potential impacts in future decades.

RESOURCES & VALUES - GENERALLY MAPPABLE

1. Forest Resilience

Large trees and mature forests are of high value for a variety of cultural reasons and they generally are underrepresented across the Sierra Nevada relative to historical forest conditions. Ecologically, they provide important ecosystem functions for forested landscapes (*e.g.* seed sources, nutrient cycling, carbon sequestration), and essential habitat elements (as living and dead trees) for many plant and animal species. Mature and old forests support a unique suite of closely associated species, many of which are species of concern because they are vulnerable to habitat degradation and loss from management activities and other sources of disturbance. Large trees also provide valuable wood products to support economies, industries, and communities.

Tribal cultural practices have influenced forest composition, and the distribution and abundance of many tree and shrub species over centuries (Kimmerer and Lake 2001, Charnley *et al.* 2008). Burning had a strong influence on the character and distribution of forest ecosystems, through resetting succession and promoting habitat heterogeneity by creating and maintaining mosaics of different seral stages. Burning and other vegetation management practices also multiplied the presence of ecotones (Turner *et al.* 2003).

Mature and Old Forests and Woodlands

Old forests (*i.e.* old growth) are a structurally heterogeneous successional or stand development stage that are increasingly rare across landscapes that are more intensively managed or experiencing frequent, extensive high severity fire. Old forests are commonly characterized by tree size, accumulation of large dead woody material, number of canopy layers, species composition and ecosystem function (Franklin *et al.* 1981). But they also represent a set of unique circumstances that make it possible for old forest conditions to develop, namely site productivity and infrequent occurrence of high impact disturbances that can reset succession.

Old forests in the dry-forest dominated Sierra Nevada ecoregion are a legacy of historical disturbances that were patchy and low to moderate in severity. Prior to European influence, old-growth conditions would have been extensive, and characterized by large pines and firs, multiple age cohorts, small patches of large standing dead and down wood, and canopy gaps (Spies *et al.* 2006). In forests with frequent historical fire, such as the mixed conifer forests of the Sierra Nevada, old-growth forests had large old live and dead trees, but amounts of deadwood were low, canopies were generally open, and dense canopy areas were less common than exist today (Dunbar-Irwin and Safford 2016, Safford and Stevens 2017, Youngblood *et al.* 2004). Old forests were historically widespread in the Sierra Nevada, as a consequence of large,

frequent, mixed severity disturbances that create structurally diverse forests that recruit and retain legacy elements, such as large trees, snags, and logs (Franklin and Van Pelt 2004, Spies 2004). The Sierra Nevada is predominantly montane mixed conifer forest, and most of the impacts of management and development have occurred in these forest types and elevational zone; however, subalpine forests and associated species (*e.g.* red fir (*Abies magnifica)*, white-bark pine (*Pinus albicaulis)*, western white pine (*Pinus monticola)*, bristlecone pine (*Balfourianae sp.)*, foxtail pine (*Pinus balfouriana)*) are also ecologically important. Although historical impacts have been largely limited to fire suppression, subalpine forests have higher vulnerability to climate change than lower elevation forests because of changes in the form of precipitation (snow to rain) and limited opportunity for range shifts (Thorne *et al.* 2018).

Old forests are linked to a wide range of tribal values, including quality water, quality air, habitat for wildlife and plant species that are part of their cultural heritage, historical and extant cultural practices, a sense of place, and a place of teaching and learning (Long 2020). Disturbance has an important role to play in maintaining both the ecological and cultural values of old forests. Fire as a process is an essential disturbance that, when operating within its historical regimes, creates and maintains the cultural and ecological functions of old forests. However, fire that operates outside of historical regimes, namely too infrequent and/or too broadly intense fire behavior, erodes these functions. Similarly, management activities of federal and state agencies, although well intentioned, may further erode the cultural function of old forests if they are not tuned to their responses and thresholds. Climate change poses a myriad of challenges in both understanding these important functions and the degree to which management can reduce their vulnerability to climate change while not doing more harm than good.

Old forests also have strong support by a range of stakeholders, but particularly conservation-oriented stakeholders. For this group, old forests have spiritual significance representing unfettered nature and the associated peace of mind it can confer, intrinsic value that they must steward, and yet-to-be-discovered solutions (*e.g.* medical, atmospheric) to current and future societal problems (*e.g.* Kimmins 2003, Moore 2007, Spies *et al.* 2018). Ecologically, old forests perform a wide range of functions, including habitat for native biota (plants, animals, fungi), nutrient cycling, stable carbon sequestration, water quality, air quality, and seed sources for plant regeneration following large-scale disturbances.

Old forests are highly vulnerable to climate change, both directly and indirectly. Changes in temperature and precipitation will both directly affect the ability of dominant forest tree and shrub species to reproduce and persist. Tree growth, survival, and recruitment are intrinsically tied to patterns in precipitation and air temperature.

Large Conifer Trees

Large, old trees play many significant roles in the lives and culture of Indigenous peoples in the Sierra Nevada. From ancient to contemporary times, trees have been important to regional tribes (*e.g.* Franco 1994). Particular tree species can be of particular importance for a variety of cultural practices, including giant sequoia (*Sequoiadendron giganteum)*, juniper (*Juniperus*), and red fir. Cultural practices depend on large trees or logs, including canoe building and smaller craftwork, the construction of traditional structures, and even burial traditions. They also are a powerful teacher for youth to respect nature and the land, and interact with them spiritually and physically. They provide shade and recreation and habitat for wildlife and a representation of the power and importance of history and wisdom that comes with time. Franco (1994), Chief of the Tule River Tribe at the time, shared that "Trees are important in Tribal folklore - in creation stories the bald eagle represents the creator of all living things who lives in a tree growing in the sky - after the eagle creates other animals, people, water and land, the tree comes down to the land to become the first tree in the world....It is through these stories that Tribal members are taught to respect trees at an early age."

Large conifer trees are highly vulnerable to climate change through a variety of mechanisms. Direct effects are primarily associated with drought stress, which is exacerbated through competition in stands with high densities of smaller diameter trees. Stovall *et al.* (2019) found that during the peak of the most recent drought (2014-2016) in the southern Sierra, large trees died at twice the rate of smaller diameter trees, and that higher temperatures, greater competition, and reduced water availability were associated with increased vulnerability and mortality of large trees. They characterized trees in three size (height) categories: small (<15 m), medium (15–30 m), and large (>30 m). For the 5 years preceding the peak of the drought, the cumulative mortality rates declined with tree size, being approximately 15%, 10% and 5% for small, medium and large trees, respectively. By 2016, these relative mortality rates flipped to be highest for large trees (45%) followed by medium (38%) and small (32%) trees. Tree mortality was most affected by temperature and precipitation. Large trees were less likely to survive on steeply sloped areas during drought. Interestingly, large trees in areas with high soil moisture under non-drought conditions (*e.g.* many low slope areas) were also more vulnerable during the drought. These trees in wetter habitats presumably were vulnerable under drought because their root systems are not trained to seek deeper water sources, where water availability is likely to be more persistent than surface soil moisture.

More often mortality of large trees is more likely a result of indirect impacts, namely beetles and fire. Beetle-caused mortality can be rapid and widespread, and larger diameter trees are commonly at greater risk of beetle attack than smaller diameter trees. Fettig *et al.* (2019) assessed causal agents and rates of tree mortality, and short-term impacts to forest structure and composition in the central and southern Sierra Nevada, following severe tree mortality. Warm temperatures may increase the length of flight activity and reproductive activity of bark beetles (*Scolytinae)*. Elevated temperatures and dense forest conditions exacerbate drought stress on trees, and as such, droughts occurring during warm periods generally lead to greater mortality than those occurring during cool periods. Fettig *et al.* (2019) found that the mortality of Ponderosa pine (*Pinus ponderosa)* was highest at the lowest elevations, concentrated in larger-diameter trees, and attributed primarily to colonization by the western pine beetle (*Dendroctonus brevi)*. Nearly 90% of the Ponderosa pine in the three largest diameter classes were killed. Similarly detailed studies are not as available for firs or other pine species, but in general the dynamics are consistent across tree species and their associated beetle predators, meaning that large diameter conifer trees are more vulnerable to climate driven stressors in dense stands and when temperature and drought conditions are combined. This would suggest that climate refugia might first be most effective in providing lower temperatures to help buffer the effects of large-scale droughts, and secondarily areas that are likely to retain greater moisture, but with an emphasis on the depth of available water.

Fire is the other primary threat to old trees. In addition to the general risk that high intensity fire poses to forest persistence in general (see old forests above), large trees can be vulnerable to fire mortality even from low to moderate intensity fires. Specifically, protracted lack of fire resulting from fire suppression commonly results in increased buildup of litter layers, particularly around the base of large, old pines that shed large quantities of bark and needles over time (Noonan-Wright *et al.* 2010). The build up of duff and litter around the base of large trees can be many meters in depth, and once fire gets into these large piles of fine fuels, they can burn hot and smolder for long periods of time, putting root systems at risk of mortal damage. Specifically, even low intensity fires can burn hot in the deep basal duff and cause extensive cambium injury at the root collar and kill roots growing near the soil surface or in the lower duff, resulting in tree mortality (Kolb *et al.* 2007). This makes large trees more susceptible to damage from wild and prescribed fires than under the historical fire regime (Spies *et al.* 2006).

Mature Hardwood Trees

Several species of large hardwood trees (California black oak (*Quercus kelloggii)*, Oregon white oak (*Quercus garryana)*, tanoak (*Notholithocarpus densiflorus)*, canyon live oak (*Quercus chrysolepis)*, giant chinquapin (*Chrysolepis chrysophylla)*, Pacific madrone (*Arbutus menziesii)*, bigleaf maple (*Acer macrophyllum)*, and California laurel (*Umbellularia californica)*) are important cultural resources as sources of food and habitat for ecologically and culturally important wildlife species (Long *et al.* 2018). They are also valued by general stakeholders for many of the same reasons, and therefore the desired outcome for the retention and recruitment of mature hardwoods is largely consistent between tribal and stakeholder interests. Many of these species are also considered desirable because they tend to be drought-tolerant and more friendly to fire management, in part because many species are deciduous and have litter that can facilitate low-intensity fire. Aspen (*Populus tremuloides)* is another riparian hardwood that also has cultural value (*e.g.* young poles are used by Washoe people) and it can also support favorable fire (Ziegler *et al.* 2020).

California black oak is the most abundant of the hardwood tree species that has particularly high cultural value as a traditional food source (Long *et al.* 2016). Giant chinquapin has very limited distribution in the region (a small area on the Eldorado National Forest) and is therefore possibly vulnerable to extirpation. These hardwood species in the Sierra Nevada may be less vulnerable to the direct impacts of climate change, since many are adapted to drought conditions. However, the mature trees are highly vulnerable to increases in high severity fires, and some species take many decades to reach an age where they produce an abundance of fruits. Many of these tree species are also vulnerable to displacement by conifers in the absence of fire; consequently, a strict "protection" strategy could be a recipe for further decline.

Effects of climate change on two lower-elevation oak species, valley oak (*Quercus lobata*) and blue oak (*Quercus douglasii*), have been evaluated in modeling and field studies. Valley oak and blue oak acorns are also important traditional foods of Native Americans (Barrett and Gifford 1933, Baumhoff 1963, Anderson 2007). Kueppers *et al.* (2005) found that the range of these oaks would generally shift upward in elevation and northward, but that the ranges of the two species were likely to greatly contract as summers became warmer and drier. Modeling of California black oak in the Southern Sierra Nevada by the Nature Conservancy found a similar decline in habitat under a hot, wet climate projection (MacKenzie 2010), but more stable conditions under a warm, dry climate projection (The Nature Conservancy's California Climate Adaptation Science Team 2010b). However, a site study of valley oak found that “rather than a complete shift northward and upward, as predicted by the species bioclimatic model, valley oaks are more likely to experience constriction around water bodies, and eventual disappearance from areas exceeding a threshold of maximum temperature” (McLaughlin and Zavaleta 2012). Young California black oaks are also sensitive to drought, so such relationships may also apply to black oak. In general, mature oaks are more resilient to drought because of their ability to trap deeper groundwater reserves (Allen 2015). As a result, wetter areas, such as the perimeter of meadows, are likely to be important long-term refugia for black oak, particularly at lower elevations.

Analysis of historical vegetation data has found that oaks have increased in the past century and are likely to become more dominant as climate change accentuates increases in climatic water deficit (McIntyre *et al.* 2015). However, rather than finding an increase, forest inventory data suggests a slight decline in basal area of California black oak; that decline was associated with fire mortality on National Forest lands, especially in the southern part of the study area that included TCSI. Another study also found that the basal area of full-crowned, medium-to very large hardwoods (>28 cm DBH) declined across all eight hardwood species (Long *et al.* 2018). A study of old-growth ponderosa pine-California black oak groves in the Ishi Wilderness (on the Lassen National Forest) found that low-severity wildfires promoted growth of resprouting black oaks, although the basal area of the species still declined as pines increased (Pawlikowski *et al.* 2019).

Various works indicate that proactive treatments focused on frequent low-intensity burning (including Indigenous cultural burning) would help to conserve these large hardwoods (Long *et al.* 2017, Pawlikowski *et al.* 2019). A number of Indigenous populations used burning to sustain acorn yields including the Dry Creek, Cloverdale, and Kashaya Pomo tribes as well as the Wappo, Yurok, Tolowa, Luiseno, Maidu, and Ohlone (Anderson 2005). Such low-intensity burning may also sustain harvest of mushrooms (Allen 2015), which are another tribal value in forests, especially those with hardwoods. Furthermore, Long *et al.* (2017) found that core areas for harvest of California black oaks, based upon ecological condition and accessibility, might represent only a small area (*e.g.* only 2.2% of the entire Sierra National Forest) and therefore targeting treatment in those areas would not likely pose conflicts with objectives associated with maintaining more closed canopy forest conditions. Similar criteria could be applied to the TCSI landscape to identify critical refugia for conservation; these may overlap with areas nearby meadows to maximize value to tribal communities and promote resilience to climate change.

2. Fire Dynamics

Fire is a natural and essential process in the fire-prone ecosystems of California and, thus, functional fire is a coveted outcome of restoration efforts across the Sierra Nevada. As such, it is inextricably linked to all of the primary values identified for this project. Fire has historically been a primary forest and landscape management tool for tribes, and historical changes in fire have been more linked to socio-ecological changes than climate change (Taylor *et al.* 2016). As the ecological importance of fire in dry-forest ecosystems is being recognized, it is also emerging as a socially acceptable management tool, which holds promise for tribes reestablishing traditional burning practices (California Forest Management Task Force 2021). It is clear, however, that tribal practices would have a much greater emphasis on the use of fire as a management tool than federal and state agencies are currently accomplishing (Kolden 2019) or are likely to accomplish where goals are focused mostly on wildfire risk reduction. Tribes are likely to burn more frequently, within smaller burns, and to often target meadows and hardwood groves, as well as other areas with high cultural values (Long *et al.* 2021). A fire history study by Van de Water and North (2010) in the Sierra Nevada noted that some riparian areas had shorter fire return intervals than adjacent upland areas, and that these sites were associated with extensive meadow systems that may have been centers of Native American use and burning.

The numbers of acres burned throughout California increased five-fold between 1972 and 2018 (Williams *et al.* 2019). Severity has also escalated (*i.e.* the amount of basal area killed in a forest stand) alongside increases in mean and maximum fire size. In dry mixed-conifer forests, these increasingly severe fires have been positively correlated with increasing springtime temperature and drought while negatively correlated with spring and summer precipitation (Miller *et al.* 2009). The severity of fires in the future will largely be dependent upon changes in vegetation, fuel load, drought, and increases in temperature (*e.g.* Figure 4) (Parks *et al.* 2016, Williams *et al.* 2019, Lenihan *et al.* 2008).

Intensity of fires (*i.e.* the temperature of the fire front) has also increased in recent years. This pattern is projected to continue where increases in temperatures, drought, and wind persist, but will be mediated in wetter, less windy areas (Fried *et al.* 2004). Over the past several decades, increases in fire severity and intensity have been coupled with increases in fire frequency and duration, shifting in the 1980s from large fires lasting a week or less to more frequent large fires lasting five weeks (Westerling *et al.* 2006). Upward trends in frequency, severity, and intensity of fire have all occurred alongside shifts to warmer springs, longer dry seasons, decreased precipitation, and earlier snowmelt, underscoring the direct impacts of climate change on functional fire. Furthermore, these direct impacts of climate change interact with other disturbances, such as bark beetle outbreaks and non-native pathogens, which can further exacerbate the effects of drought stress, leading to tree mortality and increases in both fire severity and frequency (Littell *et al.* 2016).

For drier forest types like those typical of the Tahoe-Central Sierra region, fuel load and vegetation management will be critical for moderating the impact of climate change on fire dynamics. Though the effects are complicated, both frequency and severity of fire are likely to increase in this region when dry fuels accumulate on the landscape. Most studies suggest that active and passive restoration, particularly those treatments that thin vegetation and lighten fuel loads, can help to decrease fire risk from climate change (Williams *et al.* 2019, Parks *et al.* 2016). For tribes, changing fire regimes can threaten culturally important resources in many ways, by killing key plant resources, changing forage quality, restricting access to sites, and limiting opportunities to practice cultural burning (Voggesser *et al.* 2013, Long *et al.* 2021, Long *et al.* 2014). Working alongside tribes to continue and enhance cultural burning can help to protect culturally important landscapes while increasing forest resilience and fostering climate refugia.

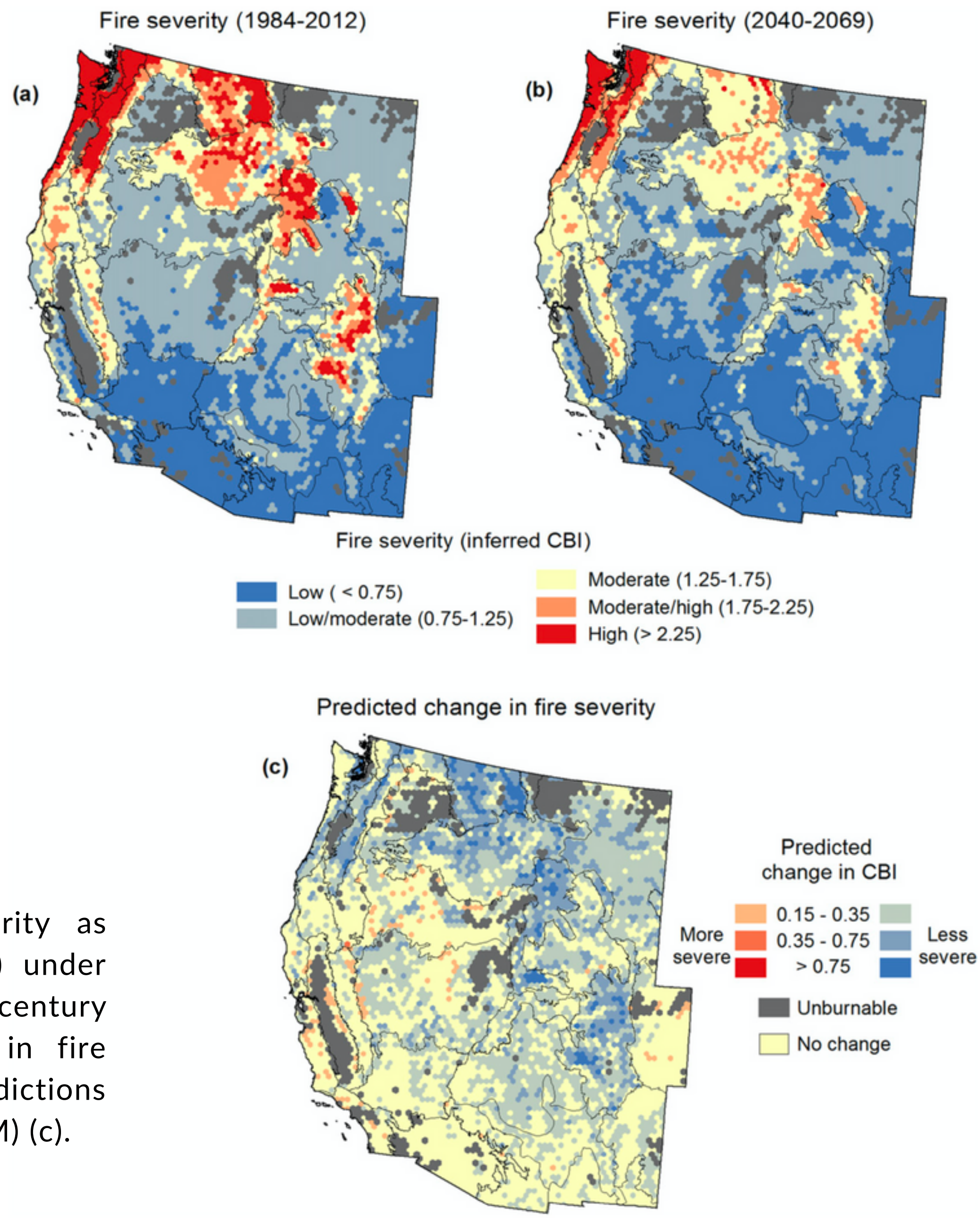


Figure 4. Predicted fire severity as composite burn index (CBI) under observed (a) and mid-century climate (b). Mean change in fire severity among the 20 predictions (one prediction for each GCM) (c). (Parks *et al.* 2016)

3. Fire Adapted Communities

With longer fire seasons, increasingly severe fires, and expansion of residential areas and cities into the wildland-urban interface (WUI), continued adaptation of communities to fire will be critical. Residents, land managers, local politicians, emergency managers, and fire professionals collectively make up a fire adaptive community (FAC). These people work together to plan for, respond to, and recover from the evolving risks that fires pose to humans. The community must recognize that historic fire exclusion models and increasing reliance on professional firefighting is unsustainable both financially and culturally. With increasing impacts from climate change and the growing development of residential communities near wildland vegetation, collective and individual action will be needed to reduce the severity of changing fire conditions (Paveglio *et al.* 2020).

Between 1999 and 2017, 1,545 residences were destroyed annually by wildfire, with over 8,000 and 20,000 residences being destroyed in the 2017 and 2018 fire seasons respectively (Schumann *et al.* 2020). Increasing the adaptive capacity - or ability to alleviate risk of impacts of natural disturbances - of communities within the WUI is site specific, with different interventions needed for individual human communities (Paveglio *et al.* 2012). Vulnerability is not only influenced by biophysical aspects such as fuel loadings, topography and weather but social and political aspects as well (Paveglio *et al.* 2012). The social diversity of residents inhabiting lands can influence a community's vulnerability to fire (Paveglio *et al.* 2019). Different values and views on natural resources can shift a community's perspective towards fire management and influence interactions between their local government and land management agencies. This allows for developing differential barriers through diverse values promoting wildfire management at larger scales (Paveglio *et al.* 2019).

To understand the interacting factors which lead to wildfire risk, certain studies utilize the seasonal severity rating (SSR), which is a seasonal mean of the control difficulty of a potential fire which can also translate into the intensity of a fire. Flannigan *et al.* (2000) projected a 10-50% increase in the SSR over most of North America by the middle of the century. SSR projections can be used to understand how fire risk is changing, where communities might be at higher risk, and where opportunities exist to foster fire adapted communities within regional climate refugia. However, fire adaptive communities are only a part of the larger picture for human adaptation to fire.

Recent work by Adams and Charnley (2020) has noted that forest fuel treatments designed to reduce wildfire risk have sometimes not provided proportionate benefits to environmental justice communities (defined as low-income and/or non-white, which often includes Native Americans). In particular within TCSI, they found that treatments on the Tahoe National Forest did not target a low-income, non-white hotspot near Truckee, likely owing to greater complexity in treating around those neighborhoods. While tribes in California have been displaced from their aboriginal lands now within national forests, some tribes do have lands close to the boundary of the study area; consequently, those tribes could benefit from treatments that reduce wildfire risk and facilitate cultural burning.

4. Biodiversity Conservation

A broad array of taxa and levels of biological organization are encompassed by biodiversity. In the context of this project, we identified two major categories of values that we address separately below: focal species of specific tribal value, and biological diversity from an overall ecological and intrinsic perspective. It is well documented that Indigenous peoples intentionally managed forested ecosystems and landscapes using a variety of methods to manipulate and enhance biodiversity (Anderson 2005, Turner *et al.* 2003). Burning was used widely to alter the abundance and distribution of plant and animal species; however burning was not the only forest management practice Indigenous peoples employed. Other techniques included: planting or broadcasting seeds; transplanting shrubs and small trees to make them more abundant and accessible; modifying soils and digging to enhance the growth of root vegetables; selective harvesting; pruning shrubs and trees to enhance their productivity and growth form; harvesting plants and animals in spatially patterned locations; and diverting water for irrigation and to reduce erosion (Anderson 2005, Deur and Turner 2005, Charnley *et al.* 2008).

Tribal values associated with biodiversity encompass all species - species diversity, as well as "the web of reciprocal relations that exist between the community of human and nonhuman beings, including their spiritual consciousness" (Kimmerer 2000). Tribal culture and those of modern ecology share the perspective that people and the biophysical world are viewed as interconnected and part of an integrated system in which biological and physical components are interdependent (Pierotti and Wildcat 2000, Charnley *et al.* 2008). Interestingly, stakeholders sometimes rank biodiversity as a low priority (see later in this report), based on the assumption that somehow biodiversity is optional - that the systems upon which human life depends are not dependent upon biodiversity. This stems from a fundamental lack of understanding that healthy forests, clean water, or clean air are interdependent with biodiverse ecosystems (*e.g.* Brockerhoff *et al.* 2017). Clearly there are a large number of individual species that are of interest to non-tribal entities, such as hunted species and watchable wildlife species. Further, some aspects of biodiversity are commonly among the top resource objectives for management projects on public lands, either as individual species or groups of species or communities. Many tribes emphasize the importance of biodiversity conservation in general, in contrast to approaches that tend to focus only on a few species that are considered rare and threatened (Long *et al.* 2020).

Biodiversity writ large is highly vulnerable to climate change, which is why climate change is of such great concern worldwide. In the Sierra Nevada, distributions of many species of birds (Tingley *et al.* 2009) and mammals (Moritz *et al.* 2008) have already exhibited shifts in their ranges over the past century in response to climate change, with responses varying among species depending on their vulnerability to temperature or precipitation (Tingley *et al.* 2012). The following sections address species of particular value and concern (Table 1), within the context of overall biodiversity.

Focal Species of Tribal Value

We identified a small set of focal species that are commonly considered to have cultural value, based on personal communications with literature and tribal experts (Table 1; *e.g.* Long *et al.* 2020). Terrestrial species are addressed directly or indirectly as part of the biodiversity conservation section, with the exception of black oak, which is addressed in detail in the Forest Resilience section above. The wetland associated species are addressed in the Wetland Integrity section below.

Table 1. Focal species of cultural value organized by taxonomic group.

Taxonomic Group	Species List
Trees	Pinyon pine (*Pinus sp.*), juniper (*Juniperus*), sequoia (*Sequoia sp.*), California black oak (*Quercus kelloggii*), aspen (*Populus sp.*)
Terrestrial plants	Wild berry producing plants like huckleberry (*Vaccinium membranaceum*), wyethia (*Wyethia sp.*), bracken fern (*Pteridium sp.*), tobacco (*Nicotiana sp.*), other traditional medicinal plants, edible plants, and plants used for basketry
Terrestrial birds	Bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila chrysaetos*), red-tailed hawk (*Buteo jamaicensis*), California quail (*Callipepla californica*), grouse, Northern flicker (*Colaptes auratus*), wild turkey (*Meleagris gallopavo*), acorn woodpecker (*Melanerpes formicivorus*)
Terrestrial mammals	American black bear (*Ursus americanus*), Belding's ground squirrel (*Urocitellus beldingi*), white-tailed jackrabbit (*Lepus townsendii*), snowshoe hare (*Lepus americanus*), chipmunks, white-tailed deer (*odocoileus virginianus*)
Old forest associated species	California spotted owl (*Strix occidentalis*), fishers (*Pekania pennanti*), martens (*Martes sp.*), northern goshawk (*Accipiter gentilis*), pileated woodpecker (*Dryocopus pileatus*)
Wetland associated plants	Sedges (*Carex sp.*), willows (*Salex sp.*), common camas (*Camassia quamash*), deergrass (*Muhlenbergia rigens*), yampahs (*Perideridia sp.*), clovers (*Trifolium sp.*)
Wetland associated animals	Native trout including Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), mountain whitefish (*Prosopium williamsoni*), garter snakes (*Thamnophis sp.*), Western pearlshell mussel (*Margaritifera falcata*)

Pinyon pine (*Pinus sp.)* has been a culturally important species for Indigeneous peoples in the western U.S. for centuries. Pinyon pine has many uses: pitch from the pinyon pine is used for basket making and as a general sealant for various applications; the nuts of the pinyon pine are a highly nutritious food source; and the needles of the pinyon pine have medicinal value (Monsen and Stevens 1999). Pinyon pines are vulnerable to climate change, generally as a function of warming temperature. Cone production was tightly linked to late summer temperatures at the time of cone initiation, with nearly 50% declines in cone production observed in a study in the central U.S that looked at cone production trends from 1970s through to 2012 (Redmond *et al.* 2012). The greatest declines in cone production were observed in trees with largest warming, which were individuals in the highest and coldest populations. Cone productivity appeared to be most impacted by high summer temperatures. Further, Minott and Kolb (2020) found that pinyon and ponderosa pine populations are also at risk of range contraction in a response to increasing temperatures, as evidenced by the extirpation of these two species along portions of the trailing edge of their ranges in northern Arizona, and a lack of commensurate upward migration beyond their current range into cooler, higher elevations.

Sequoia species, including giant sequoia and coastal redwood (*Sequoia sempervirens)*, have great significance to the tribes within the natural range of these two magnificent tree species. They are a superior building material for all manner of items (boats, houses, furniture, fences) because they have higher levels of tannin which make them more insect and rot resistant. Their fibrous bark also has many uses, including insulation, floats, dye, and clothing. Of course the living trees have cultural and spiritual significance as well (Franco 1994). The geographic range of the giant sequoia, also known as the Sierra redwood, is across the west slope of the southern Sierra Nevada, with the northern edge of the range ending around the town of Jackson. The giant sequoia propagate primarily from seed, and is considered a pioneer species, meaning it requires an opening in the canopy for seedlings to survive, which historically was created by fire or people, and as such it does well in plantations. Before the arrival of European settlers, successful recruitment of mature sequoias depended on fires intense enough to kill the forest canopy in small areas (Stephenson 1994). Although the central Sierra Nevada is largely to the north of the range of giant sequoia, it is now frequently included in reforestation efforts, particularly on private lands, because it grows quickly and produces high volume and value wood. Giant sequoia are directly vulnerable to climate change primarily from higher temperatures, which impacts canopy water content (Baeza *et al.* 2021) making it susceptible to disease, and reducing the viability of its seeds. This suggests that in a changing climate where the southern range of the giant sequoia may become uninhabitable, it has the potential to extend its range to the north, likely through assisted migration (Libby 2017). Of course migrating trees and migrating forest ecosystems are not equivalent (Parsons 1994).

Old forest species, such as California spotted owl (*Strix occidentalis)*, fishers (*Pekania pennanti*), martens (*Martes sp.)*, and pileated woodpeckers (*Dryocopus pileatus)* can be particularly vulnerable to climate change, given their narrow climate and habitat tolerances. The loss of old growth forest due to logging and natural disturbance greatly impacts the distribution of some of these species (Long *et al.* 2020). Within remnant patches of old growth, focal species may still experience habitat loss due to decreasing snowpack and increased temperatures. Martens, for example, are expected to experience range shifts and range contractions as they track the changing distribution of deep snowpack in the Sierra Nevada (Spencer *et al.* 2015). Other species, such as California spotted owl, have shown mixed responses to effects of climate change, including increasing fire severity and increasing temperatures (Jones *et al.* 2016, Schofield *et al.* 2020). Some predict that spotted owls may benefit from slightly warmer temperatures because their prey responds positively to increased temperatures (Jones *et al.* 2016).

Many terrestrial bird species hold special cultural and spiritual value among California Tribes (Gleeson *et al.* 2012). Specific birds are central to ceremonial practices (Kelly 1991), and featured in creation stories narratives as having human-like qualities (Heizer and Elsasser 1980), as well as being the focus of tribal dances (Kelly 1991). Historically and into the 20th century, significant species in central California and the Sierra Nevada include the Northern flicker (*Colaptes auratus*), acorn woodpecker (*Melanerpes formicivorus*), pileated woodpecker, western scrub jay (*Aphelocoma californica*), Steller's jay (*Cyanocitta stelleri*), mallard duck (*Anas platyrhynchos*), bald eagle, golden eagle (*Aquila chrysaetos*), red-tailed hawk (*Buteo jamaicensis*), great horned owl (*Bubo virginianus*), wild turkey (*Meleagris gallopavo*), and the California quail (*Callipepla californica*) (Gleeson *et al.* 2012, Long 2020). In addition to being a source of feathers used in regalia, baskets, and other crafted items, birds also hold spiritual significance, particularly birds of prey.

Siegel *et al.* (2014) found that 16 species were moderately vulnerable to the effects of climate change, with direct effects (temperature and precipitation) generally having more impact than indirect effects (*e.g.* fire, food sources), including the following species of particular tribal interest: osprey (*Pandion haliaetus*), bald eagle, northern goshawk (*Accipiter gentilis*), peregrine falcon (*Falco peregrinus*), Prairie Falcon (*Falco mexicanus*), great grey owl (*Strix nebulosa*). California quail, mallard, and pileated woodpecker were expected to be stable, while wild turkey, acorn woodpecker, northern flicker, and jays were likely to increase in population size as a result of climate change. Siegel *et al.* (2014) also found that species associated with alpine/subalpine habitats and aquatic habitats were more vulnerable than birds associated with other terrestrial habitats. Conversely, species associated with foothill habitats may respond to climate change in the region with population increases or range expansions.

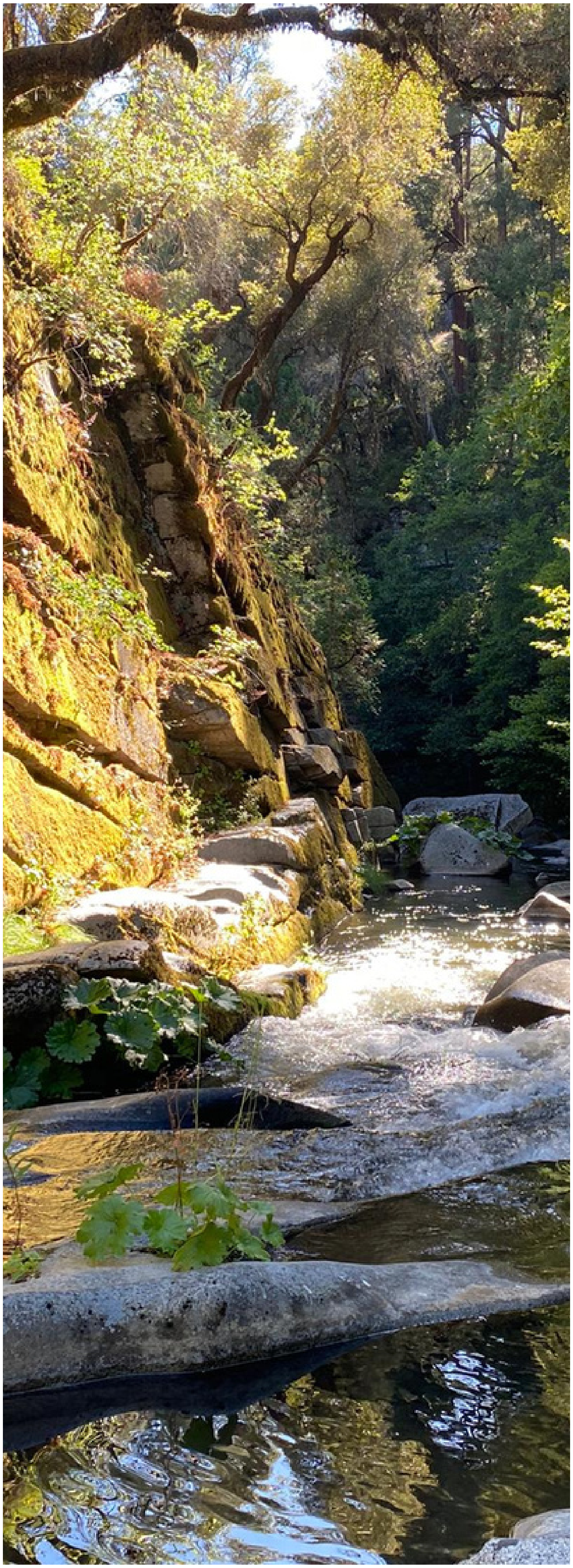
A variety of mammal species are of particular tribal cultural interest, and some of these are likely to be negatively affected by climate change. Belding's ground squirrels (*Urocitellus beldingi*) are vulnerable to changing climate conditions of meadow habitat (Morelli *et al.* 2017). In particular, recent phylogenetic studies indicated that colder meadows and meadows with high spatial connectivity to other meadows promoted allelic richness in squirrels (Morelli *et al.* 2017). Similarly, snowshoe hare (*Lepus americanus)* are vulnerable to direct effects of climate change, such as increasing temperatures, and, more specifically, indirect loss of snowpack. Decreasing snowpack has been associated with increased and prolonged predator pressure on snowshoe hares (Peers *et al.* 2020). In contrast, increasing temperatures and decreasing snow depth may be beneficial for other species, such as white-tailed deer (*Odocoileus virginianus)*. Prior studies have demonstrated that survival of white-tailed deer decreases in areas of higher snow depth (DelGiudice *et al.* 2013). With decreasing snow depth at higher elevations, white-tailed deer may expand their range upward. Other large terrestrial mammals, such as the American black bear (*Ursus americanus)*, may be vulnerable to increasing temperatures due to their susceptibility to hyperthermia, however, there is currently a paucity of literature to describe specific shifts in distribution or behavior as related to either direct or indirect effects of climate change (Sawaya *et al.* 2016).

Species Diversity and Community Integrity

In addition to focal species of specific interest and value to tribes, we also included an overall assessment of the vulnerability of biodiversity in terms of species diversity and community integrity. We characterized diversity using a range of measures based on terrestrial wildlife species composition, such as species richness (number of species within a local area), alpha diversity (wildlife diversity within a local area), beta diversity (wildlife diversity as measured between habitat patches on a regional scale), and gamma diversity (total diversity measured at a landscape scale). Elements of biodiversity included an array of levels of biological organization and functions that species perform, including patterns of local and regional diversity, community integrity, and occurrence of specific species either considered indicators of shifting climate conditions, or species that are rare, threatened and endangered. Community integrity was defined as any wildlife species-to-species interactions or wildlife-to-environment interactions that may change in response to changing climate conditions and, as a result, impact ecosystem function. Climatic conditions which appeared to most influence wildlife species occurrence included temperature and, to a lesser extent, precipitation.

Biological diversity is not only vulnerable to climate change, but climate change is surpassing direct human impact as the primary driver of changes in biological diversity. Many studies indicated that wildlife species, generalists and specialists alike, are shifting their ranges to higher elevations or latitudes to track shifts in average high annual and seasonal temperature. Some studies have shown that species-specific distribution shifts are leading to changes in community composition and patterns of diversity along an elevation gradient (Lurgi *et al.* 2012). In Sweden, researchers evaluating breeding bird species richness over an extended time scale observed that species richness increased upwards along an elevational and latitudinal gradient as birds tracked cooler temperatures (Davey *et al.* 2013). In contrast, beta diversity decreased as a result of species turnover (increased prevalence of common species at higher elevations and latitudes). In the Sierra Nevada mountains, a long-term dataset has also revealed that small mammals are experiencing range contractions and expansions along an elevational gradient as a result of shifts increasing minimum monthly temperature (Moritz *et al.* 2008). Similarly, butterflies in the Sierra Nevada mountains are shifting their distribution resulting in decreased species richness at lower elevation sites (Forister *et al.* 2010). These changes in community composition may lead to loss of community integrity due to changes in species interactions. For example, researchers have demonstrated that decreasing snowpack has led to shifts in predator-prey dynamics between snowshoe hares, lynxes, and coyotes (*Canis latrans*), with increased predation pressure from coyotes (Peers *et al.* 2020). Other studies have demonstrated that trophic asynchrony may occur with changes in community composition (Both *et al.* 2009). Alternatively, some studies have suggested that specific species, particularly small mammal granivores, may facilitate the range expansion of certain plants by caching seeds into new areas that are becoming climatically suitable for seedling establishment (Mortelliti *et al.* 2019).

Climatic conditions will continue to alter habitat quality for wildlife species in the Sierra Nevada mountains regardless of management activities. Most studies suggest identifying areas where climate and environmental conditions, such as average high temperatures and snowpack, will change more slowly and focus management and conservation activities in those areas. Other studies recommend increasing connectivity between current and predicted habitat so that species can continue to adjust their distribution as they track shifting habitat.



5. Wetland Integrity

Wetland integrity was considered with respect to mountain meadows and their influence on stream hydrology and aquatic biota. Sierra Nevada subalpine meadows are expected to experience increased conifer encroachment with climate change due to higher summer temperatures and drier soils, leading to a projection of the average meadow becoming forest by the end of the century (Lubetkin *et al.* 2017). Meadows below the 7,500 foot elevation were often maintained by indigenous peoples through burning practices and removal of conifer species, a practice continued by cattle ranchers and sheepherders until widespread fire suppression efforts by the USFS and other agencies (Anderson 2005). Of the 5,894 meadows classified in the Sierra Nevada, and climate change impacts are limited to mean annual temperature and annual precipitation, about 32% of meadows would meet refugia thresholds - located generally at higher elevations (Maher *et al.* 2017). However, meadows with limited subsurface storage in alpine and subalpine regions are most sensitive to snowpack changes (Viers *et al.* 2013).

One of the key species that rely on summer baseflow released from wetlands is the Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), which is at risk from increasing summer temperatures and drought, but 3 populations considered to be persistent with climate change are located in the eastern Sierra Nevada (Figure 5; Haak *et al.* 2010). There are a number of other aquatic and montane meadow species that may be affected by climate change: 1) Trout are expected to have low tolerance for increased temperatures and low to moderate tolerance for decreased stream flow, 2) Minnows (*Cyprinidae sp.*) are expected to be more resilient with moderate to high tolerance for increased temperatures and decreased flow, except for the Sacramento pikeminnow (*Ptychocheilus grandis*) which will have low tolerance for decreased flow, 3) Riffle sculpin (*Cottus gulosus)* are expected to have low tolerance for increased temperatures and moderate tolerance for decreased flow, and 4) Mountain sucker (*Catostomus platyrhynchus)* are expected to have moderate tolerance for both impacts (Viers *et al.* 2013). The Southern long-toed salamander (*Ambystoma macrodactylum*), Yosemite toad (*Anaxyrus canorus)*, and Mountain/Sierra yellow-legged frog (*Rana muscosa)* are highly vulnerable to climate change while the Pacific chorus frog has a broader habitat range and is expected to be less vulnerable (Figure Below; Viers *et al.* 2013). Tolerance for high temperatures is expected to be high for Sierra Nevada Yellow Legged Frog and moderate for Yosemite Toad, while tolerance for decreased flow is expected to be moderate for Sierra Nevada Yellow Legged Frog and high for Yosemite Toad (Viers *et al.* 2013).

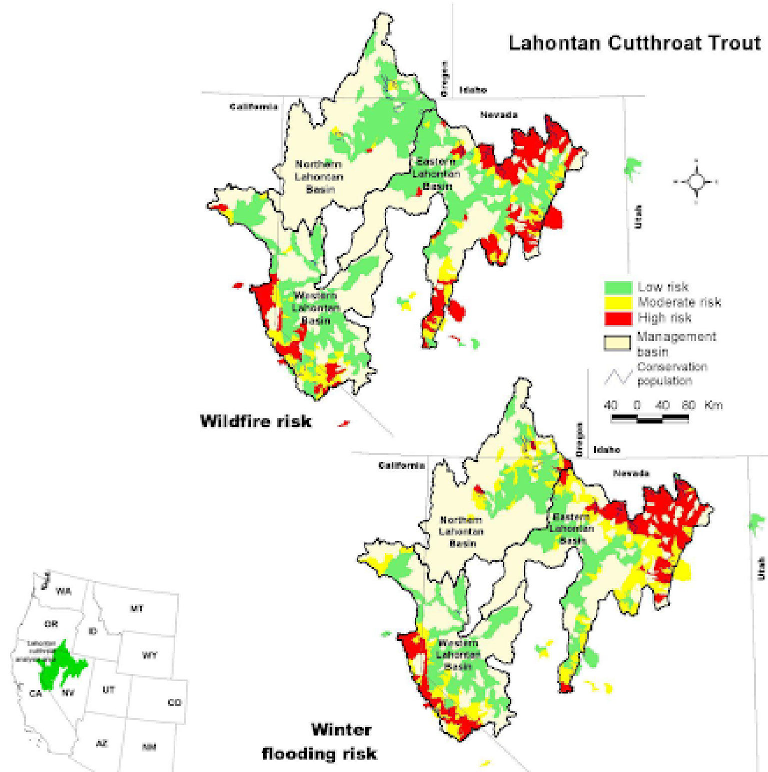


Figure 5. Wildfire and winter flooding are the major risks from climate change to the Lahontan cutthroat trout along the eastern slope of the central Sierra Nevada (from Haak *et al.* 2010).

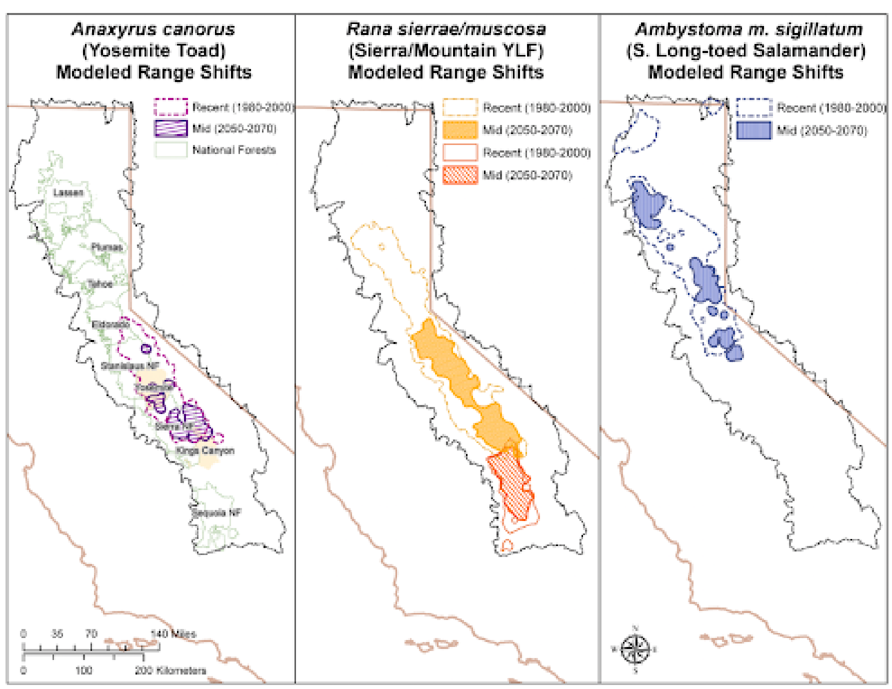


Figure 6. Projected changes in selected amphibian population ranges from recent history (1980-200) to mid-century (2050-2070) for the Yosemite toad, Sierra Nevada and Mountain yellow legged frogs, and the Southern long-toed salamander (from Viers *et al.* 2013).

6. Water Security

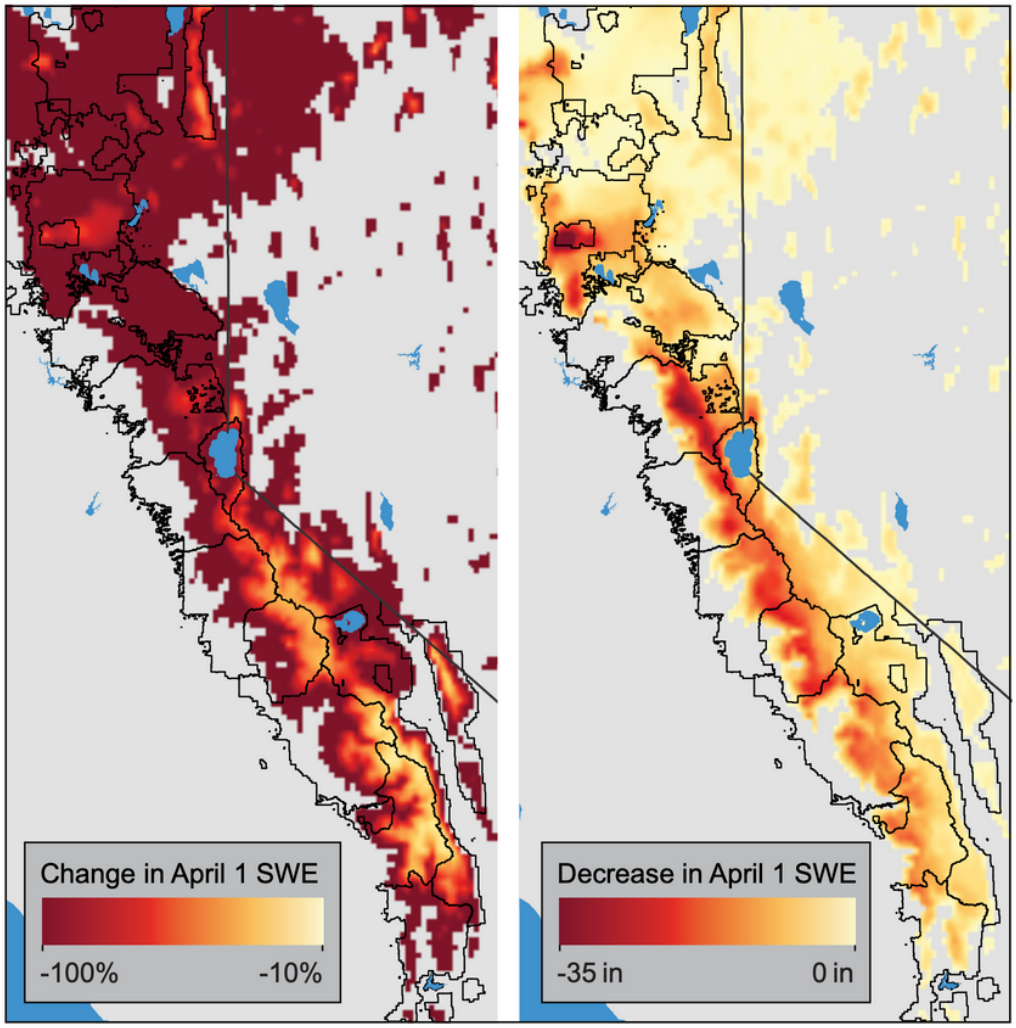
Three elements of water security were both considered and evaluated for vulnerability to climate change: water quality, water quantity, and water storage and timing. All three elements are considered vulnerable to climate change. The most significant impact to water quality is expected to be stream temperature, with 30-60 additional days per year seeing temperatures above 20 degrees Celsius, reducing habitat suitability for cold water dependent species (Luo *et al.* 2013). Increased stream temperatures will occur during spring and summer months and are predicted to lead to a 10% decrease in dissolved oxygen and 50% decrease in sediment (Ficklin *et al.* 2013). In general, stream temperatures have been projected to rise 1.6 degrees Celsius for every air temperature increase of 2 degrees Celsius (Null *et al.* 2013). Ficklin *et al.* (2013) expect the highest temperature impacts to low elevation southern Sierra Nevada streams, while Null *et al.* (2013) expect the highest resilience to stream temperature changes in the high elevation southern Sierra and the Feather River Basin. The Washoe Tribe are concerned about any negative impacts to water quality, including degraded aquatic habitat for fish and mussels (Long 2019).

Water quantity changes in the Sierra Nevada due to climate change are not expected to be driven by precipitation amounts compared to interannual variation - although wet and dry years may become more extreme (Garfin *et al.* 2013). Using evapotranspiration demand from lower elevations with higher temperatures as a proxy for climate change, evapotranspiration could increase as much as 28% by 2100 in the Kings River Basin, decreasing streamflow 26% (Goulden and Bales 2014). Projections have shown that the northern Sierra Nevada is most at risk of reduced annual streamflow down through the Mokelumne River, while the Kern River in the southern Sierra may be most resilient to climate change (Null *et al.* 2010).

Impacts to water storage and timing are expected to largely be driven by changes in snowpack, due to a combination of more precipitation falling as rain, reduced overall snowpack depth, and increased meltout in the spring. Across most of the west, the change in snowpack is expected to result in the central timing of streamflow becoming 1-4 weeks earlier, with the Sierra Nevada having some of the most significant impacts (Stewart *et al.* 2005). More recent research is predicting a shift in earlier streamflow for 2091-2100 by 30 days (moderate climate change scenario, RCP 4.5) to 80 days (elevated climate change scenario, RCP 8.5) (Schwartz *et al.* 2017). Snow residence time may decrease up to 75 days by 2080 with up to 35 inches less snow-water equivalent at the historical April 1 peak (Figure 7; Soderquist and Luce 2021). The western slope of the Sierra Nevada is expected to be most sensitive to climate change, while eastern and southern Sierra Nevada are expected to be less sensitive (Stewart 2013). Of concern to the Washoe Tribe are the effects on already declining snow-dependent wildlife such as the snowshoe hare, pika, and wolverine (Long 2019).

Management options to create refugia for snowpack zones include fuel reduction and thinning to reduce forest vegetation density. In the mediterranean climate of California, winters are relatively warm compared to snowpack in the continental or boreal regions (Lundquist *et al.* 2013). As a result, dense vegetation absorbs energy from sunlight (shortwave radiation) and air temperatures

Figure 7. Projected changes in April 1st snow-water equivalent (SWE) across the Sierra Nevada from historical conditions (1975-2005) to the 2080s (2071-2090) based on temperature increases projected from a 20 global climate model ensemble mean under Representative Concentration Pathway 8.5. (figure and caption from Soderquist and Luce 2021)



above freezing, and re-emit that energy (longwave radiation) to the surrounding snow resulting in accelerated melt (Harpold *et al.* 2020). Having fewer, larger trees with broad canopies for shading can result in a deeper snowpack that melts out at a slower rate, limiting the climate change impacts of warmer temperatures and more frequent rain (Lundquist *et al.* 2013); however, not enough trees may leave the snowpack too exposed to wind and direct sunlight resulting in increased rates of snowmelt (Harpold *et al.* 2020). Reduced vegetation through mechanical thinning also has the potential to increase streamflow in areas of the Sierra Nevada that are not water limited, such as the Yuba and American River watersheds that experienced up to 20 cm/yr in reduced evapotranspiration demand over an initial 5-year period following wildfires (Roche *et al.* 2020).

Wildfires also pose a substantial risk to water security by damaging infrastructure, including water supply systems that serve both urban and rural populations. The Rim Fire caused a shutdown of water supply to the Bay area, and the recent Caldor Fire damaged underground water systems managed by small communities. Destruction of homes and creation of other contaminants can also render water supplies unfit for use. Many tribal communities are vulnerable to impacts, with communities such as Big Sandy Rancheria Band of Western Mono Indians having to upgrade its water supply system to meet the needs of its members. These relationships reveal the strong overlap between wildfire safe communities and water security.

7. Carbon Sequestration

The storage of carbon dioxide in forests is an important social value for reducing the rate of climate change. Researchers often consider the total stocks of carbon (within forests and forest wood products as part of a broader life cycle analysis), as well as the stability of those carbon stocks. Stability of forest carbon over time is largely dependent on the severity of forest fires and associated carbon emissions. The severity of wildfires on a large, landscape scale in turn is primarily dependent on precipitation, temperature, and the extent and type of forest management. Foster *et al.* (2020) found that in Sierra Nevada forests, active treatment regimes including thinning and prescribed burning increased stable live tree carbon stocks over no-treatment, but that, "in most contexts examined, mechanical-only or no-treatment controls will maximize expected total carbon stocks when incorporating wildfire risk and the carbon stability of live biomass, dead biomass, and offsite forest products".

Without proactive forest management, changes in precipitation (*e.g.* snowline elevation, snow cover, total precipitation, timing and type, etc,) alongside seasonal changes in temperature could drive increases in wildfire severity that create losses of up to 73% of total ecosystem carbon, effectively transforming Sierra Nevada forests from a carbon sink to a carbon source (Liang *et al.* 2017). Although predicted, climate induced changes in precipitation and temperature will have a direct effect on the likelihood of high severity fires and thus decrease the stability of forest carbon, proactive forest management can partially compensate for projected losses. Krofcheck *et al.* (2017) found that forest thinning followed by prescribed burning reduced mean fire severity by 25% under an extreme fire weather scenario, helping to reduce the negative impacts of climate change on carbon stability. Although forest management can help to reduce the impact of increasingly severe fires on forest carbon levels, fuels management will only partially negate the effects of climate change by increasing carbon stability over a no management scenario (Goodwin *et al.* 2020).

The Yurok Tribe has acquired private timberlands near their reservation in Northwest California and received carbon credits in exchange for adopting management plans to sequester carbon, illustrating how carbon sequestration can support tribal management of forests (Manning and Reed 2019). In general, tribes have strong interests in maintaining large and fire-resistant trees, which are important for sequestering carbon and supporting other values including wildlife habitat (Spies *et al.* 2019). Furthermore, tribes have strong interests in restoring mountain meadows which they historically managed using fire and other stewardship practices. Mountain meadows serve as carbon reservoirs in addition to water reservoirs, and are less susceptible to losing that carbon in wildfires (Merrill and Jurjavcic 2018). Furthermore, burning to reduce the density of trees within and surrounding mountain meadows might enhance carbon storage by promoting more favorable water conditions, as suggested in a recent study from the Sierra Nevada which found that higher tree cover around meadows was associated with reduced carbon storage (Reed *et al.* 2021).

8. Air Quality

Increasing pressure from climate change is expected to indirectly elevate levels of wildfire smoke due to increased wildfire activity. Although the anticipated benefits to air quality from forest management are reduced smoke emissions and associated visibility improvements, we did not assess the vulnerability of air quality to climate change due to the challenge in explicitly mapping the link between forest management actions and changes to air quality impacts. Previous work has indicated that increased use of intentional fire and other treatments can ameliorate smoke impacts by reducing the occurrence of extreme smoke events that can have substantial public health impacts in the Central Valley and the greater Reno-Carson City area (Long *et al.* 2017), where many tribal communities are located. A recent report by the California Center for Science & Technology (Feo *et al.* 2020) on the costs of wildfire in California found wildfire smoke likely to have one of the most significant public health impacts from wildfires, but no statewide tracking system for these attributes exists. The authors recommended development of a systematic reporting framework to be able to assess public health impacts and costs due to wildfire smoke. Impacts are not consistent across sectors of society, with lower income households being particularly vulnerable because of exacerbating factors such as poor health and reduced access to health care. Health impacts of fire-related smoke to the tribal communities may be exacerbated due to housing, lack of air conditioning and filtration, underlying comorbidities, demographics, and lower income (Goode *et al.* 2018, Long 2019).

9. Economic Diversity

Economic diversity in communities throughout the TCSI and the Sierra Nevada incorporates many interrelated dynamics, including the wood products industry, recreation industries, and general economic vitality. Many easily mappable aspects of economic diversity (*e.g.* wealth) are less impacted by ecosystem management, while attributes that can be impacted by ecosystem management (*e.g.* changes in revenues from recreation due to changing forest management) are more difficult to map. The management-impacted aspect of economic diversity most readily mappable is recreation activity. Recreation is important to the TCSI region, with about three million visitors annually to Lake Tahoe alone (U.S. EPA 2022). In 2012, visitors to the North Lake Tahoe Area alone spent $487 million, with spending increasing steadily from 2003 to 2012 and projected to increase into the future (Dean Runyan Associates 2013).

The impact of climate change on recreation is complicated and difficult to project. In the Sierras, access to common winter recreation like downhill and cross-country skiing and snowmobiling may decrease as higher spring temperatures lead to shorter seasons (Wobus *et al.* 2017). In general the average days of participation in such activities per participant are projected to decrease along the Pacific Coast, though this depends on individual GCM predictions - for example a projected increase in total precipitation may lead to growth in undeveloped skiing opportunities as a whole (Askew and Bowker 2018). Summer activities like hiking may be threatened by increased summer temperatures (Askew and Bowker 2018), while hotter-than-normal temperatures influence visitors' behavior and willingness to stray from infrastructure differently in different ecoregions (Wilkins *et al.* 2021). Though large-scale studies can provide some idea of recreation trends and climate change at the regional or state level, these impacts are mediated by local effects of climate change and the particular recreational opportunities of the region. A locally specific analysis should be conducted for an accurate understanding of direct and indirect climate change impacts within the TCSI and to craft management objectives appropriately aimed at preserving the recreation industry in the region.

10. Social and Cultural Wellbeing

Social and cultural values can and will legitimately take precedent over ecological convenience in many instances. In order to understand where both conservation tracks lead (climate driven and value driven) and how they intersect (Figure 8), we need a clear vision for what those social and cultural values are, whether they are mappable or can otherwise be incorporated into decision support tools, and whether we can apply bioclimatic models of climate change to them to predict how they might respond to future climate change. With this information in hand, land managers could then make decisions on allocating resources toward resilience in a manner that best weds social values with ecological realities. This decision making process is laid out in Figure 9 below. It is important to recognize that social and cultural values can sometimes be mapped (*e.g.* harvesting sites), but other times may not be possible or appropriate to make spatially explicit (*e.g.* spirituality, sense of place). In many instances, attributes such as average income, housing value, unemployment, and average lifespan, are mappable but the ways in which ecosystem management affects those attributes are not mappable.

Including diverse stakeholders with different values is critical but challenging and raises issues of well-being, equity and environmental justice, particularly in relation to issues of empowerment, engagement, access, and benefit sharing (Farley and Costanza 2010, Primmer *et al.* 2015). Including multiple, diverse groups in planning, implementation, and funding is critical for ensuring forests are managed for inclusive and equitable goals. Failure to recognize and engage stakeholders in an equitable manner in decision-making processes can lead to suboptimal, and sometimes unethical outcomes (Chazdon and Guariguata 2018). For example, equity considerations are key when rationalizing public expenditures, as marginalized and vulnerable communities disproportionately experience the negative impacts of wildfire (Davies *et al.* 2018, Mendez *et al.* 2020). It is imperative to develop trust between natural resource managers and the communities affected by resource management decisions (Stern and Coleman 2015).

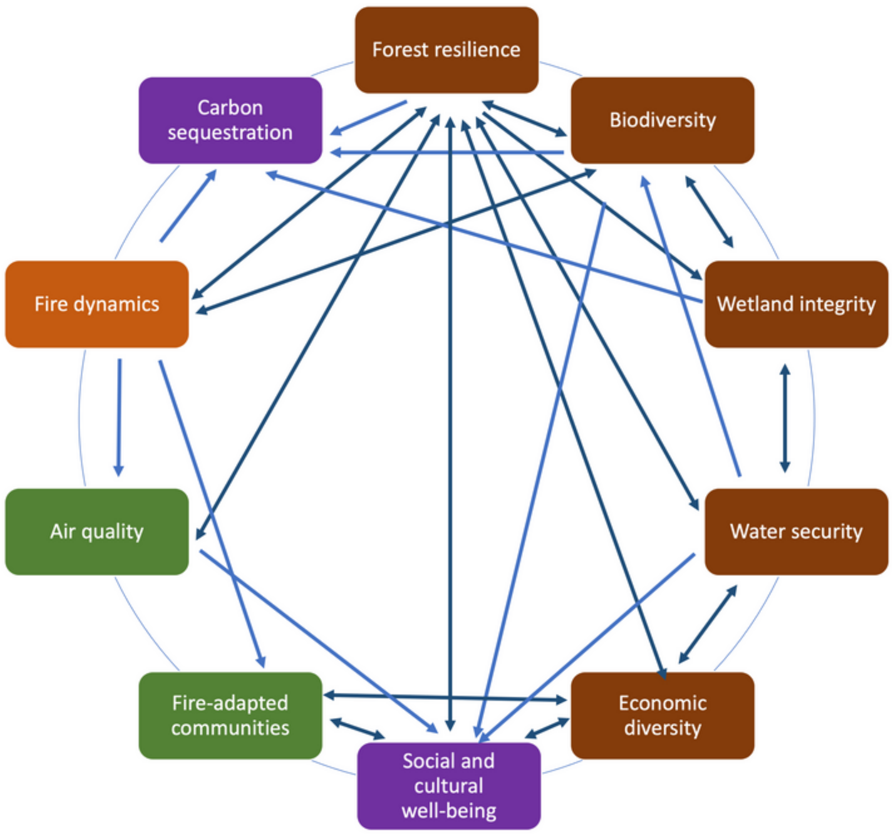


Figure 8. TCSI pillars of value are highly interdependent and outcomes for each pillar affect outcomes for multiple other pillars. Interactions can be one direction (light blue) or bi-directional (dark blue) between pillars. Pillars fall into four functional categories based on their interactions with the other pillars: drivers (brown colored boxes = many connections coming in and going out), influencers (orange boxes = many connections going out, fewer coming in), integrators (purple boxes = many connections coming in, fewer going out), and niches (green boxes = few connections in or out). (Figure and caption from Manley *et al.* 2020)

NEXT STEPS FOR DEVELOPMENT OF ECO-CULTURAL CRITERIA FOR CLIMATE REFUGIA

Effects of climate change are already apparent throughout California, such as increasing fire severity, lengthening fire season, and shifting ranges of many species. These effects are jeopardizing the resources and cultural values important to tribal and stakeholder communities alike. Considering climate refugia in planning processes provides an actionable way to understand and reduce the vulnerabilities of resource and cultural values in the TCSI landscape, and across the Sierra Nevada. Clearly, climate refugia will not be able to provide protection to all important social and cultural values, so it is also vital to understand where important values are climate exposed and will require management investment to protect and conserve them as long as possible.

What we have provided in this report is a template from which to get started. We identify numerous reasonable social and ecological values that are important to significant fractions of stakeholders and evaluate which ones can be mapped and projected into a future climate model. What we have not done, nor could we legitimately do, is to suggest how these multiple criteria are assembled to create a management plan for any particular decisional jurisdiction. Making such decisions must be done by a decision-maker. We argue that decisions will be more durable and socially acceptable if they are done using a transparent and structured decision process that includes multiple representatives of different social and cultural interests. It is a socially engaged process to determine fundamental objectives, their relative value to one another, and agree upon meaningful measures of success. Those whose values are being managed must also participate in determining the place of those objectives in the final decisions in order for decisions to be credible, legitimate and salient (Cash *et al.* 2003)

Considerations for Mapping Climate Refugia

Identifying where culturally important resources exist now and where they might exist in the future is essential to prepare for and respond to uncertainty associated with climate change (Magness *et al.* 2011) (Figure 9). Tribes have, in fact, begun to look at exactly these questions (Tribal Adaptation Menu Team 2019). Climate change refugia are places where environmental change occurs more gradually, allowing specific resources to persist for longer periods of time as climate conditions change (Morelli *et al.* 2020). There are several ways in which refugia may be spatially represented and there may be overlap in the methods used depending on the focal resource. In general, methods to map refugia include using climate projections, topographic, and hydrologic information to estimate where environmental change may occur more slowly. Assessing whether these areas are likely to support sustained ecological function and associated eco-cultural values can be initially determined based on published, expert, traditional and local ecological knowledge (TEK and LEK) information sources. These knowledge sources can then be supported and expanded through additional learning, data collection and monitoring over time (Barrows *et al.* 2020). Participatory mapping and GIS methods have also been used to guide treatments based upon tribal knowledge in light of climate change stressors (Wynecoop *et al.* 2019).

Typically, a focal resource of interest has been used to drive the modeling of climate change refugia (e.g. Maher et al. 2017, Balantic et al. 2021). When working with multiple resource values, mapping refugia becomes more complicated, as each resource value has different climate tolerances (Barrows et al. 2020). One option is to map each resource individually according to their climate tolerances and evaluate where those tolerances exist on future landscapes (e.g. Balantic et al. 2021). A second option is to discern climate tolerances of multiple refugia to identify current refugia for multiple socio-cultural values and project whether those refugia persist or are lost with changing climate conditions (Barrows et al. 2020, Thorne et al. 2020). The former option allows for maps customized to each resource or multiple resources overlaid, while the latter option allows managers to use the same base map and translate it for a variety of resources.

	1. Preliminary Ecological Assessment	2. Climate Vulnerability Assessment	3. Traditional Ecological Knowledge
Process Description	Predict the current distribution of the target resource using available ecological tools. Observation databases (e.g. eBird; Jepson herbarium; GBIF); Landscape mapping (Land cover maps, CWHR vegetation maps); landscape predictor variables (e.g. slope, aspect, elevation, hydrology), or using published models of such. **Goal: Identify locations with high probability of occurrence.**	Predict the future potential distribution of the target resource using available climatic and ecological tools. Distribution model correlations with temperature and precipitation overlain on predicted future climate maps using a variety of IPCC climate scenario predictions through 2100. **Goal: identify locations of high probability of persistence (refugia) and potential new locations.**	Identify the subset of potential refugia that is of high cultural value. Engage with Tribes and stakeholders to rate value of sites based on (a) traditional knowledge of current site productivity and use; (b) accessibility; (c) potential for stewardship. **Goal: Prioritize suite of potential priority refugia locations with additional cultural value.**
Mature Black Oak Forest	*Predicted accuracy: high* Use Black Oak occurrence data to model current distribution (e.g. maximum entropy- MAXENT). Overlay probability of distribution on current CWHR vegetation map to identify potential mismatches. 2. Use LandSat Leaf Area Index to identify locations with mature large trees. 3. Validate with available field plot data, iNaturalist observations and field surveys. **Goal: Identify locations with high probability of occurrence of mature black oak.**	*Predicted model fit: high* Use distribution model (1) correlations with current temperature and precipitation, overlain on predicted future climate maps using a variety of IPCC climate scenarios to predict locations most and least likely to persist through 2100. Augment with any known ecological information on current regeneration success. **Goal: Identify locations of high probability of persistence (refugia) and potential new locations.**	*Predicted capacity: high* Engage with Tribes to rate the value of potential Mature Black Oak refugia sites based on: (a) traditional knowledge of current Black Oak forest site productivity and use; (b) accessibility; (c) potential for stewardship. **Goal: Prioritize suite of potential priority Black Oak refugia locations with cultural value.**
Meadows	*Predicted accuracy: high* Use existing meadow occurrence data maps. Meadow distribution is well known and will likely not require a model. **Goal: Identify locations with high probability of occurrence of meadows.**	*Predicted model fit: high* Use distribution to model correlations with current temperature and precipitation, overlain on predicted future climate maps using a variety of IPCC climate scenarios to predict locations most and least likely to persist through 2100. **Goal: identify meadows of high probability of persistence (refugia).**	*Predicted capacity: high* Engage with Tribes to rate the value of potential meadow refugia sites based on: (a) traditional knowledge of current meadow site productivity and use; (b) accessibility; (c) potential for stewardship. **Goal: Prioritize suite of potential priority meadow refugia locations with cultural value.**
Functional Fire	*Predicted accuracy: high* Use state and federal databases of recent prescribed burns to evaluate where burning efforts have been successfully implemented. Use climate condition requirements for prescribed burning to predict potential burn windows across the landscape. **Goal: Identify locations with high probability of implementing functional fire.**	*Predicted model fit: high* Use climate condition requirements for prescribed burns to project future burn windows from predicted future climate maps using a variety of IPCC climate scenarios where functional fire is most and least likely to be implemented through 2100. **Goal: Identify where functional fire will still be possible to implement (refugia)**	*Predicted capacity: high* Engage with Tribes to rate the value of potential cultural and prescribed fire might be implemented based on: (a) traditional knowledge of landscape composition and conditions; (b) accessibility; (c) cultural values and potential of ongoing eco-cultural stewardship. **Goal: Prioritize suite of refugia locations that have additional cultural value.**

Figure 9. Conceptual process, and three examples, for identifying refugia locations for each value to inform a cultural and social decision-making process where management can enable persistence. Incorporating tribal engagement in each step throughout the process can help to identify priority sites for restoration and conservation, given tribal knowledge of desired attributes and long-term ecological dynamics. Predicted accuracy, model fit, and capacity may be low, moderate, or high depending on available resource information and models.

To generate customized maps of ecocultural resources on the TCSI landscape, we can use available spatial data and projections as indicated in this report, and identify key areas where specific resources may occur now and could potentially occur in the future. Many cultural values that are mappable, and many that are not, are biological in nature. Biological and demographic features, such as species richness, high endemism, high genetic diversity, and stable population growth may be used to assess the quality of current and future climate change refugia (Morelli et al. 2017, Harrison and Noss 2017). Hotspots of endemism have been linked to climate stability over extended periods of time, indicating these areas could serve as localized microrefugia as climate continues to change (Stebbins and Major 1965). Beyond localized areas, regions of high biodiversity could be indicative of high quality macrorefugia (Stralberg *et al.* 2018). Biodiverse communities are often caused by increased terrain complexity, allowing for the emergence of a large number of unique niches (Lawler *et al.* 2015).

Refugia should also contribute to genetically diverse metapopulations (Morelli *et al.* 2017). Allelic richness is indicative of highly connected communities that have persisted for extended periods of time. In comparison, ecological traps are areas where allelic richness is lost and are often characterized by low connectivity and habitat of decreased ecological quality to support persistence of key resources and functions. Understanding the range of abiotic features under which biological patterns and processes will continue to persist, will ultimately help to map where refugia may exist to promote highly diverse communities in the future. In the TCSI region, this may involve mapping current areas of high endemism using species distribution models, calculating and locating areas of high biodiversity and beta diversity, using available phylogenetic data to understand genetic diversity, and using available demographic data to determine where refugia may currently exist and how they may contribute to long-term community stability (Barrows *et al.* 2020).

After generating individual maps customized to specific resources, a next step would be to generate maps of general climate change refugia (with predictive capacity for vegetative status) that can be assessed in terms of their utility for supporting multiple socio-cultural values. Similar to Thorne *et al.* (2020) we can identify current climate tolerances of multiple socio-cultural values and project which areas may maintain the same distribution of climate conditions and which areas deviate from those conditions. Areas that retain the same distribution of climate tolerances in the future may be considered refugia for multiple socio-cultural values. Furthermore, potential refugia could be prioritized based on their degree of connectivity to other refugia and their specific contribution to a variety of ecological values. The potential interacting effects of management on maintaining, enhancing or degrading refugia could also be evaluated. Available data on climate tolerances of specific resources outlined in this report can be used to assess how networks of climate change refugia may continue to support biological, demographic, and phylogenetic patterns and processes necessary to sustain resources. This would enable the evaluation of synergies and conflicts that might exist and thereby better direct management where it will make the greatest contribution to conservation, both within and outside climate change refugia where important socio-cultural values are climate exposed.

Managing the Whole in a Rapidly Changing Environment

It is essential to recognize that there are multiple values that we hold for these montane ecosystems, we vary in how important we think these different values are, and we are not equally able to identify which ones are the most readily conserved through climate refugia. Further, these values are not likely to be equally salvageable through management. We have difficult choices to make, but choices will need to be made. Failure to explicitly recognize our many values and the consequences that management may have, arguably, led us to our current predicament with extreme wildfire. Reluctance to reinstitute fire combined with more passive management of increasingly dense and fuel-laden forests has resulted in forest conditions that foster extreme wildfire. If we were to now manage forests as if reducing wildfire risk were our sole objective, we would be making equally many mistakes that future generations are likely to regret just as we now regret complete fire suppression management decisions made from the 1950s to 1970s.

Regardless of whether one is mapping socio-cultural values to evaluate the degree to which they are protected by climate refugia or one is mapping climate refugia to evaluate the degree to which they protect socio-cultural values, the need to weigh options across multiple values will arise. We have identified many potential metrics for evaluating or defining refugia, and yet they are only a subset of values that Tribes and stakeholders hold for forested ecosystems of the Sierra Nevada. Potential metrics for refugia identification and evaluation vary in terms of both the ability to model projected climate futures as well as their social-ecological importance, and different social groups will hold different values to be differentially important. Explicit recognition of this is important because it is highly likely that the different potential metrics of value and importance of refugia for social, economic, cultural and ecological values will lead to different sets of management priorities that may compete against one another.

The pathway to making such decisions is through collaborative decision-making and multi-criteria decision-making. The tools that we discuss here provide a guide to a suite of attributes that may be suitable for refugia modeling using bioclimatic models of climate change on a resource. We do not provide a recipe for a data model to simply input the data and find the answer. There is a human element that is essential. For example, we know that acorn producing trees are of high cultural value to Tribes. We can model the distribution of oaks and project where oaks may thrive in the future. However, we have a significantly poorer capacity to model which groves of existing trees that are highly valued are also likely more resilient. For that we would require fully embedding a valuation process with the tribal communities who value these resources and are also planning for climate change adaptation (*e.g.* Tribal Adaptation Menu Team 2019). Similarly, we might differentially value the suite of young stands that could become the productive stands of the future based on accessibility (land ownership, proximity to roads). Again, specific collaboration with the groups that value the resources would be critical in making this the most meaningful model possible.

Multi-Criterion Decision Support

There are numerous decision-making frameworks that can assist in cross-evaluating the importance of multiple competing values in making environmental decisions (*e.g.* Reynolds and Hessburg 2005, Schwartz *et al.* 2018, Marques *et al.* 2021). Here we explore a few well-developed approaches to considering multiple values and identifying options for maximizing desired outcomes, including prioritizing among high value resources where necessary.

Structured Decision Making

One approach to reconciling multiple, potentially competing values that is particularly well-suited to the sorts of decisions we are describing in this report is Structured Decision-Making (Gregory *et al.* 2012). Structured-decision making is based on the fundamentals of decision science (Hammond *et al.* 2015). The core principle of this field of work is captured by the acronym PrOACT. To make decisions, one must define the Problem (Pr), define specific Objectives (O), consider Alternative (A) actions, model the consequences (C) of taking different action alternatives by looking at the Trade-offs (T) among them. Applied to our thinking about forest values, for example, we might consider how to deploy limited resources for forest thinning to reduce the probability of severe wildfire and create climate resilience across multiple values. We could choose to prioritize the protection of upper elevation wetlands (objective #1) and hydrological recharge (objective #2), but recognize that this comes at the expense of protecting mid-elevation hardwood forests (objective #3) from extreme fire through fuels management at lower elevations. We could, alternatively, propose a mixed management strategy that allocates varying effort toward protecting sites of high value for our different resource objectives (*e.g.* wetlands, hydrological recharge, mixed elevation wetlands). We might also find that such management may come at the expense of a lower ranking objective, let's say in the form of spotted owl habitat (making biodiversity objective #4 in this scenario). We may want to, then, determine if there are sites that could be exchanged to fulfill objectives #1 and #2 that would incur less cost to our 4th objective. The key point here is that clearly identifying objectives and valuing them one to another is critical in finding robust decisions for allocating management resources. Further, the relative importance of objectives is likely to vary among social groups. Thus, placing value on objectives through a socially engaged process is essential. A top-down approach where a regional government, or federal agency declares some, or any, set of objectives as taking precedence over others is likely to not be considered legitimate and credible by a significant subset of stakeholders. There are more, or less, quantitative means to evaluate solution sets once a set of values has been agreed upon. We describe these below.

Multi-criteria Decision Analysis

The Ecosystem Management Decision Support (EMDS) Tool developed by the US Forest Service uses fuzzy logic, multi-criteria decision analysis (MCDA), and a host of other analysis tools (*e.g.*, Bayesian analysis) to provide a suite of decision support options for decision makers (Reynolds *et al.* 2014) Here we focus on the MDCA analysis capacity offered by EMDS. Belton and Stewart (2002) define multi-criteria decision analysis (MCDA) as, “an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter”. Belton and Stewart (2002) classify MCDA methods into three broad categories:

1. Value measurement models: “numerical scores are constructed in order to represent the degree to which one decision option may be preferred to another. Such scores are developed initially for each individual criterion, and are then synthesized in order to effect aggregation into higher level preference models”;
2. Goal, aspiration or reference level models: “desirable or satisfactory levels of achievement are established for each criterion. The process then seeks to discover options which are closest to achieving these desirable goals or aspirations”;
3. Outranking models: “alternative courses of action are compared pairwise, initially in terms of each criterion in order to identify the extent to which a preference for one over the other can be asserted. In aggregating such preference information across all relevant criteria, the model seeks to establish the strength of evidence favouring selection of one alternative over another”.

Optimization Modeling

Finally, we wanted to touch on optimization modeling, which can be used in combination with logic models and/or MCDA or as a stand-alone approach to exploring options for achieving multiple objectives. The ForSys model was developed by the US Forest Service to support scenario planning and evaluating tradeoffs (*e.g.* Day *et al.* 2021). It can be used to generate and analyze spatial prioritization of many types of management activities as applied to various locations across landscapes, such as climate refugia. Scenarios are built by specifying one or more objectives (*e.g.* revenue), activity constraints (*e.g.* budget, area treated), and stand treatment thresholds (*e.g.* fire behavior). The outputs identify prioritized sequences of planning areas and stands to treat within them, and tradeoffs among different management objectives. ForSys solves the prioritization problem using simple optimization methods with or without adjacency constraints depending on the application. There are additional modeling tool options within this family of modeling approaches, such as mixed-integer programming, or MIP (*e.g.* Pascual 2021).

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Literature Cited

Adams, Mark D. O., & Charnley, S. (2020). The environmental justice implications of managing hazardous fuels on federal forest lands. Annals of the American Association of Geographers. 110(6): 1907-1935. https://doi.org/10.1080/24694452.2020.1727307

Alexander, J. M., Frankel, S. J., Hapner, N., Phillips, J. L., & Dupuis, V. (2017). Working across cultures to protect Native American natural and cultural resources from invasive species in California. Journal of Forestry, 115(5), 473–479. https://doi.org/10.5849/jof.16-018

Allen, M. F. (2015). How oaks respond to water limitation. Gen. Tech. Rep. PSW-GTR-251. Berkeley, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station: 13-22 251: 13-22.

Anderson, M.K. (2005). Tending the wild: Native American knowledge and the management of California's natural resources. University of California Press, Berkeley, CA. 526 p.

Anderson, M. K. (2007). Indigenous uses management, and restoration of oaks of the far western United States. Technical Note No. 2, NRCS National Plant Data Center.

Askew, A. E., & Bowker, J. M. (2018). Impacts of climate change on outdoor recreation participation: Outlook to 2060. Journal of Park and Recreation Administration, 36(2). https://doi.org/10.18666/JPRA-2018-V36-I2-8316

Ault, T. R., Cole, J. E., Overpeck, J. T., Pederson, G. T., & Meko, D. M. (2014). Assessing the risk of persistent drought using climate model simulations and paleoclimate data. Journal of Climate, 27(20), 7529–7549. https://doi.org/10.1175/JCLI-D-12-00282.1

Baeza, A., Martin, R. E., Stephenson, N. L., Das, A. J., Hardwick, P., Nydick, K., Mallory, J., Slaton, M., Evans, K., & Asner, G. P. (2021). Mapping the vulnerability of giant sequoias after extreme drought in California using remote sensing. Ecological Applications, 31(7), e02395. https://doi.org/10.1002/eap.2395

Balantic, C., Adams, A., Gross, S., Mazur, R., Sawyer, S., Tucker, J., Vernon, M., Mengelt, C., Morales, J., Thorne, J. H., Brown, T. M., Athearn, N., & Morelli, T. L. (2021). Toward climate change refugia conservation at an ecoregion scale. Conservation Science and Practice, 3(9), e497. https://doi.org/10.1111/csp2.497

Barrett, S., & Gifford, E. (1933). Miwok material culture. Bulletin of the Public Museum of the City of Milwaukee 2(4): 117-376.

Barrows, C. W., Ramirez, A. R., Sweet, L. C., Morelli, T. L., Millar, C. I., Frakes, N., Rodgers, J., & Mahalovich, M. F. (2020). Validating climate-change refugia: Empirical bottom-up approaches to support management actions. Frontiers in Ecology and the Environment, 18(5), 298–306. https://doi.org/10.1002/fee.2205

Baumhoff, M. A. (1963). Ecological determinants of aboriginal California populations. University of California Publications in American Archaeology and Ethnology. University of California Press, Berkeley CA, 155-236.

Belton, V. & Stewart, T. J. (2002). Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers, Boston, MA. 372p. https://doi.org/10.1007/978-1-4615-1495-4

Both, C., Asch, M. V., Bijlsma, R. G., Burg, A. B. V. D., & Visser, M. E. (2009). Climate change and unequal phenological changes across four trophic levels: Constraints or adaptations? Journal of Animal Ecology, 78(1), 73–83. https://doi.org/10.1111/j.1365-2656.2008.01458.x

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., Lyver, P. O., Meurisse, N., Oxbrough, A., Taki, H., Thompson, I. D., van der Plas, F., & Jactel, H. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodiversity and Conservation, 26(13), 3005–3035. https://doi.org/10.1007/s10531-017-1453-2

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D. H., Jager, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. PNAS 100(14). https://doi.org/10.1073/pnas.1231332100

California Forest Management Task Force. (2021). California's Wildfire and Forest Resilience Action Plan. Sacramento, CA. 82p. Available from: https://www.fire.ca.gov/media/ps4p2vck/californiawildfireandforestresilienceactionplan.pdf

Charnley, Susan; Fischer, A. Paige; Jones, Eric T. (2008). Traditional and local ecological knowledge about forest biodiversity in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-751. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 52 p.

Chazdon, R.L., Guariguata, M.R., 2018. Decision support tools for forest landscape restoration: Current status and future outlook. CIFOR.

Davey, C. M., Devictor, V., Jonzén, N., Lindström, Å., & Smith, H. G. (2013). Impact of climate change on communities: Revealing species' contribution. Journal of Animal Ecology, 82(3), 551–561. https://doi.org/10.1111/1365-2656.12035

Davies, I.P., Haugo, R.D., Robertson, J.C., Levin. P.S. (2018). The unequal vulnerability of communities of color to wildfire. PLOS ONE 13(11). https://doi.org/10.1371/journal.pone.0205825

Day, M.A., Houtman, R.M., Belavenutti, P., Ringo, C., Ager, A.A., Bassett, S., 2021. An assessment of forest and woodland restoration priorities to address wildfire risk in New Mexico. Gen Tech Rep RMRS-GTR-423 Fort Collins, CO. US Department of Agriculture Forest Service. https://doi.org/10.2737/RMRS-GTR-423

Dean Runyan Associates. (2013). The Economic Significance of Travel to the North Lake Tahoe Area: 2012-2013 Detailed Visitor Impact Estimates. https://www.gotahoenorth.com/wp-content/uploads/2015/09/2003_2012DetailedVisitorImpactEstimates.pdf

DelGiudice, G. D., Fieberg, J. R., Sampson, B. A. (2013). A long-term assessment of the variability in winter use of dense conifer cover by female white-tailed deer. PLoS One, 8(6). https://doi.org/10.1371/journal.pone.0065368

Deur, D, Turner, N.J. (2005). Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America. UBC Press, Vancouver, BC. 404 p.

Dockry, M. J., & Hoagland, S. J. (2017). A special issue of the Journal of Forestry—Tribal Forest Management: Innovations for sustainable forest management. Journal of Forestry, 115(5), 339–340. https://doi.org/10.5849/JOF-2017-040

Dunbar-Irwin, M., Safford, H. 2016. Climatic and structural comparison of yellow pine and mixed-conifer forests in northern Baja California (Mexico) and the eastern Sierra Nevada (California, USA). Forest Ecology & Management 363, 252-266. https://doi.org/10.1016/j.foreco.2015.12.039

Farley, J., Costanza, R., 2010. Payments for ecosystem services: From local to global. Ecological Economics 69, 2060–2068. https://doi.org/10.1016/j.ecolecon.2010.06.010

Feo, T. J., Mace, A. J., Brady, S. E., & Lindsey, B. L. (2020). The costs of wildfire in California: An independent review of scientific and technical information. California Council on Science and Technology, Sacramento, CA. 223 p.

Fettig, C. J., Mortenson, L. A., Bulaon, B. M., & Foulk, P. B. (2019). Tree mortality following drought in the central and southern Sierra Nevada, California. Forest Ecology and Management, 432, 164–178. https://doi.org/10.1016/j.foreco.2018.09.006

Ficklin, D. L., Stewart, I. T., & Maurer, E. P. (2013). Effects of climate change on stream temperature, dissolved oxygen, and sediment concentration in the Sierra Nevada in California. Water Resources Research, 49(5), 2765–2782. https://doi.org/10.1002/wrcr.20248

Flannigan, M. D., Stocks, B. J., & Wotton, B. M. (2000). Climate change and forest fires. Science of The Total Environment, 262(3), 221–229. https://doi.org/10.1016/S0048-9697(00)00524-6

Forister, M. L., McCall, A. C., Sanders, N. J., Fordyce, J. A., Thorne, J. H., O'Brien, J., Waetjen, D. P., Shapiro, A. M., & Berenbaum, M. R. (2010). Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. PNAS 107(5), 2088–2092. https://doi.org/10.1073/pnas.0909686107

Foster, D.E., Battles, J.J., Collins, B.M., York, R.A., Stephens, S.L., 2020. Potential wildfire and carbon stability in frequent-fire forests in the Sierra Nevada: trade-offs from a long-term study. Ecosphere 11. https://doi.org/10.1002/ecs2.3198

Franco Jr., F. J. (1994). Native American views and values of giant sequoia. In: Aune, P. S. (1994). Proceedings of the symposium on giant sequoias: their place in the ecosystem and society: June 23-25, 1992; Visalia, CA. General Technical Report PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 170 p.

Franklin, J.F., Cromack Jr., K., Denison, W., McKee, A., Maser, C., Sedell, J., Swanson, F., Juday, G. (1981). Ecological characteristics of old-growth Douglas-fire forests. General Technical Report PNW-118. 48 pp. Pacific Northwest Forest and Range Experimental Station, Portland, OR.

Franklin, J. F., & Van Pelt, R. (2004). Spatial aspects of structural complexity in old-growth forests. Journal of Forestry, 102(3), 22–28. https://doi.org/10.1093/jof/102.3.22

Fried, J. S., Torn, M. S., & Mills, E. (2004). The impact of climate change on wildfire severity: A regional forecast for northern California. Climatic Change, 64(1), 169–191. https://doi.org/10.1023/B:CLIM.0000024667.89579.ed

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. (2013). Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Gleeson, M., Pearlstein, E., Marshall, B., Riedler, R., 2012. California Featherwork: Considerations for Examination and Preservation. Mus. Anthropol. 35, 101–114. https://doi.org/10.1111/j.1548-1379.2012.01126.x

Goode, R., Gaughen, S., Fierro, M., Hankins, D., Johnson-Reyes, K., Middleton, B.R., Red Owl, T., Yonemura, R., Agustinez, A., Charley, D., Connolly, M., Fuller, R., Guerrero, M., Houck, D., Roy, R., 2018. California Fourth Climate Change Assessment: Summary Report from Tribal and Indigenous Communities within California, Editors S. Lucero and J. Ganion. State of California.

Goodwin, M. J., North, M. P., Zald, H. S. J., & Hurteau, M. D. (2020). Changing climate reallocates the carbon debt of frequent-fire forests. Global Change Biology, 26(11), 6180–6189. https://doi.org/10.1111/gcb.15318

Goulden, M. L., & Bales, R. C. (2014). Mountain runoff vulnerability to increased evapotranspiration with vegetation expansion. Proceedings of the National Academy of Sciences, 111(39), 14071–14075. https://doi.org/10.1073/pnas.1319316111

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T., Ohlson, D., 2012. Structured Decision Making: A Practical Guide to Environmental Management Choices. John Wiley & Sons.

Hammond, J.S., Keeney, R.L., Raiffa, H., 2015. Smart Choices: A Practical Guide to Making Better Decisions. Harvard Business Review Press.

Haak, A.L., Williams, J.E., Isaak, D., Todd, A., Muhlfeld, C., Kershner, J.L., Gresswell, R., Hostetler, S., & Neville, H.M. (2010). The potential influence of changing climate on the persistence of salmonids of the inland west: U.S. Geological Survey Open-File Report 2010–1236, 74 p.

Harpold, A. A., Krogh, S. A., Kohler, M., Eckberg, D., Greenberg, J., Sterle, G., & Broxton, P. D. (2020). Increasing the efficacy of forest thinning for snow using high-resolution modeling: A proof of concept in the Lake Tahoe Basin, California, USA. Ecohydrology, 13(4), e2203. https://doi.org/10.1002/eco.2203

Harrison, S., & Noss, R. (2017). Endemism hotspots are linked to stable climatic refugia. Annals of Botany, 119(2), 207–214. https://doi.org/10.1093/aob/mcw248

Jones, G. M., Gutierrez, R. J., Tempel, D. J., Zuckerberg, B., Peery, M. Z. (2016). Using dynamic occupancy models to inform climate change adaptation strategies for California spotted owls. Journal of Applied Ecology, 53(3), 895-905. https://doi.org/10.1111/1365-2664.12600

Kelly, I.T., 1991. Interviews with Tom Smith and Maria Copa: Isabel Kelly's Ethnographic Notes on the Coast Miwok Indians of Marin and Southern Sonoma Counties, California;Edited by M. ET Collier and S. B. Thalman. No 6

Kimmerer, R.W., 2000. Native Knowledge for Native Ecosystems. J. For. 98, 4–9. https://doi.org/10.1093/jof/98.8.4

Kimmerer, R.W., & Lake, F.K. (2001). The role of indigenous burning in land management. Journal of Forestry. 99(11), 36–41.

Kimmins, J.P., 2003. Old-growth forest: An ancient and stable sylvan equilibrium, or a relatively transitory ecosystem condition that offers people a visual and emotional feast? Answer it depends. For. Chron. 79, 429–440. https://doi.org/10.5558/tfc79429-3

Kolb, T. E., Agee, J. K., Fulé, P. Z., McDowell, N. G., Pearson, K., Sala, A., & Waring, R. H. (2007). Perpetuating old ponderosa pine. Forest Ecology and Management, 249(3), 141–157. https://doi.org/10.1016/j.foreco.2007.06.002

Kolden, C. A. (2019). We're Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk. Fire 2(2). https://doi.org/10.3390/fire2020030

Krofcheck, D. J., Hurteau, M. D., Scheller, R. M., & Loudermilk, E. L. (2017). Restoring surface fire stabilizes forest carbon under extreme fire weather in the Sierra Nevada. Ecosphere, 8(1), e01663. https://doi.org/10.1002/ecs2.1663

Kueppers, L. M., Snyder, M. A., Sloan, L. C., Zavaleta, E. S., & Fulfrost, B. (2005). Modeled regional climate change and California endemic oak ranges. Proceedings of the National Academy of Sciences, 102(45), 16281–16286. https://doi.org/10.1073/pnas.0501427102

Lawler, J. J., Ackerly, D. D., Albano, C. M., Anderson, M. G., Dobrowski, S. Z., Gill, J. L., Heller, N. E., Pressey, R. L., Sanderson, E. W., & Weiss, S. B. (2015). The theory behind, and the challenges of, conserving nature's stage in a time of rapid change. Conservation Biology: The Journal of the Society for Conservation Biology, 29(3), 618–629. https://doi.org/10.1111/cobi.12505

Lenihan, J. M., Bachelet, D., Neilson, R. P., & Drapek, R. (2008). Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. Climatic Change, 87(1), 215–230. https://doi.org/10.1007/s10584-007-9362-0

Liang, S., Hurteau, M. D., & Westerling, A. L. (2017). Potential decline in carbon carrying capacity under projected climate-wildfire interactions in the Sierra Nevada. Scientific Reports, 7(1), 2420. https://doi.org/10.1038/s41598-017-02686-0

Libby, W.J., 2017. Why are coast redwood and giant sequoia not where they are not? Gen Tech Rep PSW-GTR-258 Albany CA US Dep. Agric. For. Serv. Pac. Southwest Res. Stn. 423-427 258, 423–427.

Littell, J. S., Peterson, D. L., Riley, K. L., Liu, Y., & Luce, C. H. (2016). A review of the relationships between drought and forest fire in the United States. Global Change Biology, 22(7), 2353–2369. https://doi.org/10.1111/gcb.13275

Long, J. W., Lake, F. K., & Goode, R. W. (2021). The importance of Indigenous cultural burning in forested regions of the Pacific West, USA. Forest Ecology and Management, 500, 119597. https://doi.org/10.1016/j.foreco.2021.119597

Long, J., 2020. Integrated Vulnerability Assessment of Climate Change in the Lake Tahoe Basin Technical Memos: Washoe Cultural Resources Vulnerability Assessment.

Long, J.W., Lake, F.K., Goode, R.W., Burnette, B.M., 2020. How Traditional Tribal Perspectives Influence Ecosystem Restoration. Ecopsychology 12, 71–82. https://doi.org/10.1089/eco.2019.0055

Long, J. (2019). Washoe cultural resources vulnerability assessment. In: Integrated vulnerability assessment of climate change in the Lake Tahoe Basin: Technical memos. 2020. South Lake Tahoe, CA: California Tahoe Conservancy and Catalyst Environmental Solutions.

Long, J. W., Gray, A., & Lake, F. K. (2018). Recent Trends in Large Hardwoods in the Pacific Northwest, USA. Forests, 9(10), 651. https://doi.org/10.3390/f9100651

Long, J.W. & Lake, F. (2018). Escaping social-ecological traps through tribal stewardship on national forest lands in the Pacific Northwest, United States of America. Ecology and Society 23 (2). https://doi.org/10.5751/ES-10041-230210

Long, J. W., Goode, R. W., Gutteriez, R. J., Lackey, J. J., & Anderson, M. K. (2017). Managing California black oak for tribal ecocultural restoration. Journal of Forestry, 115(5), 426–434. https://doi.org/10.5849/jof.16-033

Long, J. W., Anderson, M. K.. Quinn-Davidson, L., Goode, R. W., Lake, F. K., & Skinner, C. (2016). Restoring California Black Oak Ecosysems to Promote Tribal Values and Wildlife. PSW-GTR-252; U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. https://doi.org/10.2737/PSW-GTR-252

Long, J. W., Quinn-Davidson, L., & Skinner, C. N. (2014). Science synthesis to support socioecological resilience in the Sierra Nevada and southern Cascade Range. PSW-GTR-247; U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. https://doi.org/10.2737/PSW-GTR-247

Lubetkin, K. C., Westerling, A. L., & Kueppers, L. M. (2017). Climate and landscape drive the pace and pattern of conifer encroachment into subalpine meadows. Ecological Applications, 27(6), 1876–1887. https://doi.org/10.1002/eap.1574

Lundquist, J. D., Dickerson-Lange, S. E., Lutz, J. A., & Cristea, N. C. (2013). Lower forest density enhances snow retention in regions with warmer winters: A global framework developed from plot-scale observations and modeling. Water Resources Research, 49(10), 6356–6370. https://doi.org/10.1002/wrcr.20504

Luo, Y., Ficklin, D. L., Liu, X., & Zhang, M. (2013). Assessment of climate change impacts on hydrology and water quality with a watershed modeling approach. Science of The Total Environment, 450–451, 72–82. https://doi.org/10.1016/j.scitotenv.2013.02.004

Lurgi, M., López, B. C., & Montoya, J. M. (2012). Climate change impacts on body size and food web structure on mountain ecosystems. Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1605), 3050–3057. https://doi.org/10.1098/rstb.2012.0239

Lynn, K., Daigle, J., Hoffman, J., Lake, F., Michelle, N., Ranco, D., Viles, C., Voggesser, G., Williams, P., Maldonado, J. K., Colombi, B., & Pandya, R. (2014). The impacts of climate change on tribal traditional foods. Climatic Change. https://doi.org/10.1007/s10584-013-0736-1

MacKenzie, J., 2010. Ensemble forecast of climate suitability for California black oak (Quercus kelloggii) in the southern Sierra Nevada and Tehachapi Mountains (California, USA) based upon multiple (n=11) downscaled 2045-2065 A2 GCM projections]. URL https://drecp.databasin.org/datasets/76ddc6386ec74790ba21ec8293f521d0/

Magness, D. R., Morton, J. M., Huettmann, F., Chapin III, F. S., & McGuire, A. D. (2011). A climate-change adaptation framework to reduce continental-scale vulnerability across conservation reserves. Ecosphere, 2(10), art112. https://doi.org/10.1890/ES11-00200.1

Maher, S. P., Morelli, T. L., Hershey, M., Flint, A. L., Flint, L. E., Moritz, C., & Beissinger, S. R. (2017). Erosion of refugia in the Sierra Nevada meadows network with climate change. Ecosphere, 8(4), e01673. https://doi.org/10.1002/ecs2.1673

Manley, P.N, N. Povak, K. Wilson. (2020). Framework for promoting socio-ecological resilience across forested landscapes in the Sierra Nevada. Final report to the Sierra Nevada Conservancy, Auburn, CA. 30 pp.

Manning, B. R. M., & Reed, K. (2019). Returning the Yurok Forest to the Yurok Tribe: California's First Tribal Carbon Credit Project. Stanford Environmental Law Journal 39, 71-124.

Marks-Block, T., & Tripp, W. (2021). Facilitating prescribed fire in northern California through Indigenous governance and interagency partnerships. Fire, 4(3), 37. https://doi.org/10.3390/fire4030037

Marques, M., Reynolds, K.M., Marto, M., Lakicevic, M., Caldas, C., Murphy, P.J., Borges, J.G., 2021. Multicriteria Decision Analysis and Group Decision-Making to Select Stand-Level Forest Management Models and Support Landscape-Level Collaborative Planning. Forests 12, 399. https://doi.org/10.3390/f12040399

Mendez, M., Flores-Haro, G., & Zucker, L. (2020). The (in)visible victims of disaster: Understanding the vulnerability of undocumented Latino/a and indigenous immigrants. Geoforum 116, p50-62. https://doi.org/10.1016/j.geogorum.2020.07.007

Merrill, A., & Jurjavcic, N.,, 2018. Mountain Meadows: Emerald Oases of the Sierra Nevada. Fremontia 46, 42–47.

McIntyre, P. J., Thorne, J. H., Dolanc, C. R., Flint, A. L., Flint, L. E., Kelly, M., & Ackerly, D. D. (2015). Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. Proceedings of the National Academy of Sciences, 112(5), 1458–1463. https://doi.org/10.1073/pnas.1410186112

McLaughlin, B. C., & Zavaleta, E. S. (2012). Predicting species responses to climate change: Demography and climate microrefugia in California valley oak (Quercus lobata). Global Change Biology, 18(7), 2301–2312. https://doi.org/10.1111/j.1365-2486.2011.02630.x

McWethy, D. B., Schoennagel, T., Higuera, P. E., Krawchuk, M., Harvey, B. J., Metcalf, E. C., Schultz, C., Miller, C., Metcalf, A. L., Buma, B., Virapongse, A., Kulig, J. C., Stedman, R. C., Ratajczak, Z., Nelson, C. R., & Kolden, C. (2019). Rethinking resilience to wildfire. Nature Sustainability, 2(9), 797–804. https://doi.org/10.1038/s41893-019-0353-8

Miller, J. D., Safford, H. D., Crimmins, M., & Thode, A. E. (2009). Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems, 12(1), 16–32. https://doi.org/10.1007/s10021-008-9201-9

Minott, J. A., & Kolb, T. E. (2020). Regeneration patterns reveal contraction of ponderosa forests and little upward migration of pinyon-juniper woodlands. Forest Ecology and Management, 458, 117640. https://doi.org/10.1016/j.foreco.2019.117640

Monsen, Stephen B.; Stevens, Richard, comps. (1999). Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15-18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 411 p.

Moore, K.D., 2007. In the Shadow of the Cedars: the Spiritual Values of Old-Growth Forests. Conserv. Biol. 21, 1120–1123.

Morelli, T. L., Barrows, C. W., Ramirez, A. R., Cartwright, J. M., Ackerly, D. D., Eaves, T. D., Ebersole, J. L., Krawchuk, M. A., Letcher, B. H., Mahalovich, M. F., Meigs, G. W., Michalak, J. L., Millar, C. I., Quiñones, R. M., Stralberg, D., & Thorne, J. H. (2020). Climate-change refugia: Biodiversity in the slow lane. Frontiers in Ecology and the Environment, 18(5), 228–234. https://doi.org/10.1002/fee.2189

Morelli, T.L., & Millar, C. (2018). Climate Change Refugia. USDA Forest Service Climate Change Resource Center. https://www.fs.usda.gov/ccrc/topics/climate-change-refugia

Morelli, T. L., Maher, S. P., Lim, M. C. W., Kastely, C., Eastman, L. M., Flint, L. E., Flint, A. L., Beissinger, S. R., & Moritz, C. (2017). Climate change refugia and habitat connectivity promote species persistence. Climate Change Responses, 4(1), 8. https://doi.org/10.1186/s40665-017-0036-5

Morelli, T. L., Daly, C., Dobrowski, S. Z., Dulen, D. M., Ebersole, J. L., Jackson, S. T., Lundquist, J. D., Millar, C. I., Maher, S. P., Monahan, W. B., Nydick, K. R., Redmond, K. T., Sawyer, S. C., Stock, S., & Beissinger, S. R. (2016). Managing climate change refugia for climate adaptation. PLOS ONE, 11(8), e0159909. https://doi.org/10.1371/journal.pone.0159909

Morishima, G. S., & Mason, L. (2017). Our nation's forests need America's first stewards. Journal of Forestry, 115(5), 354–361. https://doi.org/10.5849/jof.16-073

Moritz, C., Patton, J. L., Conroy, C. J., Parra, J. L., White, G. C., & Beissinger, S. R. (2008). Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science, 322(5899), 261–264. https://doi.org/10.1126/science.1163428

Mortelliti, A., Grentzmann, I. P., Fraver, S., Brehm, A. M., Calkins, S., & Fisichelli, N. (2019). Small mammal controls on the climate-driven range shift of woody plant species. Oikos, 128(12), 1726–1738. https://doi.org/10.1111/oik.06643

Noonan-Wright, E., Hood, S. M., & Cluck, D. R. (2010). Does raking basal duff affect tree growth rates or mortality? Western Journal of Applied Forestry. 25(4): 199-202., 25(4), 199–202.

Null, S. E., Viers, J. H., Deas, M. L., Tanaka, S. K., & Mount, J. F. (2013). Stream temperature sensitivity to climate warming in California's Sierra Nevada: Impacts to coldwater habitat. Climatic Change, 116(1), 149–170. https://doi.org/10.1007/s10584-012-0459-8

Null, S. E., Viers, J. H., & Mount, J. F. (2010). Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada. PLOS ONE, 5(4), e9932. https://doi.org/10.1371/journal.pone.0009932

Parks, S. A., Miller, C., Abatzoglou, J. T., Holsinger, L. M., Parisien, M.-A., & Dobrowski, S. Z. (2016). How will climate change affect wildland fire severity in the western US? Environmental Research Letters, 11(3), 035002. https://doi.org/10.1088/1748-9326/11/3/035002

Parsons, D. J. (1994). Objects or ecosystems? Giant sequoia management in National Parks. In: Aune, P. S., Tech. Coord. 1994 Proceedings of the symposium on giant sequoias: Their place in the ecosystem and society. (1992). Visalia, CA: U.S. Department of Agriculture, Forest Service, PSW-151: 109-115.

Paveglio, T. B., Edgeley, C. M., & Manzello, S. L. (2020). Fire adapted community. Encyclopedia of wildfires and wildland-urban interface (WUI) fires.

Paveglio, T. B., Carroll, M. S., Stasiewicz, A. M., & Edgeley, C. M. (2019). Social fragmentation and wildfire management: Exploring the scale of adaptive action. International journal of disaster risk reduction, 33, 131-141.

Paveglio, T. B., Carroll, M. S., Jakes, P. J., & Prato, T. (2012). Exploring the social characteristics of adaptive capacity for wildfire: Insights from Flathead County, Montana. Human Ecology Review, 19(2), 110–124.

Pawlikowski, N. C., Coppoletta, M., Knapp, E., & Taylor, A. H. (2019). Spatial dynamics of tree group and gap structure in an old-growth ponderosa pine-California black oak forest burned by repeated wildfires. Forest Ecology and Management, 434, 289–302. https://doi.org/10.1016/j.foreco.2018.12.016

Peers, M. J. L., Majchrzak, Y. N., Menzies, A. K., Studd, E. K., Bastille-Rousseau, G., Boonstra, R., Humphries, M., Jung, T. S., Kenney, A. J., Krebs, C. J., Murray, D. L., & Boutin, S. (2020). Climate change increases predation risk for a keystone species of the boreal forest. Nature Climate Change, 10(12), 1149–1153. https://doi.org/10.1038/s41558-020-00908-4

Pierotti, R., & Wildcat, D. (2000). Traditional ecological knowledge: The third alternative (commentary). Ecological Applications, 10(5), 1333–1340. https://doi.org/10.1890/1051-0761(2000)010[1333:TEKTTA]2.0.CO;2

Prevéy, J.S., Parker, L.E., Harrington, C.A., 2020a. Projected impacts of climate change on the range and phenology of three culturally-important shrub species. PLOS ONE 15, e0232537. https://doi.org/10.1371/journal.pone.0232537

Prevéy, J.S., Parker, L.E., Harrington, C.A., Lamb, C.T., Proctor, M.F., 2020b. Climate change shifts in habitat suitability and phenology of huckleberry (Vaccinium membranaceum). Agric. For. Meteorol. 280, 107803. https://doi.org/10.1016/j.agrformet.2019.107803

Primmer, E., Jokinen, P., Blicharska, M., Barton, D.N., Bugter, R., Potschin, M., 2015. Governance of Ecosystem Services: A framework for empirical analysis. Ecosyst. Serv. 16, 158–166. https://doi.org/10.1016/j.ecoser.2015.05.002

Quesnel Seipp, K., Maurer, T., Elias, M., Saksa, P., Keske, C., Oleson, K., Egoh, B., Cleveland, R., Nyelele, C., Wyrsch, P., Gonclaves, N. Hemes, K., Lewis, D., Guo, H., Gon Chung, M. Gritter, A., Conklin, M., Bales, R. (In Preparation). A multi-benefit framework for funding forest management in the Western USA.

Quinn-Davidson, L. N., & Varner, J. M. (2011). Impediments to prescribed fire across agency, landscape and manager: An example from northern California. International Journal of Wildland Fire, 21(3), 210–218. https://doi.org/10.1071/WF11017

Redmond, M. D., Forcella, F., & Barger, N. N. (2012). Declines in pinyon pine cone production associated with regional warming. Ecosphere, 3(12), art120. https://doi.org/10.1890/ES12-00306.1

Reed, C.C., Merrill, A.G., Drew, W.M., Christman, B., Hutchinson, R.A., Keszey, L., Odell, M., Swanson, S., Verburg, P.S.J., Wilcox, J., Hart, S.C., Sullivan, B.W., 2021. Montane Meadows: A Soil Carbon Sink or Source? Ecosystems 24, 1125–1141. https://doi.org/10.1007/s10021-020-00572-x

Reynolds, K.M., Hessburg, P.F., 2005. Decision support for integrated landscape evaluation and restoration planning. For. Ecol. Manag., Decision Support in Multi Purpose Forestry 207, 263–278. https://doi.org/10.1016/j.foreco.2004.10.040

Reynolds, K.M., Hessburg, P.F. & Bourgeron, P.S. (2014). Making Transparent Environmental Management Decisions: Applications of the Ecosystem Management Decision Support System. Springer Books, Berlin, Germany.

Roche, J. W., Ma, Q., Rungee, J., & Bales, R. C. (2020). Evapotranspiration mapping for forest management in California's Sierra Nevada. Frontiers in Forests and Global Change, 3, 69. https://doi.org/10.3389/ffgc.2020.00069

Safford, H.D., Stevens, J.T., 2017. Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA. Gen Tech Rep PSW-GTR-256 Albany CA US Dep. Agric. For. Serv. Pac. Southwest Res. Stn. 229 P 256. https://doi.org/10.2737/PSW-GTR-256

Sawaya, M.A., Ramsey, A. B., Ramsey, P. (2017). American black bear thermoregulation at natural and artificial water sources. Ursus, 27(2): 129-135. https://doi.org/10.2192/URSU-D-16-00010.1

Schofield, L. N., Eyes, S. A., Siegel, R. B., Stock, S. L. (2020). Habitat selection by spotted owls after a megafire in Yosemite National Park. Forest Ecology and Management, 47. https://doi.org/10.1016/j.foreco.2020.118511

Schumann, R. L., Mockrin, M., Syphard, A. D., Whittaker, J., Price, O., Gaither, C. J., Emrich, C. T., & Butsic, V. (2020). Wildfire recovery as a "hot moment" for creating fire-adapted communities. International Journal of Disaster Risk Reduction, 42, 101354. https://doi.org/10.1016/j.ijdrr.2019.101354

Schwartz, M.W., Cook, C.N., Pressey, R.L., Pullin, A.S., Runge, M.C., Salafsky, N., Sutherland, W.J., Williamson, M.A., 2018. Decision Support Frameworks and Tools for Conservation. Conserv. Lett. 11, e12385. https://doi.org/10.1111/conl.12385

Schwartz, M., Hall, A., Sun, F., Walton, D., & Berg, N. (2017). Significant and inevitable end-of-twenty-first-century advances in surface runoff timing in California's Sierra Nevada. Journal of Hydrometeorology, 18(12), 3181–3197. https://doi.org/10.1175/JHM-D-16-0257.1

Siegel, R., Pyle, P., Thorne, J., Holguin, A., Howell, C., Stock, S., Tingley, M., 2014. Vulnerability of birds to climate change in California's Sierra Nevada. Avian Conserv. Ecol. 9. https://doi.org/10.5751/ACE-00658-090107

Soderquist, B.S., Luce, C.H., 2021. Climate change effects on hydrologic processes and water resources in the Sierra Nevada. Gen Tech Rep PSW-GTR-272 Albany CA US Dep. Agric. For. Serv. Pac. Southwest Res. Stn. 29-47 Chapter 3 272, 29–47.

Spencer, W.D., Rustigian-Romsos, H., Ferschweiler, K. and Bachelet, D. (2015). Simulating effects of climate and vegetation change on distributions of martens and fishers in the Sierra Nevada, California, using Maxent and MC1. In Global Vegetation Dynamics (eds D. Bachelet and D. Turner). https://doi.org/10.1002/9781119011705.ch9

Spies, T. A., Hessburg, P. F., Skinner, C. N., Puettmann, K. J., Reilly, M. J., Davis, R. J., Kertis, J. A., Long, J. W., & Shaw, D. C. (2018). Chapter 3: Old growth, disturbance, forest succession, and management in the area of the Northwest Forest Plan. In: Spies, T.A.; Stine, P.A.; Gravenmier, R.; Long, J.W.; Reilly, M.J., Tech. Coords. 2018. Synthesis of Science to Inform Land Management within the Northwest Forest Plan Area. Gen. Tech. Rep. PNW-GTR-966. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 95-243., 966, 95–243.

Spies, T.A., Long, J.W., Charnley, S., Hessburg, P.F., Marcot, B.G., Reeves, G.H., Lesmeister, D.B., Reilly, M.J., Cerveny, L.K., Stine, P.A., Raphael, M.G., 2019. Twenty-five years of the Northwest Forest Plan: what have we learned? Front. Ecol. Environ. 17, 511–520. https://doi.org/10.1002/fee.2101

Spies, T. A., Hemstrom, M. A., Youngblood, A., & Hummel, S. (2006). Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology, 20(2), 351–362. https://doi.org/10.1111/j.1523-1739.2006.00389.x

Spies, T. A. (2004). Ecological concepts and diversity of old-growth forests. Journal of Forestry, 102(3), 14–20. https://doi.org/10.1093/jof/102.3.14

Stebbins, G. L., & Major, J. (1965). Endemism and speciation in the California flora. Ecological Monographs, 35(1), 1–35. https://doi.org/10.2307/1942216

Stephenson, N.L., 1994. Long-term dynamics of Giant Sequoia Populations: Implications for Managing a Pioneer Species. Proc. Symp. Giant Sequoias Their Place Ecosyst. Soc.

Stern, M.J., Coleman, K.J., 2015. The Multidimensionality of Trust: Applications in Collaborative Natural Resource Management. Soc. Nat. Resour. 28, 117–132. https://doi.org/10.1080/08941920.2014.945062

Stewart, I. T. (2013). Connecting physical watershed characteristics to climate sensitivity for California mountain streams. Climatic Change, 116(1), 133–148. https://doi.org/10.1007/s10584-012-0567-5

Stewart, I. T., Cayan, D. R., & Dettinger, M. D. (2005). Changes toward earlier streamflow timing across western North America. Journal of Climate, 18(8), 1136–1155. https://doi.org/10.1175/JCLI3321.1

Stovall, A. E. L., Shugart, H., & Yang, X. (2019). Tree height explains mortality risk during an intense drought. Nature Communications, 10(1), 4385. https://doi.org/10.1038/s41467-019-12380-6

Stralberg, D., Carroll, C., Pedlar, J. H., Wilsey, C. B., McKenney, D. W., & Nielsen, S. E. (2018). Macrorefugia for North American trees and songbirds: Climatic limiting factors and multi-scale topographic influences. Global Ecology and Biogeography, 27(6), 690–703. https://doi.org/10.1111/geb.12731

Taylor, A.H., Trouet, V., Skinner, C.N., Stephens, S., 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. Proc. Natl. Acad. Sci. 113, 13684–13689. https://doi.org/10.1073/pnas.1609775113

Tingley, M.W., Monahan, W.B., Beissinger, S.R., Moritz, C., 2009. Birds track their Grinnellian niche through a century of climate change. Proc. Natl. Acad. Sci. 106, 19637–19643. https://doi.org/10.1073/pnas.0901562106

The Nature Conservancy's California Climate Adaptation Science Team. (2010a). Hot, wet scenario forecast of climate suitability for California black oak (Quercus kelloggii) in the southern Sierra Nevada and Tehachapi Mountains (California, USA) based upon downscaled 2045-2065 IPSL-CM4 A2 projections. Databasin.org.

The Nature Conservancy's California Climate Adaptation Science Team. (2010b). Warm, dry scenario forecast of climate suitability for California black oak (Quercus kelloggii) in the southern Sierra Nevada and Tehachapi Mountains (California, USA) based upon downscaled 2045-2065 MRI-CGCM2.3.2 A2 projections. Databasin.org.

Thorne, J. H., Gogol-Prokurat, M., Hill, S., Walsh, D., Boynton, R. M., & Choe, H. (2020). Vegetation refugia can inform climate-adaptive land management under global warming. Frontiers in Ecology and the Environment, 18(5), 281–287. https://doi.org/10.1002/fee.2208

Thorne, J. H., Choe, H., Stine, P. A., Chambers, J. C., Holguin, A., Kerr, A. C., & Schwartz, M. W. (2018). Climate change vulnerability assessment of forests in the Southwest USA. Climatic Change, 148(3), 387–402. https://doi.org/10.1007/s10584-017-2010-4

Thorne, J. H., Choe, H., Boynton, R. M., Bjorkman, J., Albright, W., Nydick, K., Flint, A. L., Flint, L. E., & Schwartz, M. W. (2017). The impact of climate change uncertainty on California's vegetation and adaptation management. Ecosphere, 8(12), e02021. https://doi.org/10.1002/ecs2.2021

Thorne, J. H., R. M. Boynton, A. J. Holguin, J. A. E. Stewart, and J. Bjorkman. (2016). A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife, Sacramento, California, USA.

Tribal Adaptation Menu Team. (2019). Dibaginjigaadeg Anishinaabe Ezhitwaad: A Tribal Climate Adaptation Menu. Great Lakes Indian Fish and Wildlife Commission, Odanah, Wisconsin. 54 p.

Turner, N. J., Davidson-Hunt, I. J., & O'Flaherty, M. (2003). Living on the edge: Ecological and cultural edges as sources of diversity for social—ecological resilience. Human Ecology, 31(3), 439–461. https://doi.org/10.1023/A:1025023906459

U.S. EPA. (2022). About Lake Tahoe. https://www.epa.gov/lake-tahoe/about-lake-tahoe. [Accessed March 2022].

Van de Water, K., & North, M. (2010). Fire history of coniferous riparian forests in the Sierra Nevada. Forest Ecology and Management 260, 384-395. https://doi.org/10.1016/j.foreco.2010.04.032

Viers, J., Purdy, S., Peek, R., Fryjoff-Hung, A., Santos, N., Katz, J., Emmons, J., Dolan, D., & Yarnell, S. (2013). Montane meadows in the Sierra Nevada: Changing hydroclimatic conditions and concepts for vulnerability assessment. Center for Watershed Sciences Technical Report, University of California, Davis, CA.

Voggesser, G., Lynn, K., Daigle, J., Lake, F. K., & Ranco, D. (2013). Cultural impacts to tribes from climate change influences on forests. Climatic Change, 120(3), 615–626. https://doi.org/10.1007/s10584-013-0733-4

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. Science, 313(5789), 940–943. https://doi.org/10.1126/science.1128834

White, A.M., Zipkin, E.F., Manley, P.N., Schlesinger, M.D., 2013. Simulating avian species and foraging group responses to fuel reduction treatments in coniferous forests. For. Ecol. Manag. 304, 261–274. https://doi.org/10.1016/j.foreco.2013.04.039

Wilkins, E. J., Howe, P. D., & Smith, J. W. (2021). Social media reveal ecoregional variation in how weather influences visitor behavior in U.S. National Park Service units. Scientific Reports, 11(1), 2403. https://doi.org/10.1038/s41598-021-82145-z

Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman-Morales, J., Bishop, D. A., Balch, J. K., & Lettenmaier, D. P. (2019). Observed impacts of anthropogenic climate change on wildfire in California. Earth's Future, 7(8), 892–910. https://doi.org/10.1029/2019EF001210

Wobus, C., Small, E. E., Hosterman, H., Mills, D., Stein, J., Rissing, M., Jones, R., Duckworth, M., Hall, R., Kolian, M., Creason, J., & Martinich, J. (2017). Projected climate change impacts on skiing and snowmobiling: A case study of the United States. Global Environmental Change, 45, 1–14. https://doi.org/10.1016/j.gloenvcha.2017.04.006

Wynecoop, M.D., Morgan, P., Strand, E.K., Sanchez Trigueros, F., 2019. Getting back to fire suméŝ: exploring a multi-disciplinary approach to incorporating traditional knowledge into fuels treatments. Fire Ecol. 15, 17. https://doi.org/10.1186/s42408-019-0030-3

Youngblood, A., Max, T., Coe, K., 2004. Stand structure in eastside old-growth ponderosa pine forests of Oregon and northern California. For. Ecol. Manag. 199, 191–217. https://doi.org/10.1016/j.foreco.2004.05.056

Ziegler, J.P., Hoffman, C.M., Collins, B.M., Long, J.W., Dagley, C.M., Mell, W., 2020. Simulated Fire Behavior and Fine-Scale Forest Structure Following Conifer Removal in Aspen-Conifer Forests in the Lake Tahoe Basin, USA. Fire 3, 51. https://doi.org/10.3390/fire3030051

Appendix A: Stakeholder Survey Results

To understand stakeholder perspective, we conducted an expert solicitation survey which ranked the importance of each pillar of resilience within the Framework. Participants (n = 35) answered a series of pairwise comparisons asking “In the context of better understanding resilience goals for the region, [Pillar A] is ______ important than [Pillar B]”, where the answer options were: much less, somewhat less, equally, somewhat more, much more, and prefer not to answer. Responses of equal importance were assigned 1 point, somewhat more or less important assigned 2 points to the pillar deemed more important, and much more or less important assigned 3 points to the pillar deemed more important. After responses were collected, scores were calculated for the ten pillars by multiplying the appropriate score (1, 2, or 3) by the number of respondents who selected that answer and summing all the selections for each pillar.

While these results are preliminary, they can provide some insight into the management priorities of local groups affiliated with the Tahoe-Central Sierra Initiative. Management actions that support forest resilience, water resources, and fire adapted communities may be broadly preferred over management actions with other priorities.

Given the short timeframe of this project and survey, and after consulting with tribal resource experts, we realized it was neither appropriate nor fair to expect tribal interest or engagement without a longer-term plan for how their time and expertise would be effectively used to inform land management decisions. A critical next step of this process would be to engage tribal communities to inform the values that have cultural importance and the process for incorporating those into eco-cultural criteria for climate refugia.

Resulting pillar rankings from the stakeholder survey are shown in the table below.

Rank	Pillar	Definition from Survey	Points
1	Forest Resilience	The composition and structure are in alignment with topography, desired disturbance dynamics, and landscape conditions and are adapted to anticipated climate change effects.	120
2	Water Reliability	The quantity and quality of water are buffered against precipitation variability and disturbance through the integrity of forests and their watersheds.	102
3	Fire Adapted Communities	Communities live safely with fire, and are accepting of management and natural ecological dynamics. Beneficial fire is supported. There is sufficient capacity to manage desired fire and suppress unwanted fire.	94
4	Economic Diversity	Forest and outdoor activities support a sustainable nature resource-based economy, particularly in rural communities. Forest products are harvested sustainably, and utilized at their highest and best use, promoting workforce development, revenue and a market demand for materials, generated by forest management activities.	86
5	Fire Dynamics	Fire burns in an ecologically beneficial and socially acceptable way that perpetuates landscape heterogeneity and rarely threatens human safety or infrastructure.	85
6	Carbon Sequestration	Enhanced in a stable and sustainable manner that yields multiple ecological and social benefits.	80
7	Wetland Integrity	Meadow and riparian ecosystems have functional hydrology and biology such that they provide multiple ecosystem services, including water storage, flow regulation, sediment capture, stream bank stability, carbon sequestration, and high biodiversity.	70
8	Air Quality	Emissions from fires are limited to low and moderate fires in wildland ecosystems. Forests provide a positive contribution to air quality by capturing pollutants.	55
9	Social Well-being	Quality environmental conditions that afford a connection to place and nature, recreational opportunities, human health, cultural identities and practices and shared stewardship.	47
10	Biodiversity	The network of native species and ecological communities is sufficiently abundant and distributed across the landscape to support and sustain their full suite of ecological and cultural roles.	44

Appendix B: Funding Sources for Resource Management

To meet the desired management goal of treating one million acres per year outlined in the shared stewardship agreement signed between the state and the USFS, at least one billion dollars a year will be needed to support this objective (assuming a conservative $1,000/acre treatment costs). No single entity has the necessary resources to dedicate to landscape management, so a blending of funding from government agencies, public and private utilities, private companies, and other stakeholders will be required to be successful. These stakeholders have a vested interest in management activities because they already have funding programs aligned with management goals, bear environmental and/or financial risk from a lack of forest management or receive enhanced benefits from implementation of restoration activities. The first table below describes potential sources of funding delineated by the various benefits and co-benefits of restoring ecological health to forests (Table B1). The second table lists sources that are either specifically available to California forest management or have the potential to be used or replicated in the state, along with examples of relevant projects where they exist (Table B2).

Table B1. Public and private beneficiaries of a resilient forest achieved through management (copied from Quesnel Seipp et al., In Preparation)

Benefit	Public Beneficiaries	Private Beneficiaries
Habitat and Biodiversity	• Governments: Local, State, Federal, and Tribal • Land owners and managers, including USFS, BLM, and State Parks	• Local and regional recreational visitors • Land owners and managers
Wood Products	• Governments: Local, State, and Federal	• Bioenergy facilities • Wood products companies • Carbon credit developers
Water Security	• Government Agencies for aquatic habitat & species protection • Municipal utilities	• Private hydropower and utilities including agriculture and irrigation districts • Corporations directly (e.g. bottling companies) or indirectly (e.g. as utility customers) dependent on supply
Recreation	• Local towns & counties • Land managers, including state governments, USFS, National Park Service, and BLM	• Recreation visitors and users • Hunting and fishing groups
Infrastructure	• Federal and state departments of transportation • Municipal water and energy utilities • Local governments in high-fire-risk areas • Federal and state land managers	• Insurance companies • Homeowners Associations • Road/Rail managers and trucking companies • Private water and energy utilities
Restoration Economy	• Governments: Local, State, Federal, and Tribal Departments of Commerce • Local economies	• Unions • Wood products companies • Forestry contractors
Carbon Stability	• Governments: Local, State, Federal, and Tribal climate initiatives	• Carbon credit developers
Public Health	• Public health agencies • Public hospitals • The public (from air quality standpoint)	• Health insurance companies • Health care networks • Private hospitals • Local businesses, especially open-air enterprises • Recreation and tourism industries
Local Climate	• Governments: Local, State, Federal, and tribal	• Groups interested in climate benefits to seedling regeneration • Private businesses and households using indoor climate-control
Non-Use Values	• The public • Individuals and entities placing cultural value on the land • Future generations	• Philanthropic organizations • Environmental and cultural organizations
Sense of Place	• Local community • Communities with attachment to place	• Philanthropic organizations • Environmental and cultural organizations

Table B2. Examples of public and private beneficiary funding programs or forest management projects.

Beneficiary	Funding or Development Program	Project Examples
Federal Government	• FEMA: Building Resilient Infrastructure & Communities (BRIC) • BIA: Tribal Climate Resilience Program • BoR: WaterSMART Environmental Water Resources Program	• FEMA BRIC: Sonoma County Fire Risk Reduction
State Government	• Wildlife Conservation Board Programs • CDFW Grant Programs • CalFire Grant Programs • SNC Grant Programs	
Local Government		• French Meadows Project (Tahoe NF, Placer County) • North Yuba Forest Partnership (Tahoe NF, Sierra County)
Tribal Government	• Prescribed Fire Training Exchange Program (TREX)	• Karuk Wildland Fire Program • Yurok Prescribed Fire Training Exchange Program • North Yuba Forest Partnership (Nevada City Rancheria: Nissan Tribe)
Non-Governmental Organization	• NFWF: Northern CA, Southern CA • NFF Programs • NWTF • Central Sierra Resiliency Fund • CA Resilience Challenge • American Rivers • American Forests • AFF: My Sierra Woods • CA Deer Association	• French Meadows Project (TNC) • North Yuba Forest Partnership (SYRCL, NFF, TNC) • Lake Tahoe West (NFF) • South Fork American River Cohesive Strategy (NWTF)
Utility	• PG&E Wildfire Ready & Resilient Grant Program • SCE Community Fire-Safe Grant Program	• Yuba Forest Resilience Bond (Tahoe NF, Yuba Water Agency) • French Meadows Project (Placer County Water Agency)
Private Company	• Bonneville Environmental Foundation: Business for Water Program • California Water Action Collaborative (CWAC) • World Resources Institute: Aqueduct Alliance	• Lower American River Basin (Procter & Gamble)
Environmental Credits	• Carbon: Improved Forest Management (IFM), Biochar (in development), Avoided Wildfire Emissions (in development) • Climate, Community, & Biodiversity (CCB)	• Land Acquisition (Yurok Tribe)
Sustainable Forestry Company	• Vaagan Brothers (WA based) • New Forests • Ecotrust • Pacific Biochar	• A to Z Project (Colville NF)
Insurance	• Proposed parametric wildfire insurance product: TNC & Willis Towers Watson Report	• Wildfire Insurance Discount for Firewise Communities (USAA) • Yuba Forest Resilience Bond (CSAA)

Appendix C: Eco-cultural Resource Values Considered for Climate Refugia

OBJECTIVES	Resource or Cultural Value								
						Direct Climate Impact		Indirect Climate Impact	
Fundamental Value	Resource or Cultural Value	Description of Benefit	Value to Tribes	Stakeholders Valuing Benefit	Mappability	Climate parameters that best represent the conditions to which the value is vulnerable	Impacts from changes in temperature and precipitation	Mechanism by which indirect climate condition impacts the value	Impacts from changes in indirect climate mechanism
Water Security									
	Quantity								
	Water Yield	Consistent supply of water for drinking, hydropower, irrigation	Fisheries, wetlands, water rights, water supply	Public, water industry, agricultural industry	Predicted spatial precipitation distribution and changes in ET	Seasonal distribution of temperature	Increased temperature will lead to increased evapotranspiration and decreased streamflow	Decreased water recharge from reduced snowpack, changes in precipitation	Decreased water levels, increased competition for water
	Quality								
	Water quality	Clean water with minimum sediment and nutrient loading	Fisheries, wetlands, water rights, water supply	Water industry, conservationists, public	Increases in water temperature due to temperature increases	Average temperature	Increased temperature will result in less habitat suitable for cold water species, particularly in the spring	Decreased streamflow, reduced dissolved oxygen	Decreases in streamflow will exacerbate effect of ambient temperature on stream temperature
	Storage and Timing								
	Storage and timing	Capacity for water storage in snowpack, waterways, and reservoirs. Seasonal fluctuations in streamflow timing.	Fisheries and wetlands	Water industry, conservationists, public	Streamflow timing and snowpack accumulation	Seasonal distribution of temperature and precipitation	Increased spring temperatures reduces snowpack, increases rainfall, decreases snowfall, and increases early season streamflow.	Snowpack changes	Decreased snowpack leads to decreasing albedo and increased warming due to lack of reflected energy
Wetland Integrity									
	Structure								
	Fire Buffer Management	Wetter areas maintained on the landscape to serve as natural fire buffers for species	Wildfire hazard reduction, support of cultural burning, naintenance of frequent fire communities	Forest managers, wildfire managers	Geographic location	Average temperature and seasonal distribution	Increasing temperature threatens some wetlands, decreasing ability to act as fire buffer	Increased wildfire will impact wetlands more frequently	Potential to increase meadow area, as frequent fire by indigenous and cattle ranchers historically maintained these areas.
	Composition								
	Meadows	Water storage, carbon storage, wildlife habitat, biodiversity, water quality through sediment capture	Plants for foods, material, medicinals, and habitat for fish and wildfire	Conservationists, water industry	Geographic location	Temperature and precipitation	Changes in temperature and precipitation will affect which meadows can serve as refugia	Landscape connectivity (e.g. size, elevation, latitute, distance to roads, etc)	Reduced ability to serve as refugia
	Aquatic animals	Whitefish, Lahotan cutthroat trout	Whitefish, native trout, mussels, etc.	Conservationists	Geographic distributions	Average temperature	Increased stream temperature and decreased stream flow will reduce habitat suitability for certain aquatic species	Low summer flows and increased temperature due to timing in stream flows	Reduced habitat suitability and population distribution
	Cold water associated species	Native trout	Native trout	Conservationists	Geographic distributions	Average temperature	Increased stream temperature will reduce habitat suitability for cold water species	Low summer flows and increased temperature due to timing in stream flows	Reduced habitat suitability and population distribution
	Amphibians	Southern long-toed salamander, Yosemite toad, Mountain/Sierra yellow-legged frog	Some cultural associations	Conservationists	Habitat suitability and possibly climate envelopes	Temperature and precipitation	Decline in population range	Low summer flows and increased temperature due to timing in stream flows	Reduced habitat suitability and population distribution
	Biological diversity	Native species diversity (alpha, beta, gamma)	Native species as part of food webs	Conservationists, water industry, recreation	Habitat suitability (native species) and known geogrpahic distributions (invasive species)	Temperature and precipitation	Change in habitat suitability and local to regional-level measures of diversity (alpha and beta)	Wildfire	Direct loss of habitat, accelerated transition between habitat types
	Plants	Sedges, bracken fern, wyethia, mountain rose, willow, etc.	Plants for food, medicine, material	Conservationists, water industry, recreation	Known geographic distributions	Temperature and precipitation	Change in habitat suitability and plant distribution	Wildfire, invasive species	Elimination of native plant species
	Hydrologic Function								
	Water regulation	Water storage from the wet season is released slowly during the dry season maintaining baseflow and stream temperature for aquatic species	Fisheries, wetlands, water rights, water supply	Conservationists, water industry, recreation	Geographic location	Temperature and precipitation	Increased temperature leads to reduced snowpack and extended dry seasons	Vulnerable to reduced snowpack	Reduced snowpack leads to reduced spring and summer inflows
Biodiversity Conservation									
	Focal Species								
	Plants and fungi	Wild berry producing species, tobacco, pinyon pine, various tree species	Many species of special cultural value	Conservationists, local foragers	Moderately. Directly for certain species, partially for others through vegetation correlates	Precipitation, temperature, evapotranspiration	Reduced cone/seed production with warming temperatures in some conifer species. Increased vulnerability to bark beetle infestation with drought.	Fire drives cover type change, which can both increase and decrease the frequency of valued types (e.g., converting hardwood forests to grasslands; opening closed forests for increased berry production	Drought can impact seed production, particularly in what would otherwise have been mast years.
	Focal terrestrial animal species	Eagles, hawks, quail, grouse, flicker, swallows, bear, Belding's ground squirrel, white-tailed jackrabbit, snowshoe hare, chipmunks, deer	Many species of special cultural value, including eagles, hawks, quail, grouse, flicker, swallows, bear, belding's ground squirrel, white-tailed jackrabbit, snoeshoe hare, chipmunks, deer, band-tailed pigeon	Conservationists, forest managers, hunters, recreation	Based on habitat suitability, connectivity, and climate envelopes	Temperature and precipitation	Increasinging temperature is causing an upward elevational shift in conditions that can support some focal species. Changes in precipitation are additionally causing a shift in distribution for some species. Some species may experience overall range contraction (shrinking) due to losses within existing range combined with the inability to move into newly favorable climate zones	Species will respond indirectly to climate change through vegetation change, and shifts in linked species, such as predators, competitors, and prey. Decreasing snowpack will affect water availability. For migratory species like the swallows, eagles, and some hawks, conditions on wintering grounds will also impact populations in ways that are difficult to predict	Indirect effects are most like to reduce the range and abundance of these focal species, since most of them have some degree of specialization. Difficult to forecast,though, and it is possible that some of these species will benefit from changes in other species (loss of predators or competitors, for example). Decreasing snowpack for snowshoe hares is causing increased predator pressure from coyotes

OBJECTIVES	Resource or Cultural Value								
						Direct Climate Impact		Indirect Climate Impact	
Fundamental Value	Resource or Cultural Value	Description of Benefit	Value to Tribes	Stakeholders Valuing Benefit	Mappability	Climate parameters that best represent the conditions to which the value is vulnerable	Impacts from changes in temperature and precipitation	Mechanism by which indirect climate condition impacts the value	Impacts from changes in indirect climate mechanism
	Old forest associated species	California spotted owl, fisher, marten, Northern goshawk, pileated woodpecker, northern flying squirrel	Many species of special cultural value	Conservationists, managers	Based on habitat suitability and climate envelopes	Impacts have been found for increasing maximum annual temperature, increasing seasonal maximum temperature, and decreasing precipitation.	Range shifts or range contractions are expected for species which are sensitive to changes in these parameters. Most of these species are longer lived, so climate stress can impact fecundity and life span, as well as the ability to occupy areas. Excessive and prolonged heat is likely to be the greatest stressor for most of these species.	Fire and tree mortality from beetles are probably the greatest indirect impacts from climate change. Beetles tend to attack the largest trees, removing this essential habitat element. High severity fire that kills most or all trees results in loss of suitable habitat for at least a century, and high tree mortality from beetles increases this risk. Decrease in evapotranspiration and snowpack	Loss of old forest habitat can take a century or more to replace, particularly legacy habitat elements such as live and dead large tree habitat elements. Loss of habitat results in reduced population sizes, and chronic losses along the edge of geographic ranges are likely to result in contractions in species ranges. Fisher could possibly move higher in elevation into marten elevational ranges. Decreasing evapotranspiration may cause range contraction in some species.
	Species diversity								
	Biological diversity	Wildlife and plant species diversity (alpha, beta, gamma)	Native species as part of food and energy webs	Conservationists	Based on habitat suitability and climate envelopes	Examples predominantly discussed how changes in average season and annual temperature affect species associations and distribution	Shifts in species distributions and new combinations of species along range shifts are expected with increasing temperature. Shifts include moving to higher elevations and moving latitudinally toward the poles. Also likely that specialist species will not be as adaptable and their populations and ranges are likely to contract.	Shifting habitat range will lead to novel species combinations, which could increase competition and/or predation, reduce suitable habitat conditions for foraging or breeding.	Changes in species distributions may impact species interactions along range shifts. Asynchronous species responses to climate change is expected to negatively impact biological diversity, particularly specialist and longer lived species Reduced alpha diversity (species richness) and increased beta diversity is expected along shifts as some landscapes become more homogenized and specific areas (ex: lower elevations) lose species.
	Community integrity								
	Regulatory functions	Bark foraging birds (insect population outbreak modulation), predator-prey interactions	Woodpeckers often highly valued, also fire important for best control (weevils and worms)	Conservationists, forest managers	Geographic species occurrence, distribution, connectivity.	Seasonal and annual average temperature	Increases in temperature resulting in changes in seasonal patterns can impact ability of some species to use sites for longer or shorter periods of time during the year.	Increases in bark beetle populations, carpenter ants, and termites could increase the abundance of bark foraging species that feed on them, such as pileated woodpecker and other species of woodpecker.	Decreasing snowpack may result in increasing predation pressure on herbivores because some predators have access to prey for longer periods of time during the year
	Supporting functions	Pollinators, seed dispersers, soil aerators, cavity excavators	Many pollinators, ground-dwelling mammals, and cavity excavators are culturally important	Conservationists, forest managers	Geographic species occurrence, distribution, connectivity.	Increasing maximum temperatures and decreasing annual precipitation	Increasing temperatures is causing range shifts of species, resulting in novel species interactions or loss of important interactions	Reduced seed mast in trees, change in phenology for some plants, the potential decrease in the diversity of food plants and their productivity could all affect food resource abundance and quality.	If poor mast years become more common, granivores may have to shift their range or increase diet breadth to accomodate food loss. Change in bloom time of some plants may cause asynchrony among multiple trophic levels, from pollinators to animals (such as birds) that feed on pollinators. This could have widespread affects on breeding success and survival. Difficult to forecast if changes in animal species composition would have negative or positive conseuqences for predation and competition.
Forest Resilience									
	Structure								
	Large tree ecology	Carbon sequestration, wildlife habitat, natural beauty, clean air, spiritual value	Large trees values for many reasons, including wildlife habitat, food production, sense of place	Conservationists, forest managers	Known geographic location and habitat suitability	Max temperature, min precipitation, max drought conditions, and extreme events, such as strong winds, flooding, and signficant snow loads	High levels of mortality exihbited even among the most drought tolerant and long lived species under long and intense drought. Mortality associated with bark beetle attacks, early snow melt, lower spring flows, excessive drought conditions, extreme winds (blow down), and extreme precipitation events (flooding and snow load).	Increased mortality associated with increased high severity fire and increased competition with understory trees that have accumulated through fire suppression	Increased mortality
	Composition								
	Old forest ecosystem	Biodiversity, stable carbon storage, nutrient cycling, air quality	Large trees, sense of place, wildlife habitat	Conservationists, forest managers	Known geographic location and habitat suitability	Temperature and precipitation	Changes in temperature and precipitation are expected to directly affect forest tree species and associated wildlife species, especially in old forest (late seral) conditions	Increasing frequency and extent of high severity fires, increased mortality from beetle infestations	Increasing number of high severity fires threaten old growth forest disproportionately due to fuel load and amount of time required for old growth to regrow postfire
	Mature Black Oak forest	Mast, hardwood, wildlife habitat	Acorn production and wildlife habitat	Conservationists, forest managers	Known geographic location and habitat suitability	Temperature and precipitation	Forests were especially sensitive to changes in mean temperatures of the coldest and warmest months, total annual precipitation, and summer precipitation	Increasing frequency and extent of high severity fires	Decreasing extent of habitat

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Carbon									
	Carbon Storage Stability								
	Carbon stability	Stability of atmospheric carbon captured by trees, shrubs, etc.	Associated with large trees, healthy meadow soils	State government, public, carbon offset markets, climate initiatives	Inversely proportional to the Fire Return Interval Departure (FRID)	Temporal variation and fluctuations in temperature and precipitation	Droughts and temperature variability interactions with wildfire may transition portions of the Sierra from carbon sinks to sources.	Increased pest presence, drought stress due to precipitation variability, extreme wind, etc, may exacerbate climate impacts on carbon sequestration	General ecosystem stress from climate change impacts will reduce ability to recover post fire. Drought could increase time periods of dry fuels interacting with extreme weather/ wind
Fire Dynamics									
	Severity								
	Limited high severity fire	Reduced risk of high severity fire impacts to sensitive and high value resources	Supporting production of keystone plants (e.g., bulbs, nut production)	Conservationists, forest managers, communities	Inversely proportional to the Fire Return Interval Departure (FRID)	Temporal variation and fluctuations in temperature and precipitation	Fire severity decreased with precipitation. Temperature - limited ecosystems experienced an increase in fire severity in warmer climates.	Increasing temperature dries out fuels, which increases the likelihood and frequency of high severity fire	Increases in fire activity imply that less biomass will be able to accumulate between successive fires, resulting in less biomass available for combustion and a reduction in fire severity. Furthermore, predicted increases in water deficit are expected to increase water stress and decrease productivity in the generally water-limited western US, ultimately reducing the amount of biomass available to burn and resultant fire severity.
	Functional Fire								
	Low and moderate intensity fire	Beneficial fire regime for promoting heterogeneous environments that support biologically diverse communities	Supporting cultural burning and frequent fire communities	Conservationists, forest managers	Fire Return Interval Departure (FRID)	Minimum and maximum seasonal temperature and mean annual precipitation	Increasing temperature and decreasing precipitation increase fire intensity, particularly when human activity disrupts the vegetation-climate equilibrium and fuels persist on landscape (i.e. through fire suppression)	Wind events, accumulation of dry fuels, humidity, vegetation processes and density	High severity fire more frequent with more wind events, more dry fuels and vegetation, though this is rarely directly studied/unclear. In regions where climate change will increase temperature and wind and decrease precipitation, fires are more intense and the number of extreme fires increases though this effect is complicated by uncertainties in future precipitation and human intervention
	Frequency of fire occurrence	Benefical fire regime to which species and communities are adapted	Supporting Indigenous fire regimes, controlling insect pests	Forest managers	Fire Return Interval Departure (FRID)	Temperature and precipitation	Increasing temperature and decreasing precipitation increase fire frequency and decrease fire return interval.	Drier fuels from decreasing precipitation and increasing temperatures; insect outbreaks and non-native pathogens; climate-mediated type change; shifts in climate like wind, timing of precipitation and snowmelt.	Bark beetles and non-native pathogens increase drought susceptibility, dry fuel load, and fire risk; type change to grassland burns more frequently and carries fire further; later precipitation and earlier snowmelt increase dry season length and lead to drier fuels, increasing fire risk. Wind events increase fire risk.
Fire Dynamics **Fire Adapted Communities**									
	Fire hazard								
	Seasonal Severity Rating (SSR)	Fire potential due to weather	Informs indigenous land stewardship and cultural burning opportunities	Everyone	Seasonal Severity Rating (SSR)	Increasing temperature and decreasing precipitation lead to higher risk	Increases in temperature leads to drier fuel and more severe fires, leading to a higher Seasonal Severity Rating (SSR)	N/A	Not considered
Social and Cultural Wellbeing									
	Recreation quality								
	Recreation access	Opportunity for recreation and ecotourism	Important for tribal access for stewardship; although may have interests in closures as well	Recreationists	Access is mappable, use is less certain	Maximum temperature, daily and total precipitation	Impacts are complex, dependent on activity and ecoregion but increasing temperature and changing precipitation likely to decrease season length for winter sports. Increasing temperature likely to decrease days-per-participant for some summer (hiking) and winter (skiing) activities	Not well studied	Not well studied
	Game species	Deer, turkeys, squirrels, bears, etc.	Traditional food source	Recreationists	Habitat suitability and climate envelopes	Temperature and precipitation	See focal terrestrial animal species	See focal terrestrial animal species	See focal terrestrial animal species
	Watchable species	Bald eagle, osprey, etc.	Many have cultural significance	Recreationists	Habitat suitability and climate envelopes	Temperature and precipitation	See focal terrestrial animal species	See focal terrestrial animal species	See focal terrestrial animal species
	Game fish	Native trout, steelhead, etc.	Native fishes are a key traditional food	Recreationists	Geographic distribution	Temperature and precipitation	See wetland integrity	See wetland integrity	See wetland integrity

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