Prioritizing Forest Health Investments

Recommendations from the Science Advisory Panel to the California Forest Management Task Force

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Executive Summary

Given the increase in wildfire activity along with other emerging threats to forest health, such as drought, beetle outbreaks, and overcrowding, there is a pressing need for forest restoration. Forest health investments are a central component of fire mitigation and carbon management strategies and also provide multiple co-benefits. However, with limited resources and vast swaths of vulnerable forest communities, prioritizing landscapes for restoration treatments remains a challenge. Existing approaches to landscape prioritization vary widely in their governance structure and methodological approach.

In this report, we present findings from the Science Advisory Panel on the science behind treatment prioritization. Through panel-wide surveys and discussions, we identified factors worth considering when identifying high-priority landscapes. We summarize the state of the science on each of these factors, including the rationale for prioritizing each factor, existing data and resources that could be used for evaluation, and limitations of those data and resources. We ranked the factors based on panel-wide opinions of which should be considered most strongly in prioritization.

We also reviewed eight existing approaches to restoration prioritization, representing a range of strategies toward governance, decision-making, and quantitative prioritization. These examples come from both Washington and California and have been led by government entities and collaborative partnerships.

When prioritizing forest health investments, there are often many competing objectives, some of which are synergistic ("win-win") while others have trade-offs. Individual collaboratives or regions must identify the goals and objectives that are appropriate to their ecosystems, stakeholders, and communities. These will vary with native vegetation and fire regimes. All regions need to develop specific plans, but the need is particularly important for chaparral in southern California given how different the vegetation dynamics and fire regime are from California's conifer forests. Many treatment co-benefits available to forests are not applicable in chaparral. Additionally, treatments in chaparral may be less effective at moderating fire behavior, and alternatives to vegetation management – such as ignition control and community planning – may serve a larger role. For this reason, and because the Science Advisory Panel is primarily made up of forest, rather than chaparral, experts, we caution against an uncritical application of our findings to chaparral ecosystems.

We present 13 prioritization factors not as a one-size-fits-all solution to treatment prioritization across the state, but as a starting point for evaluating the scientific needs of more local or regional prioritization efforts. Our descriptions of each factor introduce scientific issues worth considering for any prioritization effort. The 13 factors are, in descending order of importance according to panel survey responses:

- **Treatment design impacts on wildfire**. The ability of treatments to impact wildfire behavior can be evaluated by their size, type, and spatial arrangement. Projects designed to increase connectivity among and within treatments offer the best opportunity to impact landscape-scale fire behavior. Treatment design should reflect the local fire regime. Wildfire behavior modeling may be required to compare alternative treatment designs.

- **Local fire hazard.** Prioritize areas with high fire hazard, defined as the combination of estimated likelihood and intensity of wildfire. Improvements in the Fire Hazard Severity Zone delineations may improve our ability to prioritize according to fire hazard, though the effect of recent tree die-off on fire behavior remains poorly understood.
- **Water quality.** High severity fire can have devastating impacts on water quality, primarily in the form of altered sedimentation. Such changes can damage water supply infrastructure, reservoir capacity, and aquatic ecosystems. Treatments that protect the integrity of riparian areas or that target landscapes in the contributing areas of vulnerable water supply infrastructure can support water quality objectives.
- **Proximity to human development.** Forest health treatments near human development may have greater long-term benefits on suppression expenditures, costs incurred, societal damage, and lives lost, than treatments in remote areas. To prioritize these objectives, treatments should target locations closer to human development or critical infrastructure, or those locations considered relevant to wildfire transmission to communities. Data such as the SILVIS wildland urban interface map, CalFire FRAP WUI geospatial layers, and the Fireshed Registry can inform treatment plans. Some state programs, such as CalFire's Fire Prevention Grants, specifically target community fire safety. Forest health investments, which are distinct from community safety investments, should not be prioritized solely based on community fire risk; however, proximity to human development may be one of several guiding factors.
- **Wildlife habitat.** Treatments that increase pyrodiversity and fine-scale forest heterogeneity can benefit many wildlife species by enhancing resilience of their habitat to wildfire and drought and by preventing type conversion. Projects that maintain key habitat elements for sensitive forest-dependent species can balance potential short-term negative impact in favor of reducing risk of large-scale disturbances.
- **Old growth.** Old growth forests offer disproportionate benefits for wildlife, cultural values, and particularly for carbon storage; this importance suggests that protection of these forests should be a high priority for fuels treatments. Within old-growth, priority may be considered in terms of relative fire risk and current and potential carbon storage, though most old growth will surpass second growth in terms of carbon storage. In addition to unlogged old-growth stands, advanced second growth stands that have had time to grow larger trees and begin to accumulate other old growth characteristics should also be prioritized for protection. Federal and state agencies offer some mapping of remaining old-growth forests to guide these efforts.
- **Tree mortality risk.** Mass tree mortality events have become increasingly common across the globe in recent decades. When considering future tree mortality in California, measures of expected ecosystem moisture stress and biotic agents of mortality must be considered in relation to location, forest composition, and structure. Certain stand and landscape characteristics that can be assessed with remote sensing may help to identify areas at risk of mass mortality; however, at least in the Sierra Nevada, dynamics between drought and bark beetles complicate these predictions.
- **Environmental justice and social resilience.** While environmental justice and Tribal leadership are often included as priorities, there continues to be a need for an assessment tool that adequately measures

these factors in rural forested communities. We find that there are significant limitations with using CalEnviroScreen in rural areas. Other existing social vulnerability indices rely on variables from the American Community Survey. To our knowledge, these analyses have only been performed using heuristic approaches to selecting variables to include in social vulnerability indices, rather than robust analyses of vulnerability indicators in relation to post-fire community outcomes. Three resources we recommend are a) the capitals framework – a method of evaluating the physical, financial, natural, human, cultural, and social capital of a community, b) the California Office of Planning and Research report on "Defining Vulnerable Communities in the Context of Climatic Adaptation," and c) the Social Ecological Criteria in Section V of this report. There we introduce additional considerations for addressing resilience and equity in disadvantaged rural communities. Our recommended framework is intentionally qualitative because there are few quantitative datasets available that would accurately reflect the level of detail and complexity needed to ensure environmental justice criteria are being met in rural forested communities.

- **Rare and/or highly valued plant communities.** Over 1,000 rare plant species are found in California's forests, woodlands, and shrublands. Treatments should demonstrate capacity to make meaningful changes to the trajectory of rare and valuable plant species, communities, or populations, such as: reversing or stabilizing declines, removing or reducing documented risks, or facilitating future growth and preservation. Extensive documentation is available for plant species in California, including many rare species.

- **Water quantity.** Forest management actions have the potential to mitigate hydrologic responses to droughts and floods, both directly by altering forest water use, and indirectly via impacts on fire severity. Treatments should be prioritized in areas where downstream flood impacts may be most destructive for human property, water supply infrastructure, and sensitive aquatic and riparian species.

- **Standing dead trees.** Standing dead trees are increasing in abundance in California's forests as the climate warms and dries. They provide essential wildlife habitat, store carbon and present potential hazards. It is not clear what impact extensive swathes of standing dead trees have on wildfire hazard, though they may increase the risk of dangerous "mass fires." Given this uncertainty, and the benefits standing dead trees offer, the priority for treatments should be locations in which tree mortality threatens critical infrastructure or occurs within high fire hazard severity zones.

- **Feasibility.** Feasibility of implementing treatments, though a key consideration, should not dictate prioritization. Focusing too much on projects that are "shovel ready" risks perpetuating an imbalance of treating only in areas with existing capacity and not prioritizing areas with high need or opportunities for overcoming feasibility barriers.

- **Predicted departure from historical climate.** Climate change is expected to amplify the effects of stressors and disturbance events in California's forests. Areas with high departure from historical climate may be more at risk of fire and tree mortality and, therefore, more in need of treatments. However, departure from historical climate is only one measure of climate vulnerability; a location with high climatic departure may not be highly sensitive or may have high adaptive capacity to those changes. Furthermore, investing limited resources in areas with significant climate change impacts may have lower benefits that treating other areas where resisting type conversion is more practical.

Our exploration of existing approaches to treatment prioritization revealed several insights. The spatial scale of landscape prioritization varies widely, from approximately 10-acre treatment units (ForSys, Section IV.2) to approximately 150,000-acre watersheds (Washington State DNR, Section IV.3). While small-scale prioritization may result in more precise recommendations for managers, large-scale prioritization can provide the state and regions with broad goals and a starting point for more focused assessments. We found that prioritization was more effective when performed at a regional scale rather than at the state level because ecological and community considerations were more consistent within a region. We recommend that regions identify landscapes in which a coordinated network of treated areas would provide the greatest benefits to the region's identified objectives. Treatment networks at the landscape scale increase continuity among treatments and optimize reduction of landscape fire behavior and effects compared to independent treatments not connected to a network. If a treatment prioritization analysis is conducted at a coarse scale (for example, the Washington State DNR compared watersheds that averaged approximately 150,000 ac per landscape), prioritization should recognize that forest processes occur at finer spatial scales and thus each landscape will contain considerable ecological variation. Finer-grained prioritization efforts should include increased involvement of local managers and stakeholders. Prioritization of small treatment units should also use appropriately detailed data sources. Integrating data products at different spatial scales can raise interpolation and aggregation issues, requiring careful reconciliation of data products.

We recommend embracing an adaptation and resilience framework that recognizes the close ties between social and ecological systems in addition to the importance of increasing the pace and scale of fuel treatments. Social resilience can be achieved in part by adopting the principles of adaptive governance, defined as governance that can nimbly respond to environmental change through flexible institutions and collaborations. Adaptive governance can increase the efficiency, efficacy, and equitability of forest health investments but requires strong initial investments. Forest health projects should focus on increasing adaptive capacity, or the ability to respond during and after change. These up-front investments will increase future efficiency by reducing the need to repeat stakeholder engagement and trust-building with every new forest treatment planning effort. Within current funding mechanisms, such as competitive grants from the Forest Health Grant Program and Regional Forest and Fire Capacity (RFFC) Program, project proponents and project evaluators can assess the socio-ecological aspects of plans along four axes: partnership-building, long-term commitment, building local capacity, and mobilizing traditional ecological knowledge (TEK). These criteria and the rubric presented in Section V.5 provide a significant innovation in evaluating forest health investments for socio-ecological objectives and environmental justice. They complement existing simplified quantitative metrics of environmental justice used by the state, including low-income census tracts, CalEnviroScreen, and American Communities Survey data. The socio-ecological criteria we present also highlight opportunities to adjust funding mechanisms to better match adaptive capacity needs, such as lengthening funding duration and increasing funding for capacity-building and monitoring.

I. Introduction

Forest health investments are a central component of fire mitigation and carbon management strategies and provide multiple co-benefits. With the increasing extent and severity of wildfires and other threats to tree health, such as drought, insect outbreaks, and pathogen irruptions, the importance of forest restoration has elevated in recent years. In 2018, in response to wildfires and historic tree mortality, then Governor Brown issued Executive Order B-26-18 to accelerate forest management and created the Forest Management Task Force (FMTF) to implement the Executive Order and the Forest Carbon Plan. In 2019, soon after the devastating Camp Fire, Governor Newsom issued Executive Order N-05-19 calling for the creation of the 45-Day Report, which identified 35 Priority Projects for fuel reduction. In 2020, amidst the worst wildfire year in state history, the USDA Forest Service and the State of California established a shared stewardship agreement in which each party committed to restoring 500,000 acres of forest and wildlands per year by 2025. Recommendations included in Wildfire and Forest Resilience Action Plan drafted by the FMTF in January 2021 presents steps to achieve that goal.

This report outlines a science-based framework for identifying priorities for forest health investments, as requested by the Forest Management Task Force. The Science Advisory Panel is a body of 19 scientists representing seven California universities, four state entities, two federal agencies, and one non-profit organization. The panel was created in 2019 to provide scientific analysis and advice to California's FMTF. This report is intended to provide guidance to the Task Force, and our recommendations may inform treatment prioritization at the state or regional level. This report is not intended to inform treatment prioritization decisions made at the federal level.

We present panelists' expert opinions on the components of a thorough prioritization analysis. We then review opportunities and data limitations for each component. We then provide an overview of restoration prioritization efforts performed by other government agencies and collaboratives across the Western US. We focus on investments that restore healthy forest structure through prescribed fire or mechanical alterations such as thinning and mastication. These restoration activities are collectively referred to as forest treatments throughout the report. Reforestation after fire is not within the scope of this report.

II. Survey of panelists on prioritization factors

To evaluate the factors important for prioritizing forest health investments, we first developed a list of 14 potential factors from existing prioritization efforts and scientific literature. Each Science Advisory Panel member then quantitatively scored each factor by independently completing a survey. The factors were scored on a scale between one (i.e., "Do not consider in prioritization analysis") and five (i.e., "Strongly consider").

We followed this initial survey with panel-wide discussions of the factors with the least consensus across all members, namely departure from historical forest structure and benefits to disadvantaged communities. We also refined the definitions and details of individual factors, such as water resources and benefits to disadvantaged communities, in small groups with panel members who have disciplinary expertise. After multiple panel meetings and smaller group discussions, we refined a list of factors and their definitions (**Table 1**). We added factors that were absent in the first survey but were suggested for inclusion in panel discussions or survey comments, and we removed factors with an average survey score below three. Clearly defining each factor, how it would be used in prioritization, and its potential metrics helped to improve consistency across panel members' responses.

Table 1. Final factor list used in the second survey of the Science Advisory Panel.

Rank	Factor	Name as listed in survey	Definition	Potential metrics
1	**Treatment design impacts on wildfire**	Prioritize treatment designs likely to have the highest impact on wildfire behavior	How well the proposed treatments will moderate fire severity if a fire does occur	Treatment intensity, size of treated area, type of treatment, spatial continuity of treatments, and linkages with regional treatment efforts.
2	**Fire hazard**	Prioritize treatments in places with high fire risk	Local probability of future severe wildfire outside the historical range of variability for the vegetation type. In frequent-fire forests, fire risk is defined as the potential for severe wildfire that kills the majority of dominant vegetation. In chaparral, fire risk is based on increased fire frequency relative to historical range of variation.	Ignition probability, fuels, forest structure, topography, fire history.

3	**Water quality**	Prioritize treatments that reduce risk to water quality	Local risk of reductions in water quality due to stream sedimentation, organic carbon, nitrogen pollution, and other hydrologiCalFire effects.	WEPP Tool; proximity to streams, proximity to water supply infrastructure (dams, reservoirs, conveyance), proximity to sensitive aquatic habitat
4	**Human development**	Prioritize treatments in places close to human development	Proximity to the Wildland Urban Interface (WUI), roads, and/or critical infrastructure	WUI interface and intermix locations, road networks, electric grid infrastructure, large dams, and other critical infrastructure
5	**Wildlife**	Prioritize treatments in places with important wildlife habitat	Habitat of listed and candidate wildlife species and species of conservation concern. In shrublands, fuel breaks are located near, rather than within, important wildlife habitat.	Range distribution of listed and candidate wildlife species; Forest Service maps of species of conservation concern, CA maps of species of special concern.
6	**Old growth**	Prioritize treatments in places with old growth	Occurrence of old growth forest elements. Depending on vegetation type, these treatments may be applied within high-value forest elements (e.g. giant sequoia groves) or nearby to protect them from fire (e.g. fuel breaks near old growth chaparral).	Distribution maps of groves of old growth trees or shrubs, relic stands, and ancient trees.
7	**Tree mortality risk**	Prioritize treatments in places with high risk of future tree mortality	Local probability of future forest die-off event	Pathogen populations, tree density/basal area, tree species diversity, density of high-risk tree size classes, drought susceptibility.
8	**Environmental justice/social resilience**	Prioritize treatments that increase environmental justice and social resilience.	Benefits to disadvantaged communities and social resilience/adaptive capacity	CalEnviroScreen 3.0; low-income communities; rubric of socio-ecological criteria; future Office of Planning and Research (OPR) Vulnerable Communities Platform

9	**Rare/valued plants**	Prioritize treatments in places with rare and/or highly valued plant communities	Proximity to rare plant communities or valued plant species. In shrublands, fuel breaks are located near, rather than within, important plant communities.	Range distribution of listed and candidate plant species, specially designated botanical areas, ranges of valued/endemic plant species.
10	**Water quantity**	Prioritize treatments that reduce risk to water quantity	Local drought risk, low stream flow risk, and flooding risk	Proximity to water supply infrastructure (dams, reservoirs, conveyance), drought risk models (climate data, forest density, soil), flooding risk (topography, channel characteristics)
11	**Standing dead trees**	Prioritize treatments in places with standing dead trees	Standing dead trees from recent die-off, including hazard trees.	Aerial Detection Surveys; remotely sensed metrics of die-off
12	**Feasibility**	Prioritize treatments with high feasibility	How economically and logistically difficult is it to complete treatments in a given location	Land ownership, road accessibility, local workforce, mill access, permitting
13	**Predicted departure from historical climate**	Prioritize treatments in places where climate is expected to change the most	Predicted future departure from historical climate	Past climate and downscaled future climate models; susceptibility to extreme climate events

We completed a second panel-wide survey to score each factor in this refined list. In the second survey, factors were scored from one to five along two axes: importance and measurability. The results of the second survey are shown in **Figure 1**.

We did not include the carbon benefits from treatments as a stand-alone factor because they are accounted for in the factors related to fire risk, risk of future tree mortality, old growth, and treatment designs likely to have the highest impact on wildfire behavior. These factors are more quantifiable than a forest's long-term carbon outlook given uncertainty in the trade-offs between short-term carbon stocks and fire probabilities (Campbell et al. 2012, Foster et al. 2020). Our framework aims to help decisionmakers identify landscapes and treatment designs likely to have positive effects on fire risk, carbon emissions, and other co-benefits. Only after a site has been selected and a treatment network has been designed can the long-term carbon benefits of a project be estimated (using methods like the California Air Resources Board's carbon calculator).

Similarly, we did not include departure from historical forest structure, despite its presence in some, though not all, other prioritization frameworks (see Section IV). Departure from historical forest structure was included in our initial panel survey, but after a panel discussion we determined that including it would increase redundancy between factors without added value. Local fire hazard, old growth, tree mortality risk, and standing dead trees all capture deviation from historical forest structure. In forest ecosystems, a highly departed landscape would be captured by at least one of these factors. Additionally, departure from historical forest structure is difficult to measure and the definition of "historical" can be contentious. Finally, historical forest structure may not be the best benchmark of ecosystem resilience in an era of rapid environmental change.

The next section of this report provides a detailed definition and description of each factor that the panel identified as important (**Table 1, Figure 1**). We also review available data sources and their limitations, as well as additional considerations raised by the panel. Factors are described in descending order of importance according to panel survey results. The importance rankings (**Figure 1A**) are largely based on panelist knowledge of forested ecosystems, however many of the factors are also applicable to non-forested ecosystems.

We caution that this ranked list of prioritization factors does not constitute a one-size-fits-all framework for forest health investments across California. California's diverse ecosystems, climates, challenges, and communities make it impractical to apply a single framework across the state. For example, the effects of treatments on ecosystem services may be positive in mixed-conifer forests and negative in some areas of chaparral (see Box: Chaparral). We recommend that each region or subregion of the state develop a set of weighted values appropriate to the needs of its ecosystems and communities and use this list of factors as a starting point.

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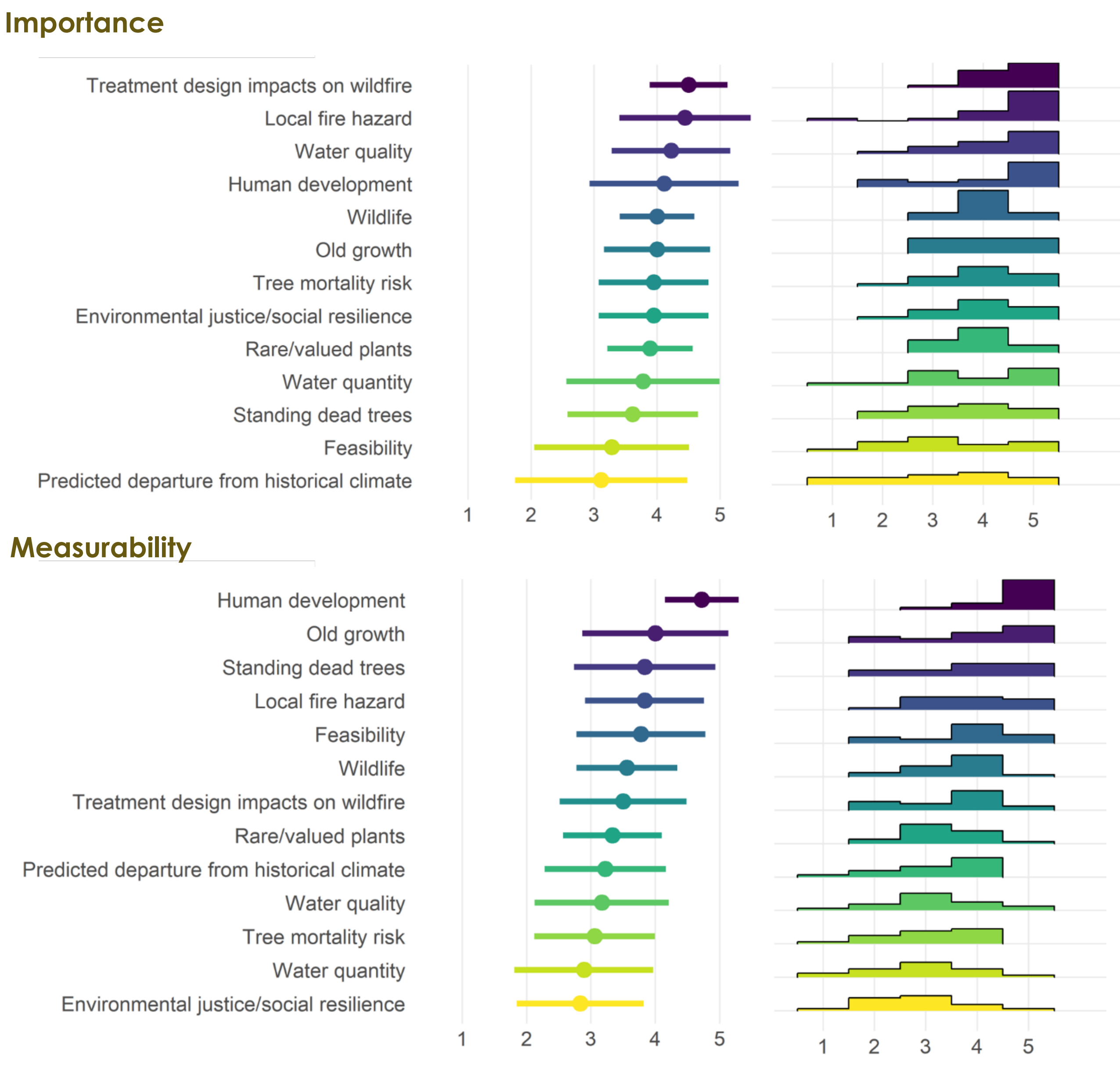

Figure 1. Results of second panel survey to rank individual prioritization factors along importance and measurability. The points and lines show mean and standard deviation of factor scores, while the bars are histograms of individual responses. The factors were scored on a scale between one (i.e., "Do not consider in prioritization analysis") and five (i.e., "Strongly consider").

III. Factors for Prioritization

1. Treatment design impacts on wildfire

A primary benefit of forest health investments is their impact on wildfire behavior. While many prioritization factors inform where treatments are placed geographically to achieve this impact, characteristics of the treatments themselves are also important in determining their benefits and co-benefits. We recommend taking the following treatment characteristics into account when evaluating plans for forest health investment:

- Treatment size
- Type of treatment and its intensity
- Spatial arrangement of treatments within projects
- Continuity of treatments within projects and between proposed project and existing nearby treatments
- Appropriateness of the treatment for the local fire regime and expected fire conditions

Most current funding structures for forest health investments do not require synergy between projects; however, to increase continuity among treatments and optimize reduction of landscape fire behavior and effects, a landscape approach must be developed. Project proponents should demonstrate that the prospective treatments are part of a coordinated network of treated areas that are placed strategically to maximize effects on high-severity fire. Although landscape-scale treatment effects can be difficult to precisely quantify and predict, existing basic understanding should be incorporated. For instance, a network may maximize effects on high-severity fire by designing treatment networks in a pattern that slows down fire spread (Finney 2001) or by placing the highest intensity treatments in areas with the highest fire hazard (Krofcheck et al. 2017). However, certain situations, such as protection of critical infrastructure, cultural sites, or other high-value assets, may justify a lack of synergy with other projects.

Project designs must be appropriate to the local fire regime. For example, to maximize treatment modification of fire behavior in frequent-fire forests, treatments should focus on reducing surface and ladder fuels in that order. In chaparral, however, fuel treatments should consist of fuel breaks that aid more effective fire suppression activities, though this may need to be balanced with other conservation goals. Local drivers of fire severity may also be considered; for instance, in areas where Santa Ana winds are common, fuel breaks may have limited capacity to slow fire spread or aid suppression efforts, and other strategies such as ignition control or investments in community preparedness may be more important than fuel treatments.

Treatment design interacts with treatment feasibility, as projects are evaluated before they are executed and are not always completed at the proposed size and intensity. For the most accurate evaluation of treatment design and impact, projects should demonstrate that they are feasible, including securing any needed environmental documents required under local, state, or federal jurisdictions, unless funding mechanisms include resources for securing necessary assessments and approvals. However, as discussed in Section III.12, feasibility should not solely dictate prioritization; over-emphasizing projects that are "shovel-ready" risks ignoring areas with the highest need along other axes like fire risk, ecological values, and cultural resources.

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Box: Chaparral

California contains diverse fire-adapted landscapes, each with unique fire regimes, drivers of change, and potential solutions. Understanding the differences between these ecosystem types is critical to addressing California's fire challenges. Shrublands represent 37% of the total area burned in California between 2000 and 2020 – more than conifer forests, which comprise one third (Calhoun et al., in review). Chaparral is one of the most important California ecosystem types because it encompasses much of the state's biodiversity (Rundel 2018, Jennings 2018) and reaches peak abundance in southern California, where many of the most damaging wildfires occur. Despite its significance, chaparral is frequently misunderstood when it comes to its relationship with fire. Unlike other ecosystem types in the state, fuel treatments and long-term ecological resilience are often antagonistic.

To date, forest health investments have tended to focus on conifer forests, but these ecosystems have different fire regimes from chaparral. In many dry conifer forests in California, the pre-colonial fire regime was characterized by frequent, low- and mixed-severity wildfire, which maintained low fuel densities. Fire suppression and active exclusion of indigenous land stewardship has decreased the frequency of fire and caused a buildup in fuels which, along with climate change, lead to more extreme wildfire behavior. Chaparral, on the other hand, historically burned at moderate frequencies (every 30-90 years) in stand-replacing fire events (Van de Water and Safford 2011). Chaparral species are well-adapted to recover from infrequent severe fire, however in recent decades, the extensive wildland urban interface and high population density of southern California has resulted in excessive human ignitions (Keeley and Fotheringham 2003, Syphard et al. 2007) thereby challenging post-fire recovery. In chaparral, short interval fires threaten ecosystem integrity because some shrubs are unable to reach maturity and develop an adequate seed bank in between fire events (Zedler 1995) and often frequently burned areas begin to convert to landscapes dominated by annual invasive species.

Unlike in conifer forests, fuel treatments in chaparral often do not restore ecosystem integrity and prescribed fire is generally undesirable because it exacerbates the fire frequency problem (Safford et al. 2018), though there are circumstances where cultural burning in chaparral can restore vegetation structures to a fine-grained mosaic by burning under moderate fire weather and harnessing Traditional Ecological Knowledge (TEK; Hankins 2021). Generally, there are fewer opportunities for "win-win" scenarios that promote ecological integrity and reduce fire risk to neighboring communities. Recognizing this trade-off, the guiding principle in chaparral has been to emphasize vegetation modification activities in strategic locations surrounding the wildland urban interface (WUI) and critical infrastructure. In these cases, fuel breaks where woody vegetation is removed may help facilitate fire suppression operations. While fuel treatments themselves may be considered sacrifice zones because they are often dominated by non-native species, they can serve to protect watersheds and neighboring lands from impacts due to future wildfire.

Many of the most devastating fires in southern California shrublands occur during extreme weather events (e.g., Santa Ana winds; Jin et al. 2015), which reduce the efficacy of fuel breaks (Faivre et al. 2016). Therefore, management considerations should be expanded beyond fuel modification and should include education, ignition prevention especially along roads and powerlines, home hardening, evacuation planning, improved zoning, and strategic community planning (Keeley and Syphard 2020).

In this report, we incorporate the unique needs of chaparral into our 13 prioritization factors, but we recognize that our panel survey results and prioritization rankings would be different if we asked the panel to respond only in the case of chaparral. We recommend that regions of the state that are primarily challenged by chaparral fires consider each prioritization factor independently based on their local fire regime and determine management values and objectives that balance the needs of the local communities with those of chaparral ecosystems.

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2. Local fire hazard

A primary goal of forest health investments is to reduce fire hazard. While the terms fire hazard and fire risk have a range of definitions (Hardy 2005), in this report we use fire hazard to describe the combination of the likelihood and intensity of fire (https://wildfirerisk.org/understand-risk). Likelihood is the annual probability of a wildfire burning in a specific location, while intensity is the energy expected from a wildfire, often expressed as flame length. Intensity is related to severity, which measures how much of the dominant vegetation is killed by fire. Areas with high fire likelihood and high fire intensity have high fire hazard. Note that hazard does not describe community outcomes such as buildings destroyed. For a complete assessment of fire risk to communities, one must combine exposure – the spatial coincidence of likelihood and intensity with communities – with vulnerability – the propensity of a home or community to be damaged if a wildfire occurs. More discussion of fire risk to communities can be found in Section III.4.

Treatments should be prioritized in locations with high pre-treatment fire hazard in combination with other factors. More precisely, priority should be given to areas where the potential for ignition is high and expected future wildfire intensity and severity are outside the historical range of variability for the local vegetation type. In frequent-fire forests like those of the Sierra Nevada, treatments should be prioritized where there is high likelihood of severe and/or intense wildfire characterized by rapid spread and/or high mortality of large trees. While lower-severity wildfire is integral to the ecology of many Sierra Nevada forests – providing benefits to some ecosystem services – and presents low risk to valued assets, high-severity fire presents major risk of ecological and societal damage.

Unlike frequent-fire forests, many California shrublands should be prioritized for treatments based on projected fire frequency and risk to communities and infrastructure rather than severity. High-severity fire is typical of chaparral ecology but is problematic when it occurs in short intervals that do not allow normal shrub recovery, or when it spreads to human-occupied areas (see Box: Chaparral).

Fuel, forest structure, topography, and fire history can help predict where a wildfire would likely result in severe fire effects. CalFire maps fire hazard according to these risk factors within the State Responsibility Area (SRA) using Fire Hazard Severity Zones (FHSZs). These FHSZs predict structural damage with good accuracy in most California wildfires; of the structures that were destroyed by fire 1985-2013, 78% were in the "Very high" risk zone, 13% were in the "High" risk zone, and 6% were in the "Moderate" zone (Kramer et al. 2019). However, in the Tubbs fire, FHSZs did not align with structure losses: only 5% of destroyed buildings were in the "Very high" zone and the most destruction occurred in the "Urban unrated" (39%) and "Moderate" zones (33%). Poor performance of FHSZs in the Tubbs Fire may be related to the strong winds driving the Tubbs Fire and high nearby housing density. Improvements to the incorporation of wind patterns into FHSZs may be required to accurately capture areas with extreme winds, such as Santa Ana, Sundowner, and Diablo winds. Fires driven by Santa Ana winds substantially alter fire behavior, shift the predictors of burn severity, account for a disproportionate share of economic losses, and are expected to increase in burned area this century (Faivre et al. 2016, Jin et al. 2015). In order to improve the accuracy of FHSZs, better monitoring of surface and ladder fuels is needed; this is an active area of research (Prichard et al. 2019).

Understanding where fire intensity intersects with high ignition probability can help identify high-hazard areas. As most modern wildfires in California are ignited by humans (Balch et al. 2017), ignition probability can be estimated using maps of housing, roads, and topography. If available, historical ignition patterns can be used to estimate ignition frequency (Faivre et al. 2014). Powerline ignitions are a special case because they tend to occur under high winds when fire behavior is often most extreme (Keeley and Syphard 2018). As a result, powerline ignitions account for a small proportion of fires but a disproportionate share of area burned and damage to communities. Fuel reduction in likely wind corridors between powerlines and communities may increase opportunities for evacuation and fire suppression effectiveness. Weighing ignition risk from powerlines more highly than other ignition sources when developing fire hazard predictions may increase accuracy. The CPUC Fire-Threat Map (https://ia.cpuc.ca.gov/firemap) delineates areas of "Elevated" and "Extreme" risk of powerline fires. However, in parts of Southern California where chaparral-dominated areas are at risk of Santa Ana winds, fuel treatments may provide little protection against fire (Faivre et al. 2016), and investments in undergrounding powerlines and home hardening or strategic community planning may be needed.

While FHSZs are the most commonly used data source for fire hazard on state and private land in California, several other fire hazard maps can inform forest investments in both state and federal responsibility areas. US Forest Service (USFS) products like the Wildfire Hazard Potential map (https://www.fs.usda.gov/rds/archive/Catalog/RDS-2015-0047-3) and the Wildfire Risk to Communities map (https://wildfirerisk.org/) provide fire hazard ratings across the entire US. (Note that the Wildfire Risk to Communities map provides estimates for both fire risk, which includes community exposure and vulnerability, as well as fire hazard, which is independent of proximity to communities). Unlike FHSZs, these USFS maps are developed using fire behavior simulation modeling, with past fires and LANDFIRE vegetation and fuels data as inputs. The Wildfire Risk to Communities map provides detailed metrics at 30-m resolution, including burn probability, defined as the annual probability of wildfire burning at a specific location, and conditional flame length, defined as the most likely flame length at a given location if a fire occurs. However, there may be tradeoffs between the large spatial scope of these USFS maps and the accuracy of their local to regional predictions.

Forest die-off in the past decade is likely to affect wildfire behavior in the coming decades. High densities of dead trees are predicted to increase the risk of poorly understood "mass fires," which result from expansive areas of large, slow-burning fuels. Potential evidence of the early consequences of tree die-off on fire behavior was seen in the 2020 Creek Fire of the Southern Sierra Nevada, which burned 380,000 acres and 856 structures. Because of the unprecedented nature of forest mortality in the past decade, its exact consequences are unknown and cannot yet be incorporated into today's fire behavior models. We therefore discuss standing dead trees as a separate prioritization factor in Section III.11 below.

Though fire risk ranked high in importance according to our panel-wide survey, responses were not unanimous. One concern was that maintenance of existing treatments and fuel breaks should be prioritized above new projects. If an existing treatment lowers an area's fire risk but requires maintenance to remain effective, it should not be penalized in funding decisions – which may occur if fire risk were the only consideration for prioritization. Setting aside resources for maintenance treatments would help rectify this concern.

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3. Water quality

Overview and definition

High severity fire can have devastating impacts on water quality (Smith et al. 2011, Neary et al. 2009, Bladon et al. 2014). Sediment flux from watersheds is often orders of magnitude greater following fire and regularly damages water supply infrastructure by clogging intakes and reducing reservoir capacity (Shakesby and Doeer 2006, Moody and Martin 2009). High sediment yields can also impact aquatic ecosystems; for example, certain fish species are particularly vulnerable when sediment impacts spawning grounds. Post-fire water quality may also reflect the mobilization of nutrients, heavy metals, organic matter, ash and other constituents that can be damaging for both water supply and aquatic ecosystems (Abraham et al. 2017, Burton et al. 2016, Shakesby and Doerr 2006, Rust et al. 2018). Water quality impacts of high severity fire are typically short lived, diminishing in the first 5 years following fire. Notably, however, water quality impacts are often associated with peak flows following high intensity storm or snowmelt events, which may increase in frequency in the next decades (Sankey et al. 2017).

Relevance to forest treatments

Forest treatments that reduce fire severity can reduce the risk of high-cost water quality impacts. A stream's "contributing areas" are parts of the landscape that are hydrologically connected through surface or subsurface water flows to the stream. Prioritization of forest treatment for water quality objectives should focus on stands in the contributing areas of vulnerable water supply infrastructure (such as a dams and other transport infrastructure; see e.g., Gannon et al. 2019) as well as contributing areas of endangered fish, amphibian or other aquatic habitat (Nunes et al. 2018). Key areas can be identified by combining estimates of risks of sediment loss with mapping of downslope/downstream vulnerable human and aquatic resources (see Thompson et al. 2011 for example of data types that could be used).

Treatments that protect the integrity of riparian areas may reduce the risk of water quality impacts. Riparian forests contribute to water quality in multiple ways. Shading by riparian trees maintains lower summer temperatures that can be critical for fish habitat. Intact riparian zones can also reduce water quality impacts of upslope fire (Isaak et al. 2010). Riparian areas may burn with higher or lower severity relative to uplands, depending on vegetation, climatic, and topographic characteristics (Dwire et al. 2016). Although fires have occurred within riparian areas, less is known about both fire and treatment effects in riparian areas relative to upslope areas. At present, fuel treatments are rarely done in riparian zones due to a variety of legal restrictions that limit disturbances within riparian areas. Many of these policies were designed to maintain water quality. However, overstocking of riparian areas does occur and, in some cases, may warrant fuel treatments (Van de Water and North 2010). In addition, riparian areas with an abundance of non-native species (e.g. *Arundo donax*) may warrant treatment to encourage proper functioning and reduce fire effects and spread (Coffman et al. 2010). In these cases, fuel treatment practices must be designed to reduce disturbance-related impacts on water quality.

Data and tools

Field based assessment of post-fire sediment loss are limited, reflecting the infrequent but high severity characteristics of these events. Tools for estimating the risks of sediment loss generally consider vegetation cover (and its changes with severe fire), climate, and site geologic and topographic characteristics. The Water Erosion Prediction Project (WEPP) and associated Erosion Risk Management Tool (ERMiT) are widely known and used. While these tools are state-of-the-science, significant uncertainties are associated with the prediction of post-fire sediment and other water quality contaminants (Miller et al. 2011, Nunes et al. 2018). With more monitoring data, including the use of high-resolution remote sensing (e.g., Staley et al. 2018), improvements are expected in the accuracy of parameterization and process representation in models used to estimate post-fire debris flow and sediment flux risk. These innovations will help improve prioritization.

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4. Proximity to human development

Overview, definition, and relevance to forest treatments

Wildland fires are more expensive to suppress and have more severe societal impacts when they are close to human development, roads, and/or critical infrastructure. Proximity to human development also contributes to fire risk via increased ignitions (see Section III.2). Forest health treatments near human development may have greater long-term benefits on suppression expenditures, costs incurred, societal damage, and lives lost than treatments in remote areas. Some state programs, such as CalFire's Fire Prevention Grants, specifically target community fire safety. Unlike Fire Prevention Grants, forest health investments should not be prioritized solely based on community safety; however, proximity to human development may be one of several guiding factors. In this section, we discuss special considerations for fire hazard near communities, such as the wildland urban interface (WUI), along with critical infrastructure including dams, electrical infrastructure, and communication systems.

Data and tools

Human development is among the most measurable prioritization factors (**Figure 1**). A commonly used data source for human development is the wildland urban interface (WUI) map created by the SILVIS project (Radeloff et al. 2005; http://silvis.forest.wisc.edu/data/wui-change). These data are based on the WUI definition from the Federal Register (USDA and USDI 2001), in which WUI is the areas where "houses meet or intermingle with undeveloped wildland vegetation." Intermingling areas are referred to as "intermix WUI" while developed areas that abut wildland vegetation are "interface WUI." The SILVIS lab combines census data with vegetation data from the US Geological Survey (USGS) National Land Cover Data (NLCD) to map intermix and interface WUI.

CalFire Fire and Resource Assessment Program (FRAP) uses an internally developed WUI data layer (https://frap.fire.ca.gov/mapping/gis-data/). Rather than census data, the FRAP methodology uses remotely sensed nighttime light emissions as a proxy for human density. Nighttime light emissions data are summarized into a map grid using methods guided by the West Wide Wildfire Risk Assessment (Wolf et al. 2013). The dataset categorizes WUI areas along three axes: housing density class, Fire Hazard Severity Zone (FHSZ; see Section III.2); and interface/intermix/influence. The Wildfire Influence Zone is defined as vegetation up to 1.5 miles from interface or intermix WUI that are susceptible to wildfire. This multivariate approach allows for stratification of WUI according to both threat (fire hazard) and assets (housing). The FRAP layer is also at finer spatial resolution than the SILVIS data. An updated FRAP WUI layer is currently under development, along with an improved FHSZ layer.

When prioritizing treatments close to human development, simple distance metrics could be used (as in the eastern Washington prioritization methods, described below in Section IV.3). Alternatively, prioritization could take advantage of more complex measures of fire transmission from wildlands to communities. If a fire originates in public lands far from the WUI and then travels to the WUI, then treatments near the fire's origin might be a more efficient way of reducing WUI damage than treating near the WUI. Wildfire transmission analyses can help identify where forest treatments may result in the largest reductions of wildfire transmission to communities. For example, the Fireshed Registry, developed by scientists at the US Forest Service Rocky Mountain Research Station (RMRS), models wildfire transmission to communities and identifies areas where the most destructive fires originate (Evers et al. 2020). The Fireshed Registry was developed using outputs from fire simulations using the model FSim across thousands of iterations (**Figure 2**; Ager et al. 2019). Results show that 80% of exposure can be treated in less than 2 million acres of forest in California (Ager 2020). Data on community wildfire risk and wildfire transmission from national forests to communities are also available in the All Lands Wildfire Risk Portal (https://arcg.is/1uqW9C), which uses a similar methodology to the Fireshed Registry. Another approach to quantifying community fire risk comes from the Wildfire Risk to Communities project (See Section III.2). This tool combines data on communities with fire hazard, defined as the combination of wildfire likelihood with wildfire intensity, to identify community exposure to wildfire.

The Healthy Forest Restoration Act (HFRA) of 2003, which authorized local Community Wildfire Protection Plans (CWPPs), stipulates that WUI treatments extend only ½ mile past a community boundary or 1½ mile under mitigating circumstances. However, landscape-scale risk to communities from large fires, which can spread tens of miles from their origins, may extend far beyond this WUI boundary. For example, one modeling study of Washington and Oregon showed that less than half of the area contributing to wildfires in the WUI was analyzed in CWPPs (Ager et al. 2016). The same study found that 78% of the WUI area exposed to modeled wildfires resulted from ignitions outside of wilderness, roadless reserves, or other conservation or amenity areas created as part of national forest plans. In other words, wildfires originating in protected areas do not pose the greatest threat to communities. While previous analyses have shown that fuel treatments are tightly constrained by regulatory barriers and protected area designations in national forests (North et al. 2015), these results suggest that protected areas may be lower priority for treatment than other areas, assuming an objective of reducing risk to communities.

Damage to critical infrastructure like large dams, electrical infrastructure, and communication systems can also have downstream impacts and make disaster response more dangerous and difficult. Geospatial information about large dams can be found in the National Inventory of Dams, https://catalog.data.gov/dataset/national-inventory-of-dams. Data on communication infrastructure such as cellular towers is also publicly available (https://catalog.data.gov/dataset/cellular-towers). Data on electrical infrastructure is less publicly available and may need to be obtained from utilities or from the Public Utilities Commission. Additionally, risk to transportation infrastructure is an important consideration for treatment prioritization in WUI communities with road network characteristics limiting safe and rapid evacuation (Dye et al. 2021).

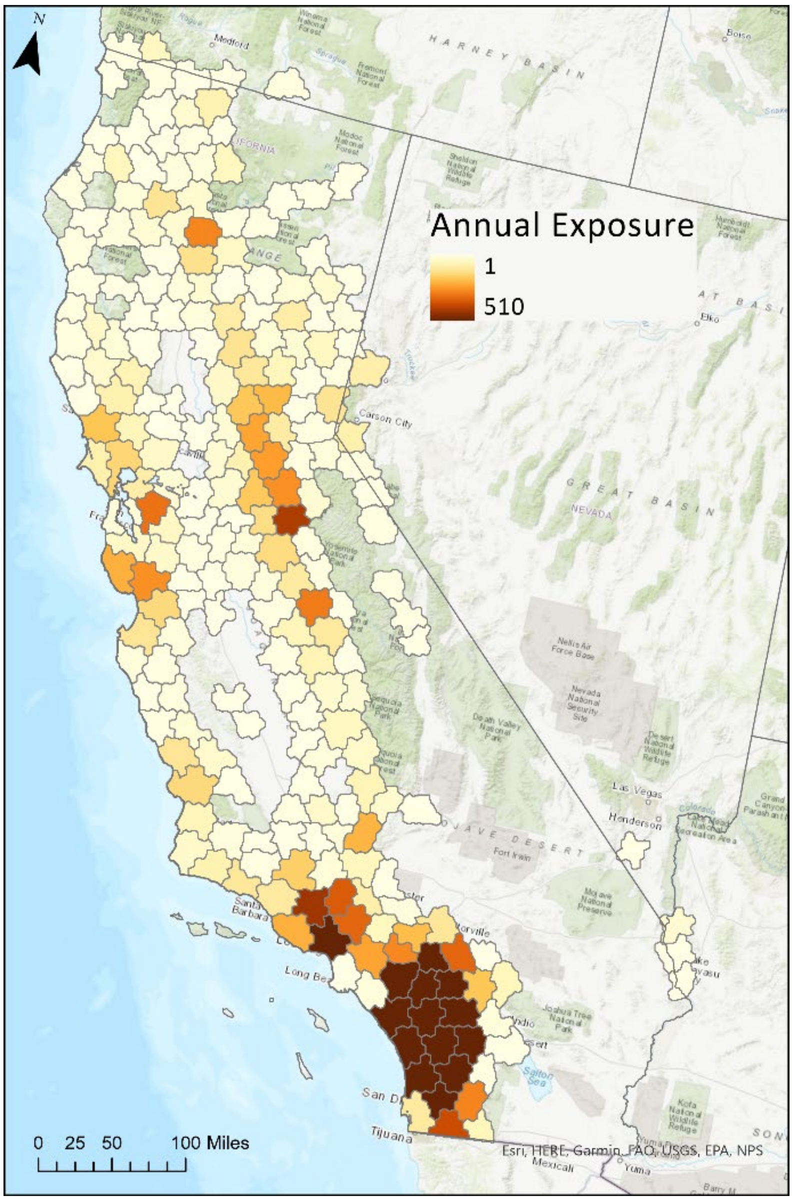

Figure 2. Firesheds from the Fireshed Registry colored according to community wildfire exposure originating from that fireshed. Annual Exposure refers to the total annual number of modeled buildings exposed to wildfires ignited within the fireshed across 10,000-100,000 simulated fire seasons. Firesheds with Annual Exposure below 1 are excluded from the map.

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5. Wildlife habitat

Overview and definition

In California, 173 animal species are protected at the state and/or federal level. Among these are well-known forest-dependent species such as the northern spotted owl, Pacific fisher, Humboldt marten, and marbled murrelet. Forest treatments have the potential to benefit important wildlife habitat in both the short and long-term.

Fine-scale forest heterogeneity and pyrodiversity are important for achieving both forest resilience (Koontz et al. 2020) and biodiversity objectives (White et al. 2013, Tingley et al. 2016). However, dense and even-aged stands have increased in many of the dry coniferous forests of the western US; this has been driven in part by fire suppression management objectives as well as single-species management targeting umbrella species of high conservation concern (White et al. 2013). Considering that pyrodiversity and forest heterogeneity promote biodiversity across taxa as well as resilience of habitat for species of conservation concern, forest health and restoration treatments can provide opportunities to both increase diversity of habitats and wildlife species, while also improving long-term persistence of key species of conservation concern.

Relevance to forest treatments

In seasonally dry forests, projects to restore and improve forest health can benefit sensitive species by enhancing resilience of their habitat to wildfire and drought disturbance (Stephens et al. 2020) and by preventing type conversion. Large, severe wildfire disturbance can lead to local extirpation of (Jones et al. 2016) and avoidance by (Thompson et al., *in press*) forest-dependent species, with long-term population implications (USFWS 2020). Treatments that modify forest structure may also result in short-term effects to sensitive wildlife species if they remove or alter key habitat elements (Scheller et al. 2011, Jones 2019). Many wildlife species rely almost exclusively on old-growth forest conditions, such as the marbled murrelet that needs complex crowns with cavities and wide, developed branches in old coast redwood and Douglas-fir trees (Ralph et al. 1995). Other species such as spotted owls will also use second-growth forests, but prefer older forests with more multilayered canopies and complex tree structures (Hunter et al. 1995). Thinning to reduce fuel build-up and water stress may reduce canopy cover that is preferred by some sensitive species. However, given the threat of large-scale severe disturbance to sensitive species, short-term impacts of forest management may be outweighed by longer-term benefits if key habitat elements can be maintained (e.g., Jones et al. 2018, Jones 2019). Further, management to increase forest resilience to disturbance may also increase structural and prey diversity for sensitive species, with potential population level benefits (Hobart et al. 2019, 2020).

Improved data sources (e.g. LiDAR) have allowed for the refinement of habitat selection metrics, which suggest that species that evolved in frequent-fire forests, like the California spotted owl, may preferentially select forest structures that would have been more prevalent prior to fire suppression and will require management to restore. For example, California spotted owls select for large and tall trees and avoid canopy cover in the lower canopy (North et al. 2017). California spotted owls also select for recent lightly burned areas, which would have been common prior to fire suppression, and avoid large areas of high severity fire, which would have been rare prior to fire suppression (Kramer et al. 2021, Jones et al. 2020). Even blackbacked woodpeckers, which are a severe-fire dependent species, select for more heterogenous landscapes and patchy fire effects that were common prior to extensive fire suppression (Stillman et al. 2019).

Data and tools

Nationwide maps of wildlife ranges, predictions of habitat distribution, and locations of critical wildlife habitat are available via projects such as the US Geological Survey Gap Analysis and US Fish and Wildlife Service Critical Habitat. The latter, however, only contains data for species listed under the Endangered Species Act; the former is intended for landscape level assessments, as the maps may not consistently capture rare habitats. The California Department of Fish and Wildlife's Areas of Conservation Emphasis maps include biodiversity metrics based on searchable lists of native and rare species richness. The California Natural Diversity Database (CNDDB) contains an inventory of rare plants and animals in California and their locations. The CDFW also maintains the Wildlife Habitat Relationship information system, which provides geographic range and habitat relationship data for over 700 species known to occur in the state and allows users to assess species' occurrence and habitat suitability ratings under specified habitat scenarios.

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6. Old growth

Overview and definition

Old growth forests offer disproportionate benefits for wildlife habitat and climate mitigation and adaptation, in the form of carbon storage, as well as cultural benefits. The term "old growth" does not have a single consensus definition, but generally refers to forests that have never been harvested for lumber or other intensive resource extraction and retain features that develop on the scale of centuries rather than years or decades, including complex crown structures on individual trees and structural diversity (Franklin et al. 2002). The term is also sometimes used to refer to individual large, old trees, which range from individuals that have been around for several hundred years to millennia in California forests.

In addition to the wildlife value of old growth described above in Section III.5, old-growth forests play an outsized role in natural lands-based strategies to combat climate change because of how much carbon they can store. Although there is some evidence that tree-level growth efficiency wanes in older, larger trees (Sillett et al. 2020), their sheer size means that an individual old growth tree's contribution to a forest's carbon storage in just one year as is comparable to the carbon stored in an entire mid-sized tree (Stephenson et al. 2014). Consequently, the total amount of carbon stored in old-growth forests is generally much greater than in younger forests (Sillett et al. 2020, Stephenson et al. 2014). California is also home to two of the forest types that store the most carbon per acre than any other forest type, due to their exceptional size and longevity: coast redwoods (up to 982 tons per acre) and giant sequoia (up to 613 tons per acre) (Sillett et al. 2019, 2020). The retention of old-growth forests on the landscape is likely to have a greater carbon benefit per acre than reforestation over the next several decades, a critical window to act on nature-based solutions (Moomaw et al. 2019).

Due to extensive timber harvesting after Euro-American settlement, old-growth forests are relatively rare across the landscape. The vast majority are restricted to wilderness areas, state and national parks and specially designated management areas on U.S. Forest Service land (e.g. Late Successional Reserves); some private timber lands also have Late Successional Forest Stands that are subject to some level of protection under California's Forest Practice Rules.

The exact extent of old-growth in California has not been well documented spatially, though a few regions and forest types are better documented than others. Estimates made in the 1980s suggest only ~20% of the forested areas in the Siskiyou region of California are old-growth; given that some old growth harvests continued after that time, the current number is most likely lower (Bolsinger and Waddell, 1993). In coast redwood forests, only 5% of the original 2.2 million acres remains (Burns et al. 2018). On the US Forest Service lands in the Sierra Nevada, roughly 6% is high quality old-growth forest, with 18% comprised of moderate quality old-growth forests, meaning forest that has retained some old-growth trees or contains advanced second growth (Sierra Nevada Conservancy, 2017). Advanced second growth includes older second-growth forests that are beginning to develop some old growth characteristics in terms of structural complexity.

Relevance to forest treatments

Given the limited extent of old growth forests, their exceptional carbon storage capacity, importance for wildland, and that their characteristics develop on the order of centuries to millennia, ensuring their persistence should be a high priority.

The type and severity of threats to their persistence depends on the forest type and its historical relationship to fire. Many old-growth forests in California are in higher elevation wilderness areas, in forest types (e.g., red fir, lodgepole pine) that less often overlap with the wildland urban interface; they also historically had longer fire return intervals than lower elevation forests, which in turn means that they are likely less severely departed from a fire resilient condition. In these areas, allowing lightning strikes to burn under the right conditions for fuel reduction benefits will be critical to foster future resilience under climate warming.

Old-growth stands that are most at risk from severe fires are those in lower elevation, historically frequent-fire mixed conifer forests, where the interaction of climatic and fuels conditions is regularly conducive to severe fire effects. Despite their adaptations to regular, low to moderate severity fires, these forests are increasingly burning at high severity, which equates with total loss of old-growth characteristics. Giant sequoia, which live to up to 3,000 years old, are the quintessential fire-adapted species with thick insulating bark, self-pruning branches and cones that are cued to open via the heat from fire. Yet in the past five years they have been impacted by four large fires with substantial components of high severity that are well outside of the historic range of variability, killing many large trees that are likely thousands of years old (Shive et al., *in prep*, Stephenson and Demetry 1995). In the 2020 Castle Fire, approximately 16,000 acres of giant sequoia grove area burned, nearly 40% of it at high severity, killing potentially thousands of ancient trees that likely experienced 100s of fires in their lifetimes.

The importance of old-growth forests for carbon and habitat suggests that these forests should be a high priority for fuels treatments. Within old-growth, priorities should be considered in terms of relative fire risk and current and potential carbon storage. In addition to unlogged old growth stands, advanced second growth forests which have had time to grow larger trees and begin to accumulate some of the other old growth characteristics should also be prioritized for treatments that can reduce the risk of severe wildfire.

Unlike old growth forests, fuel treatments in old growth stands of chaparral is undesirable. Old growth chaparral is prized for carbon storage, and it supports a unique assemblage of species, including lichens and wildlife. The commonly held view that old growth chaparral is decadent or at risk to senescence has not been substantiated in the literature (Zedler 1995).

The CalFire fire history map (https://frap.fire.ca.gov/mapping/gis-data/) can be used to delineate ancient stands (>90 years old, defined by Keeley et al. 2005) of chaparral for avoidance in vegetation management projects. Over the past decade extensive patches of ancient chaparral have been consumed by fire and therefore mature stands (> 50 years old) are becoming increasingly important to preserve on the landscape.

Data and tools

There are a variety of data sources and tools to support identifying old-growth forests. The Sierra Nevada Conservancy hosts Sierra Nevada Old Growth, which ranks old-growth forests in the region by structural complexity and contribution to late successional forest function. Gradient nearest neighbor (GNN) forest structure maps (created and hosted by the Landscape Ecological Modelling, Mapping and Analysis lab at Oregon State University) do not identify old-growth specifically, but do predict the location of forests dominated by large trees and could be used where other old-growth data does not exist. GNN maps could also be helpful for identifying advanced second growth supports. GNN predictions are based on relationships between ground (response) data and mapped (explanatory) data. The current dataset is from imagery acquired in 2012, but a 2017 dataset is complete and expected soon.

Mapped giant sequoia grove boundaries in the Sierra Nevada are hosted by the National Park Service Integrated Resource Management Applications Data Store. These include approximate bounding polygons of sequoia groves in Yosemite National Park, Sequoia and Kings Canyon National Parks, Sequoia National Forest, Sierra National Forest, Stanislaus National Forest (Calaveras Big Trees State Park), and Tahoe National Forest. The current grove boundaries include administrative buffers on most of the groves that occur in the Giant Sequoia National Monument, which were inconsistently applied. As of January 2021, the USFS Remote Sensing Application Center is working with the US Geological Survey to use remote sensing products to refine grove boundaries.

Maps of coast redwood old-growth have been created and are hosted by Save the Redwoods League. The dataset was created from a combination of field data and aerial imagery and is available by contacting smorris@savetheredwoods.org.

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7. Tree mortality risk

Overview and definition

Mass tree mortality events have become increasingly common across the globe in recent decades (McDowell et al. 2008, Allen et al. 2010). Tree die-off events are often linked to droughts, which themselves are becoming hotter and are more likely to increase in frequency as average and extreme temperatures continue to increase (Williams et al. 2013, Allen et al. 2015, IPCC 2014, He et al. 2018). The California drought of 2012-2016 included historic dryness and warmth (Swain 2015); the extended aridity of this drought generated progressive canopy water stress that ultimately induced a massive wave of tree mortality, particularly in the Sierra Nevada (Asner et al. 2016, Young et al. 2017).

It is important to recognize that drought itself does not necessarily directly kill trees; drought-stressed trees are more vulnerable to biotic agents such as bark beetles and disease agents such as root rots or stems rusts (Anderegg et al. 2015, Kolb et al. 2016). Tree stress can also be exacerbated by competition due to high stand density and basal area, increasing evapotranspiration and competition for water and thus increasing trees' vulnerability to pests and pathogens. This combination of stressors diminishes tree vigor over time, thereby increasing the likelihood of mortality (Axelson et al. 2019a).

Bark beetles are responding to enhanced tree stress at the landscape level and pose a serious threat. The role of bark beetles in the 2012-16 drought mortality is undeniable (see Stephenson et al. 2019 and Fettig et al. 2019) and the tight coupling between moisture, competition, and bark beetles is well known. This relationship is complicated by continued pressure from bark beetles after the drought ends. In the Sierra Nevada, elevated tree mortality continued for several years after the 2012-16 drought, likely due to the lag for trees to recover from drought stress and active bark beetle populations remaining in the system until their populations eventually declined. This pattern was particularly strong for the fir engraver beetle, which attacks true firs such as red fir and white fir (Axelson et al. 2019b).

When considering future tree mortality in California, measures of moisture stress and vulnerability (such as climatic water deficit, deep soil drying, canopy water loss, and vapor pressure deficit) must be considered in relation to location (latitude, slope, aspect), forest composition and structure, and of course exposure to biotic disturbance agents (bark beetles, pathogens). Certain stand and landscape characteristics that can be assessed with remote sensing may help to identify areas at risk of mass mortality. Greater tree mortality has been linked to factors such as multi-year deep soil drying, areas with greater basal area during a drought, overall hotter and drier conditions, and density of stands (Young et al. 2017, Goulden and Bales 2019).

Relevance to forest treatments

In productive Sierra Nevada forests, mortality during and following the 2012-2016 drought was highest in forests that were both more affected by moisture deficit (i.e., drying) and denser (Young et al. 2017, Goulden and Bales 2019), suggesting that forest treatments to reduce tree density and basal area may reduce risk of massive tree die-off and possibly severe wildfire, especially where dense, rapidly growing forests experience warming and drying (Tague et al. 2019). For example, Restaino et al. (2019) found that while larger pines were more likely to die due to size-selection by bark beetles, individual trees in sites previously treated by prescribed fire or mechanical thinning were less likely to die. This illustrates the positive effect of stand treatment to reduce basal area and thus competitive dynamics within stands, allowing trees to be more resistant to drought stress and bark beetle attack. However, some forests that are vulnerable to tree die-off because of warming and drying may be so deviated from a resilient condition that treatments are unable to prevent die-off. In such cases, investments may be better spent in less vulnerable forests. A more thorough discussion of this argument is presented in Section III.13.

While water deficits seem to be a strong predictor of mortality in the low elevation forests that have also experienced the greatest densification, temperature may be a more important factor in high elevation forests that also have naturally long fire return intervals (Das et al. 2013). This result suggests that forest thinning might be less helpful in higher elevation forests. Much of the recent work on tree mortality in California has focused on Sierra Nevada forests. It is critical to bear in mind that drought is not the only driver of tree mortality in all California forests. For example, non-native biotic drivers such as sudden oak death, polyphagous shot hole borer, and gold spotted oak borer can have a large effect on mortality patterns in their multiple host species with or without drought impacts.

Data and tools

Unfortunately, tools for predicting forest die-off are limited. Collaboration between researchers working at different scales (i.e., stand to landscape) is needed that synthesizes field studies into a regional tool or map showing probability of future mortality. The best available tool is currently the National Insect and Disease Risk Map (https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/national-risk-maps.shtml), but this national tool lacks predictive power at the scale of individual regions. The USFS Region 5 produced a map of priority areas at high risk of tree mortality (https://usfs.maps.arcgis.com/apps/webappviewer/index.html?id=3a2dab80192741808d635461b05a2216). The map uses heuristic benchmarks to identify risk: highest priority is given to forest stands that are dominated by dense pines or even denser firs. More sophisticated forecasting is possible with current scientific knowledge, but has yet to be completed.

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8. Environmental justice and social resilience

Overview and definition

Environmental justice (EJ) is defined by the Environmental Protection Agency as "…the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA 2020). In practice, and as reflected in President Clinton's Executive Order 12898 on Environmental Justice (1994), EJ is both distributive — referring to the equal distribution of environmental benefits and harms — and participatory — referring to equal opportunities to participate in environmental decision making. While EJ is often associated with urban areas and the environmental health risks of industrial development, environmental injustices are also common in rural areas, stemming from resource extraction activities (including both historic and contemporary logging and mining), lack of effective regulation, and multifaceted barriers to equal participation in environmental decision-making. Beyond environmental justice, Indigenous environmental justice locates Indigenous environmental health impacts in the initial seizure and ongoing occupation of Indigenous homelands, and advocates for land restitution to Indigenous communities and the foregrounding of Indigenous-led land and water stewardship initiatives (Gilio-Whitaker 2019, Yazzie and Risling-Baldy 2016, Reed et al. 2020).

Relevance to forest treatments

For contemporary communities in forested areas of California, environmental injustices range from health impacts from industrial contamination to lack of emergency infrastructure in situations of extreme wildfire or flooding, to severe socio-economic, cultural, and physical barriers to participation in planning and decision-making processes. Rural populations may also be widely dispersed and have predominantly lower value properties, thus potentially decreasing their prioritization for fire suppression (Plantinga et al. 2020). It is necessary to triangulate available assessment tools and approaches to identify vulnerable and impacted communities, in order to ensure that forest health funding addresses environmental justice. We discuss current state approaches to addressing vulnerability, some of the vulnerability assessment tools available, our concerns about which communities and vulnerabilities may be missed by these tools, and recommendations on how to move forward.

State approaches

In 2019, Gov. Newsom issued Executive Order N-05-19, directing CalFire to recommend immediate and long-term approaches to reducing catastrophic wildfire. CalFire's resulting 45-Day Plan of 2019 recognizes the heightened risk of some communities, describes a method of determining social vulnerability based on US Census American Communities Survey data, and calls for improving this method in order to better identify communities at most risk of wildfire. The current socioeconomic analysis outlined in the Plan relies on ACS data on poverty rate, disability, age, car ownership, and ability to speak English. Indeed, these are documented vulnerabilities that make people more susceptible to negative consequences of wildfires (Palaiologos et al. 2019): it is more difficult (if not impossible) to implement wildfire risk reduction on a property, or to evacuate if you are poor, elderly, disabled, and do not have access to a car. However, these ACS measures are not inclusive of all risk factors, so the Plan calls the FMTF to "...establish an interagency team with experience in spatial analysis, technology support, environmental management, public health, climate change, and social vulnerability to develop the methodology enhancements needed to inform the long-term planning needs of both state and local agencies" (2019: 12).

The approach used in the 45-Day Plan differs from the California Air Resources Board's (CARB's) classifications of "priority populations," which include disadvantaged communities (according to CalEnviroScreen 3.0), low-income communities, and low-income households. Environmental justice is incorporated into the cap-and-trade system according to its founding legislation of 2006, AB-32, which states:

"The state board shall ensure that the greenhouse gas emission reduction rules, regulations, programs, mechanisms, and incentives under its jurisdiction, where applicable and to the extent feasible, direct public and private investment toward the most disadvantaged communities in California."

Further legislation in 2016, AB 1550, amended cap-and-trade regulations and required that at least 35% of cap-and-trade revenue, a significant source of grant funding for forest health in California, must benefit priority populations.

Newsom's administration has also evidenced a commitment to addressing Indigenous Environmental Justice. In 2020, Gov. Newsom issued an executive order (EO N-82-20 on biodiversity) and a policy statement (9/25/20, Native American Ancestral Lands) that address the importance of tribal leadership in environmental conservation. These pronouncements simultaneously recognize and attempt to address past wrongs of state land seizure and genocide of California Indian peoples, and related contemporary crises of biodiversity and environmental degradation. The Lands Policy suggests "grantmaking to assist California tribes with procurement, protection or management of natural lands located within their ancestral territories," and the Executive Order recognizes the importance of tribal participation and Indigenous traditional knowledge in restoring biodiversity and building resilience to wildfire.

Data and tools

A commonly used framework for defining disadvantaged communities across California is CalEnviroScreen 3.0. This synthetic metric of environmental justice, used by CARB and CalFire, combines 20 indicator variables associated with communities' pollution burden and population characteristics. Through a weighted scoring system, CalEnviroScreen combines both the exposure to negative environmental effects (e.g. ozone, pesticides, drinking water contamination) with communities' vulnerability (e.g. poverty, asthma rates, unemployment) to estimate each community's pollution burden and vulnerabilities. An update to the index, CalEnvironScreen 4.0, is available in draft form for public review (CalEPA and OEHHA 2021). In the case of the Air Resources Board, CalEnviroScreen is combined with income thresholds to determine "priority populations."

In terms of measuring environmental justice priorities in rural forested communities, there are limitations to using CalEnviroScreen. While CalEnviroScreen has been a critical tool in supporting communities statewide in determining their pollution load, health vulnerabilities, and environmental inequity, it is not designed to help decision makers understand environmental injustices in forested communities in California. Factors such as wildfire risk, insurance rates, and Tribal access to decision-making on traditional lands are prevalent issues missing from CalEnviroScreen 3.0 and 4.0. Other factors like dependence on subsistence foods, and natural-resource-based employment could deeply affect economic vulnerability. Evacuation planning in rural communities also needs to consider factors like insufficient evacuation routes, rolling blackouts, and a lack of access to reliable internet which could lead to an information gap. There may be opportunities for future adjustments to CalEnviroScreen, or a separate initiative to spatially capture environmental justice in rural forested communities, but for now it must be noted that the current limitations are significant enough that CalEnviroScreen is insufficient in measuring inequities and vulnerability.

Several entities (including CalFire, Headwaters Economics, the nonprofit Direct Relief, the USFS through the tool wildfirerisk.org, and scholars including Wigtil et al. 2016, Palaiologou et al. 2019) have developed social vulnerability indices for fire-prone communities using American Community Survey (ACS) Data. These efforts combine several risk factors believed to increase vulnerability to adverse health outcomes, wildfire evacuation, and post-fire community recovery. Multiple different subsets of ACS variables have been used. For instance, CalFire's socioeconomic analysis in the 45-Day Plan of 2019 used six variables to help identify 35 Priority Projects: families in poverty, people with disabilities, people that have difficulty speaking English, people over 65, people over 5, and households without a car. Other efforts have used a larger set of variables and synthesized them into fewer index components using statistical techniques (Palaiologou et al. 2019, Wigtil et al. 2016). To our knowledge, these analyses have only been performed using heuristic approaches to selecting variables to include in social vulnerability indices, rather than robust analyses of vulnerability indicators in relation to post-fire community outcomes. The process of arriving at these metrics is often not described. For example, Wigtil et al. (2016) used "female participation in the labor force" as a contributing factor to social vulnerability without justification or rationale for that choice of metric. Furthermore, these contributors to social vulnerability are often treated as equally important in increasing community risk, when they may have differential and weighted impacts on risk, depending on factors such as location, ethnicity, gender, and nationality.

Another method of examining vulnerability is the capitals framework (Baker and Kusel 2003, Middleton and Kusel 2007), which examines six dimensions of community capacity -- physical (infrastructure), financial (assets), natural (resources), human (training/ education/ experience), cultural (beliefs/ norms), and social (ability to work together). The capitals framework is well-suited for approaching focused, community-based work, but is challenging to use for assessing a broader landscape for vulnerabilities and to highlight areas of investment. We recommend attention to the capitals alongside other indices of vulnerability, health, and risk.

In 2015, then- Gov. Brown signed Senate Bill 246, calling on the Office of Planning and Research to form the Integrated Climate Adaptation and Resiliency Program (ICARP), which in turn developed a 2018 resource guide on "Defining Vulnerable Communities in the Context of Climatic Adaptation" (OPR 2018). The guide defines vulnerable communities as those most at risk of climate impacts, and with the least resources to respond or rebuild. The Guide introduces several tools to assess vulnerability, including CalEnviroScreen, the Climate Change and Health Vulnerability Indicators, the Healthy Places Index, and the Regional Opportunity Index, and then provides a crosswalk table comparing indicators across tools and their ability to address factors such as institutionalized racism, environmental degradation, and disinvestment. The Guide then offers an extensive list of additional vulnerability indicators, which may be assessed alongside the indicators included in the existing tools, and advises readers on additional tools (such as the Equity Checklist and the Government Alliance on Race and Equity Toolkit) which may be applied to rank or prioritize indicators. We recommend the Guide as a helpful tool to examine and address the rural environmental justice issues that are present in forested communities. Additionally, ICARP is currently launching an effort to build a new climate vulnerability mapping platform that may complement the information provided in the Guide.

Finally, an additional framework for evaluating the environmental justice benefits of forest restoration treatments is presented in Section V: Socio-ecological Considerations. There we introduce additional considerations for the state in addressing resilience and equity in disadvantaged rural communities. Our recommended framework is intentionally qualitative because there are few quantitative datasets available that would accurately reflect the level of detail and complexity needed to ensure environmental justice criteria are being met in rural forested communities.

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9. Rare and/or highly valued plant communities

Overview and definition

A substantial portion of California's floral biodiversity is found in forest and shrubland environments, and the survival of many species is dependent on the vitality of these ecosystems. Over 1,000 rare plant species found in forests, woodlands, and chaparral, according to California Native Plant Society's (CNPS) official listing; 100 are federally Threatened or Endangered (**Table 2**). Rare and highly valued trees include eight localized cypresses and five pine species, from coastally occurring Monterey pine (*Pinus radiata*) to high elevation whitebark pine (*Pinus albicaulus*), which has a pending proposal for listing as federally threatened. Thirteen manzanita and five *Ceanothus* species are also rare according to CNPS. We recommend evaluating projects and treatments for their capacity to make meaningful changes to the trajectory of rare and valuable plant species, communities or populations. Meaningful changes may include: reversing or stabilizing declines, removing or reducing documented risks, or facilitating future growth and preservation.

In considering treatment prioritization, rare and/or highly valued plants may include:

1. Plant species and communities with state, federal, or global listing (Special Status)
2. Plant species, populations, or communities of conservation or cultural concern (candidate for listing, endemic, limited native range or wild distribution, and/or populations maintained by Native communities past or present)
3. Mapped areas designated for conservation of botanical resources (i.e. US Forest Service Botanical Special Interest Areas or Research Natural Areas, Bureau of Land Management Areas of Critical Environmental Concern).
4. Note that "old growth" forests and groves are discussed and evaluated in Section III.6.

Relevance to forest treatments

Some proposed forest treatments will be well positioned to protect rare and/or highly valued plant species and communities, either as direct or co-benefits of the project. Exact tools will vary with the species or community type and associated risks. For example, local disturbance risk to a plant population could be reduced by a treatment that provides a degree of protection from severe fire. This type of treatment might be well suited to securing habitat for a species with a very limited range. Alternatively, conditions that perpetuate a species or community could be promoted by a treatment that creates microsites to facilitate regeneration; this would be appropriate for habitat specialists.

Table 2. Rare plant species in California forests, woodlands, and chaparral

	CNPS Lists 1a-1b, 2a-2b	Federally Threatened or Endangered
All plant and bryophyte species	1722	187
Forest, woodland, OR chaparral habitats	1063	100
Forest or woodland habitats	889	78
Chaparral habitats	486	65
BOTH forest/woodland and chaparral	312	43

Table 3. Life form of CNPS listed species found in forest, woodland, or chaparral habitats

Life form	Species
perennial herb	418
annual herb	229
perennial rhizomatous herb	94
perennial evergreen shrub	89
perennial bulbiferous herb	71
other (23 types)	53
perennial deciduous shrub	38
perennial shrub	27
moss	25
perennial evergreen tree	19

Projects may be evaluated based on their potential to achieve the following benefits, in recommended order of importance:

1. Offers direct benefits to one or more rare or valued plant species/populations/communities
2. Offers indirect benefits to one or more rare or valued plant species/populations/communities

3. Promises new due diligence for rare or valued plants, such as surveys, vegetation mapping, or monitoring, with a plan for sharing with relevant agencies or integrating into future projects
4. Identifies rare or valued plants in the area, takes steps to mitigate and monitor potential impacts of treatment, or demonstrates that populations are not present and/or will not be negatively affected
5. Demonstrates compliance with State and Federal laws regarding rare species and communities (expected of all projects)

However, evaluation of projects can be challenged by the ability to compare direct and indirect benefits. Complexities may arise in weighing the benefits of proposed works for poorly mapped areas or species against those that are better documented. For example, in some regions new surveys may be the best available option – no direct benefit can be proven if no rare plant populations have been recorded. In these situations, we recommend giving maximum priority to projects that achieve benefits to the extent possible given the information available. Evaluation may also be aided by requesting supporting details, such as the durability of conservation effects, proportion of the population/range affected, and degree of confidence that the treatment will lead to positive outcomes for the species/community in question.

Data and tools

For project proponents, extensive documentation is available for plant species in California, including many rare species. This is especially true of woody and long-lived plants, whose populations have often been mapped and are available via the California Natural Diversity Database (CNDDB 2021). For information on how plant species respond to fire and changing fire regimes, USFS Fire Effects Information System reviews (www.fs.fed.us/database/feis/AboutFEIS/ContentsFEIS.html#PlantSpeciesReview) are a potentially useful resource. Sensitive communities are documented through the CDFW's Sensitive Natural Communities System (https://wildlife.ca.gov/Data/VegCAMP/Natural-Communities), which maintains a list of vegetation Alliances and Associations ranked according to their state and global rarity and threats (CDFW 2018). Sensitive community locations are available either through this system (lowland and coastal areas) or by using the rankings in combination with local vegetation classification maps (most forests). Many specially designated botanical areas on public lands have been mapped and can be identified by working with staff botanists or accessing spatial data through databases such as Special Interest Areas (Studer 2008), Research Natural Areas (https://www.fs.fed.us/psw/rna/description.shtml; Ramirez 2009), Sensitive Natural Communities (https://wildlife.ca.gov/Data/VegCAMP/Natural-Communities), and CNDDB (CNDDB 2021).

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10. Water quantity

Overview and definition

Forest management actions have the potential to mitigate hydrologic responses to droughts and floods, both directly by altering forest water use, and indirectly via impacts on fire severity. Any change in forest structure (i.e., the density, size, and distribution of the vegetation) or composition (the diversity and abundance of the species present) can alter forest water balances. Forests use substantial volumes of water through transpiration. Trees can also increase evaporation and sublimation of snow by intercepting it in their canopies.

California's climate makes it susceptible to both flooding and drought. This climatic pattern of California results in seasonal droughts, such that in most summers water limits ecological processes, such as tree growth, and streamflows are relatively low. Surface water reaches minimum values during the late summer and early fall. In contrast, peak flows and floods typically occur during winter or spring when winter precipitation that is stored as snow melts. The largest floods occur when rain falls on warm snow.

While these winter wet periods and summer dry periods occur in most years, year-to-year variation in precipitation can lead to larger floods in relatively wet years and longer, more intense summer dry periods in low rainfall years. Warm temperatures can further intensify droughts by increasing water demand by vegetation and by melting snow earlier, leading to longer summer dry periods (see California's Fourth Climate Change Assessment: https://www.climateassessment.ca.gov).

Relevance to forest treatments

Flooding

The primary effect of forest treatments on reducing flood flows occurs through the reduction of high severity fires. Following large-scale vegetation loss due to high severity fire, vegetation evapotranspiration is reduced and streamflows increase, particularly during peak flood flows. Flood risk increases substantially for several years following high severity fires, after which pre-fire surface water regimes recover along with vegetation recovery (Wine and Cadol 2016, Bart 2016). Following fire, flood flows increase due to reductions in the interception of precipitation (by vegetation), reductions in infiltration due to higher antecedent soil moisture with lower evapotranspiration, and, in some areas, increased soil hydrophobicity which reduces infiltration (DeBano 2000).

Flood risk varies with topography and channel morphology and existing infrastructure (e.g., dams and spillways) which determine the likelihood of overbank flow - thus some locations will have greater post-fire flood risk than others. The risk associated with flood flows following high severity fire are tied not only to the volume of flood flows but also with the sediment or other material carried with flood flows. See Section III.3 for more detail.

Relative to high severity fire, forest treatments result in more moderate changes to forest structure and as a result less dramatic changes to the water cycle. Studies of the impact of forest density reduction, either through controlled burning or thinning, show relatively small and highly variable changes to evapotranspiration and streamflow. Compensating factors, such as increases in transpiration of remaining vegetation and increases in surface evaporation in more open canopies, tend to limit the potential for forest management to directly increase surface water flows or groundwater recharge (Tague et al. 2019, Boisramé et al. 2017, Biederman et al. 2014). Even in cases where streamflow increases after higher intensity thinning, streamflow augmentation diminishes rapidly in the first 5 years following treatment (Wine and Cadol 2016). Any increases in surface water tend to be greater in wet years and in the wetter spring and early summer (e.g. Saska et al. 2020).

Prioritization to reduce flood flows should focus on:

1) Areas where treatments are most likely to reduce high severity fire (See Sections III.1 and III.2)
2) Areas where downstream flood impacts may be most destructive for either human property, water supply infrastructure (Gannon et al. 2019) and sensitive or endangered aquatic and riparian species

Approaches for assessing these areas would include a combination of modeling estimates of change in flood flows with high severity fire and mapping vulnerability using available maps of infrastructure (see Section III.4) and high-valued or endangered aquatic and riparian species (CNDDB 2021).

Drought

While the impact of forest treatments on surface water volumes is likely to be small, field and model-based studies have shown the density reduction can increase water availability for remaining vegetation. As a result, both vegetation productivity and resilience to drought can increase following density reduction in semi-arid regions (Bales et al. 2018). Some research indicates that sustained, extensive treatments in dense Sierra Nevada forests could increase water yield by up to 16% (Bales et al. 2011). Longer-term impacts of thinning on vegetation drought responses, however, are less clear. A few studies suggest that increased productivity and biomass of remaining trees following thinning could ultimately increase water demand and limit gains in forest resilience to drought. Thus, the timing and location of forest treatments will strongly influence potential reductions in forest drought related mortality risks (Tague et al. 2019, Clark et al. 2016).

Treatment prioritization to maximize benefits to water quantity and drought resilience are most likely to be effective if they focus on water availability for trees, rather than benefits to groundwater recharge or surface flows, since the latter are likely to be small. Increases in water availability for remaining vegetation, however, is greater in magnitude and more consistent across site variation. Prioritization in this case should focus on overly dense forests that have a high risk of drought related mortality and would benefit from water released due to density reduction. Prioritization to reduce drought vulnerability should also focus on areas where drought risks are more likely to increase, e.g. areas near the rain-to-snow transition where increasing temperature in the next decade will increase drought risk by increasing the length of the growing season (Tague and Peng 2013). Drought-related forest mortality is particularly likely when conditions change relative to the conditions that occurred during stand development. These are areas where the hydrologic benefits of forest treatment may be most important.

Data and tools

Field-based studies of the hydrologic impacts of forest treatment are relatively few, and typically short term. Inferences from field studies are particularly challenging given that hydrologic responses to forest treatments are likely to vary substantially across climate, forest and treatment type, topography, and geology (Burke et al. 2021). Ecohydrologic modeling tools provide a means to extend field-based understanding to assess changes in evapotranspiration, forest productivity and drought resilience. Tools for modeling hydrologic responses to forest management should ideally account for the following: vegetation regeneration and growth following treatment and/or disturbance, within stand dynamics (including the impact of forest gaps) on understory evapotranspiration and water exchange between trees, and finally be able to scale to hillslopes and watersheds. Widely used modelling tools to assess fire response to forest treatment include both growth models such as the Forest Vegetation Simulator (FVS) and commonly used earth system models such as the Community Land Model (CLM). While these tools account for vegetation growth and evapotranspiration, their representation of compensating mechanisms (e.g., increases in growth and water use of remaining trees) may be limited. Recent advances to ecohydrologic models that combine finer scale, within-stand processes with hillslope scale variation in energy, downslope moisture redistribution and other driving atmospheric conditions still require testing but will likely improve the ability to represent interaction among climate, forest density, drought vulnerability, and water resources.

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11. Standing dead trees

Overview and definition

In the past decade, California experienced an unprecedented increase in tree mortality, introducing new challenges for forest management. This tree mortality was associated with a 2012-2015 drought, during which the direct and indirect effects of a warming and drying climate interacted to alter forest health (Seidl et al. 2017). The hallmark of this epic drought was historic dryness and warmth (Swain 2015). The extended aridity generated progressive water stress in the forest canopy (Asner et al. 2016) and cumulative deep soil drying (Goulden and Bales 2019). The consequence was a massive wave of tree death due to both the direct effects of moisture deficits and the attendant outbreak of native bark beetles (Fettig et al. 2019, Stephenson et al. 2019). Such drought-induced tree mortality is likely to be a more regular feature of our future forests as we transition to warmer and drier climates (Anderegg et al. 2019). The spread of invasive pests and pathogens also pose serious risks to forest health and can lead to widespread tree mortality (Lovett et al. 2016, Davis 2020). Thus, we need to understand the impact of increasing abundance of standing dead trees on forest ecology and management.

Standing dead (SD) trees are vital but ephemeral elements of the forest. These trees exist at the transition between live, photosynthesizing trees and downed wood. While they remain standing, SD trees provide essential habitat for wildlife; they store a significant amount of carbon; and they present potential hazards (Hilger et al. 2012). Importantly, SD trees represent the first stages of wood degradation and decomposition. Even while standing, SD trees begin to decompose and release stored carbon back to the atmosphere (Cousins et al. 2015). As their limbs fall, they contribute to surface fuel loads. After SD trees fall and become downed wood, their direct contact with soil microbes speeds decay and the release of stored carbon (Franklin et al. 1987).

Though SD trees are vital forest elements under normal conditions, their density in California has skyrocketed in recent years. Based on the most recent US Forest Service (USFS) Forest Inventory and Analysis data (FIA 2021), the number of SD trees, defined as stems with a diameter at breast height (1.37 m) ≥ 10 cm, increased by 38% between 2010 and 2019 across California, with the abundance concentrated in the southern Sierra Nevada (Moore et al. 2019). For example, the Aerial Detection Survey Results (USFS ADS 2018) estimate almost 29 million trees died in Tulare County and almost 35 million trees died in the Sierra National Forest between 2010 and 2018. In the most severely impacted stands, more than half the live trees died during the recent drought with the greatest losses occurring in large pine trees (Axelson et al. 2019, Fettig et al. 2019, Stephenson et al. 2019).

Relevance to forest treatments

The widespread increases in dead tree abundance across California coupled with intense localized mortality in mixed conifer forests of the southern Sierra Nevada represent novel ecological conditions. Dead trees adjacent to human infrastructure threaten public safety (https://ucanr.edu/sites/forestry/Insects_and_disease/Tree_Mortality) and pose risks to firefighters during wildfires. They also contribute to carbon emissions as they decay naturally, burn in a wildfire, or are piled and burned as part of forest management (Springsteen et al. 2011). What is less clear is the impact of massive tree mortality on wildfire hazard. As Stephens et al. (2018) explain, the abundance of SD trees will inevitably increase the amount and continuity of dead and downed wood and contribute to the potential for smoldering and hot wildfires in the near future. These conditions may produce "mass fires" where the increased abundance of dry, combustible large woody material could produce extensive and severe fires. In response, the California Energy Commission has funded a study to evaluate the impact of drought-mortality on fire behavior (https://pyregence.org/).

The State of California has prioritized the removal of SD trees. The first priority (Tier 1) are areas where tree mortality directly threatens critical infrastructure (e.g., roads, utilities, and schools). The second priority (Tier 2) are areas in high fire hazard severity zones where SD trees removal not only reduces fire risk but also supports broader forest health or community protection goals (https://fmtf.fire.ca.gov/media/2592/hhz-definitions-revised-october-16-2020.pdf). Given this hierarchy, treatment of high mortality zones in remote, back country forests is a lower priority. However, due to challenging fuel and safety conditions, treatments in back country areas with many SD trees should focus on improving future forest resilience to wildfire, rather than immediate fuel reductions.

Data and tools

The USFS maintains two direct programs to monitor SD trees. The Forest Inventory and Analysis program (https://www.fia.fs.fed.us/) collects information on SD trees as part of its Phase 2 forest inventory. The main limitation of this inventory is the sparse sampling regime both in space (1 plot per every 2,419 ha) and time (plots measured once every 10 years). The Forest Health Protection Aerial Detection Surveys (https://www.fs.usda.gov/detail/r5/forest-grasslandhealth/?cid=fsbdev3_046696) consists of annual aerial surveys to detect tree mortality and damage. The accuracy of these surveys in quantifying tree mortality and damage is well documented (Coleman et al. 2019, Tubbesing et al. 2020), though their precision is lower than that of field surveys like FIA and recent methodological changes further reduced their precision. The surveys are designed to detect recent damage with the goal of monitoring major forest health trends. They do not survey the entire forest but rather focus on areas where tree dieback is occurring. Thus, they do not provide a complete picture of annual disturbances and may miss both background mortality and diffuse events in remote areas (Kautz et al. 2017).

Advances in remote sensing may improve our ability to detect and quantify SD trees. For example, a multitude of metrics have been developed from Landsat imagery that link observed forest mortality, usually as measured from ADS polygons, with remotely sensed signals. These metrics can then be used to measure the extent and magnitude of forest disturbances across space and time. Applications of this technology include eMapper (Cohen et al. 2018) and the normalized difference moisture index (Goulden and Bales 2019). Limitation of these approaches include the lack of local specificity and the uncertainty of the attribution of the causal agent of mortality. The combination of new satellites and new algorithms hold promise for improving the detection of dead trees from space, but these applications are still in development (e.g., the California Forest Observatory, https://salo.ai/projects/california-forest-observatory).

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12. Feasibility

Treatments are limited by an array of feasibility constraints, including legal (wilderness or roadless areas), operational (steep or far from roads), or administrative (riparian areas, wildlife habitat, or other protected natural areas) (North et al. 2015). Prescribed fire can be limited by CalFire burn permits (York et al. 2020), lack of expertise, liability issues, availability of qualified personnel at the right time of year, and air quality regulations (Miller at al. 2020), though air quality regulations have become a less limiting factor in California in recent years (Schultz et al. 2018, Schultz and Moseley 2019).

Panelists argued against allowing project feasibility to dictate treatment prioritization. Though some limitations (e.g., wilderness areas) present immovable barriers to treatment implementation, others (e.g., cost) must be balanced with project benefits and the valued resources that will be projected by the project. Over-emphasizing projects that are "shovel-ready" risks ignoring areas with the highest need along other axes like fire risk, ecological values, and cultural resources. In some cases, barriers to feasibility can be overcome through investments in capacity-building and partnership-building. For example, the Tahoe Central Sierra Initiative (TCSI) Framework for Resilience argues that regional-level planning can facilitate long-term infrastructure investments that shift the economic feasibility of small-diameter thinning treatments, such as biomass energy and wood mills (Manley et al. 2020). Evaluating feasibility in the context of other prioritization factors may also have value for reassessment of operational, administrative, or regulatory constraints. Assessing why otherwise high priority treatments are not feasible may discover potential operational innovations (e.g., cable assisted logging methods for thinning steep slopes), underutilized interorganizational collaborations (e.g., prescribed burning using the resources of another agency) or regulatory changes to facilitate appropriate land management (e.g., safe harbor agreements associated with threatened and endangered species).

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13. Predicted departure from historical climate

Overview and definition

California’s climate is expected to change in the coming decades, in terms of both annual average conditions and extreme events (USGCRP 2017). Climate projections show increases in temperature increases, heat and precipitation extremes, and shifts from snow to rain (NOAA 2020, Cal Adapt 2020). Forested areas in the Sierra Nevada may warm by 6-9 ^{o}F by the end of the century, forcing the rain-to-snow transition to higher elevation (Cal Adapt 2020, Dettinger et al. 2018), which will alter hydrology, streamflow patterns, wildlife habitat, and water resources. Extreme temperatures are expected to increase as well, and the future is expected to bring longer lasting and more intense droughts as well as temperature-related decreases in surface soil moisture (USGCRP 2017).

In California forested ecosystems, the effects of climate change are exacerbated by background or endemic stressors including pests, disease, fire exclusion, and wildfire.

Climate change is expected to amplify the effects of stressors and disturbance events in ways that are difficult to predict. For example, in the 2012-2016 drought, more than 120 million trees were killed by a combination of drought and a drought-facilitated bark beetle outbreak. This contributed to mass tree mortality (Adams et al. 2017, Fettig et al. 2019, Goulden and Bales 2019) and greater risk of high fire severity due to the drying effect on fuels (Keeley and Syphard 2016). Densification of these forests due to lack of understory fire also simultaneously increases the risk of drought mortality (Fettig et al. 2019, Goulden and Bales 2019) and contributes to increases in fuel loads. In the several years since, there has been a significant fuel buildup which may have contributed to the extreme fire behavior of the 2020 Creek Fire in the Sierra National Forest.

Not all species and ecosystems will be equally impacted by a given degree of environmental change, so scientists have developed various frameworks and analytical approaches to assess relative susceptibility. Among the most widely relied on tool is the vulnerability assessment. Joyce and Janowiak (2011) describe vulnerability assessments as an effort to "synthesize and integrate scientific information, quantitative analyses and expert-derived information in order to determine the degree to which specific resources, ecosystems or other features of interest are susceptible to the effects of climate change, including climate variability and extremes." These assessments can help refine resource approaches to retain management objectives in the face of climate change (Glick et al. 2011). Vulnerability assessments can be developed several different ways; among the most useful are those that evaluate the exposure of a given ecosystem (or community) to climate change and score the ecosystem's sensitivity to estimate the potential climate impact. The final step of a vulnerability assessment is often to score the ecosystem's adaptive capacity, or its ability to naturally resist or adjust to climate change stressors (Elias et al. 2015). The vulnerability assessment is thus an intersection of climate exposure, sensitivity, and adaptive capacity.

Relevance to forest treatments

Panelists generally agreed that departure from historical climate is not a high priority for management treatment for several reasons. First, climatic exposure (or departure from historical climate) is only one of several factors needed to determine climate vulnerability. An ecosystem's adaptive capacity as well as its sensitivity to climate changes must also be considered. For example, a given species could be relatively malleable in its ability to adjust or withstand climate impacts, or the species may simply not be sensitive to expected climate-mediated stressors. Similarly, plants and wildlife in areas with high climate departure may be better adapted to deal with climatic extremes than species or genetic variants in parts of the state with less climatic departure; living on the "fringes" could drive local populations to evolve adaptations to warming and drying.

Panelists also noted that areas with the highest climatic departure may be a less efficient use of treatment resources if those areas are likely to undergo climate-driven type conversion regardless of management. For example, forests on the edges of their climatic niches may no longer be well-adapted to the local climate. Unfortunately, it is well understood that not all areas that may benefit from forest management can be treated. This capacity limitation has forced land management agencies to evaluate the potential efficacy of any forest treatment to achieve the management objectives, which climate change has further complicated. Rather than treating areas where treatment success is less likely due to high climate departure, it may be more prudent to instead treat areas where treatments can achieve the objectives.

The National Park Service has taken a realistic view of ecosystem management in an era of climate change with a simple framework for resource management (Schuurman et al. 2020). The Resist-Accept-Direct (RAD) decision framework can designate a given land unit as 'Resist' (apply treatments to resist transformation), 'Accept' (accept that transformations will happen) or 'Direct' (assist and direct how the transformation occurs). This helps managers make informed and purposeful decisions around how to consider the trajectory of change.

A similar adaptation framework is founded on the concepts of resistance, resilience, and transition (Millar et al. 2007, Swanston 2007). Resistance actions should improve the ecosystem's ability to defend against changes or disturbances to essentially remain unchanged. Resilience options are ones that allow for some change but encourage a return to pre-disturbance conditions naturally or with management interventions. Finally, similar to the 'Direct' approach within the RAD framework, the transition options accommodate change by helping ecosystems adjust to changing or new environmental conditions. Areas with greater departure from historical climate (or higher vulnerability) may be more likely to fall into the transition category, or Direct per the RAD approach. In areas with low or moderate departure from historical climate (or climate refugia), resistance or resilience actions may be more appropriate.

Data and tools

Forest managers have a suite of data sets, tools, and resources to evaluate the effects of climate change and compare management options for a warmer future. Global Climate Models (GCM) can have limited applicability for understanding local patterns because they produce spatially coarse gridded data (~100 km) (Walton et al. 2020). To deal with this limitation, downscaling approaches have been applied to translate GCM results to spatial scales relevant to resource management (see Walton et al. 2020 for further reading). Another useful and practical extension of GCMs are climate exposure analyses. Climate exposure analyses combine GCMs with greenhouse gas emission scenarios to project shifts in the bioclimate space of natural communities. They are useful outputs to understand how climate change might stress spatially explicit areas of forested landscapes (Thorne et al. 2017). These too have limitations in that they include only one or two integrated climate metrics, most commonly temperature, precipitation and/or climatic water deficit.

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IV. Overview of prioritization and governance approaches

To develop our recommendations for treatment prioritization, we investigated existing approaches to natural resources decision-making processes that balance competing objectives. Here we first describe two quantitative methods for determining priority landscapes, one used by CalFire and another, ForSys, developed by the US Forest Service (USFS) and currently being applied to California National Forests. We then review regional prioritization and decision-making used by the Washington State Department of Natural Resources, which includes quantitative landscape prioritization as well as a decision-making framework. Next, we discuss the Resilience Framework recently developed by the Tahoe-Central Sierra Initiative, which includes metrics associated with ten Pillars of Resilience. We then highlight three examples of collaborative, stakeholder-driven planning efforts that use structured decision-making to arrive at landscape planning decisions. Finally, we describe allocation of the California Forest Health Grants. This last case study stands out because information is available not only on the process of prioritizing treatments, but also on the outcomes of four years of funding allocation, allowing us to evaluate results of prioritization and grantee selection.

1. Priority Landscapes developed by CalFire FRAP

To assist in the allocation of state grant funding, CalFire Fire and Resource Assessment Program (FRAP) developed a Priority Landscapes tool that ranks watersheds and communities according to restoration needs (https://arcg.is/DvCOe). The tool contains two separate Priority Landscape maps: 1) Reducing Wildfire Risk to Forest Ecosystem Services and 2) Reducing Wildfire Threat to Communities. Each of these maps was created by combining metrics of assets with threats (**Table 4**).

Table 4. Priority Landscapes developed by CalFire FRAP

Priority Landscape	Assets	Threats
Reducing Wildfire Risk to Forest Ecosystem Services	● Surface water value ● Carbon storage ● Standing timber ● Site quality ● Large trees	● Fire threat ● Fire Return Interval Departure
Reducing Wildfire Threat to Communities	● Housing density (units/ac)	● Fire Hazard Severity Zones (CalFire)

To develop the map of Reducing Wildfire Risk to Forest Ecosystem Services, all five assets were combined and the results were ranked from 1 to 5. Separately, the two indices of threat were combined and ranked from 1 to 5. The asset rankings were then combined with the threat rankings and averaged at a watershed level to rank watersheds from 1 (lowest threat) to 5 (highest threat). For the Communities map, the ranked asset and ranked threat were simply combined into the final rankings from 1 (lowest risk) to 5 (highest risk). Results for both Priority Landscapes are shown in **Figure 3**.

FRAP's Priority Landscapes are used in evaluating proposals for Forest Health Grant projects (see Section IV.8) and were used in selecting the 35 Priority Projects outlined in the 45-Day Report of 2019 in combination with a socioeconomic analysis of vulnerable communities.

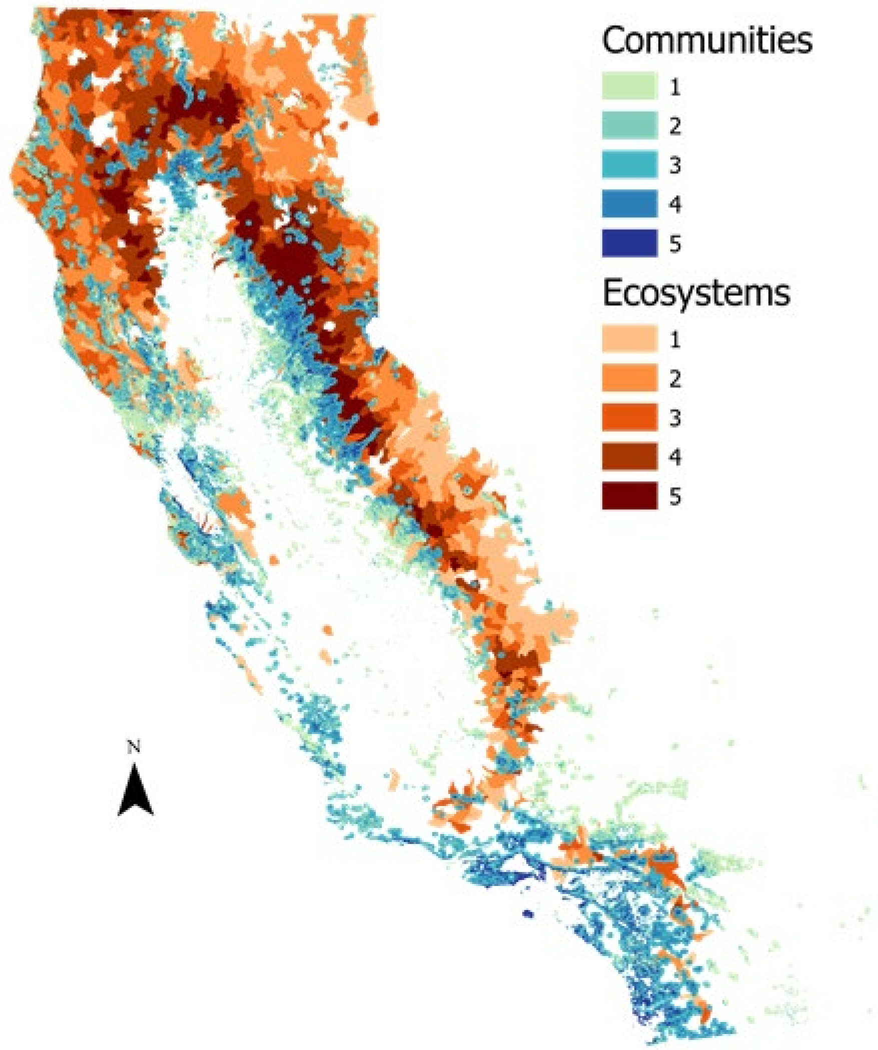

Figure 3. CalFire FRAP Priority Landscapes: Reducing Wildfire Threats to Communities ("Communities") and Reducing Wildfire Risk to Forest Ecosystem Services ("Ecosystems").

Insights and Takeaways

These Priority Landscapes are straightforward evaluations of a limited number of resource values. In both of their applications – Forest Health Grants as well as the 35 Priority Projects – the Priority Landscapes form only one of several criteria used to evaluate potential projects. Additional layers of prioritization are required to balance trade-offs between the two sets of Priority Landscapes and combine them with additional values, including but not limited to benefits to disadvantaged communities (see Section IV.8). The simplicity and accessibility of the data layers use to develop each map have advantages for transparency, though the process of combining rankings between data layers is not well documented.

2. ForSys

ForSys is a scenario planning tool developed by the US Forest Service (USFS) to help National Forests with project planning, evaluation, and execution. Recent efforts have applied ForSys to treatment prioritization in California forests. ForSys was applied to the Stanislaus National Forest's Social and Ecological Resilience Across the Landscape (SERAL) project as a pilot, with eventual goals of applying ForSys across all of California Forest Service land.

ForSys is a tool for quantitatively balancing tradeoffs in forest restoration. Though there are opportunities for win-win scenarios in forest management (e.g., reducing fire risk may also benefit wildlife habitat and water resources), tradeoffs are also common. For example, an analysis of 79 western US national forests showed that prioritizing treatments to reduce wildfire risk to the wildland urban interface (WUI) produced substantially less timber than prioritizing for harvest volume (Ager et al. 2010). However, certain areas within national forests, and some larger planning areas including the Tahoe National Forests, had high synergy between the two objectives. The goal of ForSys is to identify areas of the landscape where several treatment objectives are balanced according to users' values. The model allows for weighting of different objectives, which influences polygon selection.

Another important innovation of ForSys is its ability to account for spatial adjacency of polygons. It is impractical to prioritize treatment in disparate, spatially isolated forest stands. ForSys incorporates polygon proximity when assigning priority polygons to increase operational efficiency.

ForSys is a flexible optimization algorithm accompanied by a graphical user interface (GUI). The user defines management objectives and their metrics and divides the planning area into polygons. Each polygon must be assigned a value for each metric. The user also defines constraints (e.g., maximum area treated) and thresholds (e.g. minimum board feet harvested). A shapefile of the polygons and their associated data are input into ForSys, which identifies the polygons that maximize the chosen objectives. Finally, post-processing tools are used to analyze ForSys outputs.

Stanislaus National Forest – Social and Ecological Resilience Across the Landscape (SERAL)

In the case of the Stanislaus NF, five objectives and their associated metrics were chosen by a team of scientists and land managers with input from the Yosemite Stanislaus Solutions collaborative (YSS) and CalFire. The following objectives were identified: 1) fire-adapted communities, 2) forest resilience and biological conservation, 3) fire dynamics, 4) California spotted owl habitat, and 5) economic diversity and social well-being. The metrics used to define each objective are shown in **Table 5**.

Before applying ForSys to the SERAL project, USFS scientists divided the 116,000-acre landscape into 8,266 polygons averaging approximately 10 acres. Polygon delineations were determined by: spotted owl priority areas, including protected activity centers (PACs), territories, home range core areas (HRCAs), and nest stands; land ownership;

strategic fire management features; slope; defense zones; roadless areas; wild and scenic river corridors; near-natural areas; and POD boundaries. Delineating polygons was a complex process that included GIS techniques to reduce the number of small polygons. Next, each polygon was assigned a value for each metric shown in **Table 5**, which often required summarizing raster data to a polygon level.

Table 5. Metrics for the five objectives used in ForSys for the Stanislaus National Forest

Fire adapted communities	● Flame length probability ● Fire transmission potential to WUI ● Expected or conditional net value change, either monetary or ecological
Forest resilience and biological diversity	Based on comparison of current conditions with reference condition sites: ● Tree basal area ● Tree density ● Mean clump size ● Proportion open space ● Departure from reference conditions (composite of several metrics)
Fire dynamics	● Flame length probability ● Fire return interval departure (FRID) ● Time since last fire ● Expected or conditional net value change
California spotted owl	● Departure (current vs. desired) of owl habitat condition in PACs ● Departure (current vs. desired) of owl habitat condition in territories
Economic diversity and social well-being	● Treatment cost/acre ● Revenue/acre ● Product value/acre ● Volume removed/acre

ForSys outputs for the SERAL project helped USFS scientists identify stands that maximized the five project objectives. The model was run separately for scenarios that included all land ownership, excluded private land, and specifically targeted owl PACs. Treatment areas were identified where objectives were maximized in both the all-lands model run and the run excluding private lands. ForSys output also showed attainment efficiency: how quickly objectives were achieved at different levels of area treated or numbers of planning areas treated. These results will assist in Environmental Impact Statement (EIS) preparation for the National Environmental Protection Act (NEPA) process, which the USFS plans to complete in the near future with hopes to begin treatments shortly thereafter.

Phase 2: State-wide California analysis

The next phase in applying ForSys to California forests is to generalize the methods used in the Stanislaus NF across the entire state. USFS scientists will first divide the state into 3-4 zones with distinct objectives based on differences in ecosystem type. Some objectives will be uniform across all regions, while others will vary by region. Then, quantitative metrics will be assigned to each objective and associated datasets will be assembled. This statewide expansion of ForSys will require new capabilities to be built into the model, including shrub dynamics. Despite the increase in spatial scope, individual polygon size will remain small (~10 ac) to best inform forest managers. Maintaining this fine-scale perspective will greatly increase data storage and computer processing needs.

Insights and Takeaways

ForSys is a quantitative, standardized approach to treatment optimization based on defined priorities. The goal of prioritizing at the individual stand scale is to provide detailed guidance to Forest Service managers in designing individual treatment plans. In the case of the SERAL project, this was an appropriate scale for prioritization because a group of stakeholders collectively decided upon shared objectives and metrics for evaluating those objectives. There may be challenges in applying the same process to all forests in California in a "one size fits all" approach. Due to urgency and limited capacity, Forest Service Region 5 scientists are not able to undertake separate analyses for individual national forests or planning areas. Even with separate sets of objectives and metrics for 3-4 regions, there will likely be variation within each region that may limit buy-in from local managers, collaboratives, stakeholders, and communities. Additionally, there are currently no methods for incorporating environmental justice, social-ecological resilience, or local engagement into ForSys prioritization.

Unlike several other treatment prioritization approaches, ForSys does not identify high-priority landscapes at intermediate watershed scales; region-wide rankings will occur only at the level of individual polygons. If all national forests and ranger districts have adequate resources to complete treatments within the high-priority polygons in their jurisdiction, then intermediate priority areas may not be needed. However, other decision-making processes (e.g., the Washington State method described below) rank larger watersheds according to prioritization need to inform regional and state-level funding priorities.

The Forest Management Task Force Action Plan calls for the development of regional action plans for forest and community fire resilience. There may be opportunities for ForSys developers to collaborate with regions to determine objectives and metrics specific to the needs of each region, which can then be input into Phase 2 runs of ForSys.

3. Washington State forest management

20-Year Forest Health Strategic Plan: Eastern Washington

The Washington State Department of Natural Resources (WA DNR) recently undertook a prioritization effort in accordance with 2016 state legislation ordering a 20-Year Forest Health Strategic Plan to identify areas of forestland in "poor health." The 20-Year Strategic Plan, released in 2017, is limited to eastern Washington. Development of the Strategic Plan included a stakeholder engagement process in which a steering committee made up of a diverse range of stakeholders from 30 organizations met regularly over several months. More than 20 stakeholder meetings were held at five locations around the state. The steering committee collaboratively developed the vision, mission, and goals of the Strategic Plan.

One of the five goals in the Strategic Plan is to "conduct 1.25 million acres of scientifically-sound, landscape-scale, cross-boundary management and restoration treatments in priority watersheds to increase forest and watershed resilience by 2037." In support of this goal, a prioritization process was developed to identify "priority watersheds" as defined by their disturbance probability, resilience, and values at risk. The prioritization work was led by WA DNR staff member Dr. Derek Churchill.

Watersheds were assessed at the hydrologic unit code (HUC) 5 level, which average approximately 150,000 acres in size. Each HUC 5 was scored separately for two "tiers," or groups, of metrics: Forest Health and Values at Risk (**Table 6**).

Table 6. Metrics used in treatment prioritization for eastern Washington's 20-Year Forest Health Strategic Plan

Tier	Metric	Data source(s)
1: Forest Health	Fire probability	Mean of: Fire Threat Index (Wolf et al. 2013) MaxEnt model (Davis et al. 2017) FSim fire modeling (Finney et al. 2011)
1: Forest Health	Insect and disease risk	National Insect and Disease Risk Map (Krist et al. 2014)
1: Forest Health	Restoration need	Departure from historical conditions (Haugo et al. 2015, Ohman et al. 2011)
1: Forest Health	Climate change	Projected increase in water balance deficit based on downscaled climate projections (AdaptWest 2015)
2: Values at Risk	Wildland Urban Interface	Modified Where People Live dataset from the West Wide Wildfire Risk Assessment (Wolf et al. 2013)
2: Values at Risk	Wildlife	Mean of: Number of listed and candidate wildlife species Number of acres in "ecological systems of concern" from Washington Department of Fish and Wildlife (WDFW)
2: Values at Risk	Aquatic system health	Mean of: Number of stream miles with listed fish species Human disturbance level based on Habitat Condition Index (HCI) from National Fish Habitat Assessment Projected stream temperature in 2040 from NorWest Stream Temperature Modeling project (Isaak et al. 2016)
2: Values at Risk	Drinking water	Forest to Faucets scores based on the number of people that derive water from a watershed and quantity of water supply (Weidner and Todd 2011)

2: Values at Risk	Timber volume and large trees	Regional Gradient Nearest Neighbor (GNN) forest inventory dataset developed by the LEMMA lab (Ohmann et al. 2011)

To combine metrics, no weighting system was used to elevate certain metrics above others. Rather, each watershed was given a single score for each metric, which was then standardized to a ranked score between zero and one. Two Forest Health metrics, fire probability and insect/disease risk, were summed to produce a "disturbance probability" score between zero and two. The remaining Forest Health metrics – restoration need and climate change – were added to create a "resilience" score, which was then converted to a 1-2 scale and multiplied with the disturbance probability score for each watershed. For Tier 2, metrics from all five categories were summed. Finally, composite scores from both tiers were standardized to 0-1 and summed and the results were binned into equal-sized risk categories (**Figure 4**). Through these calculations, Tier 1 and Tier 2 values contributed equally to the final score. Unlike some prioritization methods, such as ForSys, the Eastern Washington method guards against double or triple counting individual metrics.

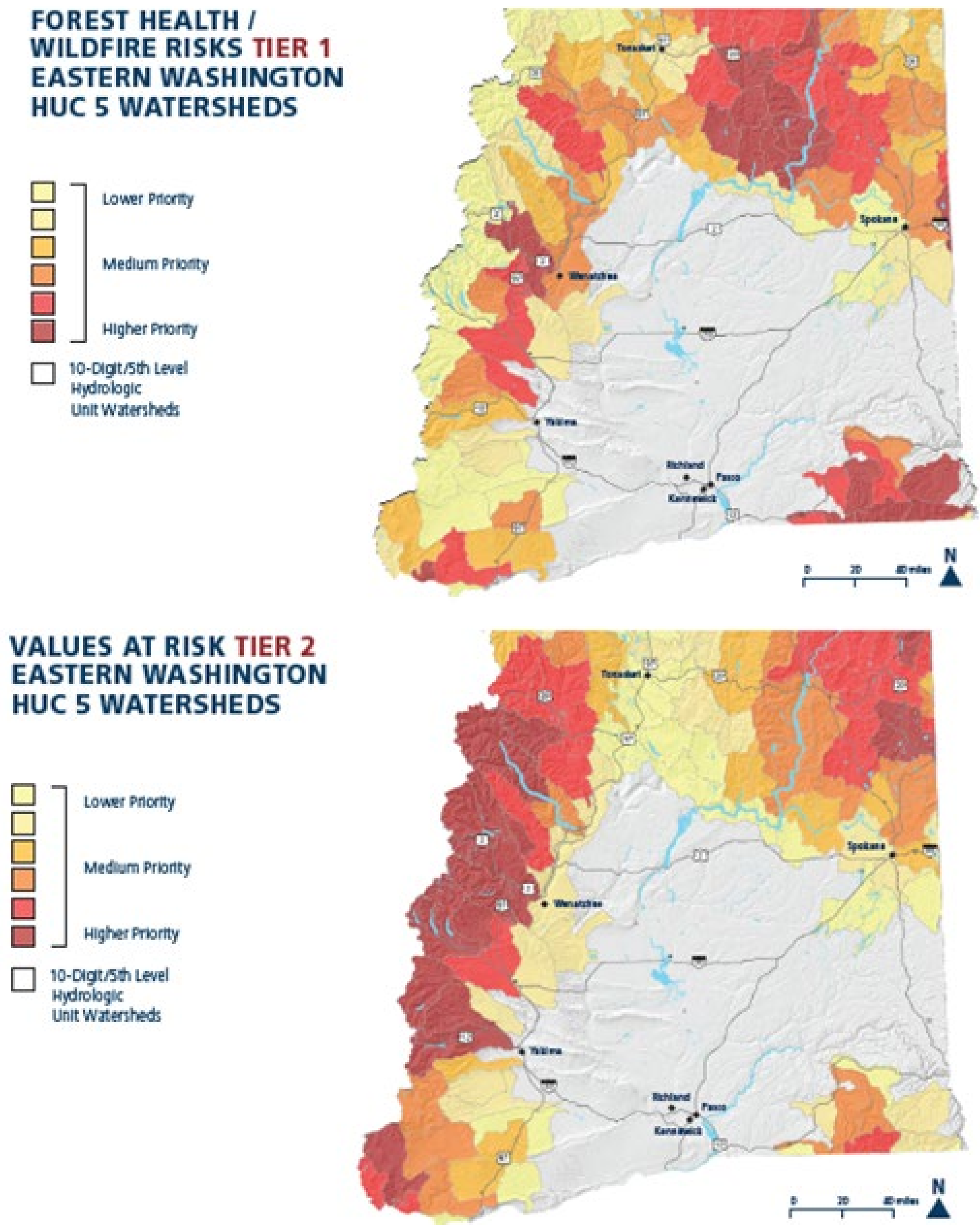

Figure 4. Prioritization results for A) Tier 1: Forest Health and B) Tier 2: Values at Risk

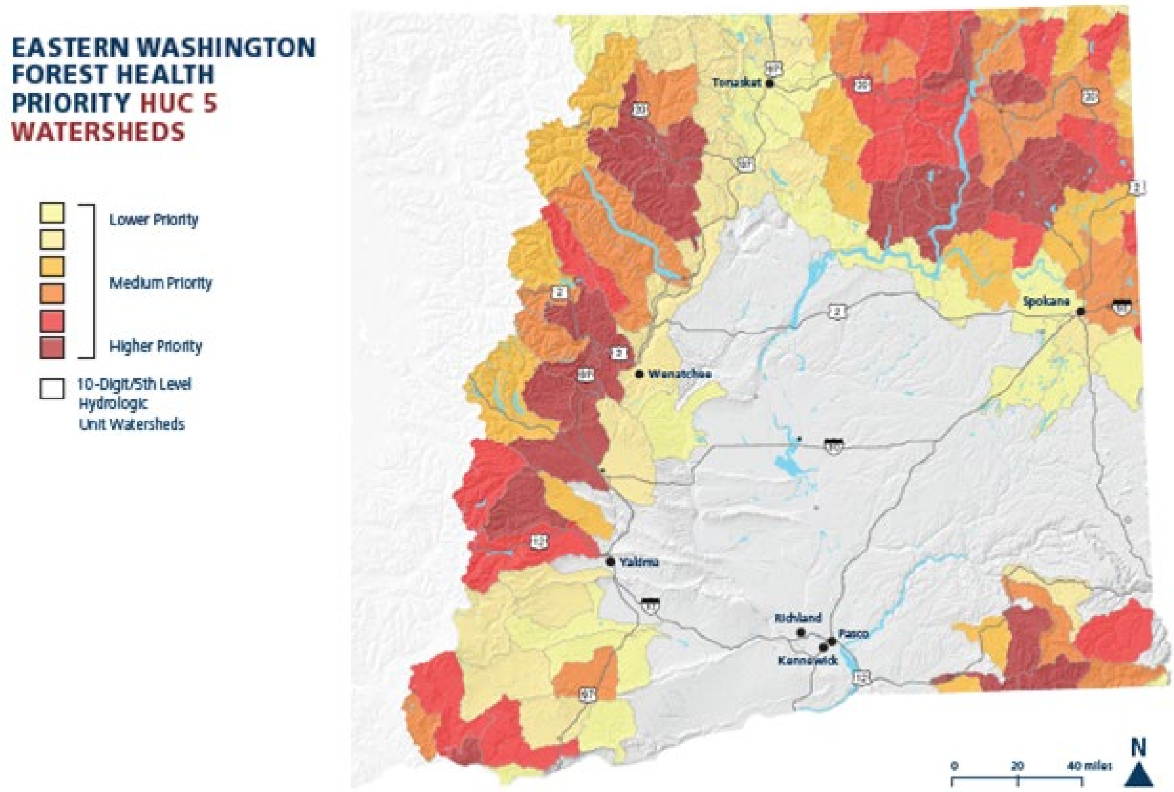

Figure 5. Final watershed prioritization, determined by combining scores from Tiers 1 and 2.

This prioritization effort was not comprehensive of all policy objectives or areas in eastern WA where treatments will be targeted. For example, areas with high community protections needs, such as those in Spokane County, will continue to be prioritized even if they do not fall within a high-priority HUC 5.

Every two years, WA DNR works with landowners and stakeholders to select 125,000 acres for treatment within high-priority HUC 5 watersheds (though there is potential for treatment areas to fall in lower priority HUC 5 watersheds). This selection occurs at the scale of HUC 6 watersheds, which are approximately 20,000 acres on average. The Strategic Plan outlines a process for evaluating potential HUC 6 treatment locations within an HUC 5 watershed. The core principles of this process are:

- A whole landscape approach should be used to focus on restoring resilient landscape conditions, reducing risk to communities, and producing economic benefits.
- Different objectives (ecological, economic, social) and treatment types (mechanical, prescribed fire) will be emphasized in different parts of the landscape and on different ownerships.
- Conduct science-based Landscape Evaluations that assess and integrate information from departure assessments, quantitative risk assessments, Community Wildfire Protection Plans, aquatic restoration needs, wildlife habitat conditions, stakeholder input, and economic and operational considerations.

- Develop projects that balance multiple goals such as reducing wildfire risk to communities, restoring the role of fire, building a backbone of large fire resistant trees, long-term wood production, and ensuring a net benefit to aquatic systems at the watershed level.

The process for identifying planning areas within an HUC 5 watershed is laid out in the Strategic Plan as follows: First, WA DNR consults with local collaboratives, landowners, and other stakeholders to identify candidate HUC 6 watersheds. Then, the Forest Health Advisory Committee reviews candidate watersheds and makes recommendations. Finally, the Commissioner of Public Lands makes the final selection.

After planning areas are selected, they undergo a landscape evaluation. This process involves:

- identifying management zones based on land ownership, management objectives, and common treatment types (e.g., long-term wood production; active restoration; wildfire protection)
- assessing their departure from resilient reference conditions
- modeling fire risk
- analyzing drought vulnerability
- evaluating aquatic restoration needs
- identifying key areas of high need
- estimating potential revenue and costs

In 2020, the landscape evaluation process was updated to now include the following steps:

- identify ownership types and management objectives
- map vegetation and forest types
- map current forest structure and species composition
- assess departure from reference conditions
- assess wildfire risk
- analyze drought vulnerability
- map habitat for focal wildlife species
- evaluate aquatic function
- estimate treatment targets
- evaluate operational feasibility and economics
- map dense forest, large tree sustainability
- prioritize landscape treatments
- prioritize wildfire response benefit
- prioritize for dual benefit using wildland fire Potential Operational Delineations (PODs)

"Dual benefit" refers to locations where fuel treatments could provide benefits for wildfire operations in addition to forest health benefits.

The final step is to develop a landscape prescription, including treatment targets, costs and revenues, and volume estimates by management zone and forest type. This prescription is the basis for packaging treatments together for state funding requests and is used to coordinate US Forest Service NEPA planning.

In 2020, WA DNR released an update on progress toward the goals outlined in the Strategic Plan. They describe how the first sets of priority planning areas were selected in

2018 and 2020. A total of 3.4 million acres were evaluated in these two biennia across 30 priority planning areas, 12 for 2018 and 18 for 2020. Priority planning areas may span multiple land ownerships. DNR estimated that 32-47% of the forested area in the 30 planning areas are in need of treatment to make the landscapes resilient. The landscape evaluation process results in recommendations to these landowners, who ultimately decide on treatments. The watershed prioritization process informed selection of priority planning areas, but "community and resources managers in each landscape ultimately determined final lines on the map."

Western Washington Landscape Resilience Prioritization

Washington's 2020 Forest Action Plan built upon the 20-Year Strategic Plan and introduced a methodology for prioritizing landscapes in western Washington. This prioritization process is similar but not identical to that used for eastern Washington, described above. Rather than the two-tiered system of data analysis, the western Washington analysis used two categories of data: 1) Landscape resilience and forest health indicators, and 2) Values at risk. Two "screens" were also used to inform selection of priority landscapes: densely populated urban areas and vegetation management priority areas. The method for combining metrics was similar to the eastern Washington method. Each landscape was ranked along a standardized version of each metrics, and then these rankings were added together to form a composite score.

Table 7. Metrics used in treatment prioritization for western Washington

Category	Metric	Data source(s)
Landscape resilience and forest health indicators	**Drought: climate change**	Projected increase in water balance deficit based on downscaled climate projections
Landscape resilience and forest health indicators	**Climate change**	Climate dissimilarity index, which combines 11 temperature and precipitation variables and compares modern values to climate projections (Adapt West)
Landscape resilience and forest health indicators	**Water quality and aquatic habitat integrity**	Human disturbance level based on Habitat Condition Index (HCI) from National Fish Habitat Assessment (Esselman et al. 2010)
Landscape resilience and forest health indicators	**Mid-seral, closed canopy forest**	Proportion of forested area in mid-seral, closed canopy condition from the Forest Service Region 6 Restoration Needs Assessment, which used 2012 GNN data.
Landscape resilience and forest health indicators	**Site productivity**	DNR Site Class
Values at Risk	**Fish and wildlife**	Mean of: Number of listed and candidate wildlife species Number of acres in "ecological systems of concern" from Washington Department of Fish and Wildlife (WDFW)

Values at Risk	**Rare and unique habitats**	Terrestrial Ecological Systems of Concern – Washington State Wildlife Action Plan (2015) and Natural Heritage Program Data
Values at Risk	**Drinking water**	Forest to Faucets scores based on the number of people that derive water from a watershed and quantity of water supply (Weidner and Todd 2011)
Values at Risk	**Merchantable accessible timber volume**	Areas with more than 25,000 board feet of timber per acre within 1,500 feet of an existing road, based on: Regional GNN forest inventory dataset developed by the LEMMA lab (Ohmann et al. 2011) DNR Road layer
Values at Risk	**Carbon stocks**	US Department of Agriculture 2017 GNN Data for Above Ground Biomass
Values at Risk	**Small forest landowners**	2012 Small Forest Landowner (SFLO) Acres, Luke Rogers, University of Washington
Screens	**Densely populated urban areas**	Watersheds that are more than 50% developed based on DNR's WUI map layer
Screens	**Forest Service vegetation management priority areas**	Areas identified by national forests

Insights and Takeaways

The 20-Year Strategic Plan was developed within a well-organized stakeholder engagement process. The Plan document is public-facing, transparent, and accessible. It outlines how continuing prioritization decisions will be made on a biennium time scale in consultation with local stakeholders. California forest health investments may benefit from this clear, organized, and transparent decision-making process.

In prioritization methods for HUC 5 watersheds for both eastern and western WA, each of the five "Values at Risk" was implicitly judged to be of equal value, as each metric is standardized and then summed without weighting. Furthermore, some ecosystem services often regarded as important – such as biodiversity – are not included in the list of Values at Risk. Weighing individual ecosystem services is a complex, subjective process that represents social/political choices. Our prioritization recommendations do not provide suggestions for quantitatively weighing individual ecosystem services. We do, however, report panel opinions on the relative importance of 13 prioritization factors that we collaboratively selected and ranked (**Figure 2**). We also suggest leveraging a structured decision-making framework that engages stakeholders and communities to identify goals and priorities. Such a process may reveal ways that ecosystem values can be differently weighted according to local priorities.

The Washington State planning process includes a multi-step process that recognizes the scale-dependent nature of treatment prioritization. While prioritization at the HUC 5 level is performed by DNR, further steps in the prioritization process are performed with more involvement from local resource managers and stakeholders. Ultimately, a flexible landscape prescription is developed that will require local solutions to achieve, recognizing that a one-size-fits-all approach is inadequate for forest management. In addition to providing recommendations and tools for developing forest management plans and grants for forest restoration, WA DNR awarded $555,000 to nine forest collaboratives for community engagement and partnership development, including professional facilitation and meeting coordination. This tiered approach with different processes for different spatial scales contrasts with the ForSys strategy described above.

Washington prioritization also recognizes the dynamic nature of forests. Prioritization is performed every biennium, allowing for incorporation of changing forest conditions over time. The final and smallest-scale step in the process, landscape evaluations, are "living documents" that shift as wildfires occur, forest grow, datasets improve, and methodologies are refined, over their 5-15 year lifespan.

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4. Tahoe-Central Sierra Initiative Resilience Framework

The Tahoe Central Sierra Initiative (TCSI) is a partnership between state agencies including the Sierra Nevada Conservancy and Tahoe Conservancy, the USDA Forest Service, non-profits such as The Nature Conservancy, and other groups. It is the first pilot project of the Sierra Nevada Watershed Improvement Program, an effort launched by the Sierra Nevada Conservancy and the USDA Forest Service. The TCSI's "Roadmap to Resilience" involves developing a framework to define landscape resilience. In collaboration with scientists, land managers, and policymakers, TCSI has developed 10 "Pillars of Resilience" (**Figure 6b**). In August 2020, TCSI scientists published a Resilience Framework defining the core elements of these pillars and metrics to evaluate those elements (**Table 8**).

The TCSI resilience framework is designed to be used to evaluate current conditions, develop target conditions, and identify places on the landscape that are important to achieving target conditions and outcomes. The framework document argues for regional-level planning, such as at the TCSI level (**Figure 6a**), because it is large enough to have measurable effects on ecosystem services that operate at large scales, such as problematic wildfires and tree die-off. Regional planning also allows for more flexible solutions than planning at smaller scales and can facilitate investments in infrastructure, such as biomass facilities or small diameter wood mills. Furthermore, regional-scale planning has the potential to facilitate resource sharing, expedite planning, develop a sustainable workforce, and address policy questions.

Figure 6. A) The TCSI boundary (source: https://sierranevada.ca.gov/what-we-do/tcsi/); B) the ten Pillars of Resilience defined by TCSI.

A

B

Table 8. The TCSI Pillars of Resilience. From Manley et al. (2020).

Pillars	Benefits	Core Elements	Core metrics
Forest resilience	• Increased drought tolerance – reduced risk of drought induced tree mortality • Increased large tree occurrence • Increased old forest habitat security • Maintain or increase tree species diversity	Structure	• Tree density • Basal area • Large/tall tree density • Clump/gap structure • ICO composite index • Seral stage (early, mid, late) • Large snag density
		Composition	• Vegetation community type • Tree species diversity
		Disturbance	• Time since disturbance • Recent disturbance return interval
Fire dynamics	• Reduced risk of large high severity fires	High intensity	• Risk of high severity fire • High intensity patch size

	• Reduced threat of fire to communities and infrastructure • Increased role of fire in creating and maintaining desired conditions • Increased capacity to contain landscape fire (wild or prescribed)	Functional fire	• Time since fire and frequency • Proportion of fire as high severity
Carbon sequestration	• Maintained or increased carbon storage to help meet greenhouse gas emission objectives • Maximized stability of stored carbon • Maintained or increased carbon refugia	Above ground carbon	• Mass
		Below ground carbon	• Mass
		Stability	• Persistence
Wetland integrity	• Maintained or increased sediment, water, and carbon holding capacity • Maintained or restored native species diversity • Maintained or restored wetland occurrence	Structure	• Stream channel morphology • Alluvium storage capacity
		Composition	• Carbon content • Benthic invertebrates
		Hydrologic function	• Surface water flow • Stream channel discharge
Biodiversity conservation	• Maintained or increased focal species habitat • Maintained or increased functional group ability to provide ecosystem services • Maintained or increased community diversity and adaptive capacity	Focal species	• Suitable habitat for focal species • Critical habitat for listed species
		Species diversity	• Species diversity • Non-native species distribution
		Community integrity	• Functional group diversity • Community diversity
Water security	• Maintained or increased water storage to support human uses • Maintained or improved water quality • Maintained or enhanced healthy river systems • Maintain or enhanced flood control	Quantity	• Ground water • Water yield • Snow accumulation
		Storage and timing	• Stream flow volume • Reservoir storage • Snow water content • Snow melt
		Quality	• Nitrogen • Phosphorus • Sediment • Pollution

Air quality	• Reduced risk of high output, toxic wildfire emissions • Reduce risk of very poor air quality days • Reduced ozone	Particulate matter	• Wildfire emissions • Prescribed fire emissions
		Visibility	• Visual quality
		Greenhouse gases	• Ozone
Fire-adapted community	• Reduced threat of wildfire to human communities • Enhanced capacity to respond to immanent threat from fires • Increased acceptance and support for the use of managed and prescribed fire as the most effective tool to reduce the threat of fire to communities	Fire hazard	• Risk of high and moderate severity fire • Threat to infrastructure
		Preparedness	• Community fire protection plans • Egress/ingress plans • Fire management plans
Economic diversity	• Increased capacity to process wood biomass and small diameter woody material • Increased revenue from natural resource-based industries that support local communities • Increased workforce diversity to support forest management activities	Wood product industry	• Biomass supply and demand • Small diameter tree supply and demand • Processing capacity
		Recreation industry	• Recreation diversity • Recreation use
		Water industry	• Water management infrastructure
		Economic health	• Job market in natural resources • Employment resilience • Income diversity
Social and cultural well-being	• Reduced public health impacts • Maintained or improved availability of culturally valued resources • Maintained or improved public and tribal engagement in natural resource management and conservation • Maintained or improved recreation experiences	Public health	• Smoke-induced illness • Public health susceptibility
		Public engagement	• Natural resource knowledge
		Recreation quality	• Costs and benefits to recreation
		Equitable opportunity	• Environmental justice

Within a region, the resilience framework defines landscape "building blocks" as subunits 124,000-247,000 acres in size based on watershed boundaries at HUC levels 8-10. The framework suggests defining a range of target conditions for each building block based on regional targets, the capacity of the building block to contribute to regional targets, and the priorities of local stakeholders.

Scientists collaborating with TCSI have developed methodologies for evaluating metrics associated with several, though not all, of the Pillars of Resilience within the TCSI geographical area. These include fire dynamics, water security, forest resilience, fire-adapted communities, carbon sequestration, and economic diversity. Geospatial layers have been developed and overlaid for these metrics with the goal of eventually identifying high-priority landscapes for treatment. Methodological details on this prioritization process are forthcoming.

Insights and Takeaways

The TCSI resilience metrics (**Table 8**) are still being defined, synthesized, and applied to the TCSI region. The specificity of metrics varies across Pillars, and several "metrics" refer to complex processes that are difficult to measure, such as environmental justice or public health susceptibility. Additionally, the Framework lacks guidance on tribal collaborations, despite the Washoe Tribe's active interest in forest management within the TCSI area. As a pilot project, the TCSI Pillars of Resilience and resilience framework are designed to inform similar regional planning efforts elsewhere in the Sierra Nevada and expedite future planning efforts. As the Framework states: "Large landscape efforts that adopt the Framework for Resilience will enhance their progress because collaborative efforts can move right to goal setting relative to the pillars."

While the pillars and their benefits can serve as a valuable starting point or facilitation tool for collaborative decision-making, the Core Elements and Core Metrics are less transferrable across prioritization efforts. Another region or subregion may have overlapping but distinct values and goals from those outlined by the Pillars of Resilience. For example, in the Western Klamath Restoration Partnership (WKRP; see Section IV.5 below), all parties agreed on shared values and targets and threats to those targets. While some targets and threats align with the TCSI metrics, others do not – i.e. two of the eight critical threats identified were "erosion of community and cultural values, including Karuk traditional practices" and "impaired fishery." We recommend that the Pillars be used as a flexible starting point for identifying a collaborative's shared values and that the Elements and Metrics be used as a reference case for how one collaborative translated shared goals and values into metrics. External collaboratives may learn more from the TCSI's process than their end result. Just as the ranked prioritization factors presented in this report are not a one-size-fits-all solution and cannot replace grassroots collaborative decision-making, neither can the TCSI Resilience Framework. There are limits to how much collaborative decision-making can be expedited by input from external groups without reducing the benefits of collaboration.

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5. Western Klamath Restoration Partnership

The Western Klamath Restoration Partnership (WKRP) is an example of structured decision making with direct application to forest health investments in California. The collaboration is led by the Karuk Tribe and the Mid Klamath Watershed Council and includes partners in state and federal agencies, NGOs, and Tribal organizations throughout the region. The WKRP formally began in 2013 when a previous collaboration focused on the middle Klamath watershed subbasin expanded to include stakeholder groups from the Salmon River (Harling and Tripp 2014). The historic and political context of this collaboration makes their success in engaging a diversity of stakeholders particularly notable. A history of attempted genocide of Indigenous communities and consistent conflict over land management, cultural protocol, and sovereignty have complicated previous attempts to find common ground between Tribes and agencies. However, through grassroots efforts, professional facilitation, and Indigenous leadership both within the formal leadership of the WKRP and in partner organizations, the group has successfully created an action plan for the region. One impetus for using structured decision-making is that diverse stakeholders have differing interests and engaging those differences can be challenging. Difference in opinion can cause conflict, indecision and ultimately inaction. Additionally, if stakeholders are not engaged properly or feel unheard they thwart the effective implementation of decisions. For this reason, it has become increasingly important to engage stakeholders from the outset in order to find the best decisions, engage the largest number of people possible in supporting that decision, and provide a pathway for those who disagree to see a transparent open process that led to a decision that they do not happen to favor. Structured decision making is a method of establishing that pathway (Gregory et al. 2012 book). Structured decision making requires:

1. Defining a problem (e.g., extreme wildfire) and identifying fundamental objectives (e.g., maintaining resilient forests, keeping people safe and healthy, protecting sensitive plants and animals protecting recreational and aesthetic values, maintaining forest livelihoods)
2. Identifying possible action alternatives (e.g., biomass removal, logging, prescribed fire)
3. Modeling the consequences of deploying these actions (e.g., reduced forest fuels, impacts to people, wildlife)
4. Considering the trade-offs among the different actions

The WKRP used a specific form of structured decision making called the Conservation Standards. The process is conceptually straightforward, but often entails substantial investment in stakeholder interactions. The Conservation Standards are an adaptive management planning process that involves five steps: Assess, Plan, Implement, Analyze & Adapt, and Share. Through a series of workshops facilitated by the US Fire Learning Network using the Open Standards Process, the WKRP was able to find the values and vision that their diverse set of stakeholders shared. The WKRP began this process by establishing zones of agreement where all parties agreed that upslope restoration needed to occur. They then established a vision: "Establish and maintain resilient ecosystems, communities, and economies guided by cultural and contemporary knowledge through a truly collaborative process that effectuates the revitalization of continual human relationships with our dynamic landscape". The WKRP identified several shared values or conservation targets as well as the threats to these targets. These included:

1. Fire Adapted Communities
2. Restored Fire Regimes
3. Healthy River Systems
4. Resilient Bio-diverse Forests/Plants/and Animals
5. Sustainable Local Economies
6. Cultural and Community Vitality

Critical threats:

1. Lack of stable jobs
2. Erosion of community and cultural values, including Karuk traditional practices
3. Lack of beneficial fire
4. Altered forest structure and composition (overly dense forests)
5. High fuel loading
6. Lack of defensible space
7. Habitat degradation (terrestrial and aquatic)
8. Impaired fishery

Insights and Takeaways

The WKRP is an example of the benefits of structured decision making and professional facilitation. Decisions around natural resource management can be deeply contentious. Historical and contemporary conflicts can further entrench an unwillingness to collaborate. Structured decision making can provide collaboratives with the framework needed to move past tension, inaction, and indecision. In the case of the WKRP, professional facilitation from the US Fire Learning Network was critical for the success of their process. As California contends with an ever more complicated and quickly changing set of circumstances it is important to build a framework that allows for adaptation and stakeholder engagement. Building that framework can be a large investment of time and resources but it also ensures that decision making, leadership, and management is responsive to change in both environmental and socio-political systems.

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6. Puget Sound Partnership

The Puget Sound Partnership (PSP) is another example of structured decision-making, albeit focused on estuary restoration rather than forest health treatments. The PSP is a joint venture of the State of Washington and the US Environmental Protection Agency to implement ecosystem recovery goals in the Puget Sound estuary. The PSP is a prime example of prioritization of multiple competing objectives in a complex ecosystem. The PSP is not striving to prioritize forest treatments, per se. Thus, the lessons learned from this example relate to the formalization of structured decision frameworks. The PSP used a structured decision-making process to arrive at shared goals and actions. As does the WKRP, the PSP employs the Conservation Standards (https://conservationstandards.org/conservation-standards).

The Puget Sound Partnership has balanced potentially competing objectives in three ways. First, they engaged in an extended effort to identify hierarchical objectives along with performance measures that signal progress toward these objectives. PSP calls these objectives "Vital Signs" (**Figure 7**). Second, PSP has geographically divided the region into geographical subunits where priorities may legitimately vary, encouraging each region to identify its own pathway toward the vital signs. Third, they have linked funding from the state and the US Environmental Protection Agency to framing the request within the PSP Vital Signs framework. If a partnering organization wants resources, then they need to be able to describe how the proposed actions will, in theory, lead to improved ecosystem Vital Signs. Although this process has taken more than a decade to 'settle in,' it is now viewed as a credible and legitimate way to manage resources to improve the Puget Sound ecosystem.

Figure 7. The Puget Sound Partnership's Vital Signs diagram illustrating six general overarching fundamental objectives (e.g., healthy Human Populations), with sub-objectives under each (e.g., healthy swimming beaches).

Insights and Takeaways

The PSP's Vital Signs framework could help California decision-makers and collaboratives ensure that forest management strategies have identified objectives and targets for treatments. For instance, fundamental objectives for management might include healthy and resilient forests, healthy rural communities, healthy wildlife, protecting endangered species, and maximizing recreational opportunities, among others. Extreme wildfire may threaten these objectives and management may seek to reduce this threat. However, this approach is different from considering our objective to be reducing the risk of extreme wildfire; reducing the risk of fire is a complex, rather than fundamental objective.

In selecting actions, we may find that prescribed fire is a potential tool for use in reducing fuels to reduce the risk of extreme wildfire. Prescribed fire creates smoke, which has adverse impacts on our fundamental objective of healthy people. An alternative, mechanical thinning, might not have adverse human health impacts, but might adversely impact other fundamental objectives. The challenge, then, is to prioritize where, when, and how much of different actions – all of which may cause complex outcomes – to implement.

7. North Coast Resource Partnership

The NCRP was awarded a Regional Forest and Fire Capacity (RFFC) block grant from the California Natural Resources Agency, administered by the Department of Conservation, for planning and the identification and implementation of local and regional projects to improve forest health and increase wildfire resiliency (Watershed Science Center). The NCRP is a long-term collaboration among Northern California Tribes, counties, and diverse stakeholders. The NCRP region covers over 19,000 square miles – 12% of the California landscape – and includes the Tribal lands and the counties of Del Norte, Humboldt, Trinity, Siskiyou, Modoc, Mendocino and Sonoma. The NCRP is by design a voluntary, non-regulatory, stakeholder-driven planning framework meant to emphasize shared priorities and local autonomy, authority, knowledge, and approaches to achieving Tribal, state, regional, and local priorities related to North Coast water infrastructure, watersheds, public health, and economic vitality (NCRP Handbook).

The NCRP has identified six major goals: intra-regional cooperation and adaptive management, economic vitality, ecosystem conservation and enhancement, beneficial uses of water, climate adaptation and energy independence, and public safety (**Table 9**). Within these larger goals, objectives address environmental justice, Tribal collaboration, and social ecological resilience. This project is also notable because of its far-reaching geographic area and its efforts to organize decision making equitably while maintaining evidence-based prioritization of projects.

Table 9. NCRP Goals and Objectives

NCRP Goals	NCRP Objectives
Goal 1: Intraregional Cooperation & Adaptive Management	Objective 1 - Respect local autonomy and local knowledge in Plan and project development and implementation
	Objective 2 - Provide an ongoing framework for inclusive, efficient intraregional cooperation and effective, accountable NCRP project implementation
	Objective 3 - Integrate Traditional Ecological Knowledge in collaboration with Tribes to incorporate these practices into North Coast Projects and Plans
Goal 2: Economic Vitality	Objective 4 - Ensure that economically disadvantaged communities are supported and that project implementation enhances the economic vitality of disadvantaged communities by improving built and natural infrastructure systems and promoting adequate housing
	Objective 5 - Conserve and improve the economic benefits of North Coast Region working landscapes and natural areas
Goal 3: Ecosystem Conservation and Enhancement	Objective 6 - Conserve, enhance, and restore watersheds and aquatic ecosystems, including functions, habitats, and elements that support biological diversity
	Objective 7 - Enhance salmonid populations by conserving, enhancing, and restoring required habitats and watershed processes
Goal 4: Beneficial Uses of Water	Objective 8 - Ensure water supply reliability and quality for municipal, domestic, agricultural, Tribal, and recreational uses while minimizing impacts to sensitive resources
	Objective 9 - Improve drinking water quality and water related infrastructure to protect public health, with a focus on economically disadvantaged communities
	Objective 10 - Protect groundwater resources from over-drafting and contamination
Goal 5: Climate Adaptation & Energy Independence	Objective 11 - Address climate change effects, impacts, and vulnerabilities, including droughts, fires, floods, and sea level rise. Develop adaptation strategies for local and regional sectors to improve air and water quality and promote public health and safety
	Objective 12 - Promote local energy independence, water/ energy use efficiency, GHG emission reduction, carbon sequestration, and jobs creation
Goal 6: Public Safety	Objective 13 - Improve flood protection, forest and community resiliency to reduce the public safety impacts associated with floods and wildfires

The governance of this collaboration relies on the input of two large committees: the Policy Review Panel (PRP) and the Technical Peer Review Committee (TPRC). The Policy Review Panel consists of two Board of Supervisors' appointees and alternatives from each of the seven member counties as well as three Tribal Representatives that are elected by Tribes in each of three subregions.

The PRP then appoints technical and scientific staff from each county and tribal representatives to the Technical Peer Review Committee (TPRC). Expertise on the TPRC includes fisheries, ecology, engineering, geology, agriculture, watershed planning and management, water infrastructure and energy (NCRP Handbook). The TCRP reviews project proposals by their technical merit, as well as on guidelines developed by the PRP and set by the funding solicitation

To incorporate equity, projects are prioritized for economically disadvantaged communities in order to continually invest in building the region's capacity. Project proponents are also required to demonstrate coordination and outreach to local governments and Tribes in order to increase collaboration and consultation throughout the region. Lastly, the PRP makes every effort to include projects from each of the seven counties and three Tribal regional areas as long as projects meet the NCRPs other qualifications.

Insights and Takeaways

By including equity, social resilience, and ecological assessment throughout their organizational objectives, governance, and project prioritization, the NCRP is creating a holistic approach to land management that could serve as a model for other regional collaboratives. The transparent, structured nature of their governance – including the Policy Review Panel and Technical Peer Review Committee, with an established method of appointing representatives from each county and tribe – ensures equal representation in decision-making. Including Tribal members throughout both of these committees ensures that each part of the process is inclusive and responsive to local Indigenous knowledge in addition to Tribal interests. Transparent funding guidelines also increase accountability.

8. California Forest Health Grants

California Forest Health Grants are funded through the California Climate Investments (CCI) program, which uses cap-and-trade revenue, referred to as the Greenhouse Gas Reduction Fund (GGRF), to invest in carbon storage and emissions reductions programs across many sectors. CCI grants are overseen by the California Air Resources Board (CARB) and Forest Health Grants are administered by CalFire. Of the projects funded by Forest Health Grants, most support "Landscape Scale Health," while lesser funds support fire prevention, conservation easements, and other programs.

Project Evaluation

Forest Health Grants are awarded through a competitive process in which project proposals are evaluated by state agency personnel. A point system is used to evaluate projects (**Figure 8**). However, this rubric is not binding and evaluators may use discretion to select proposals they feel are most likely to succeed.

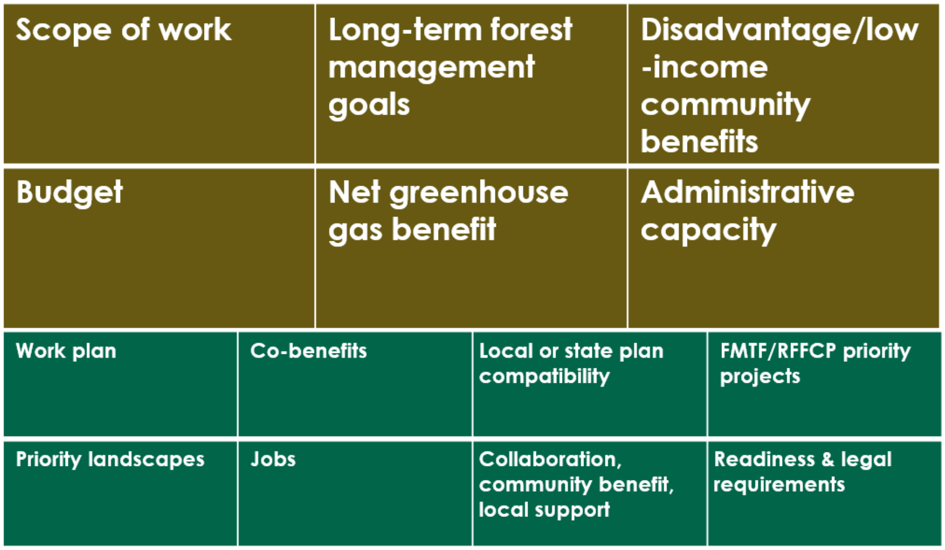

Figure 8. Criteria used to evaluate Forest Health Grant applications. Box sizes are proportional to the potential points each category is awarded. Brown = 10 points, green = 5 points

Grant guidelines for fiscal years 2020-2021 and 2021-2022 were released in March 2021. The new grant selection criteria deviate slightly from **Figure 8**: there are now 5 additional points for Scope of Work, 5 fewer points for Long Term Forest Management Goals, and the FMTF/RFFCP category was subsumed into 10 points for Collaboration, Community Engagement, and Local Support.

Applicants were formerly required to estimate the net greenhouse gas (GHG) benefit of their proposed forest treatments according to quantification methodologies developed by CARB and CalFire. These estimates were used to evaluate the "Net greenhouse gas benefit" criterion and inventory progress toward CCI climate mitigation (**Figure 8**). However, due to the complexity of the quantification methodologies and varying technical capacity of applicants, many GHG estimates were re-calculated by a third party contractor after GGRF funds are awarded. This resulted in delayed accounting of program benefits and uncertainty in project evaluation and award decisions.

For the criterion of "Priority landscapes," applicants must use the CalFire FRAP Priority Landscapes web tool (Section IV.1). In addition to the two categories of Priority Landscapes described above – Reducing Wildfire Risks to Ecosystem Services and Reducing Wildfire Threats to Communities – the web tool contains two other area delineations: Restoring Pest Damaged Areas and Restoring Fire Damaged Areas. The pest layer shows High Hazard Zones (HHZ) in Tier 1 and Tier 2 as delineated by the Tree Mortality Task Force in 2018. These zones indicate where high tree mortality from the 2012-2015 drought overlaps with critical infrastructure (Tier 1) and community and natural resource assets (Tier 2). The layer on Restoring Fire Damaged Areas shows the footprints of fires that burned between 2008 and 2017. Each 30m pixel within a footprint is assigned a rank from 1 (lowest restoration need) to 5 (highest restoration need) based on a combination of metrics related to surface water value, site quality, erosion hazard potential, and high severity burn. According to the grant guidelines, a point is given for each priority landscape type that overlaps with the project area, with a fifth point for local or regional priority designations, if applicable. Unfortunately, the Priority Landscapes web tool is rapidly becoming out-of-date, since it includes only fire footprints through 2017, excluding two of the largest burn years on record. However, according to CalFire personnel, the priority landscape criteria rarely tip the scales in funding decisions.

For the criterion of "Disadvantaged/low-income community benefits," project proponents use quantitative, standardized criteria defined by the California Air Resources Board (CARB). Disadvantaged communities are delineated using CalEnviroScreen 3.0, a synthetic index of environmental justice that combines 20 indicator variables associated with communities' pollution burden and population characteristics (see Section III.8). Disadvantaged communities are defined as census tracts in the top 25% most impacted according to CalEnviroScreen 3.0. Low-income communities are defined as census tracts and households that are either at our below 80% of the statewide median income or at or below the threshold designated as low-income by the California Department of Housing and Community Development. Disadvantaged and low-income communities are together referred to as "priority populations."

Forest Health Grants include the 35 Priority Projects determined by the 45-Day Plan of 2019, which used a separate prioritization process from other Forest Health Grants. First, CalFire Unit Plans identified priority fuel reduction projects based on place-specific expertise. These proposed projects were then intersected with the two CalFire Priority Landscape layers (Section IV.1), a wildland urban interface (WUI) layer, and the State Responsibility Areas. Additionally, each project was evaluated for socioeconomic benefit, not through the CARB criteria described above, but by using American Community Survey data (see Section III.8). Six socioeconomic variables were used: families in poverty, people with disabilities, people that have difficulty speaking English, people over 65, people over 5, and households without a car.

Funding allocation to date

The most up-to-date data available on CCI projects goes through May 31, 2020 (https://webmaps.arb.ca.gov/ccimap/). According to these data, $308 million have been allocated to Forest Health Grant projects since the program's inception in 2015, across a total of 152 projects. Over one third of the GGRF funds allocated through Forest Health Grants have gone toward the ten initiatives shown in **Table 10** and **Figure 9**.

Table 10. Highest-funded Forest Health projects in descending order of GGRF funding. Five TCSI projects are combined into one for simplicity.

Project Name	GGRF Funding (millions)	Reporting year(s)	Project Type	Estimated GHG Reductions (metric tons CO_2 equivalent)
TCSI (5 projects)	$33	2017-2018	Landscape Scale Health	Unpublished
California National Guard Deployment on the 35 Priority Projects*	$23	2019	Fire Prevention	Unpublished
My Sierra Woods-Capturing Carbon on California's Family Forest Lands	$9.0	2018	Landscape Scale Health	183,436
State Route 17 Fuel Break*	$9.0	2019	Fire Prevention	Unpublished
Redwoods Rising Phase I Project	$7.0	2019	Landscape Scale Health	84,572
Burney - Hat Creek Forest Health Project	$7.0	2019	Landscape Scale Health	Unpublished
Plumas Collaborative Forest Health Project	$6.6	2018	Landscape Scale Health	1,127,063
California Mobile Biomass Harvesting and Biopower Unit (CARIBOU)	$5.8	2020	Biomass, Fuel Reduction	Unpublished
Whiskey Working Forest Conservation Easement - Scott River Headwaters Phase 3	$5.8	2019	Conservation Easement	1,496,017
California State Parks Forest Health IAA	$5.8	2020	Fuel Reduction, Biomass	Unpublished

*allocated through separate funding process outlined in the 45-Day Plan

According to CARB accounting, 39 out of the 152 projects count toward investment minimums for benefits to low-income communities, for a total of $111 million of the $308 million invested. In published descriptions of benefits to disadvantaged communities and other project benefits, 23 of the 39 projects describe benefitting priority populations through reduced fire risk, 11 cite local job creation, 4 are tribal-led, collaborate with tribes, or protect tribal cultural resource, 2 increase local capacity, 2 reduce hazard trees, 3 increase recreation and/or outdoor education opportunities, 4 have no benefits description, and 5 simply list "reforestation." Two projects are reported as counting toward disadvantaged community investment minimums, though one may be a reporting error because it is located far from any CARB-defined disadvantaged communities and is described as benefitting low-income, rather than disadvantaged, communities. The other is the California Forest Shared Stewardship Support Program ($2.7 million), which helps provide technical support to forest restoration collaboratives and implementation partnerships. The Forest Health Grant program would benefit from improved record-keeping and transparency of how projects benefit priority populations to ensure funding allocation aligns with state environmental justice objectives.

Insights and Takeaways

Barriers in the application process may limit the number of projects that apply for Forest Health Grants. In former funding years, completing carbon calculations using the state quantification methodology presented a technical hurdle that many well-resourced groups contract out to third party experts, hire experts, or collaborate with experts at research institutions. Lower-capacity project proponents may not have had this ability. The new system of CalFire staff calculating GHG benefit for fiscal year 2021-2022 may alleviate the planning burden on applicants, which may help increase project applications from lower-capacity collaboratives that may benefit priority populations.

We recommend increased transparency in funding decisions. The evaluation rubric shown in **Figure 8** is only a starting point for agency personnel deciding between projects. A more standardized, transparent process for deciding between projects would increase program accountability. Finally, more funding for project planning, including completing NEPA and CEQA, rather than funding only "shovel-ready" projects, would also increase access for less well-resourced communities, as would longer funding duration.

In some ways, the Forest Health Grant Program and the North Coast Resource Partnership have similar mandates: to allocate limited state funds across large geographical regions in a way that is both equitable and ecologically beneficial. The two initiatives have very different approaches to achieving this mandate. While the NCRP developed a transparent, structured process for equitably allocating funds according to collaboratively determined objectives, the Forest Health Grant program relies on a top-down approach that some applicants find opaque and difficult to navigate. There is no publicly available record of who the individuals deciding between Forest Health Grant applicants are, though they are state agency personnel. In the NCRP, projects are evaluated by a Technical Peer Review Committee made up of representatives from each county and tribe, appointed by the Policy Review Panel, which is also representative of all counties and tribes in the region.

Rather than relying on metrics of environmental justice like CalEnviroScreen 3.0 and low-income census tracts, the Forest Health Grant Program would benefit from incorporating environmental justice into its decision-making processes. As described in Section III.8, existing quantitative metrics have limited utility in reflecting true benefits to tribes and to disadvantaged communities, respectively. Using CalEnviroScreen 3.0 is particularly unhelpful, as virtually no Forest Health projects have met CARB's definition of benefitting disadvantaged communities according to CalEnviroScreen 3.0. The following section presents an alternative, qualitative method of evaluating potential forest health projects. This framework for evaluating socio-ecological considerations provides a more holistic, equitable option that may enhance funding initiatives like the Forest Health Grant Program. The proposed framework may also help inform development of regional action plans as proposed by the FMTF Action Plan. Ideally, the principles of socio-ecological resilience that we describe below – Partnership-building, Long-term commitment, Building local capacity, and Mobilizing Traditional Ecological Knowledge – would be integrated into the development of the regional collaboratives themselves, rather than used only to evaluate projects at the regional level.

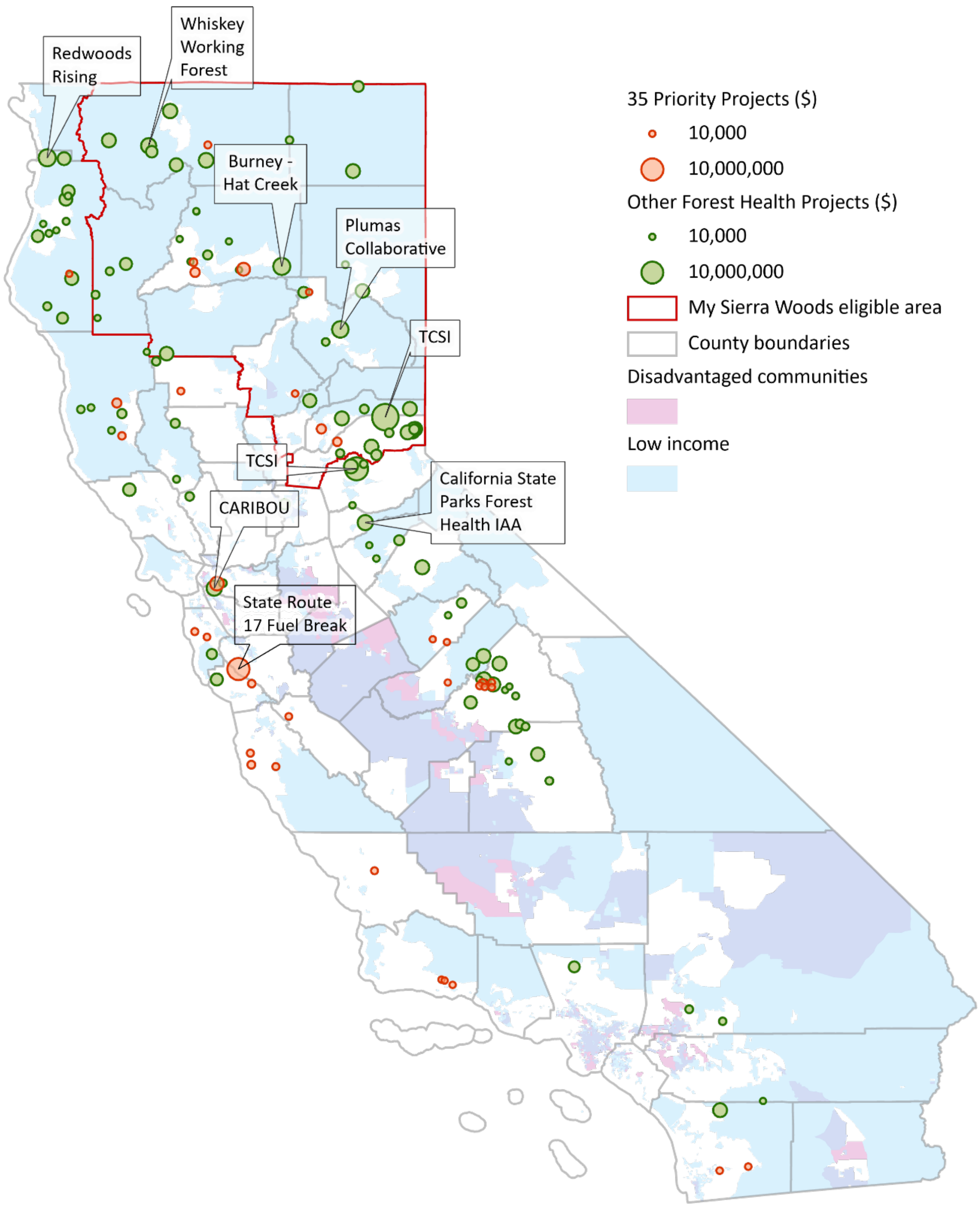

Figure 9. Forest Health Projects sized in proportion to funding received. The area in red shows the counties eligible for My Sierra Woods, a distributed funding initiative for private landowners. Pink and blue shading shows disadvantaged and low-income communities, respectively, based on CARB criteria for CCI allocation.

V. Socio-ecological considerations

California is currently facing multiple, large-scale social and ecological crises. Wildfire, tree mortality, biodiversity losses, and urbanization present the state with unique socio-political challenges that require new approaches to land management (Fischer et al. 2016, Moreira et al. 2019). As environmental conditions continue to change rapidly, it has become imperative to move from a narrow focus on increasing the pace and scale of hazard reduction treatments towards embracing an adaptation and resilience framework (Schoennagel et al. 2017, Gillson et al. 2019, McWethy et al. 2019). Such a framework recognizes the limitations imposed by rapid environmental change, uncertainty about the efficacy of mitigation options, and the constraints of top-down management, and suggests pathways based on the dynamic interplay between social and ecological systems (Spies et al. 2014, Kline et al. 2017). By building adaptive social systems at the local, regional, and state level we ensure that decision-making is equitable, evidence based, collaborative and timely. This is sometimes referred to as adaptive governance: governance that has an extensive capacity to evaluate environmental change and flexible institutions and collaborations that can learn and transform even with rapid or consistent change (Folke et al 2014). Without adaptive governance, ecological work can be costly, inequitable, and ultimately reactive instead of proactive. Adaptive governance requires a larger initial investment of time and resources but it may ensure a better more resilient environmental future.

The resilience of a social-ecological system can be evaluated by its vulnerability (which includes its exposure to negative impacts and its susceptibility to those impacts), and its adaptive capacity to respond during and after a change (Adger 2006, Kolden and Henson 2019). For example, communities in California have seen increased vulnerability to wildfire due to increasing exposure and susceptibility. However, whether those communities will be able to adapt depends on their adaptive capacity. This framework allows us to envision interventions in California forests that create both ecosystem and social resilience, increasing socio-ecological resilience by reducing vulnerability and increasing adaptive capacity. Forest restoration and fire management will be more effective when considering how interventions affect social-ecological resilience, from planning to implementation. When forest restoration and fire management does not consider the impact on socio-ecological resilience, opportunities to build adaptive capacity may be lost. This means that every decision making or collaborative effort will need to put in the same amount of effort to engage stakeholders, inform the community, and implement plans, increasing redundancy. When there is a focus on building adaptive capacity we build trust, community partnerships, and stakeholder investment that eventually lead to a more robust and efficient decision making and adaptive process.

In this report, we propose four specific pathways for achieving resilience to wildfire through the integration of a social-ecological framework in fire management. These pathways draw on our understanding of vulnerability and resilience in social and ecological systems. They include partnership-building, long-term commitment, local capacity building, and mobilization of Traditional Ecological Knowledge (TEK).

Throughout these pathways we have built in environmental justice frameworks which ensure that solutions provide climate justice for all California communities. Finally, we present a rubric with criteria for evaluating individual projects along these pathways (**Table 12**). Based on both empirical data and practitioner-based knowledge, our criteria are designed to be used by both project proponents and reviewers to evaluate the potential of projects to create more resilient social-ecological systems in California.

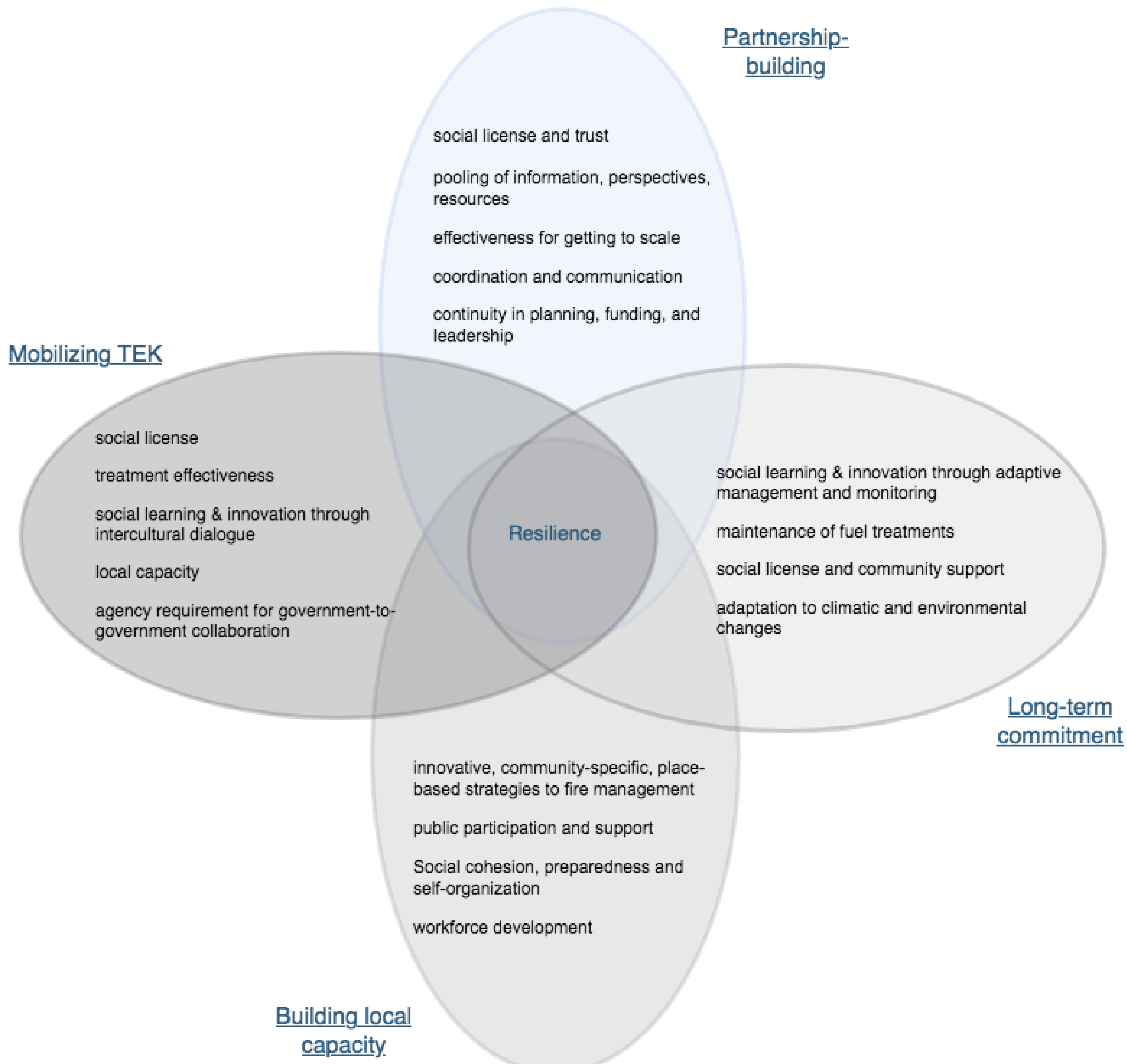

Figure 10. Socio-ecological factors influencing management capacity.

Table 11. Social-ecological pathways for enhancing management capacity

Social-ecological criteria	Improves management capacity through...	Vulnerability component(s)*	Example actions
Partnership-building	Social license and trust	E; S; AC	Cross-jurisdictional projects involving agencies, NGOs, private landowners, tribes, etc; science-management and management-policy partnerships; community engagement; involve third-party facilitators when needed
	Pooling of information, perspectives, resources	AC	
	Effectiveness for getting to scale	E	
	Coordination and communication	E; S; AC	
	Continuity in planning, funding, and leadership	E	
Long-term commitment	Social learning & innovation through adaptive management and monitoring	E; AC	Follow-up management planned, including treatment maintenance and monitoring; experimental approaches and demonstration areas; public/manager education; integration of community priorities/concerns in management/monitoring
	Project follow-up and maintenance	E; AC	
	Social license and community support	E; S; AC	
	Adaptation to climatic and environmental changes	AC	
Building local capacity	Innovative, community-specific strategies for fire management	AC	Integrate projects with local efforts by Fire Safe Councils,VPDs; build upon community plans such as CWPPs, Firewise, etc.; include training and job development opportunities; prioritize working with community leaders and developing new generation of local natural resource managers
	Public participation and support	E; S; AC	
	Local leadership	E; S; AC	
	Social cohesion, preparedness and self-organization	S; AC	
	Workforce development	E; AC	
Mobilizing TEK	Social license	E; S; AC	Prioritize Tribal leadership when possible; provide culturally relevant job training and support development of Tribal
	Treatment effectiveness	E	
	Social learning & innovation through intercultural dialogue	S; AC	

Local capacity	E; AC	workforce; facilitate Tribal access to management opportunities; use Indigenous science/knowledge in planning and monitoring

*E : Exposure; S: Susceptibility; AC: Adaptive capacity (Kolden and Henson 2019)

1. Partnership-building

Cross-sector collaboration has consistently emerged as a potential source of adaptation and resilience in social ecological systems. Partnerships can increase the effectiveness of land management projects by expanding the scope of information, perspectives, and resources available to complete a project (Butler and Goldstein 2010). Setting up points of communication, trust, and boundaries with new collaborators such as Tribes, NGOs, industry groups, or grassroots activists can be a huge investment in time and resources, but can result in long-term solutions to forest health problems. These frameworks and protocols for collaboration increase the long-term resilience of communities and ecosystems (Charnley et al. 2020). While ensuring equitable and effective partnerships can look differently depending on the partners in question, the following initial criteria can help to evaluate the strength of the collaborative processes included in the project:

Process ensures all partners/stakeholders are identified and supported to participate: A partnership that is equitable will make sure that underrepresented communities are at the table by:

- Conducting **intensive**, comprehensive outreach: Project proponents develop and implement an intensive outreach plan that acknowledges and responds to the historical relationships that may be present between underrepresented or minority communities and the project proponent
- Ensuring early involvement: Project proponents involve underrepresented communities in project development and planning
- Providing funding to support participation: While bringing every stakeholder to the table is often thought of as ideal, all partners are rarely given the support they need to participate. Entities like government agencies, NGOs, and corporations can send employees on paid time to participate in calls, meetings, and conferences. Marginalized community members, Tribal members, and others may not have that luxury and may struggle to pay for travel or their time. A dedicated fund to remove these barriers is preferable.

Inclusive and professional outside facilitation provided: Facilitation can sometimes be taken for granted but may be appropriate in order to manage differences in priorities and help resolve conflicts that may arise in a collaboration. A neutral party can help move the group out of conflict or stagnation into action. Facilitators should have experience working with Environmental Justice advocates as well as Tribal communities in order to be effective. If a project has set aside funding for facilitation, this signals a commitment to work through differences to ensure mutual respect and collaboration.

Multiple co-benefits considered in planning: Another important sign of effective collaboration is the identification of multiple co-benefits. Shared goals and outcomes of stakeholders create benefits in both forest health and communities. If the goals of a collaboration ensure that there are economic, environmental, and equitable outcomes from the planning phase forward, the project is more likely to be effective and supported by diverse community members and stakeholders.

2. Long-term commitment

Increasing the pace and scale of fire management is a key state priority. However, this initial investment, while important, must be a part of a larger adaptive management approach. Adaptive management increases social ecological resilience in several ways. In terms of the ecosystem, adaptive management ensures that any changes in an ecosystem are detected and investigated, and that the management plan reflects those changes. Given the increased pace of ecosystem changes and potential for climate-related tipping points, there is an even greater need for long-term monitoring and management. Sustained investments are critical to the safety of our forests and communities, and they are important both for ecosystems and rural economies. Building economies on maintenance of forest health moves away from boom-and-bust economies of resource extraction and towards a climate forward economy. Long-term job opportunities that fulfill needs such as monitoring landscapes, implementing treatments, convening and organizing stakeholder decision making, and otherwise increasing local capacity to manage surrounding forests are an investment in the future of our ecosystems and economies.

A project may demonstrate this by:

- Including repeat treatments (managing the interval) over time in their planning
- Maintaining local community support by creating ongoing public engagement opportunities and education
- Ensuring institutional commitment from participating agencies to ensure that projects are not relying on one or two dynamic individuals.
- Detailing a feasible monitoring plan, and a commitment to adaptive management
- Including project benefits that go beyond fuels reduction to include other forest and ecosystem health aspects
- Taking a "living laboratory" approach that includes experimentation, adaptive and iterative management that educates decision-makers and land managers and spurs novel approaches. Such an approach may include complementary restoration treatments, and long-term monitoring that incorporates locally developed indicators
- Supporting decentralized decision-making and local leadership in planning and permitting to ensure that the most current "boots on the ground" expertise can be included.

3. Local capacity building

The pace and scale of management needed to reduce fuel loads throughout California is immense. To increase workforce and structural capacity throughout the state, it is important to build local capacity to address long-term forest management needs. Moving from boom-and-bust economies to economies built on long-term forest health will require a shift in training and funding on multiple levels. Building the necessary workforce will require job training and landowner education to build an "All Lands" approach (Charnley et al. 2016). While both federal and state natural resource agencies are engaging in this type of work already, the scale at which it needs to happen to lift rural economies is immense. Innovation from projects on how best to provide job training to local workers and landowners could propel our state toward a climate and fire forward economy. Beyond increasing capacity for project implementation, supporting local authority over fire management can increase community involvement in planning and preparedness, build trust in agencies and social license for management, and lead to more locally adapted solutions (Ostergren et al. 2006). Research suggests that smaller-scale institutions are more adaptable to rapid change than larger ones, which tend to be more rigid and unresponsive to feedback (Petty et al. 2015). Building capacity should therefore be a priority at all levels of project development, from planning to implementation.

Projects may demonstrate this by:

- Providing local employment and economic development
- Supporting or instituting job training in forest restoration and prescribed fire
- Providing opportunities for local community leaders to participate in project planning and implementation
- Supporting projects on private land
- Training a prescribed fire workforce separate from fire suppression crews (Miller et al. 2020)

4. Mobilization of Traditional Ecological Knowledge

Traditional Ecological Knowledge or Indigenous Science is a complex set of philosophies and practices that inform the stewardship decisions of Native communities. This approach to creating and practicing science is as diverse as Native communities themselves. The knowledge that Native communities across California have built over millennia is invaluable to understanding California ecosystems today.

Native communities have a basic right to consultation on forest health projects (Getches et al. 2004, Donoghue et al. 2010). However, projects should go further than this basic requirement and engage in long-term partnership and collaboration. Setting up long-term collaboration facilitates ongoing communication. Investing in the capacity of Native communities to steward forest health projects can increase the longevity and consistency of stewardship (Cronin and Ostergren 2007). Native people have a vested interest in the wellbeing of landscapes that fall within their ancestral territory and collaboration could increase forest health, as well as the accessibility and abundance of cultural resources within traditional territories (Lake and Long 2014).

A project may demonstrate this by:

- Naming California Tribes as partners engaged at all levels including leadership
- Prioritizing local Indigenous knowledge in project planning and implementation
- Including cultural aims as integral goals of their project
- Seeking to learn cultural protocols and priorities in project management
- Honoring cultural protocols and priorities in management
- Demonstrating Tribal control over Indigenous knowledge mobilization and data management

5. Rubric

These criteria are designed to be used by both project proponents and reviewers to evaluate the potential for projects to create more resilient social-ecological systems in California.

Table 12. Rubric. For applicants: Rate yourself on a range of 1-10 and explain why. We recognize that all projects will not receive 10s on all criteria so if you are not at a 10 please explain what you are doing to try to get there.

	High (7-10)	Medium (4-6)	Low (1-3)
Partnerships and collaborations	Project has a plan for inclusive stakeholder outreach and inclusion. Community members like grassroots activists, Tribal members, and residents are included equitably. Once stakeholders are convened there is a plan for facilitation and moving through conflict and stagnation. The project provides multiple benefits to various community stakeholders	Project has an incomplete plan for outreach and inclusion or does not include stakeholders outside of its sector. There is no plan for facilitation or conflict resolution. The project identifies some community benefits but these are not informed by community members themselves.	Project does not identify any partners or seems to have actively failed at outreach and inclusion of specific partners. There is not a diversity of opinion within the group. The project is singularly focused on creating benefits for those sitting at the table.
Long-term commitment and benefit	Project has created an extensive plan for long-term monitoring and management. There are people in place to begin the work, and to continue securing funding. Project is expected to provide many jobs if successful.	Project has an incomplete plan for long term monitoring and management.	Project is expected to be short term. There is no desire or plan to return to this area.
Local capacity building and workforce development	Project provides job training for workers and community members in natural resource management and planning. There is an opportunity for private landowners to learn how to manage their land.	Project relies on local workers and gives opportunity for those workers to gain new experiences. New or untrained workers/landowners are not offered training.	Project relies on workers from different regions and provides no training for local workers.
Mobilization of Traditional Ecological Knowledge	Project identifies Tribal partners and leadership. Project supports both partners' shared goals of forest health. The Tribe(s) involved have a data	Project names Tribes as partners but no Tribal member is a part of core leadership. Shared goals and benefits are identified.	Project does not consider working or consulting with Tribes or only does so via a brief email or phone call.

sharing/ownership
agreement that respects
their Traditional knowledge.

Conclusion

Climate change and environmental degradation via fuel accumulation, tree mortality, and drought are challenging the adaptivity of our social and political systems. Because ecosystems are closely coupled to social systems it's important to create more adaptive and resilient social and economic systems that can quickly adapt to changes. This will require the adoption of additional criteria for investment that includes several factors that bolster resilience while taking into account equity.

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VI. Insights to consider

Prioritizing forest health investments requires combining social and political decisions with scientific analyses. As scientists, we provide a starting point for identifying forest benefits and risks. We provide recommendations for how to measure and map these risks and benefits. We provide tools to predict the effect of certain interventions on fire risk and to evaluate uncertainty. Of equal importance, we provide insight on structured processes for answering the questions that society, not scientists, must answer: Of the benefits and services that forests provide, which do we value and how much? How do we weigh these benefits against mitigation of fire risk? How do we spread benefits and risks equitably across communities? These questions require input from communities, policymakers, and stakeholders, in addition to scientists.

As a panel, we identified and ranked 13 factors that may be considered in treatment prioritization. Our rankings do not represent the social value of each of these factors. For example, whether wildlife is more important than rare plants is not our decision to make. We present 13 prioritization factors not as a one-size-fits-all solution to treatment prioritization across the state, but as a starting point for evaluating the scientific needs of more local or regional prioritization efforts. Our descriptions of each factor introduce scientific issues worth considering for any prioritization effort. The value of our ranked list comes in part from our scientific expertise on the linkages between ecosystem processes. For example, we assume that treatments will include prescribed fire and/or mechanical treatments that reduce forest fuels and tree density. Based on our expertise in fire, forest dynamics, and hydrology, we know that such treatments are likely to reduce risk to water quality and that such risks pose major threats to ecosystem services, and so we rank water quality highly among the 13 factors. Based on our knowledge of fire behavior, we know that differences in treatment plans affect their impacts on fire risk and co-benefits, and so we rank treatment design highly. Conversely, some panel members' expertise leads them to doubt that treatments in areas experiencing strong climatic change will be as effective as treatments in other areas, and so predicted departure from historical climate was ranked at the bottom of our list. Our factor rankings should be interpreted only in the context of social/policy objectives and in combination with the detailed explanations we provide highlighting how each factor is affected by forest treatments and the tools available to measure it. Care should be taken in applying our findings to non-forested ecosystems, particularly chaparral.

Our rankings of factor measurability (**Figure 2**) highlight where additional research and collaboration is needed. For example, the panel scored treatment benefits to environmental justice and social resilience as highly important (average score 4 out of 5) but disagreed on our ability to quantify this factor. More social science work is needed to develop best practices to prioritize treatments equitably and integrate social and ecological considerations. Insights from collaborative decision-making processes – including the Puget Sound Partnership, Western Klamath Restoration Partnership, and North Coast Resource Partnership – as well as our rubric for evaluating socio-ecological dimensions of treatment networks (**Table 12**) may help close this gap.

We recommend embracing an adaptation and resilience framework that recognizes the close ties between social and ecological systems, in addition to increasing the pace and scale of fuel treatments. Adaptive governance can increase the efficiency, efficacy, and equitability of forest health investments but requires substantial initial investments. Forest health projects should focus on increasing adaptive capacity. These up-front investments will increase efficiency later on by reducing the need to repeat stakeholder engagement and trust-building with every new forest treatment planning effort. Within current funding mechanisms, like the Forest Health Grant Program and Regional Forest and Fire Capacity (RFFC) competitive grants, project proponents and project evaluators can evaluate plans along four axes, as presented in Section V.5. The rubric shown in **Table 12** complements existing simplified quantitative metrics of environmental justice used by the state, including low-income census tracts, CalEnviroScreen, and American Communities Survey data. The socio-ecological criteria also highlight opportunities to adjust funding mechanisms to better match adaptive capacity needs, such as lengthening funding duration and increasing funding for capacity-building and monitoring.

In our exploration of existing prioritization approaches, we found that the spatial scale of landscape prioritization varies widely, from approximately 10-acre treatment units (ForSys, Section IV.2) to approximately 150,000-acre watersheds (Washington State DNR, Section IV.3). While small-scale prioritization may result in more precise recommendations for managers, large-scale prioritization can provide the state and regions with broad goals and a starting point for more focused assessments. We recommend that regions identify landscapes where a treatment network would provide the greatest benefits to their identified objectives. Thus, the size of landscape being evaluated for prioritization should roughly match the size of a potential treatment network.

Regardless of the scale prioritization efforts select, it is important to recognize and account for key considerations associated with scale; for instance, large-scale watershed prioritization should recognize that forest processes occur at fine spatial scales and there will be considerable variation with each watershed. Prioritization of small treatment units should use appropriately detailed data sources and recognize that integrating data products at different spatial scales can raise difficult interpolation and aggregation issues, requiring careful spatial reconciliation of data products. Additionally, the more fine-grained the prioritization effort, the more local managers and stakeholders should be involved. For example, the three-step process Washington State uses to move from identifying priority watersheds (~150,000 acres) to landscapes (~20,000 acres) to treatment prescriptions includes stakeholder input in a structured and transparent decision-making process (Section IV.3). This three-tiered process allows for flexible decision-making with greater community input at more local scales.

We found that prioritization was more effective when performed at a regional scale rather than at the state level because ecological and community considerations were more consistent within a region. For example, the North Coast Resource Partnership – which encompasses 19,000 square miles including tribal lands and eight counties – developed consistent goals and objectives that are appropriate to the coastal forests found within its range. Collaboration at that scale created more opportunity for consensus-building than would be possible across regions. Similarly, Washington State used two separate prioritization methods for the eastern and western portions of the state in response to the distinct fire regimes and socio-ecological needs of the two regions. The Puget Sound Partnership also divided their region into geographical subunits within which priorities may vary. Given the range of social and ecosystem conditions across California, it should be unsurprising that effective forest health investments in the San Gabriel may look very different from those in the Klamath region.