UNIVERSITY OF CALIFORNIA
Santa Barbara

Cumulative Impacts Assessment for Timber Harvest: How Best to Incorporate Wildfire Risk and Hazard

This report was submitted in partial fulfillment of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science and Management.

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Signature Page

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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I. ABSTRACT

Out of 32 million acres of forest, California has 17 million acres of timberland, of which 7 million acres are private timberland. In an effort to ensure sustainable forest management, private timberland owners are required to prepare, submit, and receive approval for a Timber Harvest Plan before she/he harvests her/his trees. Timber Harvest Plans (THP), which are a functional equivalent of an Environmental Impact Report under CEQA, identify potentially significant, cumulative environmental impacts of a proposed harvest in categories like watershed and biological effects. In January 2019, in response to growing concerns about how to best manage forests for wildfire, California added Wildfire Risk and Hazard as a new section in the Cumulative Impacts portion of Timber Harvest Plans. This project team identified the need for a standardized, methodological approach to assessing the change to wildfire risk and hazard that occurs as a result of a specific timber harvest action. These changes are largely a result of altered forest structure, including density and height of canopy, which affect wildfire behavior in a landscape. We examined a variety of quantitative and qualitative approaches to assessing wildfire risk and hazard and selected standard and effective approaches that Registered Professional Foresters (RPFs) can use when completing the Wildfire Risk and Hazard portion of a THP. A procedure for completing a time-series analysis of a prior timber harvest action effects on wildfire behavior was applied to a case study in Campbell Creek Planning Watershed, which can give insight to potential future changes in wildfire hazard. A supporting literature review provides additional information that can inform RPFs of the effects of forest structure and management activities on wildfire hazard and risk. The project also identified a number of knowledge gaps that currently exist in the grey and scientific literature around timber harvest actions, forest structure, and wildfire risk and hazard.

KEY WORDS: *forest management, timber harvest, wildfire, risk, hazard, CAL FIRE, Timber Harvest Plan (THP), cumulative impacts assessment, California*

II. EXECUTIVE SUMMARY

For centuries, the forested lands of California have been affected by a variety of activities and management practices which have altered the structure and composition of entire landscapes. While wildfires are a natural component of forested landscapes, they were suppressed for much of the last century to protect the communities and property that have been increasingly embedded in California's forested regions. Suppression activities have led to major shifts in the species composition and structure of forests in such a way that, when wildfires do occur, they now burn at greater size, severity, and rates of spread.

Timber harvesting and restocking activities, occurring concurrently to suppression management, have also contributed to increased density and homogeneity of tree species within forests across northern California and the Sierra Nevada range. Of 32 million acres of forested land in California, 17 million acres are timberland, and 7 million of those are privately owned. The Forest Practice Act of 1973 grants jurisdiction to all timberlands and aims to ensure sustainable practices in the development of forest resources. This Act regulates timber harvest actions, and sets the requirements for a harvest to be approved the Board of Forestry and Fire Protection (CAL FIRE).

The Timber Harvest Plan (THP) is the primary document that must be prepared, reviewed, and approved for all timbering projects undertaken on private timberlands in California. This document is completed by Registered Professional Foresters (RPFs) and serves as a functional equivalent to the Environmental Impact Report (EIR) required by the California Environmental Quality Act (CEQA). Notably, the Cumulative Impacts Assessment (CIA) section of the THP requires consideration of any potential adverse environmental effects of a timber harvest project in several resource areas. These include impacts on the watershed, soil productivity, and biological species of interest.

Until 2019, wildfire was not directly included or referred to in this list. In one recent effort to improve sustainable forest practices and address concerns over wildfire, the California State Board of Forestry and Fire Protection (Board) proposed an addition to the CIA requirements. As of 01 January 2019, "Wildfire Risk & Hazard" is now a Resource Subject that RPFs must consider when reviewing a proposed timber operation on privately-owned lands. This regulation has been encoded in the California Code of Regulations, Title 14 § 912.9, as follows:

> ***H. Wildfire Risk and Hazard***
> *Cumulative increase in wildfire risk and hazard can occur when the Effects of two or more activities from one or more Projects combine to produce a significant increase in forest fuel loading in the vicinity of residential dwellings and communities. The following elements may be considered in the assessment of potential Cumulative Impacts:*
>
> *1. Fire hazard severity zoning.*

2. Existing and probable future fuel conditions including vertical and horizontal continuity of live and dead fuels.
3. Location of known existing public and private Fuelbreaks and fuel hazard reduction activities.
4. Road access for fire suppression resources.

The intent of this addition is to use the Cumulative Impacts Assessment as a tool to reduce the risks associated with fire as a result of changes that a timber harvest plan has on forested landscape. However, this description lacks definitions for the terms of interest—Wildfire Risk and Hazard—and fails to provide guidance as to the methods or metrics by which they should be assessed.

The focus of this Group Project (Group) at the Bren School of Environmental Science & Management has been an investigation into the best possible implementation of this novel regulatory language. Multifaceted considerations were made in addressing this challenge, including but not limited to: the proper interpretation of regulatory language, consideration of the legal history over cumulative impact assessments, the application of best available science, and feasibility of assessment by Registered Professional Foresters. Given the limited information provided in the actual text of the Technical Rule Addendum #2, the Group set forth an objective of creating a Guidance Document to support its implementation. This approach has basis in existing guidelines for the implementation of CIA for other Resource Subjects, and while the Group does not have the authority to produce technical documents that will be *required* for use by RPFs, this Guidance Document should create a starting point for more official development and adoption of methodologies for the assessment of this Resource Subject.

The development of this Guidance Document involved three approaches:

1. **A literature review** to (a) define Wildfire Risk and Wildfire Hazard, (b) synthesize the best available science at the intersection of forest practices and wildfire behavior, and (c) determine which applicable technical tools and models exist
2. **A series of interviews and surveys** with practitioners and scientists to (a) gain an understanding of the practitioner perspective of the THP preparation process and (b) enhance the effectiveness of the Guidance Document.
3. **An evaluation of the efficacy of existing tools and models on fire behavior**, by (a) creating a short list of tools which were, among other criteria, accessible and feasible for use by RPFs, and (b) applying these tools to a case study

Literature Review

Reviews of both grey and peer-reviewed literature revealed significant gaps in knowledge with respect to timber harvest actions and their impacts on wildfire risk and hazard. The peer-reviewed literature was significantly less robust or available compared to grey literature. The primary source of grey literature came directly from, or was supported by, the United States Forest Service. Hazard and risk were found to be defined a number of ways, or referred to without a clear definition. CAL FIRE has provided definitions of wildfire risk and hazard, but further expansion into metrics and methods of measurement were investigated through peer-reviewed articles. A review of forest structure and forest management generated general trends that RPFs can apply when assessing wildfire risk and hazard for their plan. While this literature was largely focused on fuels management rather than specific to harvest actions, the results of these practices can be related to similar changes in forest structure from harvest activities.

Surveys

To further support our project, we administered an online survey to California RPFs. The survey aimed to collect RPF input on definitions for wildfire risk and wildfire hazard, and potential methods that could be recommended for the completion of the new CIA section. Overall, there was significant variation in use and definitions of *hazard* and *risk* as they pertain to wildfire, but over half of respondents felt positive towards the CAL FIRE definitions. The survey also revealed that RPFs generally find the addition important to the THP process, but worry about additional assessment time and potential liability issues. Importantly, the survey responses were in support of a guidance document that could assist RPFs in their assessment of wildfire risk and hazard moving forward. The survey informed the design of our final deliverables to CAL FIRE: (1) a Guidance Document and (2) an agency memo to distill our research findings and promote scientifically-backed, efficient methods of assessing wildfire risk and hazard.

Model Selection & Evaluation

A review of procedures for modeling forest structure and associated wildfire behavior were assessed across a number of criteria, including feasibility for RPFs and input data requirements. An initial review found 15 potential models, or model pairs, that could be used to determine wildfire behavior in timber harvest plots. From these models, we prioritized 5 for in-depth review, with a final selection of two models that can work together to model forest growth and wildfire hazard over time. The Forest Vegetation Simulator (FVS) and FlamMap, when paired, can model the effects of a management activity on a forest and use the modeled spatial data to determine wildfire behavior across a landscape over time. FVS requires stand-specific data that were not available for our Group to access, but may be more realistic for RPFs that are familiar with their site. Without this stand-specific data, RPFs are recommended to apply a time-series analysis utilizing FlamMap. In this approach, which we applied to our case study in Campbell Creek Planning Watershed, FlamMap is applied to historical environmental spatial data to assess wildfire behavior across regular interval timesteps. Following a specific THP from pre-harvest to up to 30 years post-harvest is our best recommendation for generating a likely trend in wildfire hazard from a harvest action. This procedure is more accessible as all necessary inputs are publicly available from LANDFIRE, a federal program that provides spatial data based on modeled and field-collected data.

The CAL FIRE definition of wildfire Risk is, "[The] risk posed to structures built in areas with significant wildland Fire Threat." Using WUI suitable housing density as a proxy for structures, we can define WUI suitable housing density as the number of houses interfaced or intermixed with wildland vegetation per unit area. Based on USDA, "*Wildland–Urban Interface (WUI) in the United States*" and the 2000 census data, 42% of housing within California are located within WUI areas . We selected "*Wildfire Risk Assessment Framework for Land and Resource Management Framework*" (WRAF), on which to base a quantitative model for wildfire risk assessment. WRAF uses burn probability modeling techniques as a key component of capturing spatial variation in wildfire likelihood and intensity as a function of topography, environmental layers, weather parameters, fuel moisture, and ignition patterns. Our Group's characterization of quantified wildfire risk combines a wildfire hazard burn probability matrix derived with the FlamMap 5.0 Mean Travel Time module, the net value change, and evenly-weighted evenly-distributed relative importance of WUI suitable housing density. Our Group's qualitative assessment of wildfire risk can be completed using Probabilistic Wildfire Risk simulation (PFIRE) method to establish burn probability and WUI suitable housing density. PFIRE identifies the likelihood of fire for each vegetation class within the planning area. PFIRE compared with the WUI suitable housing density to establishes likelihood of fire with an approximation of at risk structures in the watershed planning area.

Our project highlights a number of knowledge gaps surrounding wildfire behavior and timber harvest activities. Our research was limited by factors not well represented in available literature, such as a range of different forest types, land ownership of study area, and longer-term studies following an event that altered forest structure. We recommend further research be completed, with support from CAL FIRE and other natural resource management agencies in California, to better understand how timber harvest operations alter forest structure and composition, leading to changes in wildfire behavior over time. Further, continued efforts should include potential climate change scenarios to more fully capture potential adverse cumulative impacts that result from timber harvest actions. The findings in this report will be formatted into a Guidance Document that CAL FIRE can distribute to RPFs for direction on how best to assess wildfire risk and hazard from a proposed timber harvest action. By promoting the recommendations provided here, CAL FIRE can increase the consistency of THP applications and ensure that adequate consideration of hazard and risk is made.

III. OVERVIEW

A. Project Significance

There are approximately 32 million acres of forested land throughout California today, of which 7 million acres are privately owned.[1] California forests have been managed since the establishment of Native American communities, and various management activities have altered the structure and species composition of these landscapes through agroforestry, timber harvesting, and urban expansion.[1,2] Today, forest management is split among government agencies and private land owners and designated as either forestland, timberland, or preservation land.[1]

While wildfires are a natural component of these forested ecosystems, they also pose extreme danger to human communities and their property – namely, timberland resources and dwellings. Widespread attempts to control the frequency and size of wildfires began following the large 1910 fires in Idaho and Montana. These events led to western forest management being focused on suppression of all fires, namely to decrease damage to the valuable timber harvest industry.[3,4] This meant that irrespective of the historical wildfire regime in a region, Congress applied a complete fire suppression policy across western states with enforcement by the US Forest Service.[2] Research following these suppression activities has shown a shift in species that dominate California mixed conifer forests due to increased density and shade in these ecosystems.[5] Concurrently, timber harvesting influences patchiness throughout forests and causes a shift towards smaller diameter trees.[6,7] Overall, studies of the Sierra Nevada have found that forests are becoming more dense, with increased small diameter tree cover and a shift to species that are more shade tolerant.[8,9,10] These changes to forest structure have led to a number of changes in the natural functioning of forest ecosystems, including the return rate and severity of wildfire.

The number of large fires has increased over the last 20 years in California, as have the spread and severity of wildfires.[11] Timber harvesting and subsequent mitigation activities, such as restocking, have contributed to increased density and homogeneity of tree species within

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[1] Stewart, W. et al. *Ecosystems of California. Chapter 36: Forestry.* (University of California Press, 2016); McIver, C. et al. *California's Forest Products Industry and Timber Harvest, 2012. General Technical Report PNW-GTR-908.* (United States Department of Agriculture, 2015).
[2] Braxton Little, J. *The California Indigenous Peoples Using Fire for Agroforestry.* (Pacific Standard, 2018). Available at: https://psmag.com/environment/the-indigenous-groups-using-fire-for-agriculture. (Accessed: 20 March 2019).
[3] Pyne, S.J. & Maclean, J.N. *Year of the Fires: The Story of the Great Fires of 1910*. (Viking Press, 1910).
[4] Agee, J.K. & Skinner, C.N. *Basic principles of forest fuel reduction treatments.* Forest Ecology and Management, **211**, 83-96 (2005).
[5] Minnich, R.A., Barbour, M.G., Burk, J.H., & Fernau, R.F. Sixty Years of Change in Californian Conifer Forests of the San Bernardino Mountains. *Conservation Biology.* **9**, 902-914. (1995).
[6] McKelvey, K.S. & Johnston, J.D. *Historical perspectives on forests of the Sierra Nevada and the Transverse ranges of Southern California: forest conditions at the turn of the century.* (U.S. Forest Service, 1992).
[7] Lutz, J.A., van Wagtendonk, J.W. & Franklin, J.F. Twentieth-century decline of large-diameter trees in Yosemite National Park, California, USA. *Forest Ecology and Management.* **257**, 2296-2307. (2009).
[8] McKelvey, K.S. & Johnston, J.D. *Historical perspectives on forests of the Sierra Nevada and the Transverse ranges of Southern California: forest conditions at the turn of the century.* (U.S. Forest Service, 1992).
[9] Thorne, J.H., Morgan, B.J., & Kennedy, J.A. Vegetation Change Over Sixty Years In the Central Sierra Nevada, California, USA. *Madroño* **55***.* (2008).
[10] Mallek, C., Safford, H., Viers, J., & Miller, J. Modern departures in fire severity and area by forest type, Sierra Nevada and Southern Cascades, California, USA. *Ecosphere*. (2013).
[11] Mount, J., Hanak, E., McCann, H., & Gray, B. *Protecting Headwaters*. (PPIC Water Policy Center, 2018). Available at: https://www.ppic.org/publication/californias-water-protecting-headwaters/ (Accessed: 10 November 2018).

forests across northern California and the Sierra Nevada range.[12,13] As the State of California seeks methods to reduce the danger of wildfires, there is a need to consider the extent of the state's jurisdiction over forested land management. Of the 32 million acres of forested land in California, 17 million acres are considered timberland, meaning the forest is designated for production of commercial wood products.[1] The State's actual ownership of timberland is minimal, but its jurisdiction encompasses private timberlands (totaling 7 million acres)[1] under the Forest Practice Act of 1973. The Act aims to ensure that timber harvesting is completed in a sustainable manner to protect our natural resources.[14] By guiding forestry practices on private timberlands, the State may be able to influence improved wildfire management.

California relies on Environmental Impact Reports (EIRs) to evaluate proposed projects that may have possible adverse impacts on the environment.[15] These documents require planners to consider potential negative consequences of an action on the environment and prescribe mitigation efforts. EIRs fall under the California Environmental Quality Act (CEQA), which was passed under Governor Ronald Reagan to set a statewide precedent to match the National Environmental Protection Act (NEPA), which was passed one year earlier by Congress.[16]

For the timber industry established on California's private timberlands, a Timber Harvest Plan (THP) is a required, functionally equivalent to an EIR, and must be completed by a Registered Professional Forester (RPF). Most notably, a THP includes a Cumulative Impacts Assessment (CIA) section, through which an RPF assesses the potential of a timber harvesting project to create any significant adverse cumulative impacts in various resource areas. These resource areas include impacts on the watershed, soil productivity, and biological species of interest. Until 2019, wildfire was not directly included or referred to in this list.

While a THP provides many details pertinent to environmental planning and reduction of adverse impacts, the incorporation of potential impacts on fire behavior has been limited. Prior to 2019, wildfire was only considered in THPs relative to impacts of logging activities on potential fire fuels—such as slash and snags—near established buildings and roads and to reduce pest and fire hazard at the site. [17] These, however, do not assess the potential ongoing and future impacts that timber projects may have on a site with respect to wildfire behavior on the property and throughout the watershed.

The California State Board of Forestry and Fire Protection (Board) acknowledged this gap on December 29, 2017 in an Initial Statement of Reasons (ISOR) that announced the Board would be adding "Wildfire Risk and Hazard" as one of the Resource Subjects to be considered within the CIA of a THP (Board of Forestry and Fire Protection, 2017; 14 CCR § 912.9). This addition took effect January 1, 2019 and will become a consideration during the completion of the 500-1400 THPs that are submitted to the California Department of Forestry and Fire Protection (CAL FIRE) each year. The intent of this addition is to use the Cumulative Impacts Assessment as a tool to reduce the risks associated with fire as a result of changes that a timber harvest plan

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[12] Boisramé, G., Thompson, S., Collins, B. & Stephens, S. Managed Wildfire Effects on Forest Resilience and Water in the Sierra Nevada. *Ecosystems* **20**, 717–732 (2017).
[13] Lundquist, J. D., Dickerson, Lange, S. E., Lutz, J. A. & Cristea, N. C. Lower forest density enhances snow retention in regions with warmer winters: A global framework developed from plot-scale observations and modeling. *Water Resource. Res.* **49**, 6356–6370 (2013).
[14] CAL FIRE. *Forest Practice*. Available at: http://calfire.ca.gov/resource_mgt/resource_mgt_forestpractice. (Accessed: 21 March 2019).
[15] CEQA. Available at: http://resources.ca.gov/ceqa/flowchart/lead_agency/EIR-ND.html. (Accessed: 20 March 2019).
[16] CEQA. Available at: http://resources.ca.gov/ceqa/more/faq.html. (Accessed: 28 November 2018).
[17] CAL FIRE. *Forest* Practice. Available at: http://calfire.ca.gov/resource_mgt/resource_mgt_forestpractice. (Accessed: 21 March 2019).

has on forested landscape. While a short description of elements related to Wildfire Risk and Hazard was provided in the regulatory text (14 CCR § 912.9), neither definitions for these terms nor any guidance as to the methods or metrics by which they should be assessed are included. Our Group aims to support the effective implementation of this new Resource Subject.

B. Group Project Purpose and Scope

Our Group seeks to provide CAL FIRE and RPFs (1) a summarized understanding of the current fire science as it relates to wildfire behavior and wildfire risk, (2) recommended methods for determining the impact of timber harvesting on wildfire risk and hazard, and (3) recommendations for future research to improve predictability of wildfire risk and hazard impacts following timber harvests. The goals are aimed to support the effective implementation of the "Wildfire Risk and Hazard" resource section within the THP CIA section.

Specifically, the Group developed recommendations by asking: *How is existing scientific and practitioner knowledge best incorporated into the assessment of cumulative impacts on Wildfire Risk and Hazard resulting from a proposed timber harvest action on private timberland?* This involved a broad review of scientific and grey literature, conversations with and surveys of fire scientists and professional foresters, and development of multiple assessment methods for both wildfire risk and wildfire hazard. A case study of Campbell Creek Planning Watershed, located along California's northern coast, was conducted to demonstrate the credibility and feasibility of our recommended assessment methods for Wildfire Risk and Hazard.

Spatially, our project focuses on California's privately owned timberlands. As California's timber harvest industry is primarily in northern California, our results tend to provide more insight into this area due to data and research availability. However, we recommend our research to be extended throughout all of California's private timberland regions.

C. Approach

The following steps were taken in the completion of this Group Project:

❖ <u>Conducted literature review</u> on characteristics of and interactions between wildfire risk, wildfire hazard, and timber harvest methods in California, along with the history of timber harvest in California and the structure of Timber Harvest Plans.

❖ <u>Reviewed the CAL FIRE Timber Harvest Plan addendum (Technical Rule No. 2)</u> concerning the addition of Wildfire Risk and Hazard as a resource subject within the Cumulative Impact Assessment checklist, with specific analysis on the existing THP process and its stakeholders through literature, surveys, and workshops.

❖ <u>Evaluated existing models, applications, and/or tools</u> currently utilized by academics and industry professionals to track and/or predict wildfire risk and wildfire hazard associated with timber harvest and mitigation activities.

- Developed multiple assessment methodologies for recommendation to CALFIRE for use by RPFs in assessing potential impacts to Wildfire Risk and Wildfire Hazard.

- Demonstrated the application and utility of the proposed assessment methodologies through a case study of Campbell Creek Watershed, located along the northern California coast. This watershed was selected due to the extensive history of historic timber harvest activity and CAL FIRE's current focus on this watershed for timber-specific research.

- Developed a Guidance Document for completion of the Wildfire Risk & Hazard section, based on the synthesis of results from our literature review, model selection, and surveys and interviews. This Guidance Document aims to guide RPF evaluations of wildfire risk and hazard associated with proposed harvest and post-harvest activities to determine whether the proposed timber and mitigation plans will yield significant adverse cumulative impacts within this Cumulative Impact resource subject. (Note: This Guidance Document will be available in Spring 2019, following the submission of this Final Report.)

D. Partnerships

California Board of Forestry and Fire Protection (CAL FIRE)
CAL FIRE is a California state government agency tasked with fire protection and stewardship of the state's privately-owned wildlands, totaling over 31 million acres. CAL FIRE's role includes long-term planning and emergency response to wildfires. In relation to this project, CAL FIRE reviews between 500 to 1,400 Timber Harvesting Plans (THPs) annually and conducts over 6,500 site inspection. Our group project has benefited from the expertise of CAL FIRE through valuable insight into our project scope and direction and the open access to quality, relevant public data. CALFIRE's open data has made our analyses and final recommendations possible.

California Department of Natural Resources (CDNR)
CDNR is a California state government agency tasked with protecting and managing the state's natural, historical, and cultural resources for present and future generations. CDNR leads the state's natural resources agencies, including CAL FIRE. Our project has benefited from a larger organizational perspective and technical expertise of the CDNR.

Professional Environmental Management Association (PEMA)
PEMA is an organization that works towards building an encouraging and educational network of environmental professionals. PEMA began in Southern California in 1991 and has become the state's largest, most active environmental trade association. Our project has benefited from PEMA's financial support, making our travel to Sacramento and final presentation possible.

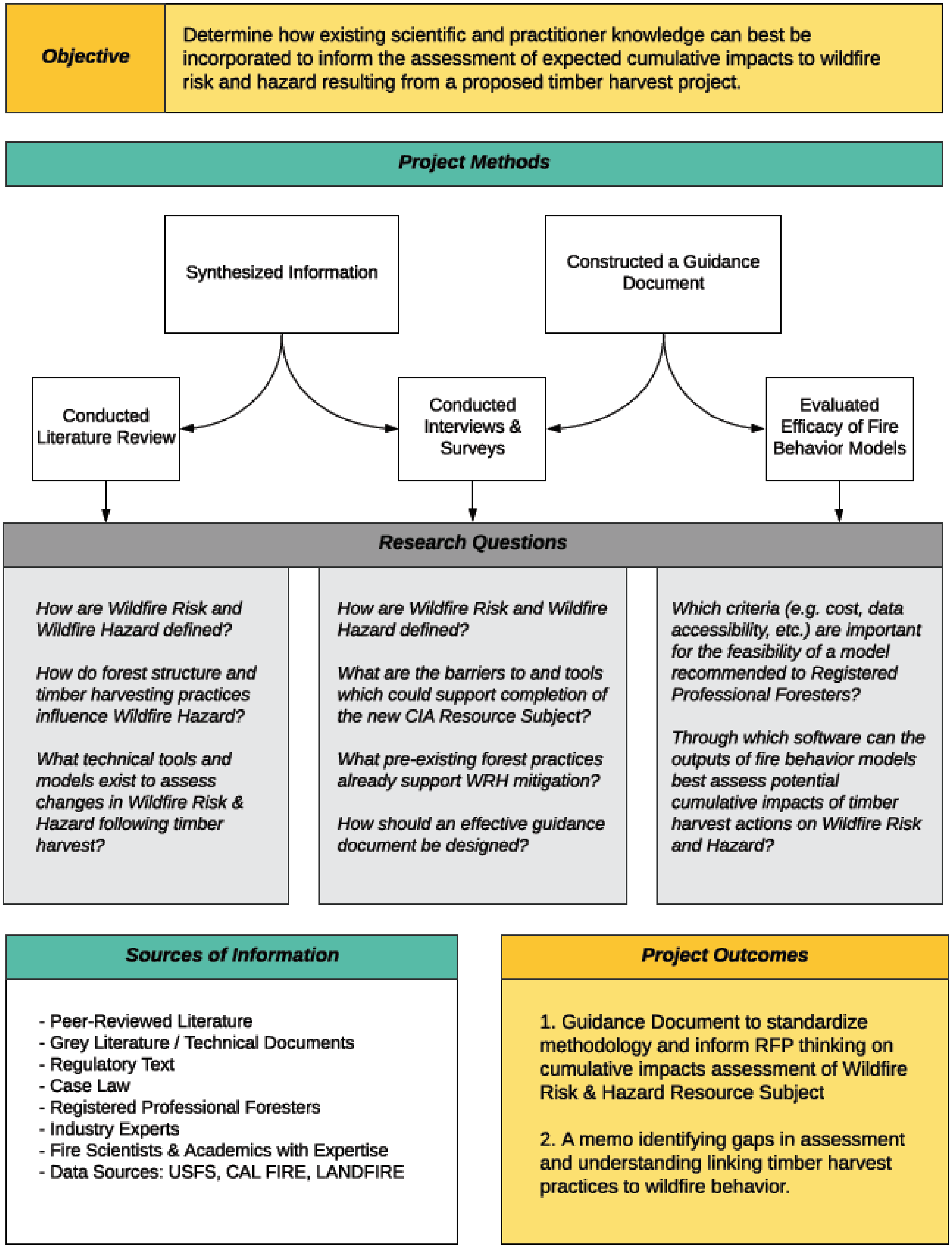

Figure 3.1. Overview of our Project.

IV. PROJECT BACKGROUND

A. History of California Timber Harvesting

Our project is applicable specifically to timber actions on privately-owned timberlands. In the following section, a brief history of the timber industry in the state is provided and pressures experienced by the timber industry for public and private land are differentiated.

Today, California holds over 32 million acres of forest and its ownership is dispersed among federal, state, and local agencies, along with Native American tribes, private corporations, and individuals[18]. Linked with this diversity in ownership is a variety in management practices. Of California's forested land, 17 million acres are considered timberland - forests that can be managed for commercial production of wood products - where about 7 million acres are on private timberland and about 9 million acres are on federal land. As some forest land is simply not productive enough to be utilized for timber growth, there is also a portion designated for preservation as a forest.[19] Our project focuses on the 22% of California's forests classified as private timberland.

The timber industry began in California during the 1800s Gold Rush Era and skyrocketed nationally following World War II in order to meet demands of the 1940s housing boom. Yet, a decade later, production plateaued across the country from the 1950s through the mid-1980s. US National Forest harvest volumes equated to about 12 billion board feet sold per year during the plateau (**Figure 4.1**). Following the passage of the National Forest Management Act of 1976, a slight impact on timber harvest and sales occurred. However, this impact is almost unnoticeable when compared to the significant industry-wide downturn during the 1990s, following the federal listing of the Northern Spotted Owl under the Endangered Species Act. In addition, the owl was listed at the state-level as threatened in Washington, Oregon, and California.[20] Due to the extensive forest industry in the Pacific Northwest and its overlap with year-round Northern Spotted Owl ,[21] as seen in **Figure 4.2.** [22]

Knowing the ownership of timberland is central to understanding the management regime, relevant regulations, and projected harvest trends. Looking specifically at California, the 2012 California timber harvest was 36% less than its 2000 harvest of 2.2 billion board feet - and the majority (84%) of that 2012 harvest was sourced from private timberlands, despite private timberland making up only 43% of the state's timberland. The majority of timberland acres in California are managed by public owners, which only contributed 16% of the 2012 harvest (**Figure 4.3**). [23] An added concern linked to the continuation of a struggling timber industry is the increased threat that private timberlands will be converted to residential, agricultural, pasture, or

[18] University of California Forest Research and Outreach. Available at: https://ucanr.edu/sites/forestry/California_forests/. (Accessed: 20 March 2019).
[19] McIver, C. et al. *California's Forest Products Industry and Timber Harvest, 2012. General Technical Report PNW-GTR-908.* (United States Department of Agriculture, 2015).
[20] US Fish & Wildlife Service: Arcata Fish and Wildlife Office. Available at: https://www.fws.gov/arcata/es/birds/nso/ns_owl.html. (Accessed: 20 March 2019).
[21] EcoWest. Available at: http://ecowest.org/2013/05/28/timber-harvest-falls-in-national-forests/. (Accessed: 20 March 2019).
[22] Headwaters Economics. *National Forest Timber Sales and Timber Cuts, FY 1980-2017.* Available at: https://headwaterseconomics.org/dataviz/national-forests-timber-cut-sold/. (Accessed: 20 March 2019).
[23] McIver, C. et al. *California's Forest Products Industry and Timber Harvest, 2012. General Technical Report PNW-GTR-908.* (United States Department of Agriculture, 2015).

recreational land uses.[24] Widespread land conversions would be a threat to local flora and fauna, compounding the impact of habitat fragmentation.

On the regulatory side, timber harvesting on private timberlands is regulated by CAL FIRE, while public timberlands are regulated by the US Forest Service. CAL FIRE requires Timber Harvest Plans to be submitted for each timber action on private land in the state. Further details on the CAL FIRE Timber Harvest Plans are provided in the following section.

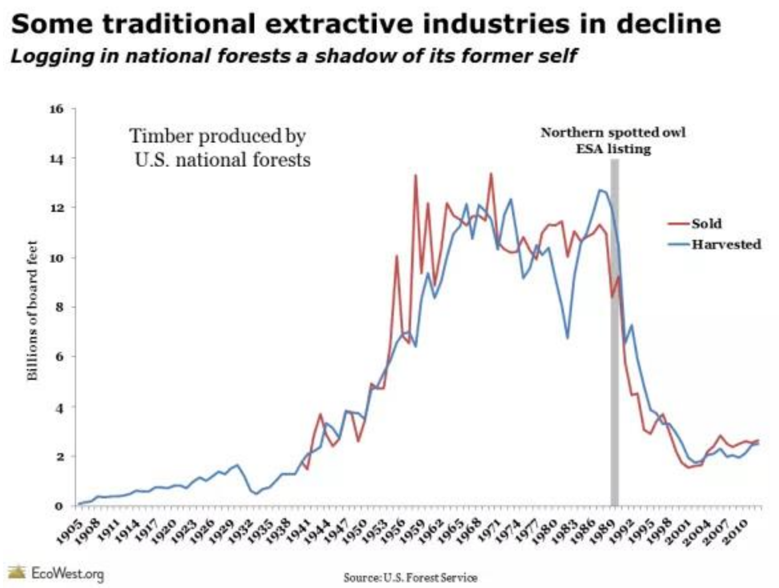

Figure 4.1. Change in timber production from U.S. national forests from 1905 to 2010. The 1950s housing boom led to the quick increase in timber harvest rates, followed by a sharp decline in the 1990s with the Endangered Species Act listing of the Northern Spotted Owl. [25]

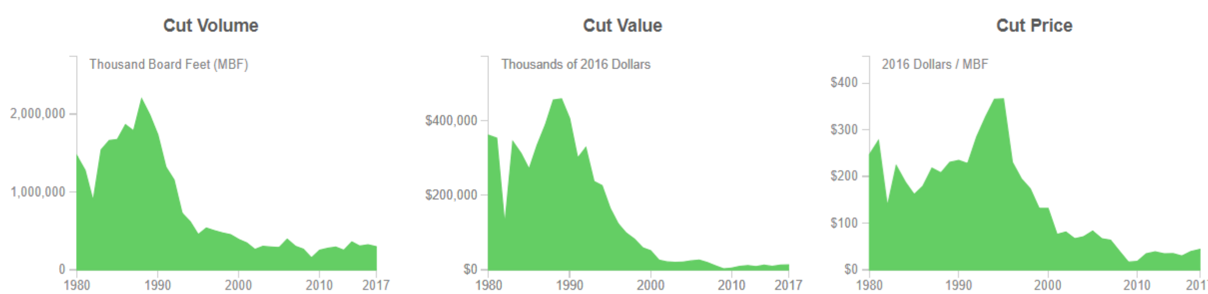

Figure 4.2. Trends for US National Forest timberland within California (1980-2017) show a steep decline in amount of timber cut, its overall value, and unit price in the mid-1990s. Since that period, the amount and values of harvest have remained well below the 1980 levels. [26]

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[24] Stewart, W. et al. *Ecosystems of California. Chapter 36: Forestry.* (University of California Press, 2016); McIver, C. et al. *California's Forest Products Industry and Timber Harvest, 2012. General Technical Report PNW-GTR-908.* (United States Department of Agriculture, 2015).

[25] EcoWest. Available at: http://ecowest.org/2013/05/28/timber-harvest-falls-in-national-forests/. (Accessed: 20 March 2019).

[26] Headwaters Economics. *National Forest Timber Sales and Timber Cuts, FY 1980-2017.* Available at: https://headwaterseconomics.org/dataviz/national-forests-timber-cut-sold/. (Accessed: 20 March 2019).

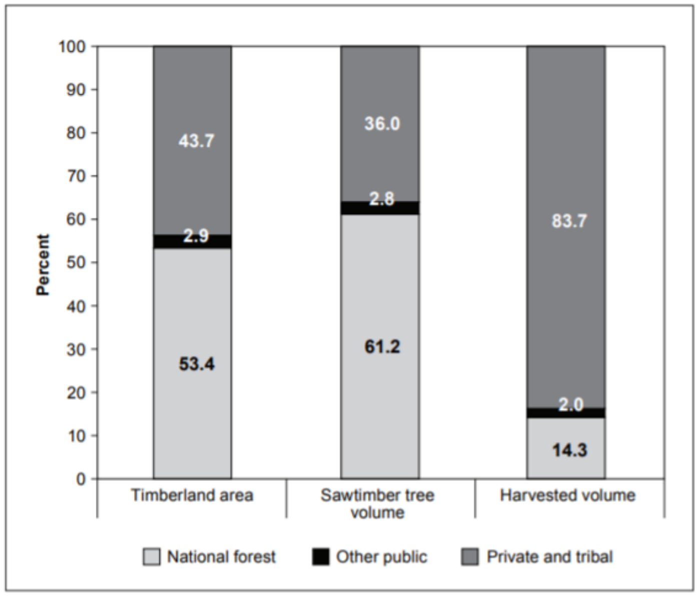

Figure 3—Characteristics of California's timberland by ownership class, 2012. Sawtimber is timber of "sufficient size and quality to be suitable for conversion into lumber."

Figure 4.3. The distribution of timber tree and harvest volumes by ownership type display the disproportion between timberland ownership and location of harvests. As of 2012, over half of California's timberland is National forest, yet only 14% of the trees harvested in California originate on federal lands. As such, a vast majority (83%) of the timber harvesting occurring in the State is on private timberland. [27]

B. Timber Harvesting Plans

The passing of the Z'berg-Nejedly Forest Practice Act of 1973 (Act) established forestry regulations and documentation in California to effectively monitor timber harvesting operations. [28] This passing was a result of a push towards regulating government action that may negatively impact the environment, as first seen in the National Environmental Protection Act (NEPA) passed in 1969, and the California Environmental Quality Act (CEQA), passed the following year by Governor Ronald Reagan.[29] A court case in 1976 ruled that the Forest Practice Rules should be exempt from some portions of CEQA requirements, and that the THP may be a functional equivalent to the Environmental Impact Report (EIR) required under CEQA.[30] The Act sets standards for THPs, including site preparation, silvicultural practices, watercourse protection, road construction, water diversion, and cumulative effects analysis. The passing of the Act also restructured the Board of Forestry, expanding it to 9 active board members, and

[27] Stewart, W. et al. *Ecosystems of California. Chapter 36: Forestry.* (University of California Press, 2016); McIver, C. et al. *California's Forest Products Industry and Timber Harvest, 2012. General Technical Report PNW-GTR-908.* (United States Department of Agriculture, 2015).

[28] Morrison H., Valachovic Y., & Nunamaker C. Laws and regulations affecting forests, part I: timber harvesting. *Forest Stewardship Series*, **19**, 2007. Available at: https://anrcatalog.ucanr.edu/pdf/8249.pdf. (Accessed: 22 October 2018).

[29] California Natural Resources Agency. *Frequently asked questions about CEQA.* Available at: http://resources.ca.gov/ceqa/more/faq.html (Accessed: 22 October 2018)

[30] California Department of Forestry and Fire Protection. *California Forest Practice Rules, 2017*. Sacramento, CA: Forest Practice Program. Title 14, California Code of Regulations Chapters 4, 4.5 and 10. Available at: https://calfire.ca.gov/resource_mgt/downloads/2017%20Forest%20Practice%20Rules%20and%20Act.pdf (Accessed: 20 March 2019).

created more concrete regulations concerning logging and its effects on the environment. The board members are appointed by the Governor based on their professional qualifications with respect to land use and management activities that the Department of Forestry oversees. A board member is typically appointed for a four-year term.

THPs include five sections - general information, plan of timber operations, supporting documentation, cumulative effects assessment, and additional attachments. The plan of timber operations outlines details about the effects of logging on the proposed site and all actions that the logging company plans to take in order to harvest. A THP must be compiled by a Registered Professional Forester (RPF), who has undergone training, 7 years of education and experience, and has passed a comprehensive forestry exam. These plans, once approved, are active for 3 years, and may be extended for one year two additional times should the harvest activity be incomplete.

Once a THP is submitted to the Board, an initial reading of the plan is completed by representatives from CAL FIRE and other parties that may have jurisdiction, such as California Fish and Game, water control boards, and the California geological survey.[31] This begins a 45 day notice period, during which interested individuals or organizations may submit a comment about the proposed rule change to the Board. If any other substantial edits are made to the rule, the edits are also subjected to a distinct 45 day comment period. As in CEQA, public comments are not required to be incorporated by the agency, but must be considered. The Board may then move to approve the final Statement of Reasons, after which county hearings further discuss the details of the proposed rule changes and incorporate feedback. With county hearings results, the proposed rule is then adopted or further amended by the Director of Forestry and Fire Protection.

Cumulative Impacts Assessment

Technical Rule Addendum No. 2, also known as the Cumulative Impacts Assessment section of the THP, was put into the THP documentation in 1991 to better match standards in CEQA.[32] This section was created to assess the effects of past, current, and potential future impacts that a project may have on a site's environmental integrity. The Cumulative Impacts Assessment includes three (3) yes-no questions about the project site's historic, current, and potential future projects, followed by a checklist of assessment categories. The RPF must identify a) if a "significant adverse cumulative impact," will occur, b) if it will occur and be mitigated by the THP, or c) if it will not cause any significant effects. If three or more of the factors are expected to have significant adverse effects, either with mitigation or prior to mitigation, the RFP is expected to describe mitigation efforts that have been considered and how they either do or do not "reduce or avoid reasonably potential significant cumulative impacts."

The broad Cumulative Impacts Assessment resource subjects include: watershed, soil productivity, biological, recreation, visual, traffic, greenhouse gases and other. Each category is associated with a set of factors that RPF's should consider. Some of these factors are more detailed than others - the biological section has considerably more factors than the recreational

[31] CAL FIRE. *Timber Harvesting Plan Review Process.* Available at: http://www.fire.ca.gov/resource_mgt/resource_mgt_forestpractice_thpreviewprocess. (Accessed: 20 March 2019).

[32] Board of Forestry and Fire Protection. *Initial Statement of Reasons: Cumulative Impacts Assessment Checklist, Technical Rule Addendum No. 2 and Appendix Amendments, 2017.* 14 CFR §912.9, 932.9, 952.9 Available at: http://bofdata.fire.ca.gov/regulations/proposed_rule_packages/cia_check/16_isor_cia_checklist_tra2_appendix.pdf. (Accessed: 10 October 2018).

section. For each subject, the RPF must include a short account of where within the site the assessment took place and provide information on the resource(s) they used in their assessment, including, "individuals, organizations, and records consulted."[33] There are lists of potential experts, records and reports that may be useful to RPFs in the assessment of cumulative impacts.

In an associated guidance document, additional factors for consideration are listed by resource subject. This includes examples of potential adverse impacts, broad categories of possible effects from logging activities on the resource, and approaches to quantify the effects of a timber harvest action on a landscape.

In September 2012, the California Senate passed SB 1241 which required plans for State Responsibility Areas (SRA) and lands within the very high fire hazard severity zone to assess the potential change in risk of wildfire resulting from the proposed actions starting in January 2014.[34] State responsibility areas are defined by those areas in California that are within the financial responsibility of the state with respect to fire containment and suppression.[35] In 2017, the CEQA environmental checklist, similar to the Cumulative Impacts Assessment within THPs, was updated to include questions about the impact of a proposed action on wildfire.[36] Shown below, wildfire was added to the "Evaluation of Environmental Impacts," in Appendix G (Environmental Checklist Form) under "Hazards and Hazardous Materials,"

> *h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?*[37]

This addition, along with other pressures, resulted in the proposal for addition of "Wildfire Risk and Hazard" to the Cumulative Impacts Assessment portion of the THP documentation.

On December 29, 2017, an Initial Statement of Reasons (ISOR) was released in which the Board announced it would be adding "Wildfire Risk and Hazard," to the Cumulative Impacts Assessment section of the THP.[38] The addition of wildfire risk was first proposed in 2014, though it was noted that this factor was not required as part of a complete assessment under CEQA.[39]

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[33] California Department of Forestry and Fire Protection (2017. *California Forest Practice Rules, 2017*. Sacramento, CA: Forest Practice Program. Title 14, California Code of Regulations Chapters 4, 4.5 and 10. Available at: https://calfire.ca.gov/resource_mgt/downloads/2017%20Forest%20Practice%20Rules%20and%20Act.pdf. (Accessed: 10 October 2018).

[34] California (state). *Land us: general plan: safety element: fire hazard impacts*. Available at: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB1241. (Accessed: 12 October 2018).

[35] California Code (state). Public Resources Code. Division 4, Part 2, Chapter 1, Article 1, Section 4102. *Prevention and Control of Forest Fires*. Available at: https://law.justia.com/codes/california/2016/code-prc/division-4/part-2/chapter-1/article-1/section-4102. (Accessed: 20 October 2018).

[36] Governor's Office of Planning and Research. *Proposed updates to the CEQA guidelines.* Avalable at: http://opr.ca.gov/docs/20171127_Comprehensive_CEQA_Guidelines_Package_Nov_2017.pdf. (Accessed: 20 March 2019).

[37] California Natural Resources Agency. California Environmental Quality Act. Appendix G: Environmental Checklist Form. Available at: http://resources.ca.gov/ceqa/guidelines/Appendix_G.html. (Accessed: 20 March 2019).

[38] California Department of Forestry and Fire Protection (2017. *California Forest Practice Rules, 2017*. Sacramento, CA: Forest Practice Program. Title 14, California Code of Regulations Chapters 4, 4.5 and 10. Available at: https://calfire.ca.gov/resource_mgt/downloads/2017%20Forest%20Practice%20Rules%20and%20Act.pdf. (Accessed: 10 October 2018).

[39] California Department of Forestry and Fire Protection (2017. *California Forest Practice Rules, 2017*. Sacramento, CA: Forest Practice Program. Title 14, California Code of Regulations Chapters 4, 4.5 and 10. Available at:

The proposed rule change to Technical Addendum No. 2 to add "Wildfire Risk and Hazard" as a resource subject was approved in 2018 and is contained within THP documentation as of January 2019. Our Group aims to provide well-researched guidance to CAL FIRE to inform their requirements for the assessment of Wildfire Risk and Hazard and to provide RPFs with tools with which they can complete an assessment.

C. Legal History

Legislation

Since enactment of the FPA, THPs have been the focus of litigation, with lawsuits brought primarily against CAL FIRE.[40] FPA was designed to establish a constitutionally sound framework for balancing the needs of the environment and California's private timber industry.[41] Litigation on private timber harvests began in 1976. Addressing the need for an EIR under CEQA, the Legislature amended CEQA to allow the Secretary of the Resources Agency to recognize CAL FIRE's program for approving timber harvest plans and the Board of Forestry's program for adopting forest practice rules as a "certified regulatory program". The Resource Agency's recognition exempted both CAL FIRE's and the Board's processes from the EIR requirements under CEQA. As a result, THPs fulfill the same function as an EIR under CEQA.[42] Legislation such as the Resource Agency's recognition and cases based on cumulative impacts, wildlife and habitat challenges, substantive or regulatory challenges, and wildfire risk and hazard liability have continued to shape the regulation and structure of THPs to present day.

Cumulative Impacts

Conflicts that initially arose in the 1980s concerning the FPA and the resulting THP processes with respect to cumulative impact assessments were predicted by the 1979 John Muir Institute report, "Assessing Cumulative Impacts of Silvicultural Activities".[43] Cumulative impacts of timber harvests over a watershed proved to be the primary argument of the majority of California cases, including those that dealt with habitat destruction and other wildlife challenges.

An early case example of this was *Environmental Protection Information Center v. Johnson* in 1985. EPIC successfully sued CAL FIRE over the lack of consideration of the cumulative impacts occurring over time from multiple timber harvests in a given area.[44] EPIC argued that minimization of adverse effects caused by each individual operation would result in a total

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https://calfire.ca.gov/resource_mgt/downloads/2017%20Forest%20Practice%20Rules%20and%20Act.pdf. (Accessed: 10 October 2018).

[40] Freed, A. *Legal Analysis of the Conflict Between the California Environmental Quality Act and the Forest Practices Act and Analysis of Case Law.* (University of California Hastings College of the Law. Public Law Research Institute,1996).

[41] Public Law Research Institute. Duggan, supra note 2, at 291. Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).

[42] Lippe, T.N., and Bailey K. *Regulation of Logging on Private Land in California Under Governor Gray Davis 31.* (2001).

[43] John Munn, CDF. *Historical Perspective: Where We're at After 20 Years of Dealing with CWE, UC Conference Notes.* Available at: https://bofdata.fire.ca.gov/board_business/binder_materials/2013/november_2013/fpc/fpc_2.5_munn_uc_conference_presentation.pdf. (Accessed: 5 March 2019).

[44] Environmental Protection Information Center v. Johnson, 170 Cal.App.3d 604 (1985) (hereafter *EPIC v. Johnson I*). Available at: http://www.wildcalifornia.org/case-history/case-documentation/1980s/epic-v-johnson-i/. (Accessed: November 25, 2018).

minimization of adverse effects to the surrounding area.[45] The court held that CAL FIRE's position was at odds with the concept of cumulative impacts.[46] The holding in *EPIC v. Johnson I* and similar cases brought against the state and state agencies: 1) *Gallegos vs. State Board of Forestry*, ruling the Board must prepare written responses to significant environmental comments;[47] 2) *Laupheimer v. State of California*, ruling a lack of showing of adequate consideration of potential cumulative effects upon environment resulted in determination that approval of the second of two THPs for a property was prejudicial abuse of discretion;[48] 3) *Californians for Native Salmon and Steelhead Assn v. Department of Forestry*, ruling the agency generally failed to comply with time required for responses to environmental objections and to consider cumulative impacts.[49] The cases lead CAL FIRE to augment the FPR to include Technical Rule Addendum No. 2 (TRAN2) in 1989.[50] TRAN2 required timber harvesters to report potential cumulative environmental effects as well as give sufficient reasonable consideration for any such significant effect.[51]

A 1994 Little Hoover Commission report found that the fundamental ecological flaw in THPs is based in the premise of a parcel-by-parcel assessment. A chief suggestion regarding cumulative effects was to adopt a uniform spatial and temporal metric beyond that of the current THP parcel requirements for cumulative impact assessment. The John Muir report also suggested the watershed spatial scale for consideration. In addition, the Little Hoover Commission found the State's focus on procedure rather than outcome meant that there was no mechanism to demonstrate harvest mitigation measures were effective at a later time. This has been the culmination of several concerns behind all cumulative impact considerations (regulative, ecological, and environmental) prior to Wildfire Risk and Hazard. That report stated that not only is there a lack of data on water quality, water behavior, or resulting terrestrial and ecological conditions from alteration by timber harvest in the region, and in addition, (i) there are no audit requirements, and (ii) if data are collected, there is a low likelihood of reported analysis.[52]

Wildlife and Habitat Challenges

The most significant motivation for THP litigation after cumulative impacts assessment is the evident conflict between the impact of logging operations on wildlife and habitat preservation.[53] The Regional Water Quality Boards regulates timber harvest waste discharge permits and the North Coast Region of the California State Water Quality Board (WQB) grants exemption waivers to agencies for waste water discharge. WQB under Resolution No. 87-113, Sep 1987

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[45] Gerstein, J. and Harris, R. *Improving the Assessment of Cumulative Watershed Effects Within the Timber Harvest Planning Process.* (Center for Forestry University of California, Berkeley, 2003).
[46] Gerstein, J. and Harris, R. *Improving the Assessment of Cumulative Watershed Effects Within the Timber Harvest Planning Process.* (Center for Forestry University of California, Berkeley, 2003).
[47] Lippe, T.N., and Bailey K. *Regulation of Logging on Private Land in California Under Governor Gray Davis 31.* (2001).
[48] Public Law Research Institute. *200 Cal. App. 3d 440 (1988).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[49] Public Law Research Institute. *221 Cal. App. 3d 1419 (1990).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[50] Gerstein, J. and Harris, R. *Improving the Assessment of Cumulative Watershed Effects Within the Timber Harvest Planning Process.* (Center for Forestry University of California, Berkeley, 2003).
[51] Freed, A. *Legal Analysis of the Conflict Between the California Environmental Quality Act and the Forest Practices Act and Analysis of Case Law.* (University of California Hastings College of the Law. Public Law Research Institute,1996).
[52] Dunne T, Agee J, Beissinger S, Dietrich W, Gray D, Power M, Resh V, & Rodrigues K. *A Scientific Basis for the Prediction of Cumulative Watershed Effects. University of California Wildland Resource Center Report No. 46.* (2001).
[53] Freed, A. *Legal Analysis of the Conflict Between the California Environmental Quality Act and the Forest Practices Act and Analysis of Case Law.* (University of California Hastings College of the Law. Public Law Research Institute,1996).

granted such a waiver to the CAL FIRE agency to allow for timber harvest operations.[54] CAL FIRE sets policies and review THP proposals to address such habitat concerns. In 1998, the Environmental Protection Agency (EPA), pursuant to Section 6217(a) of the Coastal Zone Act Reauthorization Amendments, reviewed California coastal nonpoint pollution control program of 1990.[55] The EPA found that despite the forest programs California has developed over the previous 20 years, California waters continue to experience significant impairment from forestry. Of particular concern were trout and salmon species which had experienced significant decimation to spawning, breeding and rearing habitat directly attributed to forestry related activities.[56]

The majority of the wildlife cases that challenged the approval of a THP generally allege that the defendants did not adequately address the environmental impacts of logging on habitats, which resulted in a threat to the survival of certain endangered or threatened native California wildlife. In the case *Public Resource Protection Association of California v. California Dept. of Forestry and Fire Protection*, the plaintiff argued that the logging operation did not comply with emergency regulation mandate to protect spotted owls within the area of proposed timber harvest operations.[57] In *Sierra Club v. State Board of Forestry*, the Sierra Club alleged that BOF had violated provisions of CEQA and FPA in approving the THP without sufficient information on threatened wildlife (Olympic salamander, tailed frog, red tree vole, Pacific fisher, spotted owl, and marbled murrelet) in the area of concern.[58] The Court found in this case that BOF must conform to FPA provisions as well as CEQA provisions. In the case of *Sierra Club v. CAL FIRE*, the logging operations and species of concern were the same as in *Sierra Club v. State Board of Forestry*, however Sierra alleged that CAL FIRE had not held to the fullest extent of FPR and approved a THP that had not explored all feasible mitigative measures to lessen significant environmental impacts within the area of concern or to the habitat of sensitive species.[59] That Sierra case was subsequently ordered to be de-published by the California Supreme Court due to the frequent occurrence of similar cases and may not be cited as precedent. In the case of *EPIC v. Maxxam Corp*, EPIC challenged that CAL FIRE had not responded to the California Department of Fish and Game's concerns to the fullest extent and obtained an injunction on two pending THPs.[60] While the *EPIC v. Maxxam* case was pending, CAL FIRE had changed its policies with respect to consulting other California agencies and those of cumulative impacts as well as protection of wildlife.[61]

Regulatory Violations

Allegations that there were substantive violations of CEQA, FPA, and FPR regulations are yet another significant factor behind litigation challenging THPs.[62] According to judicial review, CAL

[54] Dunne T, Agee J, Beissinger S, Dietrich W, Gray D, Power M, Resh V, & Rodrigues K. *A Scientific Basis for the Prediction of Cumulative Watershed Effects. University of California Wildland Resource Center Report No. 46.* (2001).
[55] Lippe, T.N., and Bailey K. *Regulation of Logging on Private Land in California Under Governor Gray Davis 31.* (2001).
[56] Lippe, T.N., and Bailey K. *Regulation of Logging on Private Land in California Under Governor Gray Davis 31.* (2001).
[57] Public Law Research Institute. *7 Cal. 4th 111 (1994).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[58] 7 Cal. 4th 1215 (1994). For a thorough analysis of this case, see California Supreme Court Survey - A Review of Decisions: September 1993 - October 1994, 22 Pepp. L. Rev. 2, 1266 (1995).
[59] Court on March 18, 1994. Sierra Club v. Department of Forestry and Fire Protection, 1994 Cal. LEXIS 138821 Cal. App. 4th 603 (1st Dist. 1993). This opinion was ordered de-published by the California Supreme (1994).
[60] Public Law Research Institute. *4 Cal. App. 4th 1373 (1st Dist. 1992).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[61] Freed, Ariela. 1996. Legal Analysis of the Conflict Between the California Environmental Quality Act and the Forest Practices Act and Analysis of Case Law. University of California Hastings College of the Law. Public Law Research Institute. Fall 1996-06. Note 8.
[62] Freed, Ariela. 1996. Legal Analysis of the Conflict Between the California Environmental Quality Act and the Forest Practices Act and Analysis of Case Law. University of California Hastings College of the Law. Public Law Research Institute. Fall 1996-06. Note 8.

FIRE and BOF assumed undue authority under the FPA through misinterpretation of FPR or misapplied CEQA requirements of timber harvesting. In *EPIC v. CAL FIRE*, a timber harvester attempted to harvest without a THP through use of a 3-acre size exemption.[63] The Court of Appeals found that CAL FIRE did not have authority under FPA Section 4584 to issue such an exemption as the section allowed exemptions for the removal of trees for noncommercial purposes, specifically fuel management or tree mortality. Subsequent to the Court's findings, California adopted regulations for non-industrial timber management plans (NTMP) which make allowances for commercial timber harvests on private lands less than 2,500 acres parcels in 2003.

Soon after the enactment of CEQA and FPA, there was confusion surrounding FPA standing as a functional of equivalent measure governing timber harvesting practices. As a result, a number of cases were brought by environmental groups challenging timber harvests for not filing EIRs as well as THPs.[64] The first such case was *Natural Resource Defense Council v. Arcata National Corp,*[65] which laid the foundation for the premise that CEQA provisions and EIRs were not completely analogous to FPA and THPs. However, Section 21080.5 allowed for certain limited exemptions which could be adopted for timber harvesters to file THPs in place of EIRs.[66] The addition of cumulative impact information requirements in the TRAN2 made THPs more analogous to EIRs. As mentioned in the prior Cumulative Impact Section, the adoption of TRAN2 resulted from the settlement of *EPIC v. Johnson I*, *Laupheimer v. California*, and *Sierra Club v. Board of Forestry*.

Wildfire Risk and Hazard

The most recent revision of TRAN2 by CAL FIRE, effective January1, 2019, includes a new resource subject "Wildfire Risk and Hazard". There are few reported cases addressing both timber harvest practices and preexisting wildfire risk and hazard rules. One reported case, *CAL FIRE v. Howell*, pertained to alleged timber harvest action resulting in the 2007 California Moonlight wildfire. CAL FIRE had brought the case against Howell, a timber operator who was operating under a contract with Sierra Pacific after investigating the cause of the wildfire. CAL FIRE had determined the contractors had struck rocks with a bulldozer during operations causing sparks to splinter off into vegetation, which had later ignited the wildfire. The trial court dismissed the case based on the determination that CAL FIRE's pleadings were insufficient as a matter of law to state an appropriate claim against the defendants. Later, the Court of Appeals found that the trial court properly awarded judgement on the pleadings of CAL FIRE. CAL FIRE could not assert a cause of action pursuant to California Health and Safety Code Sections 13009 & 13009.1, as those sections do not incorporate common law theories of negligence as a basis for recovery.[67]

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[63] Public Law Research Institute. *43 Cal. App. 4th 1011 (1st Dist. 1996).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[64] Lippe, Thomas N, and Kathy Bailey 2001. Regulation of Logging on Private Land in California Under Governor Gray Davis 31. Note 1.
[65] Public Law Research Institute. *59 Cal. App. 3d 959 (1976).* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[66] Public Law Research Institute. *59 Cal. App. 3d at 973.* Available at: https://gov.uchastings.edu/public-law/docs/plri/caselaw.pdf. (Accessed: 21 March 2019).
[67] Dept. of Forestry and Fire Protection v. Howell Justia Law. https://law.justia.com/cases/california/court-of-appeal/2017/c074879.html, accessed December 14, 2018.

V. INTERVIEWS & SURVEY

A. Interviews

To support our early synthesis of information on forest practices and wildfire, we conducted a series of informal interviews. Subjects included three anonymous RPFs and the nine experts listed below:

1. Dennis Hall (Assistant Deputy Director of Forest Practice, CAL FIRE), Pete Cafferata (Watershed Protection Program Director, CAL FIRE), Eric Huff (CAL FIRE), Bill Sivinski (CAL FIRE).
2. Max Moritz, Wildfire Specialist and Adjunct Professor at the Bren School
3. Sarah Anderson, Environmental Politics Professor at the Bren School
4. Carla D'Antonio, Ecology, Evolution and Marine Biology Professor at UCSB
5. Suzanne Lang, Forest Practice GIS Coordinator at CAL FIRE

The Group is grateful to the interviewees that donated their time to help inform and shape our project. Responses from the interviews have been further detailed in **Appendix A:** *Interviews and Surveys*.

B. Survey

Objectives

The digital RPF survey provided practitioner perspectives of the THP preparation process that enhanced the development of the Group's Guidance Document for the Wildfire Risk and Hazard resource subject. THPs are prepared by a requisite licensed RPF that details plans on the type of timber harvested, how it will be harvested, and steps adhered to in order to prevent damage to the environment.[68] The survey was necessary to understand RPF experiences with:

- Actions affecting fire structure and fuels
- Cumulative Impact Checklist, guidance documents and outside resources
- Expected functionality and concern over Wildfire Risk and Hazard section

Development

The survey development and analytical method best practices were drawn from the American Association for Public Opinion Research (AAPOR).[69] Requisite Human Subject Committee (HSC) researcher tutorial and training modules were completed through UCSB Office of Research.

[68] CAL FIRE. *Forest* Practice. Available at: http://calfire.ca.gov/resource_mgt/resource_mgt_forestpractice. (Accessed: 21 March 2019).
[69] American Association for Public Opinion Research. Available at: https://www.aapor.org/. (Accessed: 10 February 2019).

Following the application submission on October 23, 2019, an exemption status review took place on October 30, 2019. HSC exemption status was granted under the Federal Exempt Categories (45 CFR 46.101(b)) covering both human subject anonymity and professional evaluation of public policy.[70] HSC approval for our Group survey was granted by the UCSB Office of Research on November 9, 2019. Further development details can be read in **Appendix A:** *Interviews and Surveys*.

Methods

The RPF survey received 76 responses of roughly 1200 Board-listed RPFs, granting an approximately 6.3% success rate over three weeks. Not every RPF responded to every question. Responses were tallied independently to obtain statistics and percentages specific to each question. Every question received more than the standard threshold (n>30) for t-test statistical evaluations. Mean, standard deviation and variance analyses were all performed on Likert scale responses. Chi-squared correlation tests and covariance tests were performed to compare demographics to survey responses. The complete survey, including the categorized free responses, is presented in the **Appendix A:** *Interviews and Surveys*.

C. Results

> *...Over the course of my career I prepared over 200 harvest plans. I [am] actually retired as a Fire Chief. Fire protection as it relates to timber harvest has always been minimize[d] in importance by regulators and environmental special interest groups. A comprehensive plan to protect our wildlands as well as communities must include a timber harvest component. The Forest Practice Regulations including the Cumulative Impact Assessment have been used to discourage forest management that would lead to healthier forests that naturally reduce the risk of catastrophic fires. Special interest group have seen the management tool called timber harvest as a threat to their priority values. Ultimately all these values are lost as we see [a] growing threat[,] catastrophic fires.* *[Anonymous RPF Free Response]*

The survey was deployed by Matt Dias and Shuhani Patel of the Board through an email listserv of RPFs Jan 4, 2019. By Jan 8, 2019 the survey had received 27 responses. Based on the initial response rate, it was determined that a sufficient number of RPF respondents could be acquired by Jan 25, 2019. The Board was called upon to deploy the survey a final time on Jan 14, 2019

[70] UCSB Office of Research. *Policies*. Available at: https://www.research.ucsb.edu/policies-forms/policies/#HSG. (Accessed: 21 March 2019).

with an added notice that we would stop accepting responses by Jan 25, 2019. The maximum response of n=20 per day was received January 14. The second highest response of n=13 per day was after the initial notification. Participation declined steadily after each request for participation email was sent by the Board.

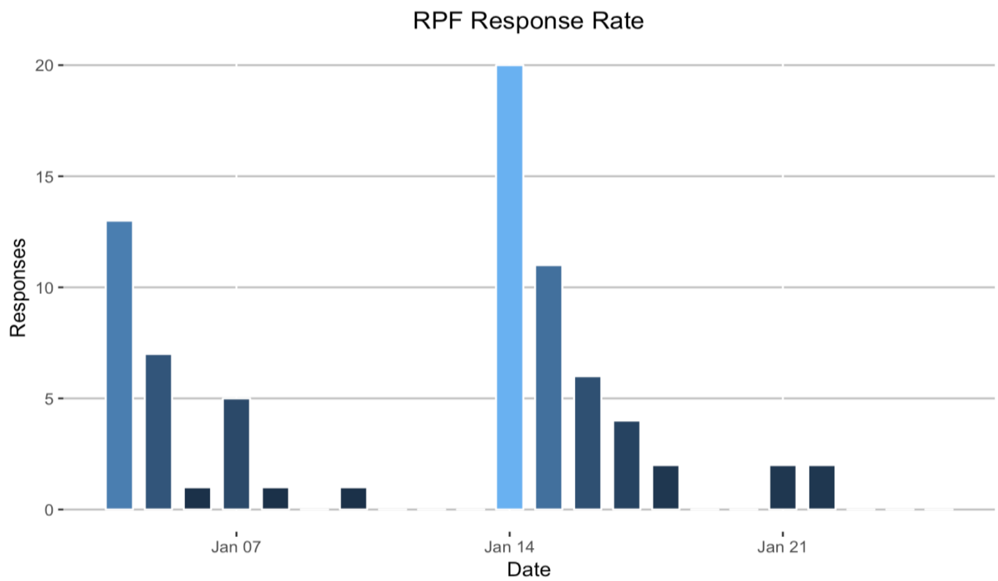

Figure 5.1: RPF survey response rate. The surveys were deployed January 4, 2019 and ended at the close of business on January 25, 2019. Two reminder notification emails were sent, the first on January 4 and the second January 14.

Demographics

Most RPFs: 1) were licensed before 1988; 2) work as a private consultant or are employed by a company; 3) did not complete a THP in 2018, or if they did, they most likely completed between 1 and 4 THPs as a private consultant or as a company employee; 4) work in the Klamath/North Coast or Sierras bioregions; 5) consider WUI a significant factor in areas they work; 6) work in population density regions between 0-100 people per square mile; and 7) require at least 40 to 80 hours to complete a THP.

Questions

The questions were developed to gain understanding on RPF experience with THP:

- Actions affecting fire structure and fuels
- THP CI Checklist, guidance documents and outside resources
- Functionality and concern over Wildfire Risk and Hazard section

Actions Affecting Fire Structure and Fuels

Most RPFs perform some fire hazard mitigation in their profession. Those mitigation efforts are primarily precommercial harvest thinning practices and creating fire breaks. RPFs perform additional fire hazard mitigation efforts, such as prescribed burns, fire suppression, fire detection, understory reduction and so forth.

THP Cumulative Impact Checklist, Guidance Documents, and Outside Resources

Respondents believe the Cumulative Impact (CI) checklist content from Watershed, Biological, and GHG sections are most likely to overlap with the Wildfire Risk and Hazard section. RPFs, on the whole, find agency-provided guidance documents for the CI assessment checklist (Technical Rule Addendum No 2 (TRAN2) Appendix) moderately useful, but RPFs find the Biological, Soil Productivity and Watershed section slightly more useful. What RPFs appreciate most from agency-provided resources are regionally specific applications, as well as precise language and comments from agencies and the public during the THP review process. The most beneficial resources relied upon by RPFs to complete THPs are agency resources and THP records from within the region. Common external tools commonly used by RPFs to assess potential significant adverse effects from THPs are field observations, sampling, and compliance with recommended best practices.

Functionality of and Concerns about Wildfire Risk and Hazard Section

Almost all RPFs have experienced wildfires within their region in the last ten years. Of those fires, over a third were started on federal lands. More than half of RPFs found wildfire at least important if not a very important consideration for THPs, particularly if the RPF was licensed within the last 10 years. Considering that RPFs find wildfire risk and hazard important we need to know how RPFs think of wildfire risk and hazard. More than half of the RPFs agree with the CAL FIRE definition of wildfire hazard and wildfire risk. However, there was considerable feedback from RPFs that CAL FIRE should include other valuable resources in addition to community and infrastructure when calculating risk. The majority of respondents believe the Hazard Reduction questions presented in Item 30 of CAL FIRE's THP forms are moderately effective to very effective at assessing wildfire risks and hazards resulting from mechanically driven logging practices.

RPFs do not usually collect additional information than outside of what is required by the THP. However, nearly half do. Those RPFs that do collect additional data, collect stand structure, understory structure, fuels assessment, future regeneration growth, adjacent land use, weather trends, regional history, and fire suppression data on timber harvest areas.

Most respondents are concerned with additional complications and additional time required to complete the new wildfire risk and hazard section of the THP. The possible complications concerning RPFs are inadequate agency support, new untested analytical methods, administrative/legal challenges to the THP, and liability issues.

D. Discussion

We understand that RPFs value agency resources highly, and find guidance documents useful, therefore our Group will endeavor to develop a Wildfire Risk and Hazard guidance document to be used by RPFs in the completion of THPs.

Completing a THP requires a considerable amount of time and exposes an RPF to legal issues. In order to minimize the additional time required and standardize approaches, our Group considered the following elements in designing recommendations for the Guidance Document:

1) Incorporation of fire hazard mitigation duties RPFs already conduct such as pre-harvest thinning and creating fire breaks
2) Requiring data that some if not most RPFs already collect (stand/understory characteristics, weather, and adjacent land use considerations)
3) Minimizing the overlap between other CI assessment sections
4) Using precise language options for agency responses/ public comment feedback in the THP review process
5) Utilizing tools already familiar to RPFs, such as field observations and GIS models

RPFs value regionally specific applications, however our Group does not have the capability for developing regionally specific applications for all eight bioregions within California. As the North Coast and Sierras bioregions contain the largest portions of California's timber industry, are represented the heaviest in literature, and host the majority of our survey respondents, our Group focused its case studies on this region.

The Guidance Document must employ spatial analyses to assess Hazard and Risk factors. Fortunately, most RPFs already have access to and use GIS software. Based on the CAL FIRE definition of risk and the fact that WUI is such a significant factor for RPFs, WUI must be a key component of our quantitative risk assessment. Our group chose to use, "*A Wildfire Risk Assessment Framework for Land and Resource Management",* by Scott, Thompson et al., hosted on the USFS website as a wildfire risk assessment framework which was validated by direct reference from RPF responses to our survey.

VI. LITERATURE REVIEW: Wildfire and Forest Practices

Wildfire and Forest Management Overview

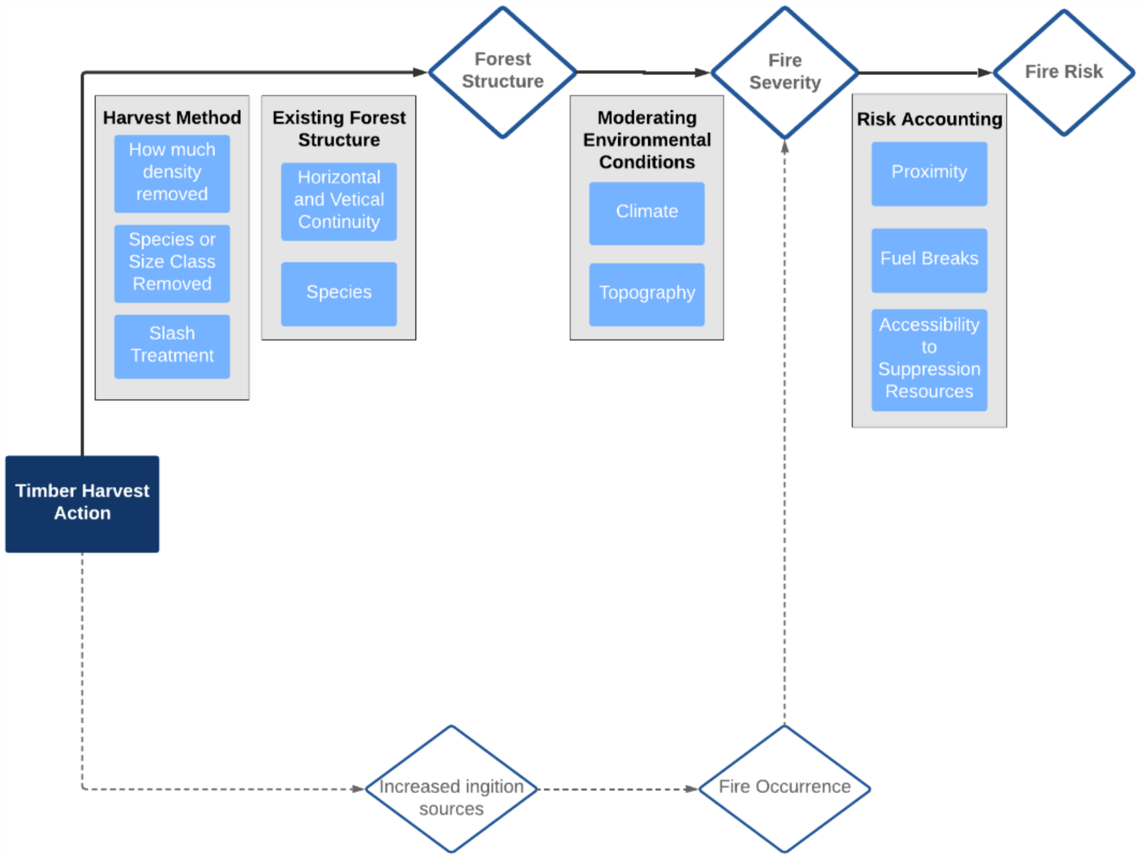

Figure 6.1. Conceptual map of Group Project research areas. The focus of this project is represented by the top portion of the graphic, on processes and conditions from timber harvest action through wildfire risk. We acknowledge that there is a potential for timber harvest actions to increase or alter the likelihood of ignition, but our Group did not focus on this component.

Wildfire behavior and the effects of burning are moderated by a number of interacting factors. Following a timber harvest action, the forest structure is altered in some way. An understanding of the forest structure prior to the timber harvest, as well as characteristics of the specific action will lead to a variety of changes in forest structure. For example, two different harvesting techniques will have a different impact on forest horizontal continuity. Changes in forest structure further change fire severity, as the forest structure is a main driver of fire behavior along with topography and climate.[71] Finally, these changes in fire severity impact the effects that wildfire has on nearby communities and structure, which represents the CAL FIRE definition of wildfire risk. Timber harvest actions have another potentially significant impact on

[71] Graham, R. T., McCaffrey, S. & Jain, T. B. *Science basis for changing forest structure to modify wildfire behavior and severity*. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2004). doi:10.2737/RMRS-GTR-120

wildfire probability, as machinery and human activity may increase the likelihood of an ignition. Our project does not focus on the probability aspect of wildfire behavior with respect to timber harvest. Our Group worked under the assumption that an ignition is equally possible anywhere, and focused our investigation on changes to wildfire hazard and risk for a given fire.

A. Wildfire Hazard

1. Definition

In California, recent legislative action has been taken to incorporate wildfire hazard into impact reporting processes. Senate Bill 1241, passed in September 2012, required city- or county-wide, long-term plans that assess the likelihood and associated risks of potential wildland fires.[72] This bill directed the addition of fire hazard impacts to CEQA and the into the THP process. The bill recommends the use of the following resources in assessing fire hazard: fire hazard severity maps from the Department of Forestry and Fire Protection, wildfire hazard areas as determined by the United States Geological Survey (USGS), and the definition of very high fire hazard severity zone within Section 51177 of the California Code. These resources were used to inform the Group's understanding of 'Wildfire Hazard."

Section 51177 of the California Code

This section places responsibility on the Director of Forestry and Fire Protection to identify areas of very high fire hazard severity,

> *based on consistent statewide criteria and based on the severity of fire hazard that is expected to prevail in those areas. Very high fire hazard severity zones shall be based on fuel loading, slope, fire weather, and other relevant factors.*[73]

This section places the definition of fire hazard and identification of very high fire hazard severity zones under the jurisdiction of CAL FIRE.

California Department of Forestry and Fire Protection (CAL FIRE)

CAL FIRE defines fire hazard as, "a measure of the likelihood of an area burning and how it burns."[74] In determining the fire hazard severity zone of a landscape, CAL FIRE models the interactions between vegetation, topography, weather, crown fire potential, and ember

[72] California Code (state). Public Resources Code. Division 4, Part 2, Chapter 1, Article 1, Section 4102. *Prevention and Control of Forest Fires*. 2016. Available at: https://law.justia.com/codes/california/2016/code-prc/division-4/part-2/chapter-1/article-1/section-4102 (Accessed: 20 October 2018).
[73] California Code (state). Public Resources Code. Section 51175-51189. 2016. Available at: http://www.fire.ca.gov/fire_prevention/downloads/GovernmentCode51175.pdf (Accessed: 25 October 2018).
[74] CAL FIRE. *Fire Hazard Severity Zone Development.* Available at: http://www.fire.ca.gov/fire_prevention/fire_prevention_wildland_zones_development. (Accessed: 21 March 2019).

production and movement. Vegetation is considered a fuel by CAL FIRE and includes vegetation cover over a 50-year period to determine fire hazard severity. The 50-year period represents the maximum time that wildfire "likelihood" is considered by CAL FIRE, which is defined as that chance of a landscape burning based on historical and other factors over a 30- to 50- year time horizon.

The CAL FIRE definition of fire hazard largely motivated the Group's decisions in determining assessment methodologies and resources that could assess Wildfire Hazard within the Cumulative Impacts Assessment.

United States Geological Survey (USGS)

USGS has many ongoing fire studies that investigate a variety of factors on wildfire likelihood and severity. Three of these major products may be of use when assessing fire hazard.[75] The fire potential index map (FPI) uses vegetation moisture compared to maximum potential moisture in a landscape, where lower actual moisture indicates higher fire potential. The large fire probability map uses information from the FPI to determine areas that are more likely to burn 100 or more acres should an ignition occur. This can assist in understanding where larger fires are likely to happen, particularly with respect to population centers and resources of interest. The final product, Expected Number of Large Fires per Predictive Service Area, aggregates the number of predicted large fires within agency areas. USGS also collaborates with LANDFIRE, a resource for geospatial data on fire hazard and fuel characteristics across the U.S.

Definitions of wildfire hazard can vary widely in the literature concerning the assessment and treatment of wildfire. In some studies, the definition is specific to the metric being used in the study. Calkin *et al*. defined hazard as the, "average flame length of all simulate fires that burned a given pixel."[76] Many studies do not provide any definition of wildfire hazard, referring instead to actions that best reduce hazards from wildfire.[77] With the range of wildfire hazard definitions used, it is imperative that a shared definition of hazard be applied when assessing changes wildfire behavior as a result of a timber harvest action. We recommend utilizing the CAL FIRE definition as it provides a baseline from which RPF's will be able to assess their specific timber plot with some flexibility in the measures used. Responses from our survey show that 75% of RPFs find the CAL FIRE definition useful, further supporting our use of this definition (See Section V - Interviews and Surveys).

[75] USGS. *Fire Danger Forecast.* 2014. Available at: https://www.usgs.gov/land-resources/lcsp/fire-danger-forecast. (Available at: 21 March 2019).
[76]Calkin, D. E., Ager, A. A. & Gilbertson-Day, J. *Wildfire risk and hazard: procedures for the first approximation*. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2010). doi:10.2737/RMRS-GTR-235
[77] Stephens, S. L., Collins, B. M. & Roller, G. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management* **285**, 204–212 (2012).

2. Metric of Wildfire Hazard Assessment

Metrics of wildfire hazard measure the intensity at which a fire burns. Fire intensity can be represented by flame length, fire line intensity (heat expelled at the head of a fire), and rate of fire spread. The chosen metric of assessment for this report is fire severity, which can described using a variety of measures. CAL FIRE uses flame length in their model that calculates fire hazard severity zones.[78] Flame length is a common metric used to measure wildfire hazard as it clearly correlates with the likelihood of a canopy fire igniting and propagating.[79] Additional studies have used flame length to determine the likelihood of a crown fire initiating.[80,81,82] Canopy fires are considered the most dangerous, as they are more difficult to put out, can be more intense, and can travel quickly with exposure to high winds.[83] Flame length has been well-established in at the national level, and applied in Sierra Nevada fire hazard studies, utilizing fire length categories to assigned a severity value (Table 7.1).[84,85] Flame length was chosen as a suitable metric as this measure is readily available utilizing FlamMap, and may clearly translate to fire hazard.

Table 6.1. Flame length categories with associated fire intensity and fire severity values. Categories created based on management need to suppress a fire of a given flame length, and the type of fire expected from that flame length (i.e. surface, torching, crowning). [86],[87]

Flame Length (feet)	Fire Intensity (Btu/ft/s)	Fire severity rating
<4	<100	Low
4-8	100-500	Moderate
8-11	500-1,000	High
>11	>1,000	High

78 CAL FIRE. *Fire Hazard Severity Zone Model A Non-technical Primer*. 4 (California Department of Forestry and Fire Protection Office of the State Fire Marshal, 2007).
79 Rothermel, R. C. *Predicting behavior and size of crown fires in the northern Rocky Mountains*. (U.S. Department of Agriculture, Forest Service, Intermountain Research Station, 1991). doi:10.2737/INT-RP-438
80 Alexander, Martin E. *Help with making crown fire hazard assessments*. 147–156 (1988).
81 Alex, M. E. & Cruzb, M. G. *Interdependencies between flame length and fireline intensity in predicting crown fire initiation*. (2011).
82 Scott, J. H. & Reinhardt, E. D. *Assessing crown fire potential by linking models of surface and crown fire behavior*. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2001). doi:10.2737/RMRS-RP-29
83 Graetz, D. H., Sessions, J. & Garman, S. L. Using stand-level optimization to reduce crown fire hazard. *Landscape and Urban Planning* **80**, 312–319 (2007).
84 Alex, M. E. & Cruzb, M. G. *Interdependencies between flame length and fireline intensity in predicting crown fire initiation*. (2011).
85 Moghaddas, J. J., Collins, B. M., Menning, K., Moghaddas, E. E. Y. & Stephens, S. L. Fuel treatment effects on modeled landscape-level fire behavior in the northern Sierra Nevada. *Canadian Journal of Forest Research* **40**, 1751–1765 (2010).
86 Andrews, P. L. & Rothermel, R. C. *Charts for interpreting wildland fire behavior characteristics*. (U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 1982). doi:10.2737/INT-GTR-131
,87 *Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense*. (Sierra Nevada Conservancy, 2014).

B. Wildfire Risk

1. Definition

The US Forest Service defines wildfire risk as a combination of the likelihood of a fire occurring, the intensity of fire when it does occur, and the susceptibility of highly valued resources or assets.[88] In scientific literature, wildfire risk definitions vary. Definitions include expected annual financial loss from wildfire,[89] the frequency of fire and effect of fire on wildland and urban areas,[90] and burn probability and impact of fire on highly valued resources.[91] Though definitions of wildfire risk vary, comprehensive reviews of the terminology note that wildfire risk analysis consistently focuses on the probability of fire occurring and the impact of the fire on people and structures.[92]

CAL FIRE does not provide a singular definition for wildfire risk. However, references to "risk" in CAL FIRE language are associated with the risk of fire damaging assets like manmade structures or other valuable properties. For example, CAL FIRE's FRAP program references a subsection, "Wildfire Risks to Assets," of *The Changing California: Forest and Range 2003 Assessment*. In this report, fire risk is defined as risk posed to structures "built in areas with significant wildland Fire Threat."[93]

CAL FIRE classifies fire threat as a numerical index based on the combination of fuel rank and fire rotation.[94] Fuel rank is a qualitative measure developed by CAL FIRE to rank regions based on expected fire behavior. CAL FIRE calculates fuel model using topography and vegetative fuels under severe weather conditions (wind speed, humidity, temperature, and fuel moistures). An initial fuel rank is calculated by combining fuel model with slope, and then the final fuel rank is calculated by incorporating the amount of ladder and/or crown fuel present in the region.[95]

CAL FIRE also calculates fire rotation interval classes, which could serve as a useful metric of wildfire risk. Fire rotation interval classes are calculated from historical data over the previous fifty years. Fire rotation intervals are calculated as the number of years it took past fires to burn an equivalent area. "Equivalent" areas are determined based on fire environment conditions,

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[88] United States Forest Service. *Wildfire Risk*. Available at: https://www.fs.fed.us/wwetac/tools/arcfuels/help/Content/02Toolbar/05-05%20-Risk.htm. (Accessed: 25 November 2018).
[89] Scott J, Thompson M, and Calkin D. *A Wildfire Risk Assessment Framework for Land and Resource Management*. October 2013. United States Department of Agriculture/Forest Service. General Technical Report RMRS-GTR-315. Available at: https://www.fs.fed.us/rm/pubs/rmrs_gtr315.pdf. (Accessed: 21 March 2019).
[90] Finney, M. *The challenge of quantitative risk analysis for wildland fire.* 6 June 2005. Forest Ecology and Management. Volume 211, Issues 1-2, Pages 97-108. Available at: https://www.sciencedirect.com/science/article/pii/S0378112705000563#bib29. (Accessed: 21 March 2019).
[91] Calkin D, Ager A, Gilbertson-Day J. *Wildfire risk and hazard: Procedures for the First Approximation*. March 2010. United States Department of Agriculture/Forest Service. General Technical Report RMRS-GTR-235. https://www.fs.fed.us/rm/pubs/rmrs_gtr235.pdf
[92] Bachmann A, and Allgower B. *A consistent wildland fire risk terminology is needed [including New definitions].* 2001. Fire Management Today. Volume 61, Issue 4, Pages 28-33. https://www.frames.gov/catalog/40960
[93] CAL FIRE. *The Changing California Forest and Range 2003 Assessment Synopsis: Wildfire Risks to Assets.* October 2003. Fire Resource and Assessment Program (FRAP). http://frap.fire.ca.gov/data/assessment2003/Chapter3_Quality/wildfirerisk
[94] CAL FIRE. *Fire Threat Data Dictionary.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/data/data%20dictionaries/fthrt.txt?rec=fthrt&ext=.txt. (Accessed: 25 November 2018).
[95] CAL FIRE. *Fire Threat Data Dictionary.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/data/data%20dictionaries/fthrt.txt?rec=fthrt&ext=.txt. (Accessed: 25 November 2018).

which are characterized as climate, vegetation, and land ownerships.[96] Thus, using fuel rank as a metric of the potential intensity of a fire and fire rotation intervals as the likelihood of occurrence, CALFIRE has the potential to measure some aspects of wildfire risk.

In addition to the metrics of fuel rank and fire rotation intervals, CAL FIRE also defines a separate metric of wildfire threat to people, which could be useful in assessing wildfire risk. Fire threat to people, differs from fire threat, as it assesses the proximity of people to higher fire threat regions.[97] Using a cost-distance function in ArcGIS, polygons representing areas with differing fire threat levels are buffered according to how the areas either impede the spread of wildfire (low threat and urban areas) or facilitate the spread of wildfire (high threat areas).[98] Buffers range from 2400m, for areas with high fire threat, to 800m, for urban or low fire threat areas. These buffered areas are then overlaid with fire threat values and areas of high threat, within the buffered urban areas, are considered to be regions with the highest potential risk to people. Thus, CAL FIRE's fire threat to people term, aligns well with the definition of fire risk.

In the *Forest and Range 2003 Assessment*, fire risk was measured by the number of housing units built in the wildland-urban interface facing Extreme, Very High, High, and Moderate Fire Threat conditions.[99] After CAL FIRE completed the *Forest and Range 2003 Assessment*, a new CAL FIRE Fire Resource and Assessment Program (FRAP) project was started on the wildland urban interface (WUI). This project focuses on assessing wildfire related risks to "people, property, and infrastructure."[100] Again, fire risk is defined as "threat from wildland fire to Wildland-Urban Interface areas of California."[101]

2. Metric of Wildfire Risk Assessment

Metrics of wildfire risk commonly include expected net value change (ENVC or NVC) and highly valued resource and assets (HVRA). ENVC is calculated as relative value assessment from expected net change caused by potential wildfires.[102] HVRA is calculated by determining the economic value of assets in the area of interest above a certain value threshold and then calculating an expected loss of value from potential wildfires.[103] In general, wildfire risk is measured in economic terms of damage to buildings and other infrastructure.

[96] CAL FIRE. *Fire Threat Data Dictionary.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/data/data%20dictionaries/fthrt.txt?rec=fthrt&ext=.txt. (Accessed: 25 November 2018).
[97] CAL FIRE. *Fire Threat Data Dictionary.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/data/data%20dictionaries/fthrt.txt?rec=fthrt&ext=.txt. (Accessed: 25 November 2018).
[98] CAL FIRE. *Fire Threat Data Dictionary.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/data/data%20dictionaries/fthrt.txt?rec=fthrt&ext=.txt. (Accessed: 25 November 2018).
[99] CAL FIRE. *The Changing California Forest and Range 2003 Assessment Synopsis: Wildfire Risks to Assets.* October 2003. Fire Resource and Assessment Program (FRAP). http://frap.fire.ca.gov/data/assessment2003/Chapter3_Quality/wildfirerisk
[100] CAL FIRE. *The Wildland Urban Interface (WUI): Assessing related risks to people, property and infrastructure in California*. 2012. Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/index. (Accessed: 25 November 2018).
[101] CAL FIRE. *Characterizing the Fire Threat to Wildland-Urban Interface Areas in California.* Fire Resource and Assessment Program (FRAP). Available at: http://frap.fire.ca.gov/projects/wui/525_CA_wui_analysis.pdf. (Accessed: 25 November 2018).
[102] Ager, A. & Barber, K. Automating the Fireshed Assessment Process with ArcGIS. *Andrews Patricia Butl. Bret W Comps 2006 Fuels Manag.- Meas. Success Conf. Proc. 28-30 March 2006 Portland Proc. RMRS-P-41 Fort Collins CO US Dep. Agric. For. Serv. Rocky Mt. Res. Stn. P 163-168* **041**, (2006).
[103] Calkin, D. E., Ager, A. A. & Gilbertson-Day, J. *Wildfire risk and hazard: procedures for the first approximation*. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2010). doi:10.2737/RMRS-GTR-235

C. Relating Wildfire Hazard to Forest Practices

Summary

While it is well-known that the behavior of wildfire across a landscape is influenced by many spatial and temporal conditions such as landscape characteristics (slope, aspect), climate, weather (e.g. wind, temperature), and forest type (e.g. mixed conifer, redwood)[104], an assessment of forest practices on a given timber plot should be the primary focus for assessing potential cumulative impacts to wildfire hazard. These forest practices may include (as in **Figure 6.2**):

(a) **harvest actions**, such as yarding method,
(b) **maintenance actions**, such as precommercial thinning or pruning,
(c) **surface fuels treatments**, such as prescribed burns or mastication,
(d) **restocking approaches**, and
(e) **the inclusion of fuel breaks or road access**.

Taken individually or together, these forest practices can influence fire behavior via modification of species composition, fuel structures, fuel moisture, and surface winds, which makes them the focus of our investigation into how best to assess and mitigate against wildfire hazard and risk[105]. The effects of these practices on fire behavior are most accurately predicted by factoring in the spatial and temporal conditions previously listed, but we find that this level of specificity is lacking in the available science (drawn from both peer-reviewed scientific literature and US Forest Service technical reports). Our approach is supported, moreover, by regulations which specify that the impacts of a Project should be the subject of consideration in conducting a cumulative impacts assessment. The logic of our approach is as follows:

Overarching Question
How will the actions proposed in a Timber Harvest Plan impact wildfire hazard?

Narrowed Question
How will the actions proposed in a Timber Harvest Plan alter the structure of a forest over time in ways that impact wildfire hazard?

Resulting Research Questions for the Literature Review
1. *How does forest structure influence wildfire hazard?*
2. *What silvicultural practices are employed in California?*
3. *How do silvicultural practices modify forest structure?*

The literature review addressing these questions is expanded on in this section, with our major findings as follows:

[104] Agee, J. K. & Skinner, C. N. Basic principles of forest fuel reduction treatments. *For. Ecol. Manage*. 211, 83–96 (2005).
[105] Graham, R. T., Harvey, A. E., Jain, T. B. & Tonn, J. R. The effects of thinning and similar stand treatments on fire behavior in Western forests. U.S. Dep. Agric. For. Serv., PNW-GTR-463 (1999).

1. Constructed from literature on forest management, broadly—as opposed to timber harvest practices, specifically, due to the lack of literature on the effects of timber harvest operations (see Section 3, below)—six key vegetative characteristics should be considered as influential on wildfire hazard. In combination, alterations to these characteristics can lead to densification of forest structure, which is correlated with increased wildfire hazard. With the goal of reducing wildfire hazard, the structure and composition of forests is typically modified through a combination of maintenance actions, harvest actions, and surface fuel treatments. Knowledge gaps remain on restocking strategies that would also substantially affect wildfire hazard.
2. By acreage, Selection, Group Selection, Commercial Thinning, and Shelterwood Removal Cut are the most common silvicultural methods, representing a mix of evenaged, unevenaged, and intermediate approaches.
3. Few peer-reviewed studies or technical reports exist specifically linking silvicultural practices with short- or long-term changes in forest structure, or evaluate how those practices may alter the likelihood or behavior of fire. Information is dispersed among cooperative extension sites, embedded in research on the effects of forest management regimes in a broad sense, or is limited to few, specific studies of narrow focus.

1. How does forest structure influence wildfire hazard?

1a. General principles, drawn primarily from USFS General Technical Reports

Forests range widely in their composition and structure due to variations in geography, management, and history of disturbance. In order to establish an understanding of the connections between forest structure and wildfire hazard, we began with a broad survey of literature across scientific journals and grey literature. To then construct a flow chart on these elements which would be broadly applicable and defensible (**Figure 6.2**), we narrowed that list down to three noteworthy General Technical Reports, published by the US Forest Service between 1999 and 2012, and one peer-reviewed paper. These were selected because of their applicability to the question at hand, the breadth of principles covered, and their common occurrence among the broader survey of literature initially conducted. Listed below, these four sources were used to construct the summary of principles provided in this section.

Agee, J. K. & Skinner, C. N. Basic principles of forest fuel reduction treatments. *For. Ecol. Manage*. 211, 83–96 (2005).

Graham, R. T., Harvey, A. E., Jain, T. B. & Tonn, J. R. The effects of thinning and similar stand treatments on fire behavior in Western forests. U.S. Dep. Agric. For. Serv., PNW-GTR-463 (1999).

Graham, R. T., McCaffrey, S. & Jain, T. B. Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity. U.S. Dep. Agric. For. Serv. RMRS-GTR-120 (2004).

Peterson, D. L. et al. Forest Structure and Fire Hazard in Dry Forests of the Western United States. U.S. Dep. Agric. For. Serv. PNW-GTR-628(2005).

Key Vegetative Forest Characteristics which Influence Wildfire Hazard

- Canopy bulk density
- Canopy cover
- Horizontal continuity
- Vertical continuity
- Community composition
- Large tree density

Key Management Strategies to Reduce Hazard and/or Promote Fire Resistant Forests

- Reduce surface fuels: reduces crown fire occurrence
- Reduce ladder fuels (increase height to live crown, canopy base height): reduces crown fire occurrence
- Reduce canopy bulk density: minimizes spread of crown fire
- Reduce continuity of the forest canopy: minimizes spread of a crown fire
- Retain fire resistant species and larger trees: increases survivability of trees

These strategies were recommended by all four literature sources with nearly identical agreement. A good summary, as follows:

> *"The best general approach for managing wildfire damage seems to be managing tree density and species composition with well-designed silvicultural systems at a landscape scale that includes a mix of thinning, surface fuel treatments, and prescribed fire with proactive treatment in areas with high risk to wildfire."*[105]

There was also strong agreement that the treatment of surface fuels is *critical* following other fuels treatments if they are to be effective at reducing wildfire hazard, and will otherwise increase intensity of surface fires since treatments such as thinning actually increase surface fuels from the aggregation of slash. As a result, the most effective strategy to reduce wildfire hazard is thinning followed by prescribed burning.

Nuances and Complications

- Multiple fuels reduction treatments are often required, especially where fire has been historically suppressed[105],[106], and the length of effectiveness varies by forest type[106] and the scale of treatment[104]
- **The effects of thinning** on crown fire potential (positive or negative) can have a variety of outcomes, depending on forest type and the method and intensity of thinning[105]. "Classically, thinning is defined as 'cuttings made in immature stands in order to stimulate the growth of trees that remain and to increase the total yield of useful

[106] Graham, R. T., McCaffrey, S. & Jain, T. B. Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity. U.S. Dep. Agric. For. Serv. RMRS-GTR-120 (2004).

material from a stand' (Smith 1962)", but also commonly refers to a variety of other methods of partial cutting in a stand, which all reduce the density of a stand but which may be employed for a range of purposes.[105]

- **Types of Intermediate (pre-harvest) thinning**[105]:
  - **Low** (from below) → removal of intermediate and suppressed trees, mimicking natural competition or surface fires but creating a range of possible stand structures and species compositions depending on the intensity of thinning; the most likely method to reduce crown fire occurrence due to the reduction of ladder fuels
  - **Crown** (from above) → reduces canopy bulk density and is used to favor more desirable tree species in a stand through release from competition; but will not reduce crown fire occurrence for most forest types because, on its own, it maintains vertical continuity and density of a stand
  - **Selection** (whole tree, diameter-limit) → typically the removal of dominant trees to favor the development of smaller trees; can be a form of high-grading in timber harvest operations; results in a limited range of stand structures and compositions that tend to favor shade-tolerant species and intermediate crown classes; not likely to reduce crown fire occurrence for most species
  - **Free thinning** (crop tree thinning) → most flexible approach, applied to any crown class to select for specific trees; can be conducted with the specific intention of reducing crown fire occurrence
  - **Mechanical thinning** → removal based on specified spatial arrangements (e.g. every other row), which is advantageous for timber harvest operations but can reduce diversity in the stand structure or composition
  - **Other types of partial cuttings**
    - **Weeding, Cleaning** → reduce competition at precommercial, sapling stages and influence future stand structure
    - **Improvement, Salvage** → removal of snags, protection from or response to disease, storms; not likely to change fire hazard, even if surface fuels are treated
    - **Seed-tree or Shelterwood Regeneration**

Additional Gaps in the Literature

- Effects of various approaches to slash management (i.e. piling and burning, broadcast burning, lop and scatter, mastication) on wildfire hazard, even though foresters may be familiar with the effects of these methods on other Resource Subjects[107] or with the decay processes of slash that could inform intuition about wildfire effects[108]. One recent review paper investigates the effects of mastication, specifically, and highlights that this

[107] Korb, J, Johnson, N, Covington, W. 2004. Slash pile burning effects on soil biotic and chemical properties and plant establishment: Recommendations for amelioration. *Restoration Ecology* 12(1): 52-62.
[108] Logging Slash: its breakdown and decay at two forests in northern California. 1972. United States Forest Service Pacific Southwest Forest and Range Experiment Station. Available at: https://www.fs.fed.us/psw/publications/documents/psw_rp083/psw_rp083.pdf. (Accessed: 21 March 2019).

treatment results in widely variable fuel bed properties and comments that "Research assessing the overall efficacy of these treatments to reduce fire hazard is as yet insufficient"[109].

- The variation in wildfire effects associated with the structural alteration of a range of forest types (species composition), despite this factor being referenced as significant to wildfire behavior
- Effects of harvest-specific actions that don't appear in general forest management literature, such as yarding methods

109 Kreye, Jesse K. et al. 2014. Fire behavior in masticated fuels: A review. *Forest Ecology and Management,* 314: 193-207.

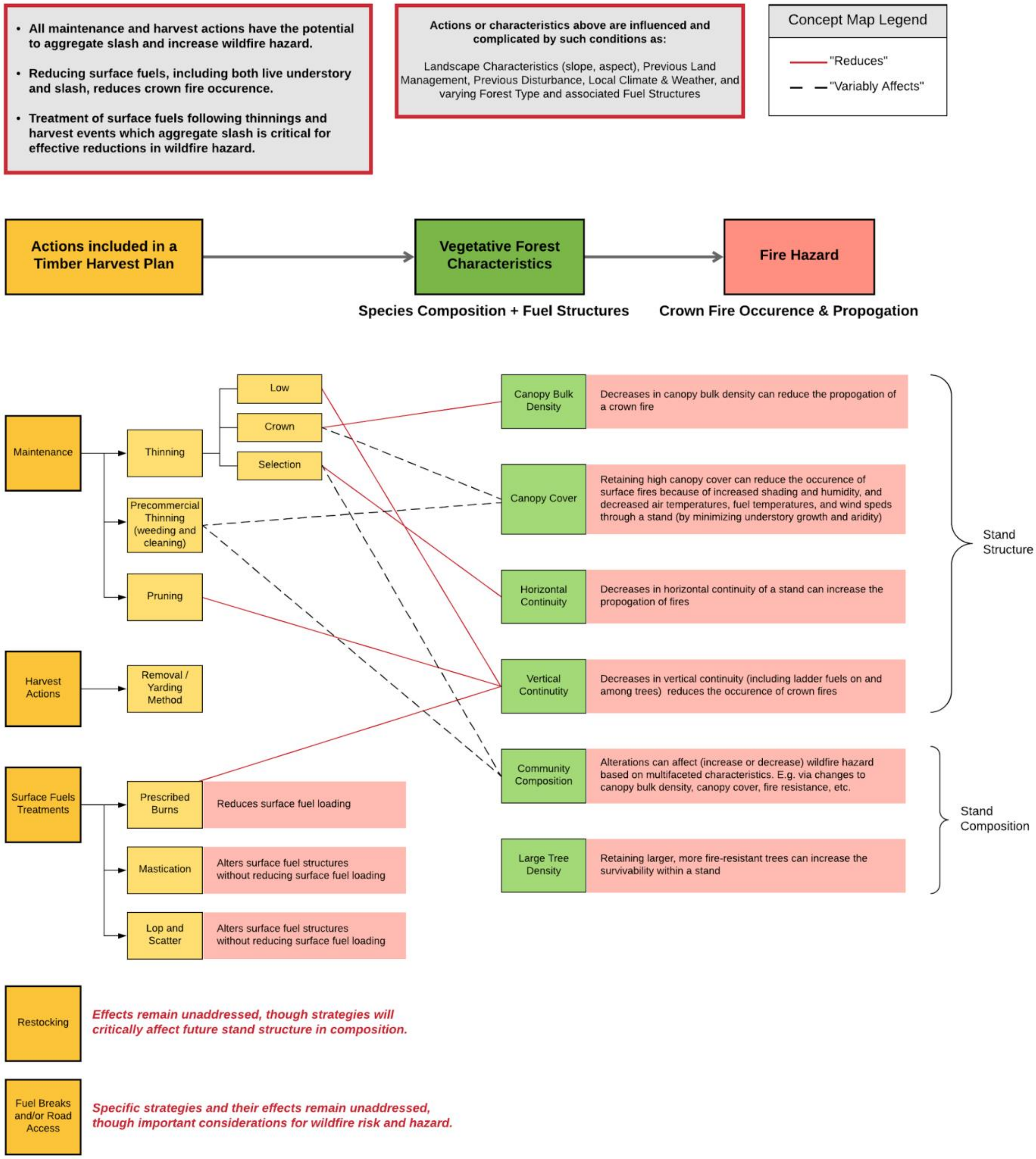

Figure 6.2. Conceptual model outlining critical relationships between forest management activities and forest structure. Timber harvest actions are grouped into five overarching categories; Six key vegetative forest characteristics are listed in green; Potential impacts to wildfire hazard are described briefly in red boxes to accompany each surface fuel treatment and vegetative characteristic.

1b. Principles for mixed-conifer forest, drawn from peer-reviewed publications

Because the effects of many timber harvest actions on forest characteristics is dependent upon forest type, the Group furthered the understanding gained, above, by more specifically investigating the literature on wildfire hazard dynamics in mixed conifer forests of California. Because of the nature of this line of research and in order to ensure a more focused and defensible concept of these effects, this portion of the literature review was limited to peer-reviewed publications.

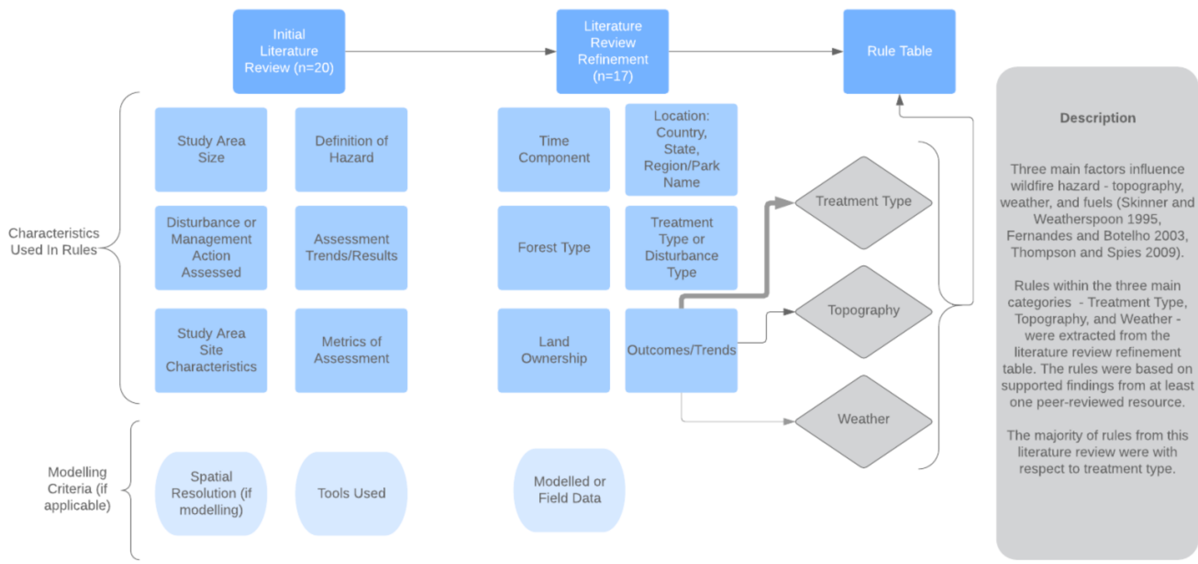

Figure 6.3. Conceptual map of the development of a Rule Table regarding wildfire hazard in mixed conifer forests. Dark blue boxes highlight the overarching flow of rule development. Each literature review iteration composed of extracting key details, shown in the medium and light blue components.

A literature review investigating wildfire hazard trends that result from management actions and landscape characteristics on timberland was completed to inform a qualitative model for use by RPFs. The overall conceptual flow of the development of a final qualitative model is shown in **Figure 6.3**. An initial literature review was conducted to broadly include assessments of wildfire hazard, the efficacy of various treatment plans, and other timber management activities. Results were further refined to include only peer-reviewed articles. A refinement of the initial review was used to organize outputs and eliminate resources with limited application to this project. Resources were eliminated if the location was not within California and the study did not indicate any useful trend regarding wildfire hazard. Two of these studies also made clear that the subject of the reports were not well-substantiated by peer-reviewed research.

Rule Table

The literature review investigating the effect of various timber management actions and landscape characteristics on wildfire hazard was used to summarize major trends of wildfire change (**Table 1**). The table was designed to support hypotheses that have emerged from the literature review here and in background sections of this report. Cawson et al. (2018) used a similar structure to support hypotheses about fuel flammability in eucalyptus forests in southeastern Australia.[110] Our rule table is organized under three categories that represent the major drivers of wildfire hazard: topography, fuels, and weather. While the focus was on fuels treatments, as these can be related to timber harvest actions, some important trends on weather and topography were also established. The full literature review can be found in **Appendix B:** *Wildfire Hazard.*

The table was designed to inform the Guidance Document, which will inform RPF's of the general trends in wildfire hazard as a result of various management actions and landscape characteristics.

Research Gaps

Four primary knowledge gaps were found in researching trends in wildfire hazard from land characteristics and management actions in Northern California timberlands.

Forest Type. Seven of the final seventeen sources used in rule development investigated wildfire hazard in mixed-conifer forests. The remaining sources listed dominant species present, namely conifers and hardwood species. There were no studies relating wildfire hazard with redwood-dominated forests. Additionally, the generic "mixed-conifer" may not consider regional differences in these forest types.

Land ownership. Four articles cited investigated wildfire hazard on privately owned forests. All other studies occurred on National Forest lands (n = 3), Bureau of Land Management lands (n = 1), exclusively or a combination of these (n = 5). One study included forests on American Indian reservations. Two studies occurred on Blodgett Forest Research Station

Longevity of Study. Eight studies had a temporal component. The longest study followed fuel treatment methods for 7 years following treatment. Additionally, no studies utilized historic management or disturbance data except with regard to previous wildfire perimeters.

Timber harvest studies. There were no studies found at any stage of the literature review covering the effects of a timber harvest action on wildfire hazard. This leaves out potentially

[110] Cawson, J. G., Duff, T. J., Swan, M. H. & Penman, T. D. Wildfire in wet sclerophyll forests: the interplay between disturbances and fuel dynamics. *Ecosphere* **9**, e02211 (2018).

significant effects unique to timber harvest action plans, such as harvest type (i.e. clear cutting or selective harvesting) and restocking.

Table 6.2. Summary of hypotheses and inferred timber harvest implications associating fuel treatment types, weather, and topographic characteristics with wildfire hazard.

Component	***Hypothesis***	***Literature Reviewed***	***Inferred Timber Harvest Implication***
Fuel Treatment Types	1a. Fuel treatments, including prescribed burning and thinning, reduce forest density, raise crown base height, and can lower crown bulk density	Fulé, P. Z., Waltz, A. E. M., Covington, W. W. & Heinlein, T. A.	Reducing density, raising crown base height, and reducing crown bulk density are linked with decreased wildfire hazard.
	1b. Mechanical thinning (including crown thinning, thinning from below, whole tree thinning) reduces fire hazard	*California mixed-conifer* - Stephens, S. L. & Moghaddas, J. J., Stephens, S. L., Collins, B. M. & Roller, G. *Conifer forest in Greece* - Zagas, T., Raptis, D., Zagas, D. & Karamanolis, D.	Activities that reduce the density of a forest will reduce wildfire hazard.
	1c. Prescribed burning is effective at reducing fine and coarse woody fuel loads up to 7 years after treatment.	Stephens, S. L., Collins, B. M. & Roller, G.	Prescribed burn treatments reduce wildfire hazard, but treatments should be regularly scheduled to maintain this reduction.
	1d. Average and maximum fire area burned decreases proportionally to increased treatment area (thinning, underburning, and mechanical treatment)	Ager, A., Vaillant, N. & Finney, M.	Increased area of fuel treatments and treatment network organization reduce the continuity of potential wildfire paths.
	1e. Tree survival following a wildfire is highest in plots that have undergone surface prescribed burning and mechanical thinning.	Prichard, S. J., Peterson, D. L. & Jacobson, K.	Maintenance of thinning programs can increase tree survival should a wildfire be ignited.
Species composition	2a. Fire resistant species in the mixed-conifer forests of Sierra Nevada include ponderosa pine, giant sequoia, and black oak.	Witherspoon *et al.*	Fire resistant species can offer some reduction in wildfire hazard if grown in harvested forests
	2b. Fire sensitive species in the mixed-conifer forests of Sierra Nevada include white fir and incense cedar.		Fire sensitive species can increase wildfire hazard in harvested forests

Management (Suppression) Activities	3a. Most forests in California have undergone change resulting in altered fire regime. 3b. The greatest increase in fire severity in recent fires is seen in the Sierra Nevada due to a higher proportion of area that has been managed and treated with suppression techniques. 3c. Overstocked mixed-conifer forests have high flame length values	Steel, Z. L., Koontz, M. J. & Safford, H. D. Steel, Z. L., Koontz, M. J. & Safford, H. D. Ager, A., Vaillant, N. & Finney, M.	Altered fire regimes introduce uncertainty about fire severity Sierra Nevada forests are most at risk for high severity fires in California due to previous management actions that reduced or removed natural fire occurrences. Overstocked mixed-conifer forests have high flame length values, leading to increased fire severity.
Topography	4a. Wildfire hazard increases with increasing slope angle 4b. Higher wildfire hazard associated with higher elevation mixed-conifer forests	Aspen, pinyon-juniper, mixed-conifer forest in CO - *Romme, W. H., Barry, P. J., Hanna, D. D., Floyd, M. L. & White, S. , Omi & Martinson* Oregon - Calkin, *et al.* 2010	Wildfires are more severe on steeper slopes due to flame tilt, providing for more horizontal connectivity. Sites at higher elevations tend to promote more severe wildfires.
Weather	1a. Average daily temperature is the most important predictor in conifer damage during wildfire.	Thompson and Spies, 2009	Wildfire hazard is higher when other hazardous conditions are compounded by high temperatures.

2. What silvicultural practices are employed in California?

2a. Overview of Silvicultural Categories and Methods

Forest management affiliated with THPs form four (4) primary categories in California: evenaged, unevenaged, intermediate, and special prescriptions. To achieve management goals for each stand, timberlands are maintained through specific silviculture methods (**Table 1**). The silviculture methods accepted and described within THPs are defined within the California Forest Practice Rules, Article 3 (pg. 66).

Table 6.3. Linking of silviculture method with a forest management category.
Source: 2017 California Forest Practice Rules

Table 1

Silvicultural Category	Silvicultural Method
Evenaged Management 14 CCR § 913.1 [933.1, 953.1]	Clearcutting, Seed Tree Seed Step, Seed Tree Removal Step, Shelterwood Preparatory Step, Shelterwood Seed Step, Shelterwood Removal Step
Unevenaged Management 14 CCR § 913.2 [933.2, 953.2]	Selection, Group Selection, Transition
Intermediate Treatments 14 CCR § 913.3 [933.3, 953.3]	Commercial Thinning, Sanitation-Salvage
Special Prescriptions and Other Management 14 CCR § 913.4 [933.4, 953.4]	Special Treatment Area Prescriptions, Rehabilitation of Understocked Area Prescription, Fuelbreak/Defensible Space, Southern Subdistrict Special Harvesting Method (14 CCR § 913.8), Variable Retention, Conversion
Alternative Prescriptions shall be put into the category within which the most nearly appropriate or feasible silvicultural method in the Forest Practice Rules is found pursuant to 14 CCR § 913.6 (b)(3)[933.6(b)(3), 953.6(b)(3)].	

Evenaged forest plots hold trees of a single age and are harvested to achieve maximum sustainable yield. As an example, for clearcutting, the entire stand is removed in one harvest and regenerated by plantings, seeding, sprouting, or natural seed fall. Ideally, stands are irregular shapes and various sizes to mimic natural landscapes. For seed tree regeneration, the entire stand is removed in one harvest - except for a few well-spaced, desirable seed trees. The seed trees are relied on for regeneration of the stand and only removed once the stand is re-established. For shelterwood regeneration, three steps occur: preparatory, seed, and removal. This approach is typically chosen for species that benefit from shade during regeneration. The preparatory step improves the crown development and seed production; the seed step promotes increased seed production; the removal step occurs once the stand is fully stocked and removes the protective overstory trees.

Unevenaged forest plots contain multi-aged, balanced stand structure and encourage natural reproduction. For selection, trees are removed individually or in small groups between 0.25 - 2.5 acres, termed group selection. For transition, trees are removed individually or in small groups from an unbalanced or evenaged stand with the goal of creating a balanced stand structure. The transition method should only be used up to two times for a stand.

Intermediate treatments include commercial thinning and sanitation-salvation. For commercial thinning, trees are removed to maintain or increase stand diameter, improve timber growth, and/or forest health. The residual stand holds healthy dominant and codominant trees. The sanitation-salvage method is applied to improve forest health. Sanitation is the removal of insect attacked or diseased trees, while salvage is the removal of trees damaged from fire, wind, or other natural events. These actions are combined in one harvest operation and allow for some economic recovery prior to avoid full loss of the product value.

Lastly, special prescriptions are methodologies only applicable in certain conditions and include special treatment area prescriptions, rehabilitation of understocked area prescription, fuelbreak/defensible space, variable retention, Aspen, meadow and wet area restoration, and White and Black Oak woodland management.

2b. Trends in privately-owned timberland silviculture

From 2006 to 2016, the top five methods applied to the greatest number of privately-owned timberland acres are Selection (SLCN; 295,000), Group Selection (GSLN; 290,000), Alternative Prescription (ALPR; 212,000), Clearcut (CLCT, 207,000), and Commercial Thinning (CMTH; 49,000) (**Figure 6.4**). Of the 212,000 Alternative Prescription acres, Clearcut accounts for 75,000 acres, followed by Shelterwood Removal Cut (SHRC; 57,000), Sanitation Salvage (SASV; 22,000), Shelterwood Removal/Commercial Thinning (SHRT; 20,000), and Commercial Thinning (CMTH; 14,552) (**Figure 6.5**).

The selection of a harvest method is heavily dependent on the regional location of the timber plot (**Figure 6.6**). Between 2006 and 2016, the most productive timber region during this period was Region 2: Cascade, where 850,000 acres were harvested with Group Selection as the primary method (217,000), followed by Selection and Alternative Prescription (16,000 each) and Clearcut (13,000). During the same period, the Coast Region (Region 1) harvested 375,000 acres with Selection as the most common method (90,000), followed by Clearcut (67,000) and Group Selection (65,000), while the Sierra Region (Region 4), harvested 97,000 acres with Selection as the primary method (36,000 acres) followed by Alternative Prescription (20,000) and Clearcut (9,000). Throughout this time period, only 36 acres were recorded in the South Region (Region) by the Conversion method.

The average size of each harvest and number of harvests can vary substantially between years. As seen in **Figure 6.7,** the number of THPs submitted each year has declined since 2016, despite a slight uptick from 2013 to 2014. However, the total number of acres harvested and the average THP size have not experienced a matching trend. All three measures - the number of THP applications, the average THP size, and the total acres harvested – experienced a near peak, followed by a sharp decline in 2015.

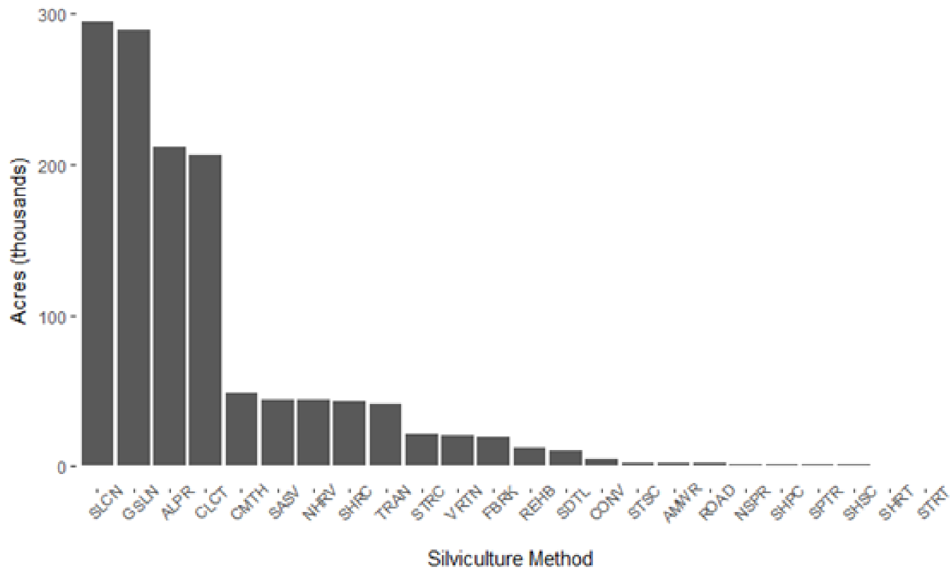

Figure 6.4. Total Acres per Silviculture Method, 2006- 2016. The top five silviculture methods in California during this decade were Selection, Group Selection, Alternative Prescription, and Clearcut. [111]

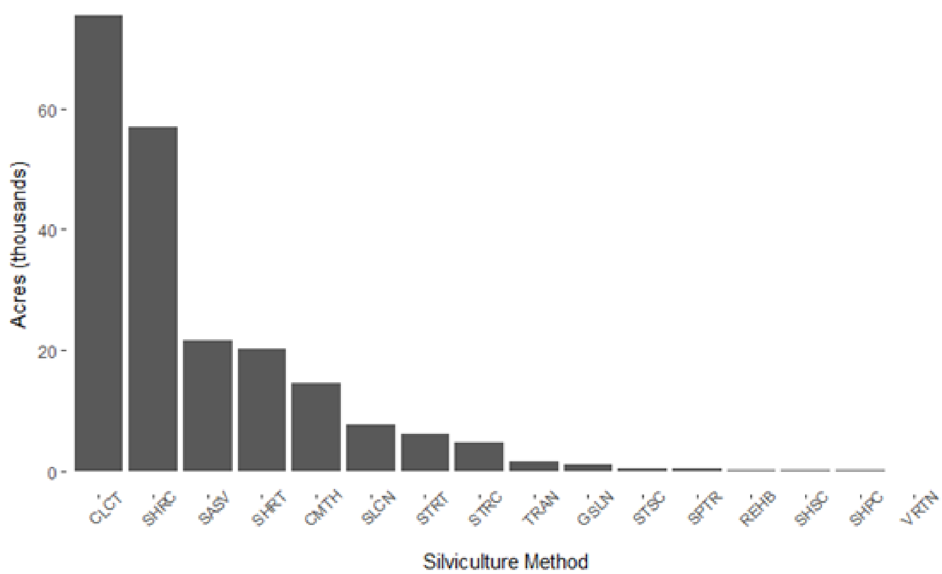

Figure 6.5. Total Acres per Alternative Prescription Silviculture Method, 2006–2016. Alternative Prescription is the third-most common silviculture method in Calfornia. Within this, the top three methods are Clearcut, Shelterwood Removal Cut, and Sanitation Salvage.[112]

[111] California Department of Forestry and Fire Protection. Index of /forest/Statewide_Timber_Harvest/. (2019). Available at: ftp://ftp.fire.ca.gov/forest/Statewide_Timber_Harvest/.
[112] California Department of Forestry and Fire Protection. Index of /forest/Statewide_Timber_Harvest/. (2019). Available at: ftp://ftp.fire.ca.gov/forest/Statewide_Timber_Harvest/.

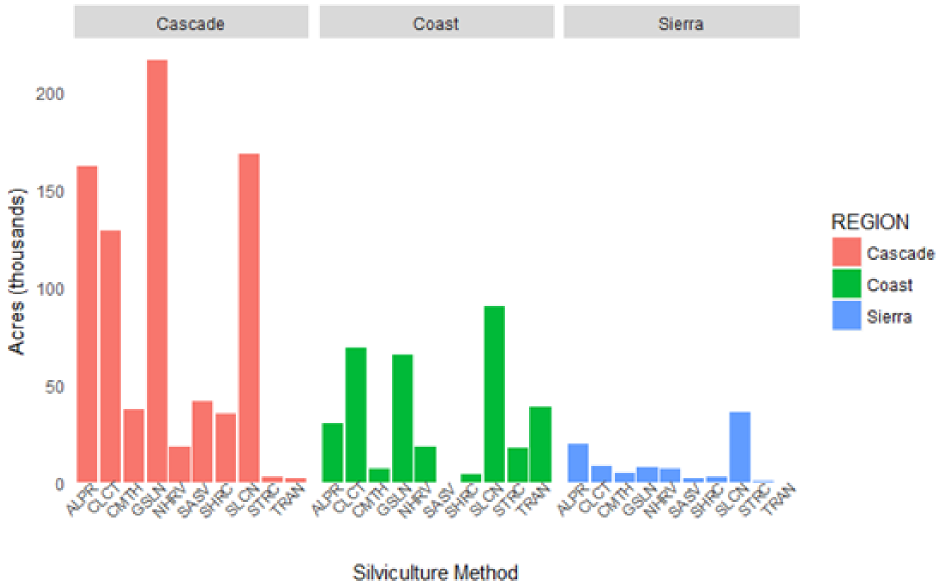

Figure 6.6. Total Acres across Top 10 Silviculture Methods by Region, 2006 – 2016. The silviculture method most common is dependent on the region. In the Cascade region, Group Selection is the most common, while in the Coast and Sierra regions, Selection is the most common. [113]

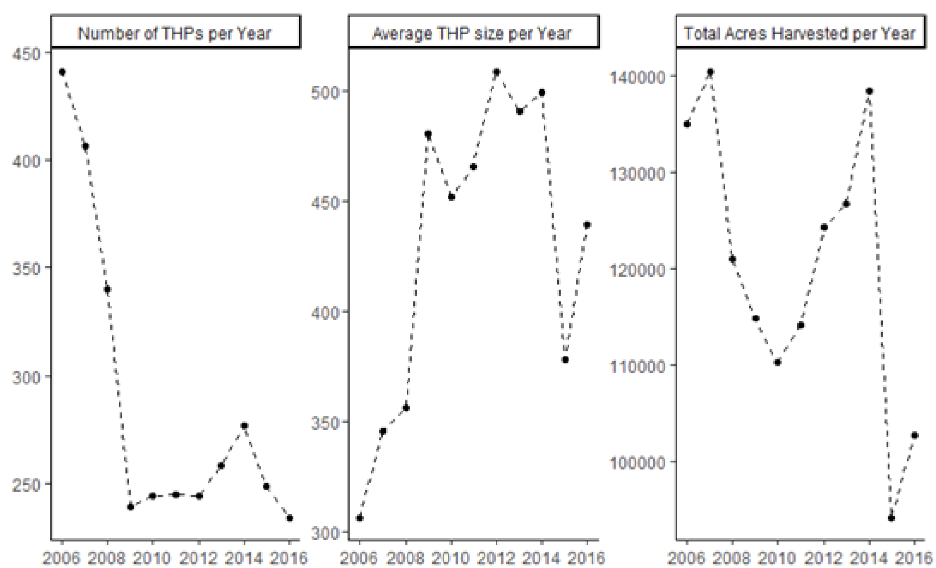

Figure 6.7. Comparison of annual THP parameters, 2006-2016.[114] The quantity of THP applications has changed during this time period substantially. However, the total acres approved for harvest has not followed a matching trend. This is due to the trend in fewer individual THP applications with more timber acres included per THP.

[113] California Department of Forestry and Fire Protection. Index of /forest/Statewide_Timber_Harvest/. (2019). Available at: ftp://ftp.fire.ca.gov/forest/Statewide_Timber_Harvest/.
[114] California Department of Forestry and Fire Protection. Index of /forest/Statewide_Timber_Harvest/. (2019). Available at: ftp://ftp.fire.ca.gov/forest/Statewide_Timber_Harvest/.

3. Gaps in knowledge regarding silvicultural methods

Taking knowledge from the literature and technical reports discussed above, we delineated five categories of "Actions included in a Timber Harvest Plan" as outlined in **Figure 6.2** and mapped onto this what we learned from forest management literature. However, the details of the operational practices actually involved in a silviculture method (e.g. Group Selection) and the corresponding harvest rotation stages described in a given THP remain ambiguous. Direct discussion of the possible effects of timber harvest on wildfire rarely showed up in our literature review, and was vague, at best. For example, Graham et al. 1999 commented only that, "Individual tree selection systems that remove and tend trees on cutting cycles of 10 to 40 years will likely maintain stands prone to crown fire behavior (fig. 7)" but seed-tree and shelterwood regeneration methods have the potential to reduce wildfires.

The primary finding in attempting to answer this question is that scientific literature investigating the operations and effects of silvicultural practices is severely lacking, especially in creating a link between silviculture and fire hazard. In one illustration, Russell 2009[115] finds that timber harvest significantly affects forest composition, structure (including canopy density and canopy cover), solar radiation, and occurrence of large woody debris within and adjacent to harvest plots in the coastal redwood region, but does not make a connection to wildfire hazard. However, not enough of this type of literature exists to be able to make conclusions about the effects of timber harvest on wildfire, and would have to be extrapolated, at best.

Limited information can also be found in publications intended for use by private landowners seeking to protect their homes against wildfire; for example, a *Fuel reduction guide for Sierra Nevada forest landowners* published on a cooperative extension webpage[116]. However, this information was found to be too broadly spread to constitute a well-substantiated list of principles as per our other findings in the sections above.

In another avenue, it is possible that enough research could be gleaned from peer-reviewed studies on the effects of historic land management regimes—which include timber harvest—on the behavior of large wildfires[117]. Perhaps this information could be aggregated to start to construct some applicable principles for modern timber harvesting, but is likely still limited in that these plots were *historically* harvested, and not subject to the same forest practices seen in actively managed plots. Again, we find that silviculture does not appear to be the focus of much research interest.

Returning attention to the flowchart (**Figure 6.2**) we were able to construct from existing literature, it is important to note that we were unable to find information on restocking

[115] Russell, W. *Forest Ecology and Management,* The influence of timber harvest on the structure and composition of riparian forests in the Coastal Redwood region. For. Ecol. Manage. 257, 1427–1433 (2009).
[116] De Lasaux, Michael & Kocher, Susan. (2019). Fuel Reduction Guide for Sierra Nevada Forest Landowners University of California Cooperative Extension.
[117] Collins, B. M., Fry, D. L., Lydersen, J. M., Everett, R. & Stephens, S. L. Impacts of different land management histories on forest change. Ecol. Appl. 27, 2475–2486 (2017).

approaches that would be adequate for making links to wildfire effects. We anticipate, however, that this would be a critical stage of timber harvest in determining future forest structure and therefore wildfire conditions.

Additionally, we did not assess any literature that may exist on strategic planning for fuel breaks and/or road access in wildfire-prone landscapes or timber plots. Up to this point, our investigation was primarily focused on the effects of modified vegetative structure of a forest on wildfire behavior, and not these other features. Although spatial management arrangements and strategies were listed as important by the general technical reports summarized above, specific approaches were not detailed.

One limitation of cumulative impact assessments is the likelihood of wildfire due to instantaneous events. While silvicultural practices can impact wildfire hazard *instantaneously* by causing ignition—as was the subject of *CAL FIRE v. Howell,* described earlier in this Report—this is neither a primary cause of wildfire, historically, or something that can readily be accounted for in planning for a harvest. Therefore, the focus of our investigation is on changes to wildfire hazard over time. Our approach aligns with the nature of a cumulative impacts assessment, which is to take into account "other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." (CEQ Guidelines, 40 CFR 1508.7, issued April 23, 1971). Where timber harvest plots are concerned, this could refer to previous land management regimes or disturbance cycles. This would typically include, but is not limited to, long-term stand rotations, repeating THPs, and suppression activities on the same and adjacent plots. To best align with the motive of cumulative impact assessments and, specifically, Appendix H, our question of interest was narrowed to the following: ***given that a fire occurs****, how will it interact with a timber harvest area?*

VII. ASSESSMENT METHODS

Introduction

Using the understanding about timber harvest operations, the implementation of cumulative impacts assessments, and wildfire behavior constructed from all background reading and literature reviews previously detailed in this report, the Group developed and explored multiple approaches for assessing the potential impacts of a timber harvest operation on wildfire risk and hazard, to satisfy the regulatory requirements of the recent Technical Rule Addendum.

Our research has revealed the major gaps that exist linking timber harvest operations with fire science. Even a narrowed investigation of the peer-reviewed literature on mixed conifer forests of California demonstrated the many nuances inherent to minimizing the likelihood of wildfire or predicting its behavior across a landscape. Moreover, we find that data limitations are a major constraint on assessment capabilities for the privately owned timberlands of interest.

Therefore, the following approaches were developed to ensure the best possible cumulative impact assessments using the most accessible and best available science, data, and modelling software. This section will first justify the recommended temporal and spatial scales at which assessments should be conducted, and then detail the multiple recommended options developed for assessing Wildfire Hazard and then Wildfire Risk.

A. Scales of Assessment

1. Temporal Scale

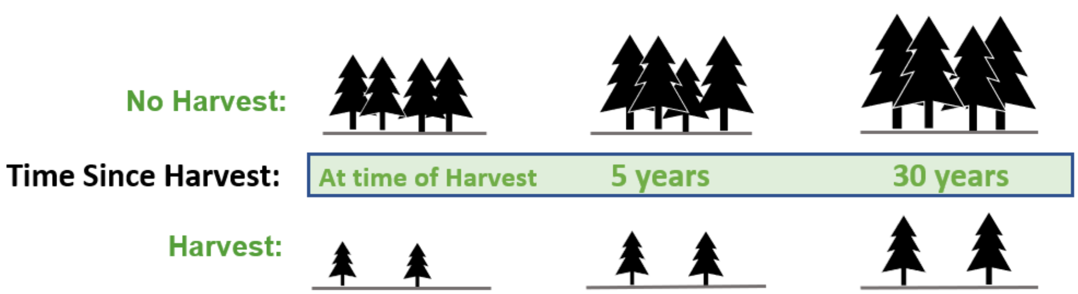

Figure 7.1. This image is a simplification of forest structure changes over time. Due to the relation between forest structure and wildfire hazard, our Group recommends a three-step evaluation between a non-harvest simulation and a post-harvest simulation. These comparisons are suggested to be directly after harvest, 5 years post-harvest, and 30 years post-harvest.

Given that wildfire hazard changes as a forest grows and develops, an assessment of the change to wildfire hazard and risk following a timber harvest action must consider the regrowth and development of a forest following a timber harvest action. In order to model changes to wildfire risk and hazard, the Group proposed three time steps for assessment.

First, using current data for the forest stand of interest, wildfire risk and hazard should be assessed for the forest as it is before any harvest actions occur (T = 0). Using simulations for changes to forest structure following the proposed timber harvest actions, wildfire risk and hazard should be assessed again, immediately post-harvest ($T_H = 0$). The pre-harvest and post-harvest wildfire risk and hazard assessments allow for comparison of immediate changes to wildfire risk and hazard resulting from a specific timber harvest action.

In order to assess the changes to wildfire hazard following a timber harvest action, the regrowth of the forest must be simulated. Simulating continuous changes in forest growth is not practical over the span of a timber harvest cycle, so the Group selected two specific post-harvest time points at which wildfire hazard should be reassessed: 5 years post-harvest and 30 years post-harvest.

Five Year Post-Harvest Wildfire Hazard Assessment
First, wildfire hazard should be assessed at five years post-harvest because this is the length of a standard THP and the point at which (a) all proposed actions should be complete and (b) the THP may be up for renewal. Therefore, the post-harvest wildfire risk and hazard assessment at five years should provide an idea of the change to wildfire hazard from the entire THP. Forest growth should be simulated at this point for two scenarios: (1) as if the forest were harvested according to the proposed THP ($T_H = 5$) and (2) as if the forest continued to grow with no timber harvest actions from its preharvest state (T = 5). Changes to wildfire risk and hazard should be compared both between the five year growth harvest and no-harvest scenarios, as well as between the five year growth to initial pre- and post-harvest scenarios.

Thirty Year Post-Harvest Wildfire Hazard Assessment
Wildfire risk and hazard should also be assessed thirty years following the initial timber harvest action because this is a standard timber harvest rotation length. Timber stand rotation lengths vary according to the tree species and desired quality for product (e.g. pulp and paper vs furniture), but several industry reports and technical papers indicate that thirty years is a viable length for stand rotations.[118,119,120] Additionally, the 2001-2010 California Forest Inventory Analysis (FIA) (**Figure 7.2**) shows that nearly half of California's forests (including state and federal lands) are less than 80 years old, meaning that the standard timber harvest rotation length is no greater than 80 years.[121] Wildfire hazard should be assessed for thirty years post-harvest using simulated results of changes to forest structure, both as if the forest had continued to grow (T = 30), and as if the forest were harvested ($T_H = 30$).

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[118] Forests NSW. The Pine Plantation Rotation. *Forestry Corporation* Available at: http://www.forestrycorporation.com.au/__data/assets/pdf_file/0009/238473/pine-plantation-rotation.pdf. (Accessed: 21st February 2019)
[119] Forest Finance 8: To Cut or Not Cut- Deciding When to Harvest Timber. *Penn State Extension* Available at: https://extension.psu.edu/forest-finance-8-to-cut-or-not-cut-deciding-when-to-harvest-timber. (Accessed: 21st February 2019)
[120] Green Diamond Resource Company. California Timberlands Forest Management Plan. *Green Diamond* (2017). Available at: https://www.greendiamond.com/responsible-forestry/california/reports/FMP_Final_11-8-17.pdf. (Accessed: 21st February 2019)
[121] Christensen, G. A., Waddell, K. L., Stanton, S. M., Kuegler, O. & Editors, T. California's Forest Resources: Forest Inventory and Analysis, 2001–2010. 302

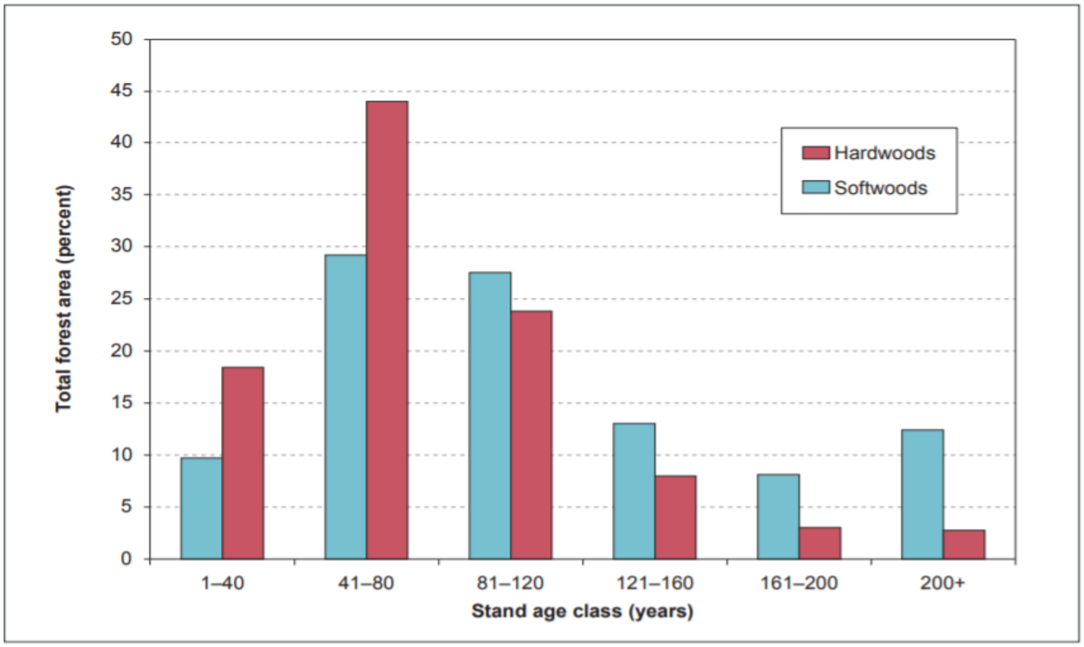

Figure 7.2. Percentage of forest area by stand age class for softwood and hardwood forest types in California, 2001 – 2010. As shown, nearly half of all California's forests are less than 80 years, indicating the length of a typical timber harvest rotation is no more than 80 years. [122]

2. Spatial Scale: Watershed (Resources Area as a Watershed)

The Cumulative Impacts Assessment within THPs requires that each resource subject be investigated across an assessment area, as determined and described by the RPF. The assessment area defined should be appropriate in scale for capturing potential cumulative effects of the timber harvest action(s) within the THP.

Our recommended unit of assessment for the Wildfire Risk and Hazard resource subject is the California Planning Watershed. Further, any Planning Watersheds that are altered by the timber harvest action should be considered for the cumulative impacts assessment, should the THP cross the bounds of a delineated Planning Watershed. Planning watersheds are a California-specific measure that outlines drainage regions ranging from 3,000 to 10,000 acres.[123] This unit is a fourth-order delineation of watershed bounds and is the smallest unit of watershed assessment used in the state. A summary of all THPs passed from 2006 to 2016 shows that the average size of a harvest project is 416 acres. Thus, utilizing the smaller Planning Watershed Unit will better capture the scale at which timber harvest actions are typically completed.

The Planning Watershed scale is a widely accepted, readily available metric for RPFs to use when assessing the impacts of a timber harvest project on wildfire risk and hazard.

[122] Christensen, G. A., Waddell, K. L., Stanton, S. M., Kuegler, O. & Editors, T. California's Forest Resources: Forest Inventory and Analysis, 2001–2010. 302

[123] Conservation Biology Institute. Planning Watersheds: Sierra Nevada region, California Interagency Watershed Map of 1999. *Data Basin* (2004). Available at: https://databasin.org/datasets/8e1155d918b34f119ba0aabdf483315a. (Accessed: 21st March 2019)

Additionally, identification of the Planning Watershed unit is already required for every THP as part of the description of past and reasonably foreseeable probable future projects. A review of recent THPs has confirmed that many RPFs already use this metric to assess other resource subjects.

Importantly, the Planning Watershed Unit represents characteristics of the landscape (topography, vegetation type, climate, and weather) that impact how a wildfire burns through a landscape. Fire is a naturally occurring disturbance across most of northern California, so using a landscape metric for assessment will consider those landscape factors that have guided wildfire presence throughout time.[124,125] Topography, along with weather and vegetation, have been shown to be the major drivers of wildfire severity and burn patterns.[126,127] Topography and vegetation both influence the pattern of burning, providing corridors for fire continuance and natural fuelbreaks.[9] This pattern is a bottom-up driver of wildfire behavior, creating physical barriers and corridors for wildfire travel.[6]

Finally, wildfire effects are frequently assessed at the watershed level.[128,129,130] Wildfires significantly change forest characteristics such as soil erodibility and moisture, which can contribute to altered sediment loading in bodies of water.[131] Thus, using a watershed boundary as the resource area defined for wildfire risk and hazard will complement the expected physical effects a change in hazard would have on the landscape.

B. Wildfire Hazard

1. Qualitative Assessment

Using the information gleaned from the literature review (see *Section VI: Literature Review),* the Group developed the following template for a qualitative assessment of impacts on wildfire hazard to be conducted by RPFs.

[124] Perry, D. A. *et al.* The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. *For. Ecol. Manag.* **262**, 703–717 (2011).
[125] Franklin, J. F. *et al.* Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *For. Ecol. Manag.* **155**, 399–423 (2002).
[126] Dillon, G. K. *et al.* Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. *Ecosphere* **2**, art130 (2011).
[127] Thompson, J. R. & Spies, T. A. Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire. *For. Ecol. Manag.* **258**, 1684–1694 (2009).
[128] Campbell, R. E., Baker, M. B., Folliott, P. F., Larson, F. R. & Avery, C. C. Wildfire effects on a ponderosa pine ecosystem: An Arizona case study. *USDA For. Serv.* 17, Available at: https://www.fs.fed.us/rm/pubs_rm/rm_rp191.pdf. (Accessed: 21 March 2019).
[129] Murphy, J. D. *et al.* Wildfire Effects on Soil Nutrients and Leaching in a Tahoe Basin Watershed. *J. Environ. Qual.* **35**, 479–489 (2006).
[130] Pierson, F. B., Robichaud, P. R. & Spaeth, K. E. Spatial and temporal effects of wildfire on the hydrology of a steep rangeland watershed. *Hydrol. Process.* **15**, 2905–2916 (2001).
[131] Ice, G. G., Neary, D. G. & Adams, P. W. Effects of Wildfire on Soils and Watershed Processes. *J. For.* **102**, 16–20 (2004).

For the actions included in a THP*, assess the following components in terms of whether they will likely increase (+) or decrease (-) wildfire hazard at multiple time steps, relative to baseline, pre-harvest conditions.

*Including maintenance actions, harvest actions, surface fuels treatments, and restocking approaches (guided by the interactions illustrated in **Figure 6.2** and **Table 6.2**).

Table 7.1. Checklist A, to guide a qualitative assessment of potential cumulative impacts of a proposed timber harvest project on wildfire hazard.

Category	Condition	Immediately Post-Harvest	5 Years	30 Years
Stand Structure	Canopy Bulk Density (crown fuels)			
	Canopy Cover			
	Horizontal Continuity (stand density)			
	Vertical Continuity (ladder fuels)			
Stand Composition	Community Composition			
	Large Tree Density			
Surface Fuels	Surface fuel loading			
	Surface fuel structure			

Additionally, how will landscape, regional climate conditions, past management activities, and the inclusion of fire breaks and/or road access likely interact with the actions proposed in timber harvest to modify wildfire hazard?

Table 7.2. Checklist B, to guide a qualitative assessment of potential cumulative impacts of a proposed timber harvest project on wildfire hazard.

Category	Condition	High Hazard, or will Increase Hazard	Low Hazard, or will Reduce Hazard
Topographic	Slope		
	Aspect		
	Elevation		
Climate	Regional Climate		
	Microclimate of TH Site		
Prior Land Management	Fire Suppression		
	Overstocking		
	Altered Fire Regime		
	Timber Harvest		
Defenses	Fire breaks		
	Road access		

2. Quantitative Model: FVS + FlamMap

Literature Review

A literature review was conducted to evaluate existing models and methodologies that quantify/calculate change in wildfire hazard as a result of changes in forest structure. This literature review focused on a broad array of models, tools, and specific case studies used by academics and industry professionals to track and/or predict wildfire hazard as part of a forest management plan or study. In our literature review, the Group found limited studies and industry reports that included wildfire hazard assessments specifically linked to timber harvest actions so we also considered how various forest management studies could be employed in the evaluation of wildfire hazard changes resulting from timber harvest activities.

The fifteen quantitative tools identified in this literature review were initially selected based on their feasibility and credibility, as defined below in *Criteria Selection*. Then, the models were filtered based on their ability to (1) evaluate the effect of harvest actions on forest structure and wildfire hazard and (2) evaluate the effect of regrowth following a harvest action (post-harvest) on forest structure and wildfire hazard.

Table 7.3. Table summarizing models evaluated and referenced sources.

Wildfire Hazard: Possible Models and Tools			
Initial Models Considered	**Round 1 Filter**	**Round 2 Filter**	**Source**
ENVISION			http://envision.bioe.orst.edu/
FARSITE	✓		www.firelab.org/project/farsite
BehavePlus	✓		www.frames.gov/behaveplus/home
FlamMap	✓	✓	www.firelab.org/project/flammap
ArcFuels			www.fs.fed.us/wwetac/tools/arcfuels
CalFire Fire Hazard Severity Zone Mapping			www.fire.ca.gov/fire_prevention/fire_prevention_wildland_zones
LANDFIRE			www.landfire.gov
CA BIOS Viewer			www.wildlife.ca.gov/data/BIOS
NEXUS			http://pyrologix.com/downloads/#software
LEMMA GNN			https://lemma.forestry.oregonstate.edu/data/structure-maps
Fuel and Fire Tools Program (FFT)			www.fs.fed.us/pnw/fera/fft
Fuel Network	✓		
Surface Fuels Map & Data			
Fuel Ranking			
Forest Vegetation Simulator (FVS)	✓	✓	www.fs.fed.us/fvs/software/index.shtml

Criteria Selection

Our group defined a set of criteria that we used to assess each of the models identified in this literature review. The purpose of applying these criteria was to establish credibility and feasibility of each model recommended for use by an RPF working under temporal and budgetary constraints. The criteria defined included metrics of credibility (whether the models were used in peer-reviewed citations or grey literature citations) and feasibility (cost of use, accessibility and availability of data required in model, time and computer processing requirements). Each model was assessed for these criteria as shown in **Table B.2** in **Appendix B**. Based on our assessment of our criteria, we selected five models for further review. The five models included one model, the US Forest Service's Forest Vegetation Simulator, that evaluates change to forest structure and four models that evaluate change to wildfire hazard, including FlamMap, ArcFuels, Behave Plus, and Fuel and Fires Tool.

Review of Five Selected Models

Models evaluating change to forest structure:

1) **Forest Vegetation Simulator (FVS), particularly the Fire and Fuels Extension (FFE):** The Forest Vegetation Simulator (FVS) is a simulation model developed by the US Forest Service for forest growth. Using stand-level forest inventory data in addition to forest inventory metadata, the model is capable of simulating forest growth in response to management decisions and disturbances. Extension packages offer additional functions for FVS. For example, the Climate-FVS extension allows for the simulation to vary outputs based on predicted climate changes. The Fire and Fuels Extension of FVS provides a way to simulate the effect of fire on forest growth and to model fuel availability and fire behavior in the forest. FVS model outputs include forest characteristics such as biomass, density, canopy cover, and tree volumes.

Models evaluating change to wildfire hazard:

1) **FlamMap:** FlamMap is a program that spatially models potential wildfire behavior using environmental characteristics as inputs. The software was designed by the Fire, Fuel, Smoke Science Program at the Rocky Mountain Research Station.[132] FlamMap calculates fire behavior characteristics, such as surface fire spread, crown fire activity, and burn probability in each pixel of the selected landscape.[133] FlamMap requires eight (8) input spatial layers which guide the fire behavior calculations: elevation, slope, aspect, fuel model, canopy cover, canopy height, crown base height, and crown bulk density.[134] These layers, and additional information about fuel moisture conditions, are

[132] FlamMap | Fire, Fuel, and Smoke Science Program. Available at: https://www.firelab.org/project/flammap. (Accessed: 17th March 2019)
[133] FlamMap | Rocky Mountain Research Station. Available at: https://www.fs.fed.us/rmrs/tools/flammap. (Accessed: 17th March 2019)
[134] Mark A. Finney. *An Overview of FlamMap Fire Modeling Capabilities*. 8 (2006).

used to run chosen fire behavior models at each pixel. In addition to basic fire behavior conditions, FlamMap also has the capability to calculate Mean Travel Time (MTT), a measure of fire growth over time, and optimize fuel treatment locations based on areas that are found to best prevent major MTT pathways.[3]

2) **ArcFuels:** ArcFuels is a fire behavior modeling and geospatial information systems (GIS) analysis tool kit for fire and fuels management planning and wildfire risk assessment. The ArcFuels toolkit enables the potential impacts of fuel treatments to be demonstrated in the context of land management goals and public expectations. ArcFuels accomplishes effective fuel management planning and wildfire risk assessment via an ArcGIS platform that creates a trans-scale (stand to large landscape) interface. This interface provides a visual context for the analysis of forest growth characteristics and fire behavior models as well as fuel treatment alternatives which are also inherent within the toolkit.[135]

   With landscape prescriptions, treatment analysis, and stand shape inputs, landscape files and stand characteristic databases, rasters and attributed shapefiles are developed utilizing the Forest Vegetation Simulator (FVS), visualized with the stand visualization system (SVS). Fuel treatment comparisons can be analyzed from fuel treatment prescriptions, treatment analysis resulting from Fire Fuels Extension (FFE) of the FVS. Additional externally developed Wildfire behavior models included with the Arcfuels toolkit include NEXUS, FARSITE, FlamMap with FlamMap5 outputs, BehavePlus, FOFEM, and Fire Family Plus. ArcFuels toolkit also provides and Internally coded Behave Calculator for easy stand-level comparisons of fire behavior. Outputs can be quickly converted to raster, ASCII, or tabular attribute files.[136]

3) **BehavePlus (including sub-models: surface, crown, safety, and ignite):** BehavePlus is a Windows-based computer program developed to aid in fire management by predicting fire behavior and utilized by a broad spread of fire and fuel managers. Originally designed to predict the spread and intensity of forest fires using Rothermel (1983), the program as expanded to aid in planning fire treatments, assessing fuel hazard, and understanding fire behavior via educational visualizations. BehavePlus aims to be user-friendly, while also providing flexibility for the user to specify the specific analysis/output they are interested in obtaining. There are nine (9) main modules within BehavePlus, each with a different purpose. These modules contain relevant mathematical fire models and interlink with other modules as needed for the appropriate results.

[135] Vaillant, Nicole M., Alan A. Ager, and John Anderson. 2013. ArcFuels10 System Overview. Gen. Tech. Rep. PNW-GTR-875. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 P. 875. https://www.fs.usda.gov/treesearch/pubs/43065.

[136] Vaillant, N. M., Ager, A. A. & Anderson, J. *ArcFuels10 system overview*. (U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2013). doi:10.2737/PNW-GTR-875

Modules relevant to this project include SURFACE, CROWN, and SAFETY. SURFACE applies the classic Rothermel surface fire spread model and provides a fire characteristics chart as an output that shows the relationship among the rate of spread, heat per unit area, fireline intensity, and flame length. CROWN incorporates models for spread rate and intensity, surface to crown fire transitions, evaluates the conditions present, and fire type to determine the likelihood of a crown fire. Unlike FARSITE, this does not include a reduction to spread rate based on the crown fraction burned. SAFETY works to determine the minimum distance needed between the fire and a person (i.e. firefighter) as a function of flame height. Notably, radiant heating is relied on to calculate this distance, while convective transport (i.e. gusts, fire whirls) are not incorporated into the module.

4) **Fuel and Fire Tools (FFT):** The Fuel and Fire Tools (FFT) application integrates pre-existing tools to predict fire behavior and hazard based on fuel bed characteristics, with estimates for fuel consumption and emissions stemming from those predictions. These fire management tools, run in succession from a user-friendly interface, include the Fuel Characteristics Classification System (FCCS), Consume, and the Fire Emission Production Simulator (FEPS), which were developed by the Fire and Environmental Research Applications Team (FERA)[137]. Default fuel beds and values for several environmental variables can be selected by users within the application, though the user may customize inputs for cases where conditions vary across the landscape of interest. Outputs are summarized in pdfs and provided in full as .csv files and include predictions for fire size and rate of spread, flame length, reaction intensity, fuel loading, emissions of multiple pollutants, heat release, and consumption estimates by fuel type (canopy, shrub, herb, etc.). This application would primarily be used in planning fuel reduction projects and prescribed burns.

Model Inputs and Outputs

For each of the four wildfire hazard assessment models, the Group organized data inputs and outputs into categories (See **Appendix B, Table B.3, B.4, and B.5** for a complete list of variables and categories). The input and output categories were used to examine the potential uses of each tool and determine which models were best suited to assessing wildfire hazard. The range of model outputs were compared to the selected primary metric by which fire hazard will be determined: conversion of land area from surface to crown fires (as described in Section 4).

[137] Fuel and Fire Tools (FFT). US Forest Service Climate Change Resource Center. Available at: https://www.fs.usda.gov/ccrc/tools/fuel-fire-tools-fft. (Accessed: 21 March 2019).

Final Model Selection

The US Forest Service's Forest Vegetation Simulator (FVS) is the only free, publicly available tool that this Group identified for simulating how timber harvest actions affect the structure of a forest both immediately after a harvest and during the period of regrowth that follows a timber harvest action. Thus, FVS was selected as the first tool in our quantitative modeling methodology to simulate changes to a forest structure.

Of the four tools that met our criteria for credibility and feasibility, our Group identified FlamMap as the best option for modeling wildfire hazard resulting from a timber harvest action, when paired with FVS. FlamMap uses output data from FVS to represent information about forest characteristics, along with topographic data, to calculate metrics for wildfire hazard, including flame length and fire line intensity. Thus, when paired together, FVS and FlamMap can evaluate the effect of a specific timber harvest action on wildfire hazard. The quantitative modeling combination of FVS and FlamMap has been used in numerous research and assessment documents.

Limitations of Modeling System

The main challenge with using FVS is that the data required for FVS are highly specific, stand-level data typically unavailable to land managers. The studies that used FVS were performed for sites where the stand-level data were collected specifically for the use of FVS. According to our survey, some Registered Professional Foresters collect stand-level data that could be used for FVS, but this is not common. Given this limitation, our Group recommends using FVS with FlamMap whenever feasible, likely for larger scale, industrial projects, or projects with larger budgets where the necessary data can be collected. For sites where this is not possible, we recommend using our Qualitative Model, or the following time-series methodology.

3. Quantitative Model: Time-Series Methodology

Our Group developed this time-series methodology to provide a standardized approach to quantifying wildfire hazard that relies solely on data publicly accessible to RPFs. This approach addresses some of the limitations affiliated with the FlamMap+FVS model by eliminating the need for RPFs to have 1) stand-level data of their timber plot and 2) the expertise to run FVS.

By relying on historical spatial data, this method will allow RPFs to study the impact of past timber harvest events on local wildfire hazard. As many timberland plots have been re-harvested overtime using similar harvest methods, it likely that this analysis can be conducted on the same timber plot, covering the same harvest method, that is being proposed in the THP.

Literature Review

This time-series study will provide an understanding of how timberland plots respond to harvest-specific disturbance events, as has been considered in previous studies to study forest disturbance events.[138,139,140] This methodology does allow for extended time series analysis when the spatial data are available. An analysis period extending at least 20 years after the harvest is more likely to capture changes to the forest biota and, in turn, the wildfire hazard impacts.

A similar approach has been applied in Canadian boreal forests to understand how each disturbance type impacts carbon dynamics. In our case, we are applying this method to understand how each harvest-specific disturbance type impacts wildfire hazard. While the boreal forest study looks to RGB color composite change analysis, our project relies on LANDFIRE products to assess a wildfire hazard metric change.

Satellite mapping technology advances allow for the variety of existing algorithms that track and characterize forest changes and disturbances.[141] Our project looks to the vegetation layer products of LANDFIRE.[142] These products were developed by the use of Landsat data[143] to classify existing vegetation types into the National Vegetation Classification (NVC) and describe the vegetation structures, i.e. canopy cover.[144]

Many case studies look to percent change in vegetation composition to infer forest regrowth and recovery following a disturbance. Our study looks at percent change in wildfire hazard metrics to infer wildfire hazard following a timber harvest.

Data Availability

Looking to a source with historical coverage of California, along with a likelihood of continued funding, our Group looked to LANDFIRE data. LANDFIRE[145] is a joint program between the US Department of Agriculture Forest Service and the Department of Interior, along with The

[138] Hermosilla, T., Wulder, M. A., White, J. C., Coops, N. C. & Hobart, G. W. Regional detection, characterization, and attribution of annual forest change from 1984 to 2012 using Landsat-derived time-series metrics. *Remote Sens. Environ.* **170**, 121–132 (2015).
[139] Kennedy, R. E. *et al.* Bringing an ecological view of change to Landsat-based remote sensing. *Front. Ecol. Environ.* **12**, 339–346 (2014).
[140] De Palma, A. *et al.* Chapter Four - Challenges With Inferring How Land-Use Affects Terrestrial Biodiversity: Study Design, Time, Space and Synthesis. in *Advances in Ecological Research* (eds. Bohan, D. A., Dumbrell, A. J., Woodward, G. & Jackson, M.) **58**, 163–199 (Academic Press, 2018).
[141] De Palma, A. *et al.* Chapter Four - Challenges With Inferring How Land-Use Affects Terrestrial Biodiversity: Study Design, Time, Space and Synthesis. in *Advances in Ecological Research* (eds. Bohan, D. A., Dumbrell, A. J., Woodward, G. & Jackson, M.) **58**, 163–199 (Academic Press, 2018).
[142] LANDFIRE. LANDFIRE Program: Home. *LANDFIRE.* Available at: https://www.landfire.gov/index.php. (Accessed: 21st March 2019)
[143] Earthzine. LANDFIRE 2015 Remap – Utilization of Remotely Sensed Data to Classify Existing Vegetation Type and Structure to Support Strategic Planning and Tactical Response. *IEEE Earthzine* (2017).
[144] LANDFIRE. LANDFIRE Remap (LF 2.0.0). *LANDFIRE* Available at: https://www.landfire.gov/lf_remap.php. (Accessed: 21st March 2019).
[145] LANDFIRE. LANDFIRE Program: Home. *LANDFIRE* Available at: https://www.landfire.gov/index.php. (Accessed: 21st March 2019).

Nature Conservancy. It was formed in 2000, following a directive from President Clinton to address the threat of wildfires to both communities and firefighters.[146] LANDFIRE provides a national dataset of vegetation and wildland fire/fuels information for strategic fire and resource management planning.[147] This program maintains and updates spatial data for the entire state of California from LANDFIRE about every two years. Currently, there is data available from 2001 through 2016, where 2008 through 2016 occurred in 2-year intervals. A 2019 spatial set will be released mid-2019. As described below in the methods, all eight layers of spatial data required for this methodology are available from LANDFIRE.

Gaps / Limitations

As this approach compares changes in wildfire hazard metrics during a past harvest rotation for the same location as the one described in a proposed THP, there is an underlying assumption that the historical changes observed will provide a relevant insight about future land-use implications on a similar piece of land. However, as climate and land-use changes occur in a watershed, the past conditions may not be able to fully reflect future correlations between climate, forest structure, and fire behavior.[148]

Limitations to this method include the compounding effect of coincidental events - such as extreme weather, wildfires, climate change, and timber harvests occurring simultaneously. Due to lacking a control plot that does not experience timber harvesting, it is difficult to differentiate the impact of harvesting and the impact of a coincidental event. From this limitation, our Group recommends comparing the change in wildfire hazard on the timber plot against that of the entire watershed. This approach will improve the ability to segregate simultaneous impacts. It is advised to annotate this methodology's results with known local events, such as wildfires and/or timber harvests in the surrounding area.[149]

Another potential limitation to this approach is the accuracy of the LANDFIRE satellite data to capture the smaller changes in canopy cover and vegetation type between time steps.[150]

Methods

FlamMap 5.0 was used to investigate historic land use changes, namely previous timber harvest actions, and their effect on wildfire hazard at the Planning Watershed scale. Using LANDFIRE data, the Group looked at metrics of wildfire hazard in Planning Watersheds that have had historic and recent timber operations to determine possible trends in hazard over time.

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[146] About LANDFIRE. *LANDFIRE* Available at: https://www.landfire.gov/about.php. (Accessed: 21st March 2019).
[147] Deis, J. LANDFIRE 2017 Program Report. *LANDFIRE* (2018). Available at: https://www.landfire.gov/documents/LF_2017_Program_Report_final.pdf. (Accessed: 21 March 2019).
[148] Hessburg, P. F. *et al.* Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. *For. Ecol. Manag.* **366**, 221–250 (2016).
[149] De Palma, A. *et al.* Chapter Four - Challenges With Inferring How Land-Use Affects Terrestrial Biodiversity: Study Design, Time, Space and Synthesis. in *Advances in Ecological Research* (eds. Bohan, D. A., Dumbrell, A. J., Woodward, G. & Jackson, M.) **58**, 163–199 (Academic Press, 2018).
[150] Hislop, S. *et al.* Using Landsat Spectral Indices in Time-Series to Assess Wildfire Disturbance and Recovery. *Remote Sens.* **10**, 460 (2018).

LANDFIRE has spatial data for the years 2001, 2008, 2010, 2012, and 2014. By looking at various metrics over time with the number and type of timber harvest actions that occurred in the Planning Watershed, trends of hazard metrics could be extrapolated.

Campbell Creek was selected as the case study as it is a well-researched Planning Watershed that is currently managed by the California Natural Resources Agency, under the Timber Regulation and Forest Restoration Program.[151] This site has a large cache of historic and current data at the Planning Watershed scale. This site is representative of typical timbered areas, as the Planning Watershed has been harvested many times over the last few decades, often covering the same tracts of land over and over again.

FlamMap requires eight spatial layers that convey environmental characteristics crucial to wildfire hazard determinations (**Table 7.4**). The spatial layers can all be sourced from LANDFIRE, an open source collection of spatial environmental data managed by the Department of Agriculture Forest Service and the Department of the Interior. The vegetation layers were acquired from LANDFIRE and the data were extrapolated from field observations, Landsat images, and biophysical data (LANDFIRE). The layers used as inputs are summarized in Table 1. All layers were loaded into ArcGIS to be edited for use in FlamMap. The Extract By Mask tool was applied to clip each layer to the desired Planning Watershed from CalWater 2.2.1 dataset. This ensured all layers had an identical extent and raster dimensions. Each clipped layer was then converted to ASCII (.asc), the format required by FlamMap.

The prepared layers were then used to build a landscape file ArcFuels, a toolbar extension within ArcGIS. Once the landscape file was created, the fire behavior model(s) could be run.

Table 7.4. Spatial layer inputs for FlamMap. All layers for this study were sourced from LANDFIRE.

Environmental Layer	***Units***
Elevation	Meters
Slope	Grade (%)
Aspect	Degrees
Fuel Model	Anderson 13
Canopy Cover	Percent
Crown base height	Meters
Canopy bulk density	kg/m^3
Crown base height	Meters

[151] CALTREES. Campbell Creek Pilot Project. *Campbell Creek Pilot Project* (2017). Available at: http://campbellcreek-calfire-forestry.opendata.arcgis.com/. (Accessed: 21st March 2019)

Basic FlamMap

Basic FlamMap was used to investigate two primary fire hazard metrics: flame length and crown fire activity.

For each run, a Fuel Moisture layer was required. Values from a study that utilized actual conditions during large spread events in two fires in the region near the Blodgett Forest Research Station were used (**Table 7.5**). These values were chosen as the Blodgett Forest has similar vegetation types and characteristics as Campbell Creek and represent the 85th percentile weather conditions that would provide for a wildfire occurrence. The 85th percentile has been shown to be a significant value in landscapes, including conifer forests, as the point at which crown fire is likely across a varied landscape.[152] While fires are likely to start below the 85th weather percentile, it is at this point that fires and are more often more difficult to extinguish.[153] Additionally, these values represent a severe weather condition, both for the Sierra Nevada location of Blodgett forest, and even further for the more coastal Campbell Creek site. Thus, fire behavior under these conditions represent a worst-case scenario. Wind speed (km h^{-1}) was chosen from a different study looking at fire behavior at Point Reyes National Seashore to more closely mimic the coastal wind speeds that are present at Campbell Creek.

Table 7.5. FlamMap fuel moisture parameters used for Campbell Creek model runs. Values were extracted from two different studies from regions with either similar vegetation type or location. [154]

Weather Parameter	*Value Used*
Wind speed (km h^{-1})	14
Fuel Moisture (%)	*Value Used*
1 h	2
10 h	3
100 h	5
Live herbaceous	30
Live woody	60

Identical fuel moisture and weather conditions were run for all years LANDFIRE has data for the Campbell Creek region - 2001, 2008, 2010, 2012, and 2014. Two methods were applied to

[152] Stratton, R. D. Assessing the Effectiveness of Landscape Fuel Treatments on Fire Growth and Behavior. *J. For.* **102**, 32–40 (2004).
[153] Rodrigues, M., Alcasena, F. & Vega-García, C. Modeling initial attack success of wildfire suppression in Catalonia, Spain. *Sci. Total Environ.* **666**, 915–927 (2019).
[154] Stephens, S. L., Collins, B. M. & Roller, G. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. *For. Ecol. Manag.* **285**, 204–212 (2012).

investigate trends of wildfire hazard: 1) Follow an individual THP plot, harvested earlier in the time series, through 2014 and 2) calculate Planning Watershed statistics concerning proportion of land cover treated, by harvest type, and proportion of land cover with metrics that indicate high fire hazard.

Flame length was used as the primary metric to indicate a change in wildfire hazard. This metric is useful in predicting the likelihood of crown fires. Based on the vegetation structure of the forest, a typical, average canopy base height can be determined - flame lengths higher than this average would tend to lead to crown fire should an ignition be provided. Once FlamMap outputs were produced, the flame length output raster was brought into ArcGIS to be clipped for analyses. In order to compare the difference and potential opposing trends in the actual timber harvest site and the overall Planning Watershed, the flame length raster was clipped to include only the selected timber harvest and again to include the Planning Watershed excluding the timber harvest area.

R Analysis

The two sets of rasters, one for the THP area in each of the selected years and one for the Planning Watershed excluding the THP area in each of the selected years, were imported to R Studio as .adf files using the raster package. Each raster was initially plotted to view visual trends in changes to flame length. Then frequency tables were created for each raster, for each year, with all years of "no data" filtered out. Using these frequency tables, a set of histograms for each selected year were created with normal curves to visually display trends in flame length changes.

Using CAL FIRE's classifications for flame lengths as high (11 or more feet), medium (8-11 feet), low (4-8 feet), and insignificant (less than 4 feet), we binned our flame length frequency tables. CAL FIRE did not specify whether the classification boundaries were inclusive or exclusive, so our team assumed that lower boundaries were inclusive and upper boundaries exclusive. For example, the "medium" bucket included flame lengths of 8 feet up to, but not including 11 feet.

From our binned counts for flame length frequency, we calculated percent distributions of area falling in the insignificant, low, medium, and high flame length categories for each year. From this we created a table providing the percent distributions of flame lengths in each of the categories, as well as the percent change in flame length distribution between each year and the pre-harvest, base-line year, which was 2001 in this case.

Finally we performed a series of t-tests between each selected year of mid- to post-harvest data against the initial, pre-harvest, base-line year of 2001. We performed both two-tailed t-tests to determine whether there was a significant difference between any year and the baseline, and then one-sided greater and less than t-tests to determine whether there was significant directionality in the changes between any year and 2001. From these t-tests results we created another table displaying the p-values and significance results.

The script created for this analysis was formatted as a template that can easily be used for any set of THP data, but replacing a few key file directories and variables for the years of analysis. Additionally, the data analysis tables were formatted in order to make comprehension of significant trends in wildfire hazard as simple as possible.

Results

Our findings for this particular time-series study was that there were no significant changes in flame-lengths or flame length distributions between the baseline year and mid- and post-harvest years, both within the THP and in the area surrounding the THP.

Table 7.6. Percent areas of selected THP in Campbell Creek Watershed with range of flame lengths over years.

	Insignificant Flame Length		**Low Flame Length**		**Medium Flame Length**		**High Flame Length**	
Year	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)
2001	0.20	-	0.70	-	0.10	-	0.00	-
2008	0.36	0.16	0.58	-0.12	0.06	-0.04	0.00	0.00
2010	0.36	0.16	0.62	-0.08	0.02	-0.08	0.00	0.00
2012	0.29	0.09	0.63	-0.07	0.09	-0.01	0.00	0.00
2014	0.35	0.15	0.62	-0.08	0.04	-0.06	0.00	0.00

Table 7.7. Percent areas of area surrounding selected THP in Campbell Creek Watershed with range of flame lengths over years.

	Insignificant Flame Length		**Low Flame Length**		**Medium Flame Length**		**High Flame Length**	
Year	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)	Percent Area	Change in % Area from Baseline (2001)
2001	0.21	-	0.45	-	0.32	-	0.02	-
2008	0.34	0.13	0.53	0.08	0.11	-0.21	0.02	0.00
2010	0.51	0.30	0.44	-0.01	0.05	-0.27	0.00	-0.02
2012	0.30	0.09	0.44	-0.01	0.26	-0.06	0.00	-0.02
2014	0.52	0.31	0.43	-0.02	0.06	-0.26	0.00	-0.02

Table 7.8. Summary table of T-test data for selected THP area in Campbell Creek Watershed.

Year compared to baseline (2001)	P-value	T-test Type	Significant finding?
2008	0.99	two-sided	no
2010	0.85	two-sided	no
2012	1.00	two-sided	no
2014	0.85	two-sided	no
2008	0.50	less	no
2008	0.50	greater	no
2010	0.42	less	no
2010	0.58	greater	no
2012	0.50	less	no
2012	0.50	greater	no
2014	0.42	less	no
2014	0.58	greater	no

Table 7.9. Summary table of T-test data for area surrounding selected THP in Campbell Creek Watershed.

Year compared to baseline (2001)	P-value	T-test Type	Significant finding?
2008	0.14	two-sided	no
2010	0.71	two-sided	no
2012	0.61	two-sided	no
2014	0.75	two-sided	no
2008	0.93	less	no
2008	0.07	greater	no
2010	0.64	less	no
2010	0.36	greater	no
2012	0.31	less	no
2012	0.69	greater	no
2014	0.38	less	no
2014	0.62	greater	no

Table 7.10. FlamMap flame length spatial outputs for Campbell Creek Planning Watershed. Flame length was modelled under 85th percentile wildfire weather conditions for the area. Darker red colors indicate higher flame length values, all measured in feet.

C. Wildfire Risk

The Group designed a quantitative model for wildfire risk after reviewing 30 literature sources for wildfire risk assessment. The complete table of literature reviewed is found in **Appendix X**. All of the wildfire risk assessments reviewed in this literature review were conducted in either the US (mainly Oregon, California, or other Southwestern states) or in the Mediterranean over a 5-10 year time frame. The most common disturbance assessed for determining a change to wildfire risk was the expansion of the WUI (eight of the thirty studies focused on WUI expansion). Some studies investigated general land management effect on wildfire hazard, but only one of the thirty papers specifically studied changes to wildfire risk resulting from timber harvest. This supports our finding that the effect of timber harvest specifically on wildfire risk and hazard presents a large knowledge gap. However, this paper focused on risk to owl populations, rather than human populations. The knowledge gaps that exist in wildfire risk assessment are recognized in scientific literature and gray literature. Seven of the thirty papers reviewed specifically set out to critique the current framework of wildfire risk management and assessment and suggest ways to improve the process.

Table 7.11. Selected tools for assessing wildfire risk.

Wildfire Risk: Possible Models and Tools		
Initial Considerations	**Selected Tools**	**Source**
LANDFIRE		www.landfire.gov
ArcFuels		www.fs.fed.us/wwetac/tools/arcfuels
Comparing the role of fuel breaks across Southern Ca national forests management		
Probabilistic Wildfire Risk simulation. Has a necessary burn probability component. (PFIRE)	✓	
Wildfire Risk Assessment Framework for Land and Resource Management Framework (WRAF)	✓	

In terms of the tools commonly used for wildfire risk assessment, five of the thirty papers used tools developed specifically for their geographic location and none were for parts of California or other geographically or ecologically similar areas. Of the remaining studies, five used surveys to assess the perception of wildfire risk. Though this is a viable method for this project, our Group's goal was to quantify changes to wildfire risk, rather than assessing perceptions of risk. Of the remaining studies, six used various economic models to calculate the expected net value change or change to highly valued resources. Four studies used multi-criteria decision analysis for their assessment to compare different mitigation options for reducing wildfire risk within a given community. Expected net value change (NVC or E(NVC)) and highly valued resources (HVRAs) were the two most common metrics used to assess wildfire risk amongst these studies.

1. Qualitative Model

The qualitative assessment of wildfire risk can be completed using Probabilistic Wildfire Risk simulation (PFIRE) method. The PFIRE approach will be used to establish burn probability over the watershed planning unit. The PFIRE approach is similar in methodology used in CAL FIRE's fire rotation interval class calculations.[155] PFIRE uses 47 years of fire data from 1950 to 1997 to overlay historical fire perimeters over vegetation class maps, and then calculates the likelihood of fire for each vegetation class.

The CAL FIRE definition of Wildfire Risk is, "[The] risk posed to structures built in areas with significant wildland Fire Threat." High hazard thresholds set by fire intensity and flame length are terms which we will use synonymously with wildfire fire threat.[156] By using *WUI suitable housing density* as a proxy for structures, we define WUI suitable housing density as the number of houses interfaced or intermixed with wildland vegetation per unit area. 42% of housing within California are located within WUI areas based on 2000 census data.[157] Suitable housing density can be approximated by using the housing density from 2000 California census data referenced by county time the approximate area of the watershed planning unit to find the number of houses within that area and taking 42% of that value to find the housing count within WUI.[158]

The resulting burn probability from PFIRE can then be compared with the suitable housing density. Burn probability is a function of flame length and fire intensity, as described in the following sections, and thus serves as a good metric for hazard threshold. The comparison will complete the qualitative assessment of wildfire risk by providing some likelihood of a wildfire burn and an estimated count of structures at risk within the Planning Watershed area.

2. Quantitative Model

Following our review of Wildfire Risk literature, we selected a 2013 paper published by the United States Forest Service, written by Joe Scott, titled "Wildfire Risk Assessment Framework for Land and Resource Management Framework" (WRAF),[159] on which to base a quantitative model for wildfire risk assessment. In addition, a number of RPF respondents to our survey that

[155] CAL FIRE Findings on Predicting Future Fire Threats. 2003. Trends in Wildland Fire. Chapter 3. Health. October 2003. Available at: https://frap.fire.ca.gov/data/assessment2003/Chapter3_Quality/wildfiretrends_2.pdf. (Accessed: 12 February 2019).

[156] CDF Fire and Resource Assessment Program. Characterizing the Fire Threat to Wildland-Urban Interface Areas in California. Available at: https://frap.fire.ca.gov/projects/wui/525_CA_wui_analysis.pdf. (Accessed: 12 February 2019).

[157] Stewart, Susan I., Volker C. Radeloff, and Roger B. Hammer. 2006. The Wildland-Urban Interface in the United States. Available at: https://www.nrs.fs.fed.us/pubs/8710. (Accessed: 2 March 2019).

[158] California Census Data: Population & Housing Density. Available at: https://www.census-charts.com/Density/California.html. (Accessed: 19 March 2019).

[159] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available at: https://www.fs.usda.gov/treesearch/pubs/44723. (Accessed: 14 February 2019).

referenced the WRAF article as their preferred definition for the term "Wildfire Risk." See **Appendix A:** Surveys and Interviews.

We selected the WRAF method based on several criteria. WRAF uses burn probability modeling techniques as a key component of capturing spatial variation in wildfire likelihood and intensity as a function of topography, environmental layers, weather parameters, fuel moisture, and ignition patterns. Risk characterized wildfire is the combination of wildfire hazard, such as fire intensity and likelihood of effects, with the relative importance of HVRAs that wildfire could impact (**Figure 7.3**). The WRAF wildfire simulation is similar to the wildfire hazard assessment that we developed and utilizes common risk metrics such as NVC, E(NVC), and HVRAs to find quantifiable wildfire risk. NVC, particularly the negative aspect of NVC with respect to structure and community, is quantified by fire impacts to HVRAs. The WRAF method employs multi-criteria decision analysis to evaluate the relative importance as it is applied to HVRA characterizations. WRAF then utilizes the HVRA characterizations that a wildfire would impact and effectively integrates the relative importance of loss evaluated over and area.

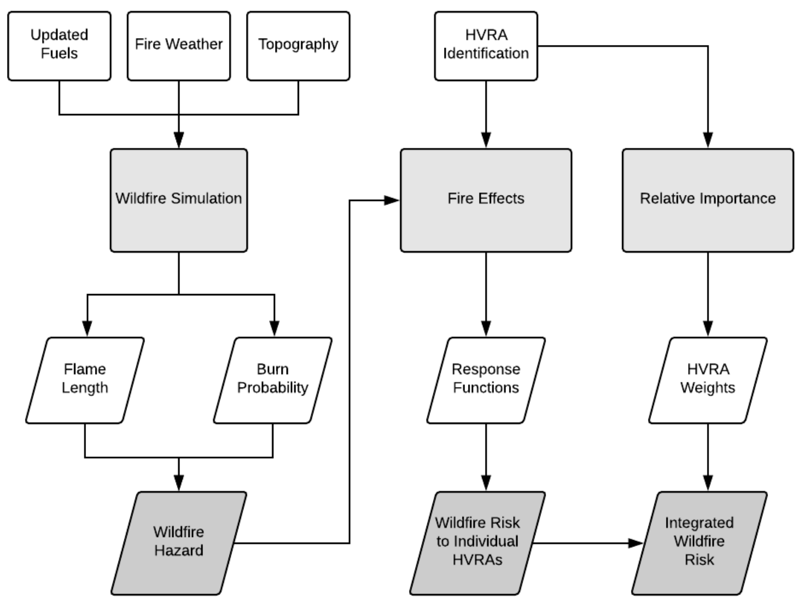


Figure 7.3. Conceptual flowchart for integrated wildfire risk assessment process.[160]

[160] Thompson, M. P.; Scott, J. H.; Helmbrecht, D.; Calkin, D. E. 2013a. Integrated wildfire risk assessment: framework development and application on the Lewis and Clark National Forest in Montana, USA. Integrated Environmental Assessment and Management. 9(2): 329-342.

Methods

The evaluation of wildfire risk can be assessed in four components:[161]

- **Wildfire simulation:** utilizes tabular and geospatial fuel, topography, weather and ignition input data to produce geospatial fire intensity (crown fire activity, flame length, and fire intensity) outputs as well as burn probability which we will simulate with FLAMMAP.
- **HVRA characterization**: identifies the resources and assets including in the assessment, location on the landscape, susceptibility to wildfire, and relative importance. Per the CAL FIRE definition for wildfire risk, our Project considers risk posed to structures with in WUI as a proxy for HVRAs.
- **Exposure analysis:** combines the fire simulation results with data regarding HVRAs to produce tabular and graphical results depicting the wildfire risk to individual HVRAs.
- **Effects analysis:** similar to the exposure analysis, yet also integrates the importance and susceptibility of HVRAs.

The integrated wildfire risk model is expressed by an expected weighted NVC of [E(wNVC)] (*eq*. 1). [E(wNVC)] is derived from a basic expected NVC or E(NVC) function which sums the fire effect or burn probability over different fire intensity classes (i). The E(NVC) is combined with a relative spatial component to find the E(wNVC). The spatial component is the weighted scheme for the relative importance, which is analogous to the HVRA characterizations, divided by the relative extent, which gives the HVRA the spatial context (units = hectare or grid cell (j)). The resulting function is E(wNVC) or integrated wildfire risk.[162]

$$\mathrm{E}(wNVC) = \sum_j \sum_i \left(BP_i * NVC_{ij} * \frac{RI_j}{RE_j} \right) \qquad [1]$$

- i - fire intensity classes
- j - spatial units
- E - (wNVC), expected weighted NVC
- BP_i - fire effects from burn probability function
- NVC_{ij} - net value change
- RI_j - relative importance summed by unit area
- RE_j - relative extent as the spatial analysis

[161] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available at: .(Accessed February 14, 2019): 14 February 2019).
[162] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available at: .(Accessed February 14, 2019). (Accessed: 14 February 2019).

Flammap 5.0 uses a Minimum Travel Time (MTT) module to calculate burn probability over a selected area. Suggested environmental layers, weather parameters, and fuel moisture inputs needed for parameterizing MTT are detailed in the "Quantitative: time-series method" of the "Wildfire Hazard" section in this report. The MTT has an option to produce a Flame Length Probability (FLP) matrix which is necessary for the NVC function. FLP is burn probability as a function of fire intensity level per cell (**Figure 7.4**). Fire Intensity level is binned by flame length range (**Table 7.12**). To calculate a reasonable FLP probability matrix by simulating enough burns over the entire watershed planning area, the Group recommends simulating at least 1000 random fires.

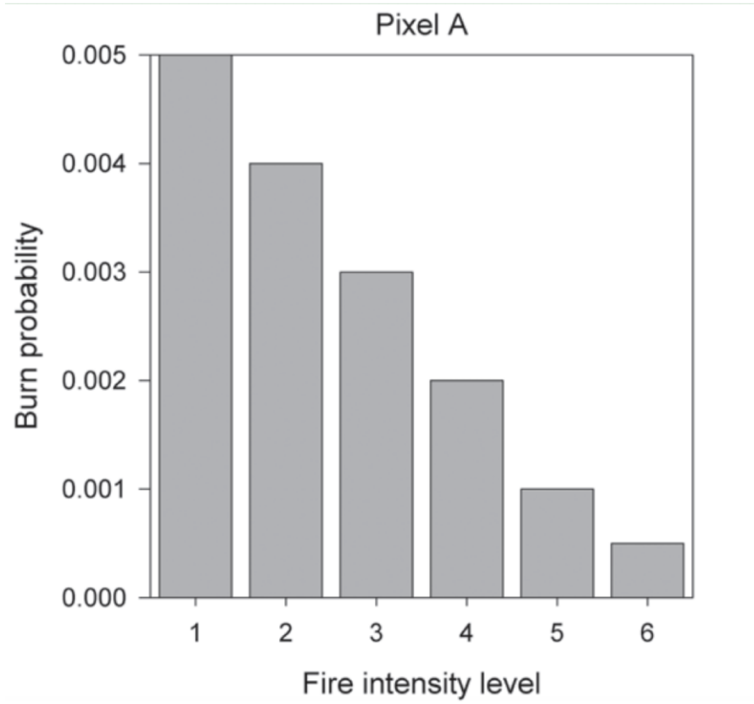


Figure 7.4 Sample pixel (A) calculation of burn probability as a function of fire intensity level. Fire intensity level is determined by flame length range as seen in table 1.[163]

Table 7.12. Fire intensity levels based on flame length ranges by feet. The negative percent damage that critical infrastructure suffers is dependent on the fire intensity levels.[164]

Fire Intensity Level	*1*	*2*	*3*	*4*	*5*	*6*
Flame Length Range (feet)	0 - 2	2 - 4	4 –6	6 - 8	8 - 12	12+
Critical Infrastructure	-50	-60	-70	-80	-90	-100

[163] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
[164] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

NVC (NVC_{ij}) is the percent of damage critical infrastructure that will be potentially induced at each fire intensity level. The negative percentage of critical infrastructure damage scales from (–50) at fire intensity level 1, to (–100) at fire intensity level 6 (**Table 7.12**). The resulting calculations of burn probability and NVC from the sample pixel (A) (**Figure 7.4**) are shown in equation 1.

$$(BP_a * NVC_a) = (-50 * 0.005) + (-60 * 0.004) + (-70 * 0.003) + (-80 * 0.002) + (-90 * 0.001) + (-100 * 0.0005) \quad \text{Eq. 1}$$

WRAF includes a relative value-based (RI_j/ RE_j) assessment of vegetation, watershed, and habitat as well as WUI and infrastructure over the planning area. Based on the CAL FIRE definition of Wildfire Risk, the Group will modify WRAF to use WUI suitable housing density as a proxy for HVRAs. WRAF characterizes HVRAs by overlaying significant relatively important infrastructure layers (RI_j) with areas that have high flame length or high fire hazard thresholds. By using the expected suitable housing density found in the above "Qualitative" section, the number of HVRA considerations for the relative importance score is greatly simplified. Relative importance can be evenly distributed over all pixels for use in the effects analysis calculations. The revised effects analysis calculation will then be evenly weighted for all structures across all cells within the planning area.

The result is the quantitative Wildfire Risk assessment model calculated using an evenly weighted expected net value change function. The function considers burn probability times the net value change of WUI structures summed over each fire intensity level and over every cell of the watershed planning unit.

Gaps

Uncertainty with respect to modeling wildfire risk relates strongly to the same gaps in uncertainty of wildfire hazard. There exists no scientific method with which to predict the location or timing of fire occurrence, just as there is no method to predict weather patterns that drive fire behavior. Furthermore, fire predictability varies spatially and temporally and predictions become more complicated by the prospect of future disturbances other than fire. Understanding future fire effects is further challenged by gaps in core fire science and fire effects science, lack of reliable models, and limited reliable empirical observations.[165]

[165] Scott, Joe H., Matthew P. Thompson, and David E. Calkin. 2013. A Wildfire Risk Assessment Framework for Land and Resource Management. RMRS-GTR-315. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Available at: .(Accessed February 14, 2019). (Accessed: 14 February 2019).

VIII. DISCUSSION

A. Discussion of Outcomes

Survey Outcomes

We understand that RPFs highly value agency resources and find guidance documents useful; therefore our Group will develop a Wildfire Risk and Hazard guidance document for RPFs that will include methodological recommendations and support materials for completion of the new resource subject, Wildfire Risk and Hazard. The guidance document will endeavor to efficiently address issues raised by RPFs regarding completion of the WFRH section by: (1) focusing on regionally specific applications; (2) minimizing the overlap with other CI assessment sections; (3) recommending fire hazard mitigation strategies that RPFs already conduct for other purposes; (4) making use of data that RPFs already informally collect; and (5) utilizing tools already familiar to RPFs such as field observations and GIS models.

Knowledge Outcomes

Forest management actions across different temporal and spatial units have been shown to impact wildfire risk and wildfire hazard. While many actions associated with timber harvesting do initially decrease (values of the metric of choice for) wildfire hazard, similarly reducing risk, over time the pattern of forest regrowth can lend itself to increased hazard.

When striving to understand wildfire risk and wildfire hazard, regionally- and species-specific information must be central to the evaluation. Fire behavior is heavily affected by species, fuels loading, forest structure, topography, and climate. In the timber industry, several of these factors are controlled by the landowner, for example through restocking methods, harvest categories (e.g. even-aged, uneven-aged), and actions which contribute to fuels loading (e.g. aggregation of slash via pruning or thinning). As such, each of these decisions plays into future wildfire risk and hazard conditions on a property and throughout a watershed.

Model Outcomes

Our Group has developed three verifiable, informed approaches for the assessment of whether a timber harvest will cause cumulative adverse impacts to the landscape at the Planning Watershed scale. The recommended methodology for qualitative assessment highlights the influence of timber harvest and mitigation efforts on wildfire behavior, specifically conversion to crown fire. These same links can be computed and quantified using either the FVS-FlamMap coupling or a historical time-series FlamMap analysis.

Due to the wide range of timber harvest projects from small landowners to industrial practices, each of the three methods can fit a separate user. We recommend the use of the qualitative assessment tool during all THP evaluations to ensure a holistic, baseline consideration of expected relationships between a forested landscape (characterized by its composition and structure) and wildfire hazard at the present and into the future. For larger THPs with available stand-level data, we highly recommend the use of FVS-FlamMap. And finally, for larger THPs lacking stand-level data, we recommend conducting a historical time-series FlamMap analysis.

In order to complete the wildfire risk and hazard assessment, the Group recommends two additional approaches which satisfy the risk component. The first approach simply uses the qualitative wildfire hazard method of vegetation evaluation to identify burn probabilities and connects that with an approximate quantification of risk structures within the WUI of the planning area. The second combines a spatial burn probability hazard matrix created using FlamMap, with net value change, and the relative important of WUI structures within the watershed planning area to form a quantified wildfire risk assessment.

B. Knowledge Gaps

Throughout the development of our Group's knowledge and models there existed gaps and limitations that challenged our research. Those challenges can be reported under the following four classifications, and currently pose a barrier to developing the best possible standards for implementation of Wildfire Risk and Hazard into Cumulative Impacts Assessment for Timber Harvest Plans:

Forest Management Actions

Despite the decades of timber harvests action and cumulative impact assessments within California, little is known about the impact of timber harvests on forest ecosystems. Timber is harvested in multi-decadal cycles over centuries. Harvest actions likely alter wildfire risk and hazard, yet there is limited literature on this process across temporal and spatial scales. Likewise, there is minimal documentation on regrowth, particularly with respect to a variety of harvest practices. With a lack of understanding of THP action and climate change in general, it follows that there is little known about the compounding effects that both of those dynamics will have on forested ecosystems.

The existing literature on management actions such as piling and burning, broadcast burning, lop and scatter, mastication, or yarding methods is insufficient to inform the potential impacts of these actions on wildfire risk and hazard.

Wildfire Behavior

Science cannot predict the location or timing of fire occurrence nor can it predict weather patterns that may drive fire behavior. The predictability of fire varies across spatial and temporal scales and predictions are complicated by the prospect of future disturbances other than fire. Understanding future fire effects is further challenged by lack of reliable models and limited empirical observations in core fire science and fire effects science. Furthermore, without solid foundational knowledge of wildfire behavior, understanding how variations in wildfire behavior (e.g. by crown height, flame length, fire line intensity) cause structural alterations in a range of forest types (species composition) remains enigmatic.

Data

Since a majority of RPFs submit THPs for the North Coast and Sierras bioregions, our Group focused our research within these areas. Unfortunately, our Group found there was not enough up-to-date quality data on existing fire conditions within these two bioregions to adequately inform our research. In part, this is due to a lack of data in general from privately held timber lands. To improve forest management decisions, more data should either be collected on or disseminated from privately held timberlands. Data are collected explicitly for the purpose of preparing THPs; however, this rarely, if ever, translates to any publicly available reporting of those data or analyses.

Research

To better inform on cumulative impacts assessment and the incorporation of wildfire risk and hazard into THPs, substantial research needs to be conducted on timber harvest activities in multiple directions. Research or literature that would have been of great value to this Group Project include: (1) studies with greater longevity (> 7 years) that utilize historic management or disturbance data; (2) cumulative impacts assessment studies evaluating timber harvest action plans across different harvest categories (e.g. clear cutting, selective harvesting) and restocking approaches; (3) similarly, wildfire behavior studies which consider the effects of different harvest categories, across multiple timber harvest regions, and capturing a variety of spatial and temporal patterns; (4) studies at any stage of timber harvest covering any management effects on wildfire hazard; (5) studies evaluating the compounded effects of coincident disturbance events such as extreme weather events, wildfires, climate change, and timber harvests.

Finally, wildfire risk and hazard literature mainly focused on mixed-conifer forests or conifers and hardwood species. As a result, there were no reliable studies relating wildfire risk and hazard with redwood-dominated forests, which are commercially important in California.

C. Recommendations

1. Recommendations to CAL FIRE

Recommendation 1*: Provide substantiated and consistent definitions of wildfire risk and wildfire hazard that should set the standard in the THP CIA process.*

CAL FIRE should work to create detailed and cohesive definitions of both risk and hazard as they pertain to wildfire, with specific emphasis on metrics by which RPFs should measure these. This is critical because the variety of definitions for hazard and risk used in the literature around wildfire decrease the likelihood of defensible or standardized assessments of this new Resource Subject (**Section VII - Literature Review on Wildfire and Forest Practices**). These definitions should either be used within the Forest Practices Rules or THP documentation to ensure standardization of all assessments by RPFs. This will assist in the need that CAL FIRE has expressed for more consistent applications.

Recommendation 2*: Provide additional resources towards studying the effects of timber harvest actions on forest structure that can change wildfire risk and hazard within the scope of the Cumulative Impacts checklist.*

There is a serious lack of scientific literature reviewing the specific effects of timber harvest actions on a forest and the potential short- and long-term consequences on wildfire risk and hazard (**Section VII - Literature Review on Wildfire and Forest Practices**). It is recommended that within their capacity to assist in these types of studies, CAL FIRE encourage and support research in the unique ways that timber harvest actions can affect a forest. This will provide more substantial evidence for trends of hazard and risk in California's forests. Additionally, there are limited long-term studies of any type of management action on forest structure. This is also an important endeavor for CAL FIRE to support to better satisfy the required projection into the future used in the Cumulative Impacts section. This also extends to studying the effects of forest management in different forest types, as the literature currently focuses primarily on mixed-conifer forests in the Sierra Nevada.

Recommendation 3*: Support efforts to increase the availability and update frequency of necessary spatial data at the state level to be able to apply wildfire behavior models to timber harvest plots.*

The spatial data used in this project were limited to those available from LANDFIRE, the most recent of which were from 2014 (**VIII - Methods of Assessment, Wildfire Hazard**). This can severely limit the time-series analysis that we recommend, by reducing the quality and/or feasibility of assessing some immediate or longer term trends. LANDFIRE provides data in a consistent format easily used as an input for a landscape file needed for FlamMap 5.0. It is recommended that CAL FIRE support continued efforts to increase the availability of similar raster data for the state of California to encourage use of models that require this type of data that can assist in estimating wildfire risk and hazard.

Recommendation 4*: Provide incentives for further research and understanding of burn probability and the likelihood of wildfires in and near timber harvest plots.*

Our project did not focus on the likelihood of a fire starting, and instead worked under the assumption of conditions conducive to wildfire ignition (**VIII - Methods of Assessment, Wildfire Hazard**). We do recommend that CAL FIRE support research into the causes of wildfire, and, importantly, whether timber harvest actions may increase the likelihood of ignition. There is currently limited research on this subject, despite relevant legal cases.

Recommendation 5*: Encourage the use of flame length as a metric for crown fire potential to increase consistency in assessments of wildfire hazard.*

Flame length was chosen as the metric for measuring wildfire hazard in this evaluation (**VII - Literature review on Wildfire and Forest Practices**). This metric is valuable as it can be modeled using a number of different software programs available, and is directly linked to the likelihood of crown fire. Crown fires are of particular interest as they are characteristic of very hazardous wildfire scenarios that can be very difficult to suppress. Flame length was also chosen as a metric because of its preexisting use within CAL FIRE's model for calculating fire hazard severity zones.[166] We recommend that CAL FIRE continue to encourage the use of this metric for RPFs to use when assessing wildfire hazard in their timber harvest documentation. This will work to increase consistency in THPs that are submitted for review and RPF understanding of wildfire risk and hazard.

Recommendation 6*: Determine relevant thresholds for significant adverse changes in wildfire hazard and risk as a result of a timber harvest action.*

While available literature outlines many of the interconnected effects that alterations to forest structure have on wildfire behavior, the thresholds for *significant* changes in wildfire hazard or risk are less clear. In order for RPFs to determine whether a proposed timber harvest action will significantly impact wildfire risk or hazard across the Planning Watershed unit, these thresholds should be well defined. One possible way to do this is to create a rating system by which different types of actions would have different weight on the total hazard rank. Currently, the literature does not provide sufficient quantitative values for different actions that may be part of a timber harvest plan to rank such actions. Further research and evaluation of such timber harvest-specific actions and their impact on wildfire hazard can inform such thresholds.

[166] California Department of Forestry and Fire Protection. Fact Sheet: Fire Hazard Severity Zone Model, A Non-technical Primer. *CAL FIRE* (2007). Available at: http://www.fire.ca.gov/fire_prevention/downloads/FHSZ_model_primer.pdf. (Accessed: 22nd February 2019).

2. Recommendations to Registered Professional Foresters

Recommendation 1*: Use spatial data with vegetation and wildfire behavior modelling programs to investigate the potential impact of a given timber harvest action on the wildfire hazard across a landscape.*

Overall, we recommend that RPFs utilize the procedures provided by this project in their assessment and understanding of wildfire risk and hazard within their timber harvest plan (**Section VIII**). Importantly, we recommend the use of spatial data over a time period of at least 5 years in order to understand the potential changes that their harvest action may have on forest structure. We strongly recommend the use to FVS: FFE paired with FlamMap to model the change in wildfire behavior from their particular harvest plan. However, utilizing FlamMap in a time-series evaluation of their site following a previous, similar THP in the landscape, can provide valuable information on the likely future timber harvest and subsequent wildfire behavior changes.

Recommendation 2*: Utilize scientifically-backed trends in forest structure and wildfire hazard to further inform the spatial assessment of wildfire hazard within the Cumulative Impacts section of a THP.*

In the case that there are no similar timber harvest plans in the same or a nearby landscape, it is recommended that RPFs utilize the provided qualitative rule table summarizing trends in the effects of fuels management, topography, and weather on wildfire behavior (**VIII - Methods of Assessment, Wildfire Hazard**). This, and similar meta-analyses of literature, can inform RPF intuition on the potential impacts of their proposed timber action on future wildfire behavior. This project has provided a qualitative list of effects of management actions on wildfire behavior, with particular emphasis on mixed-conifer forests.

Recommendation 3*: Assess wildfire risk utilizing burn probability and WUI suitable housing density relationships to identify risk to structures in the area of timber harvest plots and potential wildfire burn areas.*

In order to complete the wildfire risk assessment the Group recommends one of two additional approaches for risk (**VIII - Methods of Assessment, Wildfire Risk**) that follow the qualitative and quantitative hazard methods. The first qualitative approach simply the uses the qualitative wildfire hazard method of vegetation evaluation to identify burn probabilities using PFIRE. Burn probability or likelihood of fire can then be connected with the approximate quantity of at risk structures within the WUI of the planning area for a wildfire risk approximation. The second quantitative approach, combines a spatial burn probability hazard matrix created using FlamMap 5.0, with percent net value change, and the relative important of WUI structures within the watershed planning area to form a quantified wildfire risk assessment.

3. Recommendations for Future Work

Recommendation 1*: Encourage more scientific research and peer-reviewed assessments on the relationships between forest structure, timber harvest actions, and wildfire risk and hazard. This includes more studies across the range of forested ecosystems in California and longer study periods.*

Overall, this project has revealed large knowledge gaps in the scientific and gray literature surrounding timber harvest actions and wildfire behavior. It is recommended that further research into trends wildfire behavior of frequently harvested forests, as is common in California, be completed and provided to RPFs and CAL FIRE as continuing guidance. Most research has taken place in the Sierra Nevada mixed-conifer forest types. While this is a common forest type in the timber harvest industry, there is very little literature reflecting the more coastal conditions of some frequently harvested areas.

Recommendation 2*: Work towards incorporating factors specific to timber harvest plans into wildfire modelling programs for a consistent and accessible procedure for assessing wildfire risk and hazard within the Cumulative Impacts section.*

The creation of models that can include both the harvest and restocking unique to timber harvest plans in California would be useful in the assessment of wildfire risk and hazard under these conditions. Currently there are very limited modelling programs that can predict forest growth following a management action (**VIII - Methods of Assessment, Wildfire Hazard**).

Recommendation 3*: Future work should include investigation into potential climate change scenarios and the effect that different climate projections will have on wildfire hazard and risk*

We recommend that climate change be considered moving forward in research about wildfire risk and hazard. Future climate changes may cause a series of changes to wildfire hazard, both a weather patterns change and potential changes to forest structure and types occur.[167] Following the prior recommendations, it will be necessary to include climate change in studies of forest structure, timber harvest actions, and wildfire hazard. Currently, our recommended modelling procedure can account for changing climate conditions only if those conditions are inputted from another resource. It is recommended that a variety of climate change conditions be considered to assess wildfire hazard into the future to account for potential serious increases in hazard.

[167] California Climate Change Center. *Climate Change Impact on Forest Resources*. (State of California Energy Commission, 2006).

IX. APPENDIX

Appendix A. Interviews and Surveys

1. Interviews

As part of the synthesis of knowledge within the field, the Group conducted eight (8) interviews with the following experts:

Dennis Hall (Assistant Deputy Director of Forest Practice, CAL FIRE), Pete Cafferata (Watershed Protection Program Director, CAL FIRE), Eric Huff (CAL FIRE), Bill Sivinski (CAL FIRE). *The discussion was focused on the incorporation of Wildfire Risk and Hazard into the THP process as a result of changes to CEQA. The group made it apparent that a reasonable Planning Unit for Wildfire Risk and Hazard assessment should be set in order to ensure consistency in approaches. There was also a discussion of the temporal aspect of cumulative impacts being about 10 years in the past and 5 years in the future.*

Max Moritz (UCSB, Bren School).*The Group met with Professor Moritz to discuss the suggested planning unit for Wildfire Risk and Hazard at the watershed level and the usefulness of various fire behavior modelling applications.*

Sarah Anderson (UCSB, Bren School). *Discussions with Sarah were carried out during late 2018 through early 2019. These conversations assisted in the development of our survey questions and analysis. Sarah encouraged a linear regression analysis to gain predictive power. In addition, Sarah recommended coding the free response questions to extract response trends.*

Carla D'Antonio (UCSB, Environmental Studies Department). *Spoke to the group on historic timber harvest practices which may be a significant driving factor in current wildfire trends especially in the Sierras. She suggest maybe picking 2 major harvest methods to evaluate models with. There was a consensus that there is little useful literature on THP action and the impact that has on wildfire behavior. She advised on a unique approach of studying agency reports associated with individual wildfire to learn how the fires behaved as they burned through areas where harvest action took place. She made a case for us to build/frame our case in a way that states: If we do not go down the path of evaluation then we will find ourselves with more crown fires due to homogeneous even aged stand structures. Alway with the understanding of implementing fuels strategies with harvest action as a management mitigation suggestion pattern. Finally, we discussed Fuel Aridity arguments from canopy removal which adds to the drying surface fuels and suggested we examine work by John Abatzoglou such as, "Impact of anthropogenic climate change on wildfire across western US forests."*

Suzanne Lang (CAL FIRE). *Conversations with Suzanne centered around the available CAL FIRE data for our project. Her assistance was extremely helpful in providing our Group the most recent*

Timber Harvest Plan data. In addition, Suzanne explained to our Group the differences in political and geographic regions relevant to THP applications and their approval process.

RPFs
Their expertise helped formulate a more sophisticated body of questions which allowed us to gather a more in depth knowledge of RPF practice and concerns. That knowledge acquired from survey analysis has been included in the Survey section of this report and has also been incorporated into the resulting guidance document.

Anonymous RPF Respondent #1
How would you define wildfire risk and hazard?

- Give definitions for Wildfire Risk and Hazard otherwise could have a wide variety of result from the and possibly canned responses from the basic definition.

Models or Analytical Tools

- Most RPFs do not use tools or models.
  - Scale of THP makes it difficult to evaluate at on scientific principles this includes using GIS analysis and data to leverage data into models
- Tools prescribed by the state are useful for assessing potential for a significant adverse effect from a timber harvest plan.
- Review State historic fire layers. https://caltopo.com/map.html#ll=40.51142,-123.20914&z=9&b=mbt&a=fire

Wildfire Risk and Hazard

- Fires now as they are, are not driven by forest practice they are driven by absence of forest practice in general or building in WUI areas that are not defensible. Creating fire models that under these catastrophic conditions is not a function of timber harvest. There no connectivity to THPs. High probability of ignition of forest fire is associated with lightning, arson, mechanical, or power lines
- All the lighted regions on the map are fires started on public unmanaged lands.
- Tubbs fire reference was not timber harvest related, it was more of an issue with WUI
- THPs are too small to effect scale of wildfires
- Fire Economically: Preserving income and preventing damage of their economic interest.

Effectiveness of Item 30 Hazard Reduction.

- No evidence of correlation between WRAH with mechanical logging practices. Not effect for this purpose
- Originally design for mitigation of high potential for fire starts
- Large scale fires are a combination effect of failure of land management happening at a Federal level. Not coming from THPs.

Fuels/Fire Protection

- Slash adjacent WUI is already addressed in THP
- Clear cuts are widely used and actually reduce fire hazard
- Most landowner do not use prescribed fire with CAL FIRE
  - State will sign off on a burn, but CAL FIRE cannot manage prescribed burns.

- Reduce management slash around WUI not designed to treat fuel loading level. Originally item 30 was design to mitigation around WUI interface.
    - Types of WUI
        - High density WUI
        - Intermixed 10-20 acre lots prepped once
- Weather conditions promote wind driven fires not fuel driven; wind stokes these fires beyond control
- Doesn't matter how the timber is managed
- Silviculture method does not have an impact in how fire takes out a region
- Few individuals can functionally pull off a prescribed fire - it's a lost art.
- Reduce risk reduce reducible ignition sources
- Continuity roads reduced
- Reduced stand density & crown fuels
- Aerial fuels harder to deal with than ground fuels
- Better measures for mitigation are on the homebuilder's association.

Climate Change

- Should not be included in the questions. Compounding WRAH with climate change "we sink the ship".
- All RPFs trained to deal with dynamic changes
- Climate change models all use over 100yrs timescale. Based on model trend lines from HI model curves they yield exponential growth factors which are not feasible or telling in fire hazard modeling.
- Can only look at fire in terms of now otherwise it looks like everything should be on fire in the future.

THP loopholes

- Most private landowners use some state loophole harvest method such as harvesting 10% dead, dying or disease and use it drought mortality removal any method to avoid full THP
- Prescription methods within Forest Practice Rules are positive or negative
- Reducing fuel load anytime there is a take; net BTUs automatically reduces fuels therefore all take actions are deemed positive from a fire perspective.
- Argument: Clear Cut vs Variable Take
    - Clear cut burns the same way a fully stocked forest burns

Public trust and safety

- Best practice at mitigating fires under a THP is around WUI.
- Currently most effective method for mitigation is Fire Level Watches & Red Flag Day Weather Watches Cause shutdowns during high fire watch
    - Have resources on hand to deal with fires started on site

Can THP cause significant adverse cumulative impacts (CI) related to Wildfire Risk and Hazard

- Does not believe timber harvest [at THP scale] could have CI on landscape
- CI occurred historically under historic practices, but modern methods have built too many failsafe to mitigate and nullify possibility

    - Example: THP did not because increase changed ground fuel it was already there, it just changed the arrangement

Opinions on THP

- THPs originally were not designed to be scientifically rigorous
- THP is a disclosure document only the analysis is not meant to be there
- GIS data of THP sites are not accurate so scientific doesn't mean anything there
- Public trust not a goal of the THP process
- Addendum No. 2
    - Needs to be removed makes no sense to make it more rigorous

Anonymous RPF Respondent #2

Background:

- Consulting forestry forest in Grass Valley undergrad and masters at Cal in forestry and consulting business space is small family timber management and couple of industrial with timber sale layout and THP writing accredited 3rd party verifiers for forestry in cap and trade documentation review and audit on inventory.
- RPF years: 7 yr exp. Before RPF 4 yr education and 3 yr before being an RPF

Objective

- Tool for RPFs to move quickly for analysis and more efficiently through the development and acceptable to CALFIRE and defensible subject to lawsuits this is good
    - Rejection tool based on not fitting into model, then it will be negative
    - Evaluation needs to be transparent
    - Needs to avoid lawsuits. Check rule and legal practice act
    - Lawyers will contact experts to critique models as well
    - Too complex model won't get used
    - Example: GHG calculator
    - WFRH specific should be written to address specifically residential proximity

CAL FIRE as a Client

- Our client is the regulator, the decisions on enforcement the advice is coming from are the regulated. RPFS are under a high level of scrutiny and criticism. The RPF community feels attacked and yet they care about the woods and ecology. They are disciplined and take it personally to do it correctly. They are highly misunderstood.

Define Wildfire Risk and Hazard

- Higher response rate of predefined optioned responses for these two and another.

Wildfire Risk and Hazard data/tools already in use

- Maybe larger companies are doing this already but at a smaller level the RPF have experience for discussion responses.
- If a model or tool is developed the model need to be in line with the reality
    - Detailed, open ended
    - Divided between coastal and inland applications
    - Example GHG calculator, RPFs like these models
        - Bill Stewart at UCExt has developed another calculator

Suggested prescription methods within Forest Practice Rules

- This is a site-specific question - depends on where you are, what condition the stand is in, and what species are out there
- Clear cutting is bad due to fuels at ground level. Big Environmentalists are pushing on the point of clear cutting
- No silvicultural prescriptions will contribute to managing wildfire risk. The slash or regrowth are the problem
- The more sunlight the more the brush will grow back in the area
    - Natural fire regime 10-12 year

Barriers to inclusion of Wildfire Risk and Hazard in THPs?

- More burden to demonstrate no impact
- Slash disposal is really expensive
    - Unless burned but there is an air quality and liability cannot burn so slash is left in place, usually.
    - Used to broadcast burn mimic natural disturbance regime now it goes into a pile and burn in safe periods
    - Another method is chipping
    - If paper and pulp industry were larger, slash should go there
        - pulp mills used to pay to take slash out and make paper, but environmental regulations forced pulp industry out.
    - Could be used by biomass manufacturers as power however, it's expensive and most companies won't take it.
        - Limbs taken off at landing and the chipper chip the logs and mill would burn the material and put elect into grid due to lack of mills now
- Non-functioning economy from over regulation
- Chipped or masticated onsite helps break it down and left and spread.

How would you alter the THP process to make it more rigorous in terms of improving public trust and safety?

- Not more rigorous. It needs to be easier for the professionals to assess.
- Regulations: RPF have obligation via CEQA legally
    - Context other states on private lands not NEPA like on federal public lands
        - Other states range from nothing on other states like West VI to 3-5pg notification in WA & OR where no approval is necessary
    - CA has way more regulation requiring approval
        - CA timber has to compete with WA and OR and they do so under harsher regulatory oversight probably the most regulated in the world
    - CEQA does not require change just assessment of impact
        - Ultimately [WFRH] change means more work and another opportunity for public complaint & suits
        - Potentially stalling THP process by 1-2 years
- Completing a THPs
    - Cost about $20,000 in the Sierras
        - In North costs more; Landowner would pay $100,000
    - Takes 6mo-1 year to complete a THP in larger lands for writing and

        - On the coast and North 2 year to include spotted owl + visual.
    - Field work that goes into the process
- Timber Industry
    - Intention of industry is to develop sustainable wood products, and everybody values real wood products which is more sustainable than steel.
    - Global econ
    - Money issue, if no one is making money then no economic reason to address fuel issues or managing forests
    - Mills help timber make back money which make forests easier to manage
- Wildfire Risk and Hazard
    - Problem triangle (weather, location, & management)
        - Ignition fuel and oxygen
        - Can defend against ignition sources and fuel but not oxygen - wind driven.
- RPFs
    - RPFS believe that what they are doing is in the interests of public safety
    - Need RPFs for functioning timber economy means they need the tools and the people
- Mitigation Issues
    - Forest and board regulate mandatory over restocking with too many trees after harvest.
    - Improved tree genetic and planting techniques and seed storage and quality results in inefficient restocking
        - Restocking needs to be reassessed since there is a 90% survival and 50% have to be cut after 10 year due to density issues

If you prepared a THP and determined the plan had the potential to cause significant adverse cumulative impacts related to Wildfire Risk and Hazard, how would you approach mitigation or avoidance for those impacts?

GIS

- GIS needs to be really accessible the state is requiring ArcGIS license or QGIS (has software issues). Accessibility and purchasing
- Excel sheets are really the best method
    - Everyone uses some form of excel model
    - The larger industrial Co. have their own tools and attorney defensible method
    - [A tool] will be used more by consultants so more like 100 individuals
        - Web based application

Anonymous RPF Respondent #3

Length of survey

- Long answers may deter people from info we want. RPFs don't want to do this.
    - Be more specific and give options instead of long responses

Background

- Works in Santa Cruz

    - Has to address the slash and chop it up and dispose of it.

Which data/tools would you use to evaluate the impact of a THP on Wildfire Risk and Hazard?

- Does not run any models or do fire regime condition assessment ahead of time. No need on the coast. No hazardous fire regime on coast.
- Does look at the potential adverse effects on site by site basis, since looking to harvest in WUI areas which there are a lot in the coastal region.
- SC the community's subdivisions and developments on either side of 200-300 acre tree farms.
    - Need to address fuels conditions and fire behavior in those areas.
    - Worry about sources of fire and how it spreads is it uphill downhill.
    - No model tool use to address fuel loading at this time.
- Future needs may depend on what the department requires the RPFs to do. If they require a specific output, then…
- Not required to provide flame height or fire spread number on post-harvest conditions
- If left open no need for model
    - If specific output required, then need specific metrics
        - Ex. X we want less than 24-foot height flame height and 100-acre fire spread
        - EX: GHG spreadsheet with plugin growths and behavior to give a specific value

How important do you think the consideration of Wildfire Risk and Hazard is for Cumulative Impact Assessment in a THP?

- Important consideration but do have standard practices that address it thoroughly.
- Standard rules are effective at addressing fire hazard conditions.
- Existing there with road infrastructure and increased access factors are effective at addressing fire hazard and risk.
- When WF have started at private and burn into management properties are easily dealt with because of access and mitigation factors.
- Local forest practice rules from CALFIRE sub-district within CAL FIRE rules, due to WUI to address fire hazard and ascetics.

Which prescriptions suggested within Forest Practice Rules do you think positively contribute to managing wildfire risk and hazard? Negatively contribute?

- This one issue: all of these are designed to improve the management of risk and hazard in harvest area. All piling and burning all pulled out of 917 all geared towards stepped up mitigation.
- Rethink this question to address a variety of silvicultural practices.
    - Ex clear cut bad but can create an effect fuel break for fighting fires an intersperse with silvicultural practiced cuts

What barriers do you see to the inclusion of Wildfire Risk and Hazard in THPs?

- If the department were to require specific outputs, before and after, then extra analysis and extra work load to model.
- In discussion format then no issue with discussing in more detail. Depends on what the department is asking for specifically. If specific, then they should supply the tools.

How would you alter the THP process to make it more rigorous in terms of improving public trust and safety?

- No perception from his experience. The public has a great fear of harvest activity being the cause or contributing factor in wildfire…latent concern about fuels and fuel treatment.
- No large public concern that forest practices are contributing to that. Forest management can reduce fire severity and fuels conditions.
- Treatments around WUI actually reduces risk and hazard.

If you prepared a THP and determined the plan had the potential to cause significant adverse cumulative impacts related to Wildfire Risk and Hazard, how would you approach mitigation or avoidance for those impacts?

- Not a likely situation given the theoretical situation.
- Review process is geared to address and mitigate a level of insignificance
- In terms of soil disturbance and erosion, cannot just say yes impact and move on
    - Detailed analysis is required, and further mitigation is required.
- Significant adverse CI is dealt with in the THP process.
    - Looking at fuel treatment day in day out automatically addresses the mitigation efforts created shaded fuel breaks etc.
    - More fuel treatment than necessary is done voluntarily to create strategic fuel breaks and protects their own property.
- Recommends [our team] goes into the field to see the fuels treatment process

2. RPF Digital Survey

The survey went through five revisions between the initial development and final draft review. Revisions and contributions were drawn from Naomi Tague, Will Burke, and Elizabeth Hiroyasu of the Bren School as well as Kim Rodrigues of the UC ANR Hopland Research & Extension Center, Matt Dias of the Board, Russ Henley of CAL FIRE, three anonymous RPF interviewees, and our Group team members. The revisions steps are as follows:

1. Added complexity to the questions and employed neutral composition
2. Formalized agency regulation concepts and included specific agency references from THP documentation
3. Integrated specific RPF professional practice concepts
4. Transitioned from a concentration on free response questions to a primarily quantifiable question style using agency specific material, multiple-choice, and Likert scale responses.
5. Included visual references, digitize/formatted the survey, and used practiced revisions.

The RPFs survey was deployed via google forms and responses were collected automatically to a tabular file which was downloaded and analyzed. The population under study were adult (age > 18) California state licensed registered professional foresters (RPF). RPFs were contacted through the Boards agency database email listserv. No identifiable personal information was collected from the respondents.

Demographics

Question 1: How many years of experience do you have as a licensed RPF?

- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- More than 40

53.4% of RPFs respondents were licensed before 1988, 18.7% were licensed in the 1990s (1989-1998), 13.3% were licensed in the 2000s (1999-2008), and 14.7% have been licensed in the last ten years.

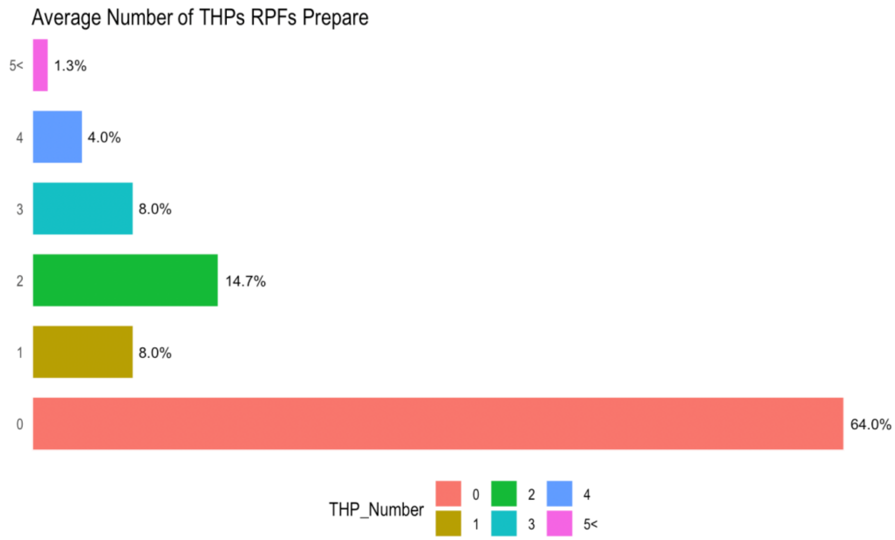
Question 2: Which professional practice best describes your current RPF position?

- No Firm
- Company
- Partnership
- Corporation
- Retired
- Government
- Consultant

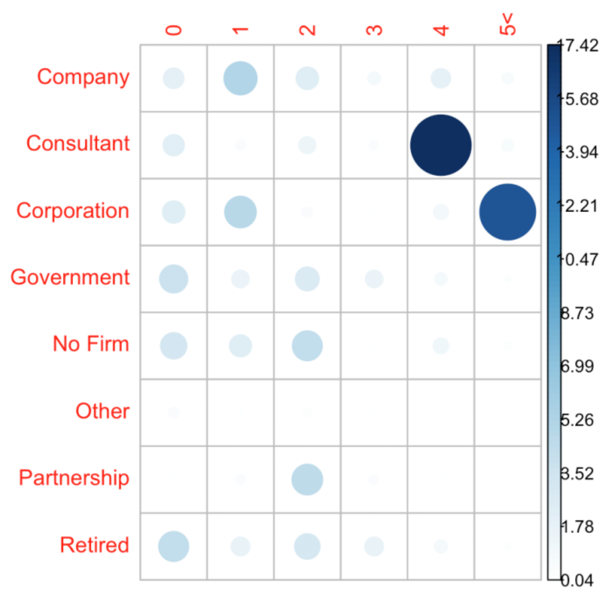
The majority of licensed RPFs (22.7%) are private consultants (25.3%) or employed by a company. The remaining 41.3% work for themselves, in a corporate environment, for the government, or in a partnership. 10.7% of respondents were retired.

Question 3: How many THPs did you write in 2018?

- 0
- 1
- 2
- 3
- 4
- 5 or more



64% (n=49) of licensed RPFs respondents did not complete a THP in 2018, while 34.7% (n=26) completed between 1 and 4 THPs, 1.3% (n=1) completed at least 5 THPs last year. From our survey, we calculated 63 THPs were completed by 27 of the survey respondents. If roughly 6.3% (76 of ~1200) of the licensed RPF community responded, we can extrapolate from our survey results that RPFs filed approximately 1000 THP last year. The CAL FIRE website indicates that on average, 500-1500 THP are filed every year. We take this to mean our survey captured a fairly good representation of the RPF community.



A correlation test was performed between the number of THP completed last year to the type of working position the RPF help. The *chi-squared* test revealed a high *chi-squared* and *p-value* above the significance threshold (*chi-squared* = 37.9, *p-value = 0.3384)* which indicated the number of THPs completed are highly correlated with the type of position the RPFs held. In fact consultants and corporate RPFs tend to complete more THPs than other RPF positions held

Question 4: Based on the 2002 FRAP bioregion boundary definition within CA, which of the eight regions have you written THPs for?

42% of RPFs work in Klamath/North Coast, 26% in the Sierras, and remaining 32% work in Sacramento Valley, Bay Delta, Modoc, Central Coast, San Joaquin Valley, and South Coast CA bioregions.

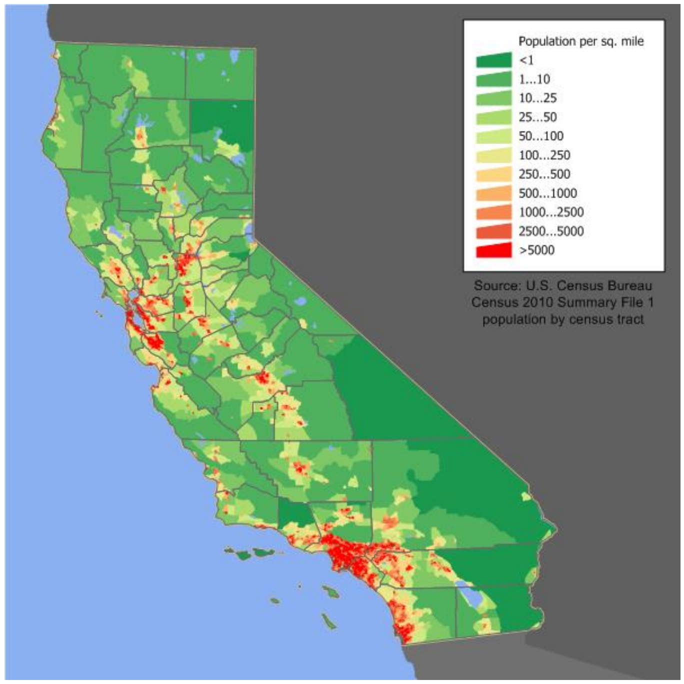
Question 5: Do you typically complete THPs in a region(s) where wildland urban interface (WUI) is a significant factor? [y/n]

WUI	n	Percent
No	24	34.8
Yes	45	65.2

65% of respondents stated WUI is a significant factor in their professional region. 35% of respondents stated WUI was **NOT** a significant factor in their professional region.

Question 6: How densely populated (people per square mile) is the region in which you complete THPs? Please give your best estimate based on the 2010 US Census Bureau map below.

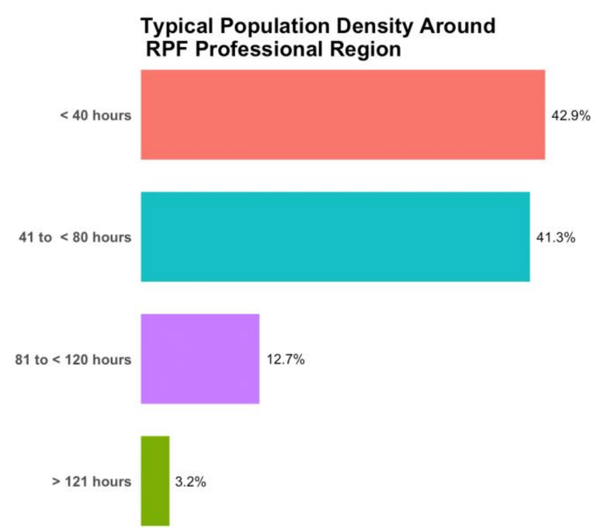
- 0 - 100
- 101 - 500
- 501 - 2,500
- 2,501 - 5,000



Most RPFs 68.7% state that population density in regions they work is between 0-100 people per square mile, 22.5% work in regions between 101-500, and the remaining 8.8% work in areas more densely populated.

Survey

Question 1: How much time do you typically spend completing a single Cumulative Impact (CI) Resource Section of a THP? Include all time taken in preparing the initial submission to CAL FIRE; do not include time responding to public comment or agency questions.



Not including time responding to public comments or agency concerns, 42.9% of RPFs take less than 40 hours to complete an THP, 41.3% take between 41 - 80 hours and the remaining 15.8% take 81 hours or more to complete a THP. A correlation test between RPF profession type and time to complete a THP revealed the null hypothesis holds in this case (*chi-squared = 56.858, p-value = 0.001*). In other words, the RPF profession type and time to complete THP are not correlated.

Question 2: How useful do you find each section of the existing Guidance Document for CI Assessment Checklist, Technical Rule Addendum No. 2 Appendix?

- Watershed
- Soil Productivity
- Biological
- Recreation
- Visual
- Traffic
- Greenhouse Gases
- Other

Statistics	Watershed	Soil	Biological	Recreation	Visual	Traffic	GHG	Other
Count	65	65	65	65	65	65	65	40
Mean	3.32	3.15	3.26	2.83	2.85	2.78	2.32	2.55
STD	1.17	1.24	1.18	1.28	1.19	1.21	1.15	0.90
Variance	1.38	1.54	1.39	1.64	1.41	1.45	1.32	0.82

RPFs on the whole RPFs find the agency provided guidance document for the CI assessment checklist (Technical Rule Addendum No 2 (TRAN2) Appendix) moderately useful. The mean was slightly above the norm for the Watershed (mean=3.32, std=1.17, variance=1.38), Biological (mean=3.26, std=1.18, variance=1.54), and Soils (mean=3.15, std=1.24, variance=1.65) sections, but not significantly enough to draw any concrete conclusions.

Question 3: Which of the following (if any) of the current sections of the THP do you see as overlapping with the Wildfire Risk and Hazard section? [FINISH]

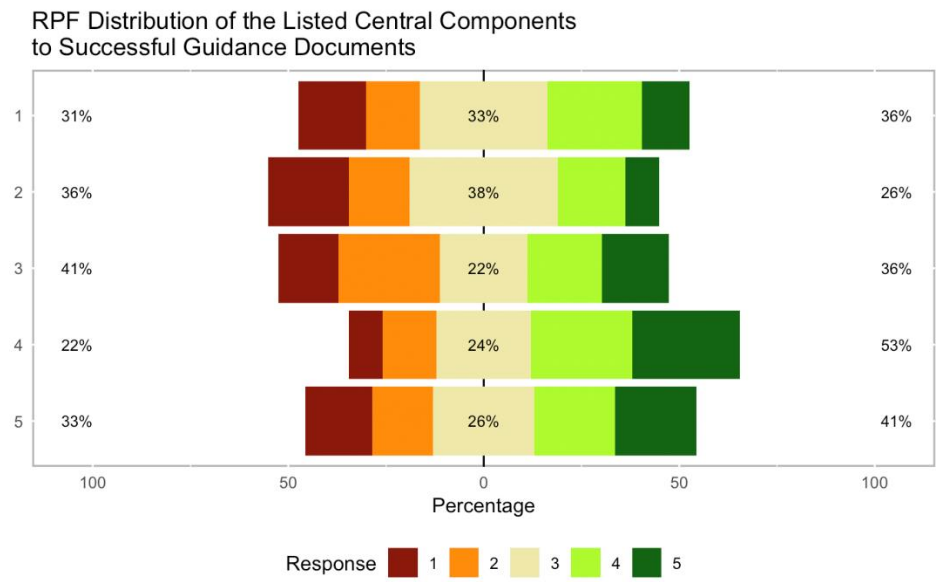
- Watershed
- Soil Productivity
- Biological
- Recreation
- Visual
- Traffic
- GHG
- Other
- None

RPFs think that Watershed, Biological, and GHG sections are over 50% more likely to overlap with the Wildfire Risk and Hazard section.

Question 4: Please prioritize the following components in terms of importance to a successful technical guidance document for cumulative impact assessment, from "most central" to "least central":

1. Thorough supplemental information on the CI resource sections
2. Regulation approved tool/model/application
3. Suggested quantification methods
4. Regionally specific application
5. Precise language for agency or comment responses

Statistics	Supplement	Application	Quantification	Regional	Precise
Count	59	58	59	60	61
Mean	3.03	2.78	2.98	3.52	3.15
STD	1.27	1.21	1.33	1.27	1.41
Variance	1.62	1.48	1.78	1.61	1.99



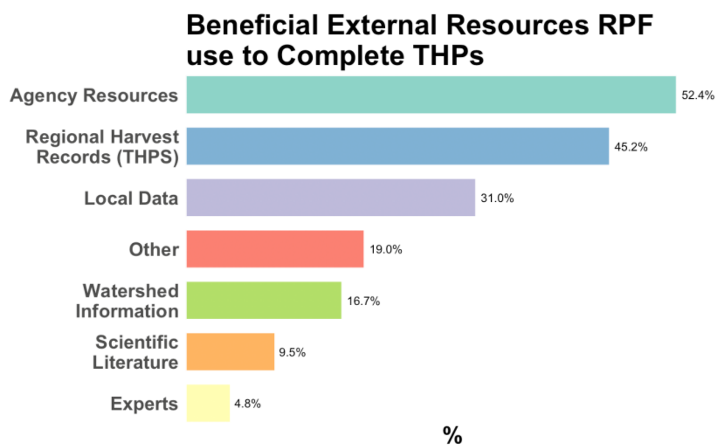
Question 4 Results: 1) Supplemental documentation, 2) agency supplied documents, 3) quantification models, 4) regionally specific applications, and 5) precise language from agency feedback and public comments.

From a list of central components to a successful guidance document, RPFs prioritized regionally specific applications and use of precise language in agency comments and public response more highly than supplemental documentation, agency provided applications, quantification methods (fig. *VI.B.2*). From a free response categorized question RPFs found Agency resources and regional harvest records most significantly [...] useful.

Question 5: What are the most beneficial external sources of information for completing the CI Resource sections? [Free response]

This was a free response question that was categorized:

- Agency Resources
- Regional Harvest Records (THP)
- Local Data
- Watershed Information
- Scientific Literature
- Experts
- Other



Agency Resources
CEQA document in the area
FRAP
BIOS
California Wildlife Habitat Relationships (CWHR)
The California Natural Diversity Database (CNDDB)
Resources Conservation Districts
CAL FIRE Library
USFS

BLM

California Historical Resources Information System

State and federal agencies

CAL FIRE Website

CA Biological Diversity Base

State Clearinghouse on Archaeology/Cultural Resources

CAL FIRE Technical Specialists

Management on National Forest Lands

CAL water Watershed

Online tools like CNDDB

CAL Rain Gauge

CAL maps

CAL FIRE Forestry Mapper

CAL Flora

FRAP GIS layers

ECOS (USFWS)

USFS SOPA

Regional water plans for 303d listing

Forest Practice Rules

Regional Harvest Records (THPS)

Past THP operations

Past THP in the same assessment area

Approved Timber Harvest Plans

Existing THPs

Previously approved THP's/NTMP's

Past and adjacent THPs

Other projects in the area

Past THPs

Previously approved THPs can provide good guidance for "what works"

Regional Harvest Records (THPS)

Local Data

Local and regional resource data/study

Actual existing site conditions as influenced by historical uses.

Personal knowledge of the area and local information sources.

Local public comments

Local knowledge

Local knowledge

Local knowledge base

Adjacent landowners

County GIS data

Local knowledge

Local knowledge

Scientific Literature/ Experts

Scientific papers

Recent research publications

Biological references

Research publications

Educators & Researchers

Resource professionals with experience on the property

Other

SCS Global Services

PWA booklets

UC Extension

Open Source GIS Layers

Private Database

Lawsuits

Company records

Information on endangered species

Suggested methods of quantification

Personal Records or Database

Fire Safe Councils

Comments

It is common for Agencies to have emergent concerns that occasionally focus on the CI resource section. Often these emergent concerns are programmatic in nature and will affect a series of THPs. Previously approved THPs can provide good guidance for "what works".

Local knowledge and collaboration with local and state survey efforts to provide information on current survey efforts and data acquisition.

I and the other RPF's I work with developed a boiler plate CI analysis 10-12 years ago that is pretty generic and passes agency review with little to no modifications plan to plan. In other words, we came up with our own list of external sources of info.

Question 6: Do you find the CAL FIRE definition for Wildfire Risk useful? [y/n]

WF Risk Definition	n	Percent
No	28	41.2
Yes	40	58.8

58.8% of RPFs found the CAL FIRE definition of wildfire risk useful.

Question 7: If you answered "No" above, what definition and source for that definition for Wildfire Risk would you use?

Alternate Definitions

Wildfire risk = hazard +weather conditions – of setting mitigation. the source is my opinion.

Wildfire risk is the threat to natural resources, structures and the public from natural or man caused fires of any origin.

Wildfire risk is defined as risk posed to Wildland Resources within the immediate and adjacent communities.

Wildfire risk is the product of the likelihood of a fire occurring (likelihood), the associated fire behavior when a fire occurs (intensity), and the effects of the fire (susceptibility) on highly valued resources and assets (Calkin et al. 2010, Finney 2005, Scott 2006, Scott et al. 2013).

Wildfire risk mitigation is achieved when any of the three aspects are reduced. Or the probability and consequence of a wildfire burning in and area (based on wildfire hazard, potential losses, and weather conditions.

Wildfire risk is defined as an anthropogenic activity that increases the probability of wildfire to poise harm or damage to all assets at risk. (See California Fire Plan for comprehensive list and *discussion)*

Wildfire risk is the product of the likelihood of a fire occurring (likelihood), the associated fire behavior when a fire occurs (intensity), and the effects of the fire (susceptibility) on highly valued resources and assets.

Suggestions

Much more inclusive, including wildland resources.

Needs to have active fuel management occurring within a significant portion of the watershed.

Fuel loading within one mile.

Natural resource

Wildland threat should also include risk posed to wildlife and watershed values.

Visual assessment, local regional/statewide knowledge.

Wildfire risk should not focus solely on the risk posed to "structures".

Site specific conditions.

I would modify the CAL FIRE definition to include other resources.

Forest Service language.

Replace structures with communities.

References

See California Fire Plan for comprehensive list and discussion.

Calkin et al. 2010, Finney 2005, Scott 2006, Scott et al. 2013

https://www.fs.fed.us/wwetac/tools/arcfuels/help/Content/02Toolbar/05-05%20-Risk.htm

Comments

Wildfire risk is the chance that a wildfire will start in or reach a particular area and the potential loss of human and natural resource values if it does. Risk is dependent on variable factors such as human activities, weather patterns, availability of wildfire fuels, and the availability or lack of resources to suppress a fire.

The problem with the current risk definition has nothing to do with the definition itself. It is a problem of limiting the scope of the assessment. The risk factors are affected much more by the totality of the landscape and factors not addressed by strictly focusing on the fuel factor. Things like the development around the property being assessed. Weather issues and microclimate issues. The future management to adjacent properties. A simple definition is not going to address they interrelated components of the risk analysis.

A risk cannot be defined by a single set of parameters when the risk they are assessing has many components.

Other

Wildfire risk is defined as risk posed to structures.

What is the cumulative impact (if any) that the project pose to increasing fuel loading to person, property or the environment?

I use my professional experience and judgment.

Most of CA should probably be high risk.

Feels like a deep question. the CAL FIRE definition seems very broad. Is "Fire Threat" defined? If not, then it seems like just about any structure located near timberland would be "in an area with significant wildland fire threat."

Question 8: Do you find the CAL FIRE definition for Wildfire Hazard useful? [y/n]

WF Hazard Definition	N	Percent
No	17	25.0
Yes	51	75.0

75% of RPFs found the CAL FIRE definition of wildfire hazard appropriate.

Question 9: If you answered "No" above, what definition and source for that definition for Wildfire Hazard would you use?

Alternate Definitions

Wildfire Hazard is a measure of an area burning based on existing conditions.

Wildfire risk is defined as the risk posed to vegetation communities and developed human inhabited communities alike; and their interaction under flammable conditions for both survivability and resilience to withstand destruction.

Suggestions

Should be more inclusive (eg. should it burn?)

Fuel loading on entire THP

References

None

Comments

Wildfire hazard refers to the fuels in a given location and represents the intensity with which an area is likely to burn if a fire does occur there. The difficulty of controlling potential wildfire. It is commonly determined by fire behavior characteristics such as rate-of-spread, intensity, torching, crowning, spotting, and fire persistence, and by resistance- to-control.

Comment: There is no way for the RPF to know the likelihood of an area burning or how it will burn. In the Sierra region the measure of likelihood will always be "high".

Remove "a measure of" from the definition as it indicates there is a quantifiable value to wildfire hazard which cannot be fully determine due the multitude of factors that both cause a fire and effect fire behavior.

Definition needs to be an established parameter, none exist. We know the relative frequency rates, but…

There is no good science, especially none relating THPs to fire incidence,

The way fires burn has too much to do with weather conditions. How do you assess the "measure of likelihood?" I just find this too open and don't know an alternate definition.

Other

I use my professional experience and judgment.

I don't need their assessment.

Same answer as above (Referring to previous definition for Risk), a simple definition of the hazard is not going to help mitigate the issues.

Maps seem arbitrary.

Question 10: How important do you think the consideration of Wildfire Risk and Hazard is for CI Assessment in a THP?

1. Not important
2. Less important
3. Moderately important
4. More important
5. Very important

55% of RPFs found wildfire at least important if not very important to the THPs.

Question 11: Are the implementation of fire breaks or roads as a preventative measure part of your current forestry management practice?

Fire Breaks	n	Percent
No	17	24.6
Yes	52	75.4

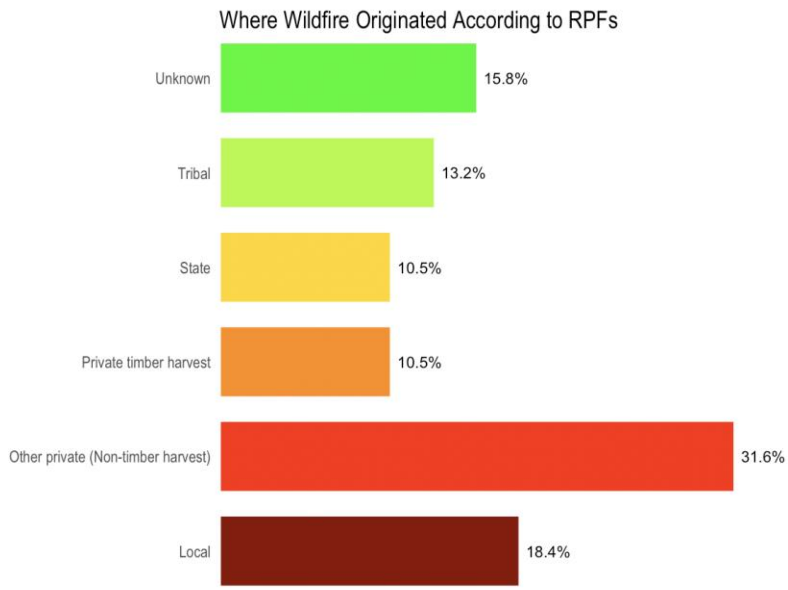
75% of RPF respondents create fire breaks or roads as fire preventative measures in a professional capacity.

Question 12: Has there been wildfire in a county in which you have completed a THP for in the last 10 yrs?

Wildfire in County	N	Percent
No	3	4.5
Yes	63	95.5

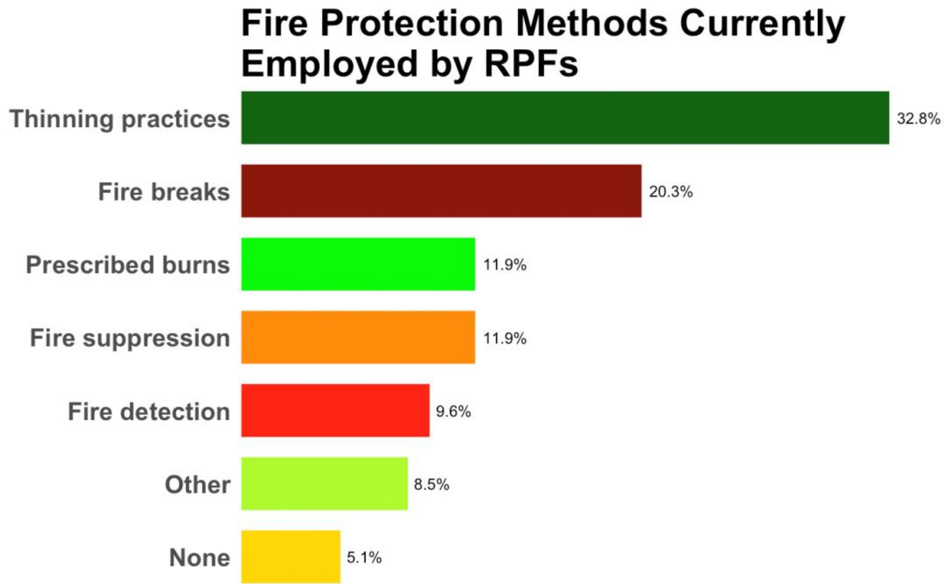
95% of RPF respondents have experienced wildfire in their regions of professional practice in the last 10 years.

Question 13: If so, on what type of lands did the wildfire originate?



Question 14: Do you currently apply any of the following fire protection methods on managed timber plots that could be relevant to the Wildfire Risk and Hazard section?

- Fire detection
- Fire Suppression
- Fire breaks
- Fire Prescribed burns
- Thinning practices
- Mastication
- Slash Removal
- Understory fuel reduction
- Other
- None



Most RPFs perform some fire hazard mitigation in their profession. Those mitigations efforts are mostly pre-commercial harvest thinning practices and fire breaks. RPFs admittedly perform additional fire hazard mitigation efforts such as prescribed burns, fire suppression, fire detection, understory reduction and so forth.

Question 15: Is there any information that you collect on timber harvest plots (outside of THP required items) that is applicable to the Wildfire Risk and Hazard section?

56.1% of RPFs state they do not collect additional information than what is required by the THP while 43.9% do.

Question 16: Please explain either answer to the previous question?

Of those RPFs that do collect additional data, they freely responded that they did in fact collect additional data. The feedback from RPFs that do collect additional data was categorized: 1) stand structure, 2) fuels assessment, 3) understory structure, 4) future regeneration growth, 5) adjacent land use, 6) weather trends, 7) regional history, and 8) fire suppression.

Understory Structure

Relative stand densities and overstory/understory stand structures and composition.

Understory structure and composition

Total vegetation components

Field observations on surface vegetation and ladder fuels.

Tree density

Understory density

Stand Structure

Stand structure

Relative stand densities and overstory/understory stand structures and composition

Pre and post-harvest inventory and stocking surveys to determine stand density.

Stand structure and composition

Total vegetation components

Information on stand density

Inventory

Tree density

Tree density (i.e. BA is critical)

Height

Future Regeneration Growth

Future growth

Pre and post-harvest inventory and stocking surveys to determine stand density.

The vegetation changes over time

Inventory plots run in FVS fire model. Output used in developing treatment guidelines.

Fuels Assessment/ Fire Protection

Suppression access

Pre-commercial thinning, pruning and slash burning

Surface fuels and standing dead trees.

Dead tree and fuel loading per acre measurements.

Total vegetation components

Information on fuel loads

Field observations on surface vegetation and ladder fuels.

Possibly dead and down [trees], but we don't use that data in that capacity

Sudden Oak Death and required slash treatment within Fire Protection zones.

Treatment of slash

Site specific re tree mortality/fuels.

Woody debris

Un-natural fuel loads

Quantifiable surface fuel loading (FIA)

Adjacent Land Use

Adjacent land uses

Developments adjacent to the THP area.

THP's are too extensive to try and focus on things outside the THP area. Of course during initial planning phase you would look to see how you can protect your tract of land from encroaching fires from other landowners but also so if a fire starts on your property that it doesn't escape onto others and become a major liability. So answer is yes only in initial phase after that focus only on the THP area.

Community egress issues

Weather Trends

Predict weather and wind trends

Geospatial analysis of possible weather events

Regional History

Previous fire history helps assess the hazard

Fire history and aerial imagery

I put in a blurb about local fire history

Other

Client requirements

GIS Map based and tabular information on specific resources

Immediate project area controls usually dictate my fire hazard focus.

We have prepared an In-house fire risk assessment for our ownership.

Biological information

Comments

Your question is not worded very well.

Not having any other opportunity to expand on my experience and opinion I will use this space to do so. Over the course of my career I prepared over 200 harvest plans. I actually retired as a Fire Chief. Fire protection as it relates to timber harvest has always been minimizes in importance by regulators and environmental special interest groups. A comprehensive plan to protect our wildlands as well as communities must include a timber harvest component. The Forest Practice Regulations including the Cumulative Impact Assessment have been used to discourage forest management that would lead to healthier forests that naturally reduce the risk of catastrophic fires. Special interest group have seen the management tool called timber harvest as a threat to their priority values. Ultimately all these values are lost as we see the very growing threat of catastrophic fires.

You cannot control other agencies or private practices outside of a THP boundary, therefore to report or sample those properties is useless and not preventative.

Clients do on their own.

THP's are too extensive to try and focus on things outside the THP area. Of course during initial planning phase you would look to see how you can protect your tract of land from encroaching fires from other landowners but also so if a fire starts on your property that it doesn't escape onto others and become a major liability. So answer is yes only in initial phase after that focus only on the THP area.

Fuel data is extremely costly and isn't the issue with regard to timber harvest plans as the definition of a cumulative impact would suggest that the harvest combines with another known issue to add to a problem. Harvest plans reduce the fuel loading and by definition don't have the ability to cause an impact. Furthermore, how can a single landowner address something (fuel loading) which can be seen as all other properties are not visible from maps, aerial photographs or any other source. There is no way to assess what others are doing outside of your control and *speculating such would jeopardize my license. Finally, wildfire risk makes assumptions of weather, where and when a fire may start, and the time of year. These are all so variable, that there isn't any possible way to make an accurate assumption.*

Notes re habitat (NOT REQUIRED)

We always assess wildfire risk, but we don't actually collect data to support that.

I have completed a number of California Cooperative Forest Management Plans, not THP's.

Fire isn't a huge problem where I prepare THPs; the THP required items seem adequate.

Current data collection is as needed for long-term forest management and to provide backup information for THP preparation. Development of silvicultural prescriptions is informed by the data and the project location, which help determine where wildfire risk and hazard will be given more or less attention.

Do not collect fire data for ladder fuels, down debris, hazards such as brush fuels

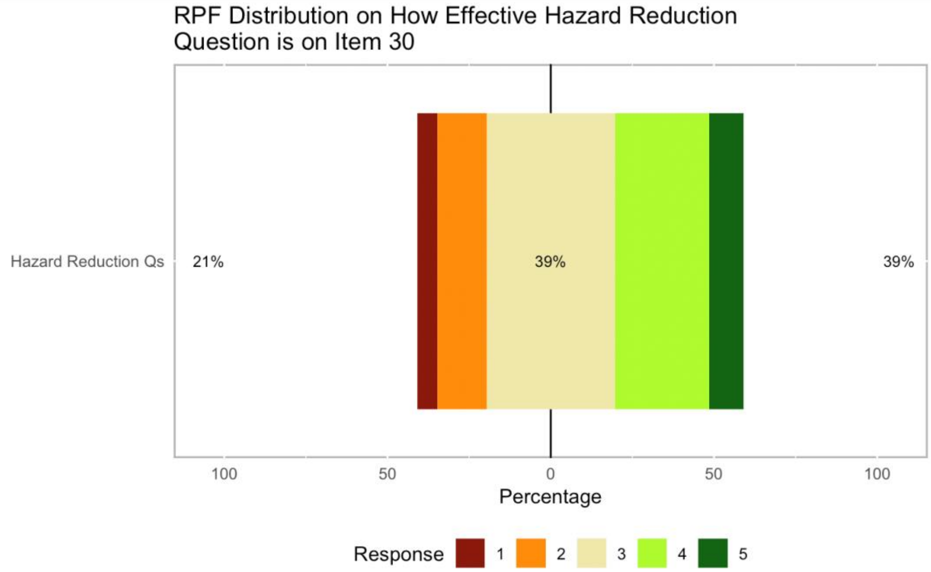
What is a "Timber harvest plot" ? If you mean timber harvest plans, then yeah, I put in a blurb about local fire history and the vegetation changes over time that has resulted in un-natural fuel loads that pose a threat to life and property.

Mark-cruise timber volume for harvest.

Current data collection is as needed for long-term forest management and to provide backup information for THP preparation. Development of silvicultural prescriptions is informed by the data and the project location, which help determine where wildfire risk and hazard will be given more or less attention.

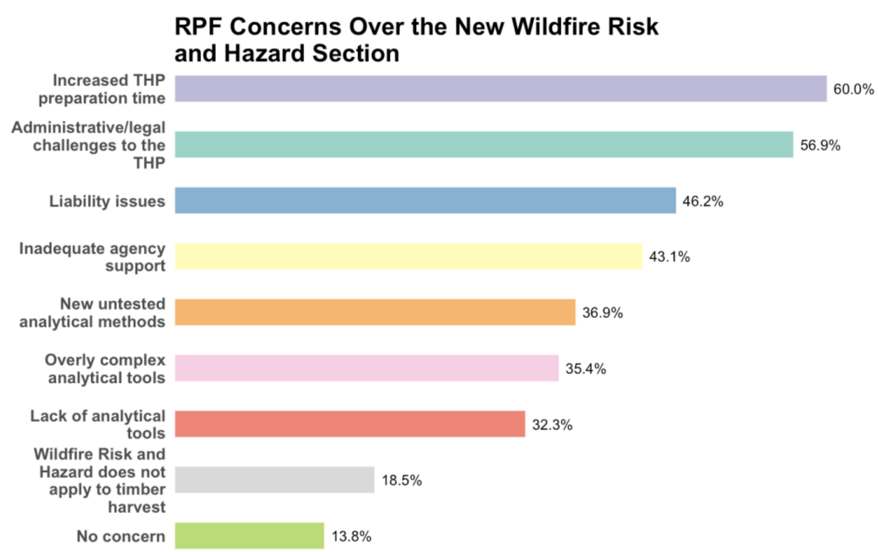
Question 17: How effective do you believe the Hazard Reduction questions presented in Item 30 of CAL FIRE's THP Forms are at assessing wildfire risks and hazards resulting from mechanically driven logging practices?

1. Not effective
2. More effective
3. Moderately effective
4. More effective
5. Very effective



Question 18: What concerns (if any) do you have about completing the Wildfire Risk and Hazard section? Select all that apply:

- Increased THP preparation time
- Inadequate agency support
- Lack of analytically tools
- New untested analytically methods
- Overly complex analytical tools
- Administrative/legal challenges to the THP
- Liability issues
- Wildfire Risk and Hazard does not apply to timber harvest
- No concern



Question 19: Which tools are most useful for assessing potential significant adverse effects from a timber harvest plan? Select all that apply:

- Models
- Field observations/sampling
- Compliance with recommended best practices
- Other

Other

Experience, communication.

Past practices

Professional Judgement and Experience

Research

Communication

Cumulative effects analysis

Meeting landowner objectives

Comments

The models all require actual data, so without on the ground data (which you aren't going to get as it is on other people private property) the models aren't going to work. Field observations without sampling don't work. And as already discussed, you aren't going to be able to sample other people's property.

Modification of BMPs for the site (eg. don't call spotted owls so much!)

Appendix B. Wildfire Hazard

Table B.1: Literature review informing the rule table for wildfire hazard. Resources are from peer-reviewed journals.

Citation	Time Component	Forest Type	Country	State	Land Ownership	Treatment Type	Disturbance Type	Gaps	Outcome Category	Notes
Scott, J., Helmbrecht, D., Thompson, M. P., Calkin, D. E. & Marcille, K. Probabilistic assessment of wildfire hazard and municipal watershed exposure. Natural Hazards 64, 707–728 (2012).	0	Douglas-fir, spruce-fir, whitebark pine, Engelmann spruce	US	Montana	National Forest	N/A	Probability of large fire	Single time period	Burn Characteristics	Hazard defined: physical situation with the potential for wildfire to cause damage
Romme, W. H., Barry, P. J., Hanna, D. D., Floyd, M. L. & White, S. A Wildfire Hazard Assessment and Map for La Plata County, Colorado, USA. Fire Ecology 2, 7–30 (2006).	0	Aspen, Pinyon-juniper, mixed conifer	US	Colorado	Public, private, American Indian reservations	N/A	Fire behavior	No time consideration / potential land uses that may alter vegetation over time (just measuring current fire hazard)	Burn Characteristics	Hazard: potential to cause harm, Risk: likelihood of harm
Stephens, S. L. & Moghaddas, J. J. Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a California mixed conifer forest. Forest Ecology and Management 215, 21–36 (2005).	1	Mixed conifer	US	CA	University of CA	Mechanical thinning (crown thin in 2001, followed by thinning from below, harvest of hardwoods, mastication) mechanical + fire (same as above plus backing fire), fire only (strip head-fires in 2002)	N/A	Only research forest land, 5 year study period (4 measurements)	Treatment Type	N/A
Pollet, J. & Omi, P. N. EFFECT OF THINNING AND PRESCRIBED BURNING ON WILDFIRE SEVERITY IN PONDEROSA PINE FORESTS. The Joint Fire Science Conference and Workshop	1	Ponderosa pine with recent fire	US	Montana, Washington, CA, Arizona	National Forest	Precommericial thinning, broadcast burn, whole tree thinning all followed by wildfire	Wildfire	Only one forest type, treatment within 10 years of study	Treatment Type	N/A

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Fernandes, P. M. & Botelho, H. S. A review of prescribed burning effectiveness in fire hazard reduction. International Journal of Wildland Fire 12, 117 (2003).	1	Many; conifer	Australi a, US, Portugal			Prescribed burning	N/A	A review of other studies	Treatment Type	Litter hazard typically reappears 2-5 years after burn
Fulé, P. Z., Waltz, A. E. M., Covington, W. W. & Heinlein, T. A. Measuring Forest Restoration Effectiveness in Reducing Hazardous Fuels. 6	1	Pondersa pine, Gambel oak, pinyon	US	Arizona	BLM	Restoration (retain old growth trees, plant 3 of same species per dead tree, thinning, duff layers raked, burned)	N/A	N/A	Treatment Type	fire severity less in treated plots
Huggett, R. J., Abt, K. L. & Shepperd, W. Efficacy of mechanical fuel treatments for reducing wildfire hazard. Forest Policy and Economics 10, 408–414 (2008).	0	Ponderos a pine, hardwoo d, Douglas-fir, pinyon-juniper	US	Colorado	All potential timberland s	Uneven-aged treatment (thin trees from all size classes depending on forest and ecoregion type), Even-aged treatment (thin from below, remove smaller trees first) -- minimize treatment to reach a set hazard reduction goal	N/A	Single treatment with no regrowth	Treatment Type	N/A
Stephens, S. L., Collins, B. M. & Roller, G. Fuel treatment longevity in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 285, 204–212 (2012).	1	Sugar pine, ponderos a pine, Douglas-fi, white fir, incense-cedar	US	CA	University of CA	Mechanical thinning (crown thin in 2001, followed by thinning from below, harvest of hardwoods, mastication) mechanical + fire (same as above plus backing fire), fire only (strip head-fires in 2002)	N/A	N/A	Treatment Type	Different paper, but same/similar data to "Experimental fuel treatment impacts on forest structure, potential fire behavior, and predicted tree mortality in a California mixed conifer forest" - longer time study
Thompson, J. R. & Spies, T. A. Vegetation and weather explain variation in crown damage within a large mixed-severity	1	Mixed-conifer, evergree n hardwoo d	US	southwe st OR, northwe st CA	National Forest, BLM	N/A	Wildfire	Didn't indicate treatment types, if any, on the burn area	Burn Characteristics	N/A

wildfire. Forest Ecology and Management 258, 1684–1694 (2009).										
Steel, Z. L., Koontz, M. J. & Safford, H. D. The changing landscape of wildfire: burn pattern trends and implications for California's yellow pine and mixed conifer forests. Landscape Ecol 33, 1159–1176 (2018).	1	Yellow pine, mixed-conifer	US	CA	National Park, Forest Service, private (?)	N/A	Wildfire	Only one vegetation type	Burn Characteristics	N/A
Zagas, T., Raptis, D., Zagas, D. & Karamanolis, D. Planning and assessing the effectiveness of traditional silvicultural treatments for mitigating wildfire hazard in pine woodlands of Greece. Natural Hazards 65, 545–561 (2013).	0	Conifer	Greece	N/A	Forest Service	Thinning: low thinning (remove smaller individuals), crown thinning, selective thinning (remove some dominant trees to encourage younger tree growth) Pruning ad establish broad-leaved species (enrich forest)	N/A	N/A	Treatment Type	N/A
Lindsay Aney Chiono. Long-term Effects of Fire Hazard Reduction Treatments in the Southern Cascades and Northern Sierra Nevada, California. (University of California, Berkeley, 2012).	1	Yellow pine, mixed-conifer	US	CA	National Forest, 11 plots on private lands	Mechanical thinning only, mechanical thinning + burning (broadcast prescribed burn and/or slash pile burning)	N/A	Forest type	Treatment Type	N/A
Ager, A., Vaillant, N. & Finney, M. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. Forest Ecology and Management	1	ponderosa pine, subalpine fire, Englemann spruce	US	OR	National Forest, Private land, residential area	Varying insentisty of: underburning, thinning from below, and mechanical treatment of surface fuels (i.e. removal)	Reduce wildfire risk	WUI and topographical relationships w/ fuel treatment strategies (need more case studies)	Treatment Type	1) Stand density index thinning from below improves vigor for large trees, reduces crown fire potential 2) Avg/Max fire size decreased with increased treatment area (i.e. treating 20% of landscape = ~30% avg WF size) 3) Overstocked mixed conifer stands have higher flame length

259, 1556–1570 (2010).										
Effect of Thinning and Prescribed Burning on Crown Fire Severity in Ponderosa Pine Forests. Available at: *https://www.fs.fed.us/projects/documents/Omi_pollet_2002_thinning_effects.htm.* *(Accessed: 20th Feb 2019)*	Varied	Ponderosa pine	US	MT, WA, CA, AZ	National Forest	Prescribed fire only; whole-tree thinning, and thinng followed by perscribed fire	Wildfire (<3 yrs ago)	Poor tracking of fuel treatments by land managers limits post-fire analysis	Treatment Type	1) Under drought and high wind conditions, fuel treatment impacts are limited 2) Treating high-volume areas with mechanized equipent may offset treatment on steep slopes 3) Fuel treatments may be more effective in short fire-return interval ecosystems than long fire-return interval ecosystems
Prichard, S. J., Peterson, D. L. & Jacobson, K. Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA. Canadian Journal of Forest Research 40, 1615–1626 (2010).	0	mixed conifer, low-to-mid elevation	US	Washington	National Forest	thin from below (understory), shelter wood harvest (understory and overstory), 8-15 years prior to fire, prescribed burns 0 to 6 years before wildfire	Tripod Fire	Land ownership	Treatment Type	57% tree survival in thinned + burned plots relative to just thinned or control (significantly higher) Crown scorch and burn severity also lower in thin + burn plots, tree diameter larger in thinned +burn plots compared to control Species mortality 3 years after fire = highest for lodgepole pine and Engelmann spruce
Martinson, E. J. & Omi, P. N. Fuel treatments and fire severity: A meta-analysis. (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2013). doi:10.2737/RMRS-RP-103	0	Long needle pine forest, mixed conifer forest, woodlands other than conifer, grasslands	Several, US	N/A	N/A	Thinned with slash and surface fuels reduced by burn or spread, surface fuels burned/removed, canopy thinning via whole tree extraciton, surface rearranged (herbicide, chipping...), canopy thinned and surface fuels rearranged, canopy thinned	N/A	N/A	Treatment Type	Overall mean effect of fuel treatments are large and significant --> reduce canopy scorch 60%, reduce sorch height/flame length Treatments most effective in grasslands and conifer forests
Winford, E., Stevens, J. & Safford, H. Effects of fuel treatments on California mixed-conifer forests. California Agriculture 69, 150–156 (2015).	0	Yellow pine and mixed-conifer forests	US	CA	N/A	Prescribed fire, mastication, hand-thinning, mechanical thinning	N/A	N/A	Treatment Type	N/A
Stevens, J. T., Safford, H. D. & Latimer, A.	0	Dry mixed conifer	US	CA	national forest	commericial thin +pre-commercial	N/A	N/A	Treatment Type	basal area and stand density decrease with treatments

M. Wildfire-contingent effects of fuel treatments can promote ecological resilience in seasonally dry conifer forests. Canadian Journal of Forest Research 44, 843–854 (2014).						thin, commercial thin (whole tree yarding), commercial thin + pre-commercial thin + hand pile + pile burn, pre-commercial + (thin + hand) + (pile + underburn), commercial thin (whole tree) + underburn, commercial thin + pre-commercial thin + underburn, pre-commercial thin, salvage harvest + pre-commercial thin + chipping + underburn, commercial thin + machine pile + pile burn, underburn only				treated areas that have been burned have no significant difference to unburned areas
Arkle, R. S., Pilliod, D. S. & Welty, J. L. Pattern and process of prescribed fires influence effectiveness at reducing wildfire severity in dry coniferous forests. Forest Ecology and Management 276, 174–184 (2012).	0	mixed conifer	US	Idaho	National Forest	prescribed burn	N/A	N/A	Treatment Type	N/A
Miller, J. D., Safford, H. D. & Welch, K. R. Using one year post-fire fire severity assessments to estimate longer-term effects of fire in conifer forests of northern and eastern California, USA. For. Ecol. Manag. 382, 168–183 (2016).	1	confir: yellow pine, dry mixed conifer, moist mixed conifer, fir	US	CA	US Forest Service	N/A	Wildfire	N/A	Burn Characteristics	1) Delayed tree mortality occurs at all levels of severity following a wildfire 2) Litter, duff, and coarse wood fuels incrase with time since fire - dependent on tree species, diameter, and degree of scorch and/or mortality
García-Llamas, P. et	0	pine forests	Spain	Sierra del	N/A	N/A	Wildfire	N/A	Burn Characteristics	1) Models suggest there are higher

al. Environmental drivers of fire severity in extreme fire events that affect Mediterranean pine forest ecosystems. For. Ecol. Manag. 433, 24–32 (2019).				Teleno						probabilities of highly severe fires in areas with dense live biomass 2) "Relationships between individual environmental predictors and fire severity were mostly nonlinear, suggesting possible thresholds to the general detected patterns" 3) There is no single driving factor for fire severity. Best combo found: NDWI, NDVI, time since last fire, spring cumulative rainfall, and VC of vegetation heights 4) In pine forests, live fuel is more flammable, leading to the link of density and live fuels to high fire severity
Tamm Review: Reforestation for resilience in dry western U.S. forests. For. Ecol. Manag. 432, 209–224 (2019).	0	Yellow pine and mixed-conifer forests	US	California	Federal land	N/A	N/A	There is an absence in studies testing variable or adaptive planting patterns	Regeneration	1) Regular spacing at high density does not aid fire resilience or a diversified structure for wildlife 2) In Sierra Nevada, reforestation should adapt with altered disturbance regimes and climate conditions 3) Lower stocking density and more spatially heterogeneous planting pattern may be more resilient to fire and adaptive to summer-dry climate 4) Fire severity is typically higher in young plantations than surrounding forest, esp. without fuel treatments 5) Water stress increases with density, associates w/ moisture stress 6) Periodic thinning is important to reduce the risk of stand-replacing fire 7) Planting in clusters with some individual trees between can allow for more fire resilient structure 8) Prescribed burns in young plantations can reduce surface fuels, maintain fire-resistance evolutionary selection, and reduce activity fuel after thinning/mastication
Hessburg, P. F. et al. Tamm Review: Management of mixed-severity fire	0	Mixed conifer, ponerosa, Jeffrey pine, etc	US	OR, WA, CA	N/A	N/A	N/A	N/A	Treatment Type	1) When treatments can be strategically placed, reducing fueld on a portion of landscape can substantially alter fire

regime forests in Oregon, Washington, and Northern California. For. Ecol. Manag. 366, 221–250 (2016).										behavior. i.e. 15-25% reductions resulted in simulated reduction in fire size, flame length, and spreat rate 2) Increasing area treated improved protection of the whole landscape, but with tendency for diminishing return 3) When proportion without treatment was about 45%, random and optimized treatment simulations resulted in no effectiveness differences
York, R. A., Battles, J. J., Wenk, R. C. & Saah, D. A gap-based approach for regenerating pine species and reducing surface fuels in multi-aged mixed conifer stands in the Sierra Nevada, California. For. Int. J. For. Res. 85, 203–213 (2012).	0	Mixed conifer	US	CA	Sierra Nevada - Blodgett Forest Research Station	Small gap fuel treatments (piling and burning in 0.04 ha gaps)	N/A	N/A	Burn Characteristics	Fuel treatment (pile and burn in gaps) on only 10% of stand area was effective in avoiding increase in stand-level surface fuel following harvests 2) Surface fuels provide substrate that carries fire and determines intensity and spread rate 3) Canopy attributes influence probability of crown fire 4) Forest structural attributes modulate wind speeds and fuel moisture, and fire behavior 5) Harvests had only minor impacts on fire behavior and fire effects 6) Fuel treatment methodology plays a large role in effectiveness - piling slash for fuel treatment accounted for >10% of slash

Table B.2. List of criteria that forest structure and wildfire behavior modelling programs were assessed against. These criteria are listed in order of priority in order to best suit the needs and capabilities of RPFs.

Model Assessment Criteria
Cost
Input data source availability
Quality of input data required
Ability to input management action
Spatial resolution
Accounts for disturbance
Accounts for climate change

Table B.3. Input data types needed for models reviewed. An “X” indicates that some data within that category is needed in order to utilize the tool.

Input Type	FlamMap	FVS	FVS: FFE	ArcFuels	BehavePlus SURFACE	BehavePlus CROWN	BehavePlus SAFETY	BehavePlus IGNITE	FFT
Topography	X	X	X	X	X				X
Canopy Characteristics	X	X	X	X				X	
Predicted Fire Behavior	X	X	X	X	X	X	X		X
Fuel moisture Characteristics			X		X	X		X	X
Climate			X			X		X	X
Site Environmental & Ecological Characteristics		X	X						
Site Management/ Land Use Characteristics (i.e. humans)		X	X				X		
Forestry Equipment							X		
Stand/ Vegetation Characteristics		X	X						

Table B.4: Outputs generated by models reviewed. An "X" indicates that a model generates an output within the output type category.

Output Type	FlamMap	FVS	FVS: FFE	ArcFuels	BehavePlus SURFACE	BehavePlus CROWN	BehavePlus SAFETY	BehavePlus IGNITE	FFT
Flame and Ember Characteristics	X		X	X	X	X	X	X	X
Spreading Characteristics	X		X	X	X				X
Fire Type	X		X	X		X			X
Fuel Moisture	X		X						
Burn Probability				X					
Changes to Fuel Load			X	X					X
Vegetation Changes		X	X	X					
Other Fire Byproducts			X	X					X

Table B.5. Specific variables included as inputs for all models considered.
These variables were grouped into summarizing categories to better provide for decision-making and elimination of models that are insufficient for this project.

Input Type	Specific Variables Included
Topography	Elevation, slope, aspect,
Canopy Characteristics	Canopy cover, canopy base height, canopy bulk density, fuel shading from the sun
Predicted Fire Behavior	Midflame wind speed (upslope) , transport wind speed, flame length, shrub consumption (%), canopy consumption (%), pile consumption (%), length of ignition, fire shape
Fuel moisture Characteristics	1-hour fuel moisture, 10-hour fuel moisture, 100-hour fuel moisture, 1000-hour fuel moisture, live woody moisture (%), herbaceous moisture (%), foliar moisture (%), shrub moisture (%), crown moisture (%), duff moisture (%), litter moisture (%),
Climate	20-foot wind speed (upslope), wind speed, air temperature, season, days since rain, relative humidity (%)
Site Environmental & Ecological Characteristics	Habitat type, location (nearest National Forest of Ranger District), Site index
Site Management/ Land Use Characteristics (i.e. humans)	Number of personnel, area per person, treatment schedule
Forestry Equipment	Number of heavy equipment, area per heavy equipment
Stand/Vegetation Characteristics	Stand density index maximum, basal area factor for large trees, fixed plot area for small trees, critical breakpoint diameter, number of inventory plots, number of non-stockable plots, plot identification (tree inventory), species (tree inventory) , diameter at breast height

Table B.6: Specific variables included as outputs for all models considered. These variables were grouped into summarizing categories to better provide for decision-making and elimination of models that are insufficient for this project.

Output Type	**Specific Variables Included**
Flame and Ember Characteristics	Flame length, fire line intensity, heat per unit area, critical surface intensity (Btu/ft/s), safety zone separation distance, safety zone size, probability of ignition from a firebrand, reaction intensity (Btu/ft^2/ min)
Spreading Characteristics	Rate of spread(chains/hour), horizontal movement rate, midflame windspeed, spread vectors, major fire paths, flow paths, maximum spread direction, elliptical dimension, arrival time, node influence, surface rate of spread, fire size
Fire Type	Crown fire activity, torching and crown fire indices, transition ratio, transition to crown fire expected, fire type, summary fire potential
Fuel Moisture	1-hour dead fuel moisture, 10-hour dead fuel moisture, 100-hour dead fuel moisture, fuel moisture in fuels greater than 3 inches,
Burn Probability	Burn probability
Changes to Fuel Load	Fuel loading over time, fuel consumption, surface fuel loading over time, biomass removed
Vegetation Changes	Potential stand/tree mortality, standing wood, total biomass, basal area killed in fire, total tree area (ft^3) killed, simulated tree growth for treatment period, simulated tree removal for treatment period,
Other Fire Byproducts	Smoke production, stored carbon, percent mineral exposure, pollutant emissions