Effectiveness and longevity of fuel treatments in coniferous forests across California

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Abstract

To date the majority of research surrounding the effectiveness of fuel treatments only considers the time immediately after treatment. Starting in 2000, permanent plots were established in areas planned for hazardous fuel reduction treatments across National Forests in California. Forest structure and fuels data has been collected at 26 sites across 14 National Forests in coniferous ecosystems for pre-, one year post-, and often two year post-treatment. Treatments include prescribed fire, mechanical methods, and a combination of the two. Analysis of the effectiveness of treatments to alter forest structure and fuel characteristics has been completed for pre- versus one year post-treatment. In general it was found that prescribed fire significantly reduced ground and surface fuel loads but did not significantly alter forest structure. Mechanical methods significantly altered forest structure and had varying effects on surface and ground fuels, often increasing larger diameter fuel loads. In general, modeled fire behavior was reduced for both treatment types; however, mechanical methods had mixed effects. Starting in 2009 there will be 27 sites capable of providing data to quantify changes in forest structure and fuel characteristics at 5 to 10 years post-treatment. We propose to re-measure these permanent plots and address the needs outlined in FA-RFA-09-0001A “Lifecycle fuels treatment.” This project will directly address the questions pertaining to: 1) the length of time fuel treatments are effective in reducing undesirable fire behavior and effects and how the effectiveness changes over time; 2) what re-treatment intervals are needed for various treatment types to maintain desired fire effects; and 3) the uncertainty associated with using standard fuel models in assessing treatment effectiveness, longevity, and maintenance. The longevity of treatment effectiveness and determination of appropriate re-treatment intervals will be assessed by quantifying changes in fuel conditions and potential fire behavior over time. The progression of fuel (ground, surface, and canopy) accumulation over time will be assessed to see how long different treatments in varying coniferous forests last from a fuel mass standpoint. In addition, fire behavior modeling will be applied to predict the effectiveness of fuel treatments according to metrics such as modeled fire type and flame length. In addressing potential fire behavior, we will answer the third question posed, “what are the key uncertainties associated with these analyses”. Modeling potential fire behavior requires assumptions on the application of quantitative fuel data to the models. We will contrast potential fire behavior changes found when using existing fuel models and custom fuel models with actual fuel conditions. The information on longevity of fuel treatments and uncertainty in fire behavior model inputs will be of direct benefit to managers preparing burn plans, other fuel hazard reduction plans, fire management, and other land management planning. Results will be shared with managers via several means including: 1) website (including an interactive database), 2) workshops; 3) manager’s summary; 4) presentation at one or more regional or national fire conference(s); and 5) two or more refereed publications.

I. Introduction

Expansive stand replacing crown fire is the most severe and negatively impacting fire type in many of the coniferous ecosystems within California. The most successful way to change potential fire behavior is to reduce surface fuels (typically with pile or broadcast burning), increase the canopy base height (through removal of ladder fuels and/or pruning of existing trees) and reduce canopy bulk density (removal of trees). This multi-tiered approach breaks the continuity of surface, ladder and crown fuels (i.e. Agee *et al.* 2000; Scott and Reinhardt 2001). Typically fuel treatments that alter more than one component of the fuel continuum or use more than one treatment type are more effective (i.e. Stephens and Moghaddas 2005; Schmidt *et al.* 2008). Benefits of fuel treatments at the stand-level have been well studied and proven effective at reducing wildland fire intensity and severity (Pollet and Omi 2002; Martison and Omi 2003; Finney *et al.* 2005).

To date the majority of research surrounding the effectiveness of fuel treatments in California only considers the time immediately after treatment (Stephens and Moghaddas 2005; Vaillant *et al.* 2009a;b). Little is known about how long these treatments last, or how often they will need to be re-treated to maintain desired levels of reduced fire behavior and effects (Graham *et al.* 2004). The duration of treatment effectiveness will vary between forest types and between sites within a given forest type due to differences in microclimate, soils and other factors which influence site productivity (Keyes and O'Hara 2002). Treatments are likely to last longer in less productive sites where forest and vegetation change will be slower (Weatherspoon and Skinner 1996). Few studies have quantified the duration of fuel treatment effectiveness, and those which exist consider only the effects of prescribed fire. Kiefer *et al.* (2006) found fuel accumulation to return to 66 to 83 % of pre-treatment values within 10 years of prescribed fire treatments in Yosemite National Park (YNP). In a ponderosa pine forest at YNP fuel loads reached 55% of pre-prescribed fire level after 6 years (van Wagtendonk and Sydoriak 1987). Finney *et al.* (2005) found time since treatment (<4 years) and treatment size were the largest contributors to changing fire behavior in a wildfire in a ponderosa pine forest in Arizona.

The most reliable test of fuel treatment effectiveness over time is to observe what happens when a wildfire encounters a treated area and determine if fire behavior is changed (Pollet and Omi 2002; Finney *et al.* 2005). In the absence of this information and in necessity for fuel treatment planning, it is necessary to "test" fuel treatment effectiveness using fire behavior modeling (i.e. Stephens and Moghaddas 2005; Vaillant *et al.* 2009a;b). Many studies which utilize fire behavior modeling couple data collected to characterize stand characteristics (specifically canopy base height, canopy bulk density, stand height and canopy cover) with standard fuels models (Anderson 1982; Scott and Burgan 2005). When resulting potential fire behavior predictions are used to quantify effectiveness of fuel treatments uncertainty remains in the accuracy of the results due to the subjective nature of fuel model selection because it is unknown to what extent fuel model selection influenced the results. In addition, there are few fuel models constructed specifically to represent post-treatment conditions. Agee and Lolly (2006) presented an alternative approach, where they avoided selection of fuel models and the associated uncertainty to compare pre- and post-treatment fire behavior by creating custom fuel models for each site using empirical fuel data. This approach reduces uncertainty, but may result in predicted fire behaviors that are less accurate to an unknown degree because fuel model selection is often based on how a given fuel model matches expected fire behavior. It is important for managers to understand the differences in these two different approaches for fire behavior modeling and to have some measure of uncertainty which they can disclose in planning documents.

1. Project Justification & Expected Benefits

A better understanding of longevity of effectiveness of fuel treatments is needed to aid managers in fuel treatment prescription development and planning. Limited long-term research is available for quantifying the effects of treatments on fuel load, configuration, and potential fire behavior. These data are particularly limited for more recently applied mechanical treatments. As part of the Region 5 fuel treatment monitoring project, fuel treatment plots exist in many of the National Forests in California. From 2000 through 2006 data on stand characteristics and fuel loads were collected pre-treatment and at one, two and sometimes five years post-treatment in sites treated with prescribed fire, mechanical methods or a combination of the two. Although substantial data was collected during the first and second years post-treatment, starting in 2009 there will be a large number of plots due for five to 10 year post-treatment measurements. This data would provide additional and much needed information on fuel treatment longevity for a variety of treatment methods and forest types. In addition, one site that previously had not been treated following the installation of the monitoring plots, has now been treated and is due for one and two year post-treatment measurements. We propose to re-measure these permanent plots and address the needs outlined in **FA-RFA-09-0001A "Lifecycle fuels treatment**." This project will directly address the questions pertaining to: 1) the length of time fuel treatments are effective in reducing undesirable fire behavior and effects and how the effectiveness changes over time; 2) what re-treatment intervals are needed for various treatment types to maintain desired fire effects; and 3) the uncertainty associated with using standardized fuel models in assessing treatment effectiveness, longevity, and maintenance.

The longevity of treatment effectiveness and re-treatment intervals will be assessed by quantifying changes in fuel conditions and potential fire behavior over time. Vaillant *et al.* (2009a;b) have analyzed pre- and one year post-treatment data for the sites mentioned above. The first study investigates how prescribed fire affected fuel loads, forest structure, potential fire behavior, and modeled tree mortality at 90^{th} and 97.5^{th} percentile fire weather conditions on eight National Forests in California (Vaillant *et al.* 2009a). Vaillant *et al.* (2009b) found prescription burning did not significantly change forest structure at most sites; however, total surface fuel loads were reduced by 23 to 78 % across the sites. The reduction in fuel loads altered potential fire behavior by reducing fireline intensity and increasing torching index and crowning index at most sites. Predicted tree mortality decreased post-treatment as an effect of reduced potential fire behavior and fuel loads. The second study, Vaillant *et al.* (2009b), assesses the effectiveness of 26 fuel treatments across 14 National Forests in California to reduce potential fire behavior. This study found mechanical treatments significantly altered forest structure and generally increased surface fuel loads as compared to pre-treatment. Whereas, prescribed fire significantly reduced ground and surface fuel loads and increased canopy base height, but did not appreciably alter other forest structure metrics. Fire behavior was modeled using 90^{th} percentile and gusting windspeed. In general, the changes in forest and fuel structures from mechanical methods had mixed effects and prescribed fire reduced predicted fire behavior metrics. Continuation of data collection in relation to this monitoring project will allow further insight to the expected longevity of fuel treatments in California. Additional field work and analysis will allow for insight on how long treatments are effective at maintaining desired fire behavior and effects, and at what intervals existing treatments will require maintenance. In addition to fire behavior modeling, we will analyze changes in fuel accumulations over time for comparisons between forest types and treatment types.

By assessing potential fire behavior, we will address the third question posed, "what are the key uncertainties associated with these analyses?" Modeling potential fire behavior requires assumptions on the application of quantitative fuel data to the models. Managers generally apply standard fuel models that are stylized representations based upon the fuel component thought to be the primary carrier of fire (i.e. litter, grass, or shrub) and resulting fire behavior thought to be within the range of what might actually occur. There is uncertainty associated with fuel model selection as well as potential fire behavior characterized with the standard fuel model inputs compared to actual measured values of inputs. We propose to address this uncertainty in fuel model selection for potential fire behavior predictions by comparing potential fire behavior based on stylized fuel model inputs and actual fuel data inputs. The information on longevity of fuel treatments and uncertainty in fire behavior model inputs will be of direct benefit to managers preparing burn plans, other fuel hazard reduction plans, fire management or land management planning. Results will be shared with managers via several means including: 1) website (including an interactive database), 2) workshops; 3) manager's summary; 4) presentation at one or more national or regional fire conference(s); and 5) two or more refereed publications.

A better understanding of the effectiveness and longevity of prescribed fire and mechanical fuel reduction treatment types in forests in California is an expected benefit of this proposal. By increasing the knowledge base to determine effective treatment longevity, as related to the treatment and forest type, managers can continue to improve planning and implementation of future projects. Managers need feedback and some parameters for meeting successful fuel treatment criteria. One of the factors that will be included in the parameters provided to management is time since treatment for each forest and treatment type.

2. Project Objectives and Hypotheses

Objective 1: Determine the length of time which fuel treatments are effective at reducing undesired fire behavior and effects for fire and non-fire treatments in various forest types within California. This will be completed in two ways by: 1) measuring changes of fuel accumulation between pre- and post- plots; and 2) incorporating values based on measured fuel accumulation into custom fuel models for fire behavior modeling. In order to complete this objective we will consider four components:

1. *Forest stand structure:* How do fire and non-fire treatments alter forest stand structure over time? Metrics to be tested will include: tree density, canopy base height, canopy bulk density, canopy cover, and diameter at breast height.
2. *Understory live fuel loads:* How do fire and non-fire treatments alter live fuel loads and plant species composition over time? This will include: tree seedlings, shrubs, herbaceous plants and grasses.
3. *Ground and surface fuel loads:* How do fire and non-fire treatments alter surface and ground fuel loads over time? Fuel loads include: litter, duff, 1-hr, 10-hr, 100-hr, 1000-hr fuel load, and fuel bed depth.
4. *Potential fire behavior:* How do changes in stand structure and fuel loads alter potential fire behavior and effects over time?

Hypotheses:

a) The longevity of desired fuel conditions will vary according to treatment type.
b) The longevity of desired fuel conditions will vary according to forest type.

Objective 2: Quantify the uncertainty associated with the use of standard fuel models in predicting potential fire behavior for determining treatment effectiveness, longevity, and maintenance.

Hypotheses:

a) Predicted fire behavior using standard fuel models will differ from that predicted using actual measured fuel characteristics.
b) Differences in predicted fire behavior from pre- to post-treatment over time will be greater using actual fuel characteristics as inputs compared to the standard fuel models.

II. Methods

1. Study Site(s)

Each National Forest in California was asked to provide at least one candidate project which would be treated the following year. From 2000 through 2006, permanent monitoring plots were established in coniferous ecosystems throughout California (Figure 1). Although it would have been ideal to randomly select study sites, preference was given to those suggested by the forests to optimize likelihood of treatment.

Plots were assigned subjectively to three forest types based on dominant tree species, similarities in fuel characteristics, and expected fire behavior. The forest types include short-needle dominated conifer stands, long-needle dominated conifer stands, and red fir stands. The red fir group was not included in the short-needle conifer group because of differences in fuel characteristics. The long-needle group is dominated by ponderosa pine, Jeffrey pine or coulter pine. Other tree species present include white fir, black oak, incense cedar, Douglas-fir and sugar pine. The short-needle group is dominated by Douglas-fir, white fir or a combination of both. Other tree species present include ponderosa pine, sugar pine, incense cedar and black oak. The red fir group is dominated by red fir but may also contain white fir.

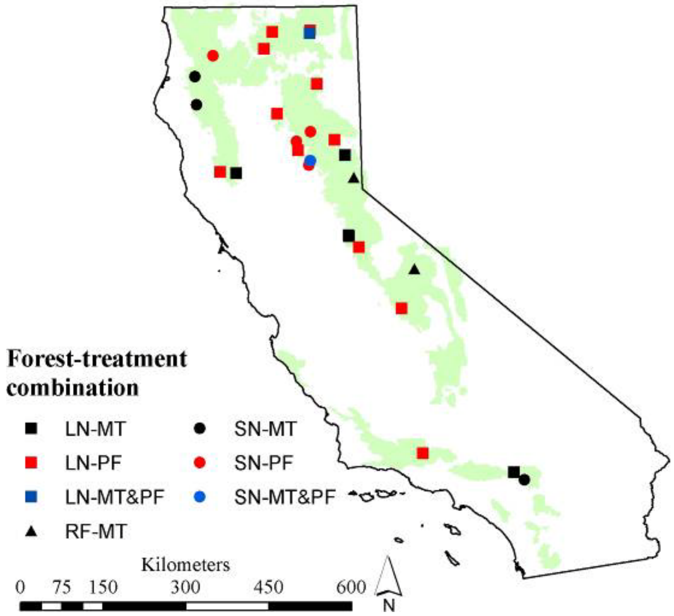

Figure 1: Locations for all study sites depicting forest and treatment combinations. Squares are dominated by long-needle (LN) conifers, circles short-needle (SN) conifers, and triangles red fir (RF); red is prescribed fire (PF), black is mechanical treatments (MT) and blue is a combination of the two (MT& PF).

2. Sampling Design

The sampling design was created for region-wide analysis and not for individual projects, so the data can be summarized by dominant vegetation types, treatment types, and time since treatment. In statistical analyses conducted with data to date, each plot has been treated as a replicate based on consultation with PSW statisticians (Mori 2007, pers. comm., see the "Data Analysis" section below for details). Three to six plots were randomly placed within individual fuel treatment study sites.

To date 82 plots at 26 fuel treatment sites on 14 National Forests in California have been installed and have at least one year post-treatment data recorded. Many of these plots have had 2 and 5 year post-treatment measurements already collected. We propose to revisit these plots in addition to six plots which have been already established and recently treated which were not included in the above mentioned data set. During the field seasons from 2009 through 2011 we are proposing to re-visit 96 plots which are in the 1, 2, 5, 8 and 10-year post-treatment time period (Table 1).

Table 1: Proposed number of plots by forest type, treatment type, and year since treatment to be re-visited during the 2009 through 2011 field seasons.

Forest type	**Treatment type**	**2009**		**2010**			**2011**	
		1 yr	**5 yrs**	**2 yrs**	**5 yrs**	**8 yrs**	**8 yrs**	**10 yrs**
Long-needle	Prescribed fire		4		1	18	5	2
	Mechanical		15				3	
	Mechanical + prescribed fire	6		6				2
Short-needle	Prescribed fire					1	10	1
	Mechanical		10		1			
Red fir	Mechanical		5				6	
	Total	**40**		**27**			**29**	

3. Field Measurements

Two different monitoring protocols were used depending on the establishment year of the study site. Both variations of the protocol were modified versions of the National Park Service's fire monitoring protocol (USDI NPS 2003). Starting in 2003, the number of plots per site increased, and quantity of data per plot decreased to better capture the inherent variation in understory plant composition and surface fuels. The number of plots increased from three per site to six; with three each of "detailed" and "rapid" plots. The detailed plots included collection of tree data, whereas the rapid plots did not. In addition, the number of shrub transects, fuel transects, and canopy cover readings were reduced in 2003. Details of differences in data collection will be described as relevant below. All post-treatment plots are re-read according to the initial protocol.

Tree data was collected on all plots established before 2003, and for detailed plots only starting in 2003. Overstory, pole-sized, and seedling tree information is gathered within fixed area nested plots sized 0.1 ha, 0.025 ha, and 0.005 ha, respectively. Overstory trees include those greater than 15 cm diameter at breast height (DBH), pole-sized trees are ≥2.5 cm and ≤15 cm DBH, and seedlings are <2.5 cm DBH. For all live overstory and pole-sized trees the following data are collected: species, DBH, height to live crown base, total height, and canopy position. For snags, species, DBH, and total height are measured. Post-prescribed fire sites included additional measures of bole char, needle scorch, and torch heights for all pole-sized and overstory trees. Seedling trees are tallied by species in height classes. Additionally, a moosehorn (canopy sight tube) is used to measure overstory canopy cover (50 points) along each 50 m transect. Shrub data are collected along the same transect and include: species, vigor (live or dead), range along the transect, and average height. Herbaceous plants and grasses are quantified in five one-by-one meter quadrats located every 10 m along each transect. Within each quadrat, species, cover class (ocular estimate in 10 classes), and vigor for each rooted herbaceous plant and grass is recorded. The number of canopy cover, shrub, and herbaceous plant and grass transects was reduced from two to one starting in 2003.

Surface and ground fuels are assessed using a modified version of the planar-intercept method (VanWagner 1968; Brown 1974). Plots established before 2003 have four 15.24 m fuel transects per plot. Starting in 2003 only two transects were established per plot. One-hour and 10-hr time lag fuels are tallied along the first 1.83 m of each transect. One-hundred-hour time lag fuels are tallied for the first 3.66 m of each transect. Finally, species, diameter and condition (rotten or sound) for all 1000-hr time lag fuels are recorded along the entire transect. Litter and duff depths are measured at 10 locations along each transect. Maximum fuel bed depth is measured for 10 equidistant intervals along each transect.

4. Data Analysis

Fuel and stand characteristics: To remain consistent with the analysis completed on pre- and one year post-treatment data tree density, 75th percentile quadratic mean diameter, canopy base height, canopy bulk density, and canopy fuel loading will be calculated using Canopy Fuels Inventory Processor (CFIP, Wilson 2008). CFIP is a vegetation simulation program largely based on the algorithms used in the Forest Vegetation Simulator (Crookston and Stage 1991) and the Fire and Fuels Extension (Reinhardt and Crookston 2003). Live understory vegetation loads will be calculated following the methods created by Burgan and Rothermel (1984). Surface and ground fuel loads will be calculated using coefficients specific to California tree species (van Wagtendonk *et al.* 1996).

Potential fire behavior modeling: Potential fire behavior modeling will be completed with NEXUS (Scott 1999) for each individual plot. Modeling will be completed with both standard and custom fuel models, under the 90th and 97th percentile fire weather conditions for pre-treatment and 1 yr, 2 yr, 5 yr, 8 yr and 10 yr post-treatment conditions where data exists. Due to the high number of assumptions associated with fire modeled outputs, results will not be statistically tested, rather outputs will be summarized (Stephens and Moghaddas 2005; Vaillant *et al.* 2009a;b).

Assessment of longevity/effectiveness: We will evaluate effectiveness of treatments over time based upon changes in fuel loading and potential fire behavior. The resulting potential fire behavior will be evaluated against commonly used management objectives, such as surface fire (compared to crown fire), or ability to suppress with direct attack (i.e. flame lengths less than 4 feet). An experienced Fire Behavior Analyst (FBAN) will assist in these interpretations.

Statistical analysis: Data will be analyzed with a General Linear Mixed Model (McCulloch and Searle 2001) such as Proc GLM or GLIMMIX in SAS (SAS Institute, Inc. 2005). This analysis approach has been developed with consultation by a PSW statistician (Mori 2007, pers. com.) and was applied to the pre- and post-one year treatment data (Vaillant *et al.* 2009b). Response variables will include stand and fuel characteristics (litter, duff, 1-hr, 10-hr, 100-hr, 1000-hr fuel load, fuel bed depth, live fuel loads, tree density, canopy base height, canopy bulk density, canopy cover, and diameter at breast height). Since this is not a blocked experiment, statistical models will be used to test changes through time. Fixed effects will include time since treatment, treatment type, and forest type. The coefficients are functions whose shape (i.e. polynomial, exponential, logarithmic) could be determined from the data, possibly using the General Additive Model fitting technique (a semi-parametric statistical technique that uses smoothing functions such as Splines). During analysis, we may find more than one candidate model for selection; to select the best model we will use the Akaike Criterion (AIC). The AIC is a measure of the goodness of fit of a statistical model which allows for tradeoffs between model complexity and fit (Akaike 1974).

Fixed effects: Year = Time since treatment (i.e. 0, 1, 2, 5, 8, 10 years)
$Treat_i$ = Treatment (i.e. prescribed fire, mechanical treatment)
For_i = Forest type (long-needle, short-needle, red fir)

Random effects: Block = Project (each fuels treatment project)
Plot = Plot(Project) (each plot within projects)

Possible Model: $Response_i = Treat_i + F(Year*Treat_i) + G(For_i) + . . . +$ Block error + Plot error + Residual error

IV. Deliverables and Science Delivery

The information gathered in this proposed research will be delivered to managers and researchers in many ways. First, we will add a link to the project on the (AMSET) webpage. We will update the webpage annually and create a link to an interactive database to share the plot level data with whoever is interested near the end of the proposed research. The interactive database will include information on fuel loads (ground, surface, understory and overstory), canopy structure, fuel model (stylized and custom) and modeled fire behavior for each plot at each time step where data exists. We will also present our findings and conduct a workshop sessions at the annual Region 5 Vegetation Management Workshop to guide managers through the process used to gather monitoring data, calculate fuel loads, create custom fuel models and model potential fire behavior using a sub-sample of the collected data. We will create a manager's summary and mail it to all the participating National Forests and Districts within the study area; we will also post it to the link on the AMSET webpage. We will present our findings at one or more regional or national fire conference(s) near the end of the project. And finally, we will prepare and submit two or more manuscripts for a refereed publication. The manuscripts will include at least one which addresses the effectiveness of the treatments to alter fire behavior over time, and a second which will discuss the changes in fuels over time by vegetation type and treatment method. As we delve further into the data more manuscripts might be possible.

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