Performance of Fuel Treatments Subjected to Wildfires

Erik J. Martinson[1] and Philip N. Omi[1]

Abstract—*Fire severity was evaluated in eight recent wildfires with standardized methods in adjacent treated and untreated stands. Sampled sites occurred in a variety of conifer forests throughout the Western United States. Treatments included reduction of surface fuels and crown fuels, both in isolation and in combination. Synthesis of our results indicates that treatment effectiveness is related to differences in tree size (mean diameter) between treated and untreated stands (p<0.001), as well as estimated historic fire frequency (p<0.1). Our results suggest that fuel treatments will be most effective when they complement ecosystem restoration objectives, such as the removal of small trees from ecosystems that historically experienced frequent fire.*

Introduction

Treatments to mitigate fuel accumulation and fire hazard have long been advocated (Weaver 1943). Federal land management agencies have greatly expanded fuel treatment programs in response to increased public attention on wildfire hazards. The unprecedented scale of current fuel treatment activities has intensified debate regarding their means, objectives, and outcomes. Some interest groups maintain that fuel treatments via mechanical thinning are a disguise to expedite timber harvest. Others wonder if potential negative impacts of fuel treatments (e.g., smoke production, exotic invasions, soil damage) outweigh any benefits. Some question whether fuel treatments even decrease fire potential.

Theory does suggest that fire intensity may be exacerbated by fuel treatments (Agee 1996). Canopy reduction exposes surface fuels to increased solar radiation, which would be expected to lower fuel moisture content and promote production of fine herbaceous fuels. Surface fuels may also be exposed to higher wind speeds, accelerating both desiccation and heat transfer. Treatments that include prescribed burning may increase nutrient availability and further stimulate production of fine fuels. All these factors facilitate combustion, increase rates of heat release, and increase surface fire intensity.

However, theory also indicates that treatments can reduce the likelihood of extreme fire behavior involving forest canopies. Crown fire initiation and spread depends on vertical and horizontal fuel continuities (Van Wagner 1977) that are typically reduced by treatment. Thus, treatments that reduce canopy fuels may increase and decrease fire hazard simultaneously. Justifications for expansion of fuel treatment practices are therefore tenuous without empirical assessments of their performance in wildfires. However, the question of fuel treatment effectiveness has received surprisingly little scientific attention.

[1]Western Forest Fire Research Center, Department of Forest Sciences, Colorado State University, Fort Collins, CO.

Previous Research

An exhaustive literature search for evidence of fuel treatment effectiveness in the United States uncovered just 31 such publications since 1955. Some perspective on the void this represents is gained by considering the number of citations in the Fire Effects Information System (more than 25,000 op. cit. Fischer et al. 1996). Further perspective is gained when these publications are organized by the methods used to assess treatment effectiveness. Fuel treatments in more than half of these publications were not tested by actual wildfires and the treatments themselves are also hypothetical in nearly a third of them. Among the 14 studies of treatments subjected to actual wildfires, just five quantify how fuels were changed by the treatment: a necessity if effective guidance is to be provided for future fuels management. Nonetheless, these publications do indicate with near unanimity that fuel treatments mitigate wildfire behavior and effects (table 1).

However, even among the 10 studies that assess the severity (as opposed to size) of actual wildfires, comparisons are complicated by lack of consistency both in the criteria for evaluating fire severity and in definitions of fuel treatments and controls. Several studies evaluate damage to tree crowns, but some authors define severe damage as more than 50% scorch, while others use 100% scorch or complete consumption as their highest rating. Treatments involve commercial harvest in several of the studies with activity fuels subsequently burned. Some of these assess treatment effectiveness with comparisons to areas where no management activity occurred; others use harvested areas where slash was left untreated. One study (Weatherspoon and Skinner 1995) makes comparisons to both types of areas, allowing interpretation of treatment effects as either positive or negative. This was the only study found that provides any indication that fuel treatments may be ineffective. But the weight of evidence represented in these few studies is far from overwhelming, especially since sampling designs are inadequately described in the earlier publications. Thus, neither existing theory nor available empirical evidence provides much clarity on the question of fuel treatments and the conditions that influence their effectiveness when tested by wildfire.

Table 1—Characteristics and findings of published studies that document the performance of fuel treatments in actual wildfires.

Study	Treatment	Control	Response	Direction[a]
Moore et al. 1955	Prescribed burn	No activity	Crown damage	↓
Cumming 1964	Prescribed burn	No activity	Tree mortality	↓
Wagle and Eakle 1979	Prescribed burn	No activity	Live tree density	↑
Van Wagner 1968	Thin and prune	No activity	Tree survival	↑
Agee 1996	Thin and burn	No activity	Crown fire	↓
Oucalt and Wade 1999	Thin and burn	Thin	Tree mortality	↓
Vihanek and Ottmar 1993	Harvest and burn	Harvest	Soil damage	↓
Hall et al. 1999	Harvest and burn	Harvest	Crown fire	↓
Weatherspoon and Skinner 1995	Harvest and burn	No activity	Crown damage	↑
Omi and Kalabokidis 1991	Harvest and burn	No activity	Crown damage	↓

[a]Direction indicates the amount of the measured response in the treated areas relative to that measured in the untreated control areas. For example, less crown damage was evident in the treated area than in the control area of the Moore et al. (1955) study.

Objectives

A project was initiated in 1995 to begin filling the research void on fuel treatment effectiveness. Eight wildfires have been investigated to date with details previously described (for details see Pollet and Omi 2002; Omi and Martinson 2002). Here we use meta-analytical methods to synthesize the results from these eight study sites. We investigated the ability of several variables (type, age, and intensity of treatments and the historic frequency of fire in the treated ecosystems) to explain differences among study sites in observed treatment effects.

Methods

We identified potential study sites for this research by advertising our interest at professional conferences and over the internet, networking with federal land managers, and initiating contact after large wildfires in areas known to have an active fuels management program. Thirty-eight wildfire areas were considered for sampling, but most of these failed to meet our selection criteria.

Potential study sites were restricted to wildfires that included adjacent treated and untreated areas within the perimeter and where treatment histories were documented and spatially explicit. We chose a narrow definition of fuel treatment that included only non-commercial or pre-commercial activities involving mechanical thinning (i.e., "low thinning"), debris removal, and/or broadcast burning with moderation of wildfire potential as a stated objective. Areas were defined as "untreated" if they had received no management action within the last 20 years, while treatments were applied within the last 10 years. We avoided areas where significant barriers (e.g., cliffs, major roads or drainages) or suppression activities likely impeded fire spread, as well as areas where post-fire salvage activities had taken place or were imminent. We further restricted our sampling visits to forested ecosystems, since these are where treatments are most often applied (Morrison et al. 2001) and where our methods are most applicable. Ten sites met our selection criteria, but two of these were excluded due to their proximity to areas we had sampled previously. Characteristics of the eight sampled sites are provided in table 2.

Data were collected at all sites from variable radius plots (Avery and Burkhart 1994) in adjacent treated and untreated stands. Measurements included stand density and basal area, tree diameter and height to pre-fire live crown, height

Table 2—Characteristics of the eight study sites included in the synthesis.

Site	Treatment type	Treatment age (yr)	Vegetation	Historic MFI[a]
'94 Webb fire, MT	Prescribed burn	4	Ponderosa	14
'94 Tyee fire, WA	Thin and burn	10	Ponderosa	22
'94 Cottonwood fire, CA	Thin, slash removed	4	Ponderosa	28
'96 Hochderffer fire, AZ	Thin and burn	1	Ponderosa	16
'99 Fountainebleau fire, MS	Prescribed burns	1	Slash pine	9
'99 Megram fire, CA	Pile and burn	2	Mixed conifer	59
'00 Cerro Grande fire, NM	Thin	1	Ponderosa	17
	Thin and burn	4	Ponderosa	17
'00 Hi Meadow fire, CO	Prescribed burn	1, 3, 5	Mixed conifer	52
	Thin	9	Mixed conifer	52

[a] Historic mean fire interval (MFI) was estimated for each site from the nearest available fire history information.

of needle scorch and bole char, percent crown volume scorch, and standardized ratings for stand damage and depth of ground char (Omi and Martinson 2002).

We used the standard meta-analytical software Metawin (Rosenberg et al. 2000) to relate fuel treatment effect sizes (i.e., Hedge's standardized mean difference, see Rosenberg et al. 2000) on percent crown volume scorch to each of several site characteristics. These included the type of treatment (in terms of the fuel stratum treated: canopy, surface, or both), treatment age when tested by wildfire (grouped into categories of 1 year, 2 to 4 years, and 5 to 10 years), standardized mean differences in tree densities and diameters between treated and untreated areas, and the estimated historic fire frequency of each site.

Historic fire frequency was estimated for each study site from proximal fire history studies. We identified and selected applicable fire histories from those included in a quantitative synthesis of fire history information (for details see Martinson and Omi, in press). Historic fire frequency was standardized from each fire history by calculating the inverse of the average annual point-specific probability of fire in the period 1710-1779. We estimated the historic fire frequency for each site as a weighted (inversely proportional to variance) average of fire frequencies calculated from the nearest (in terms of latitude, longitude, and elevation) available fire histories.

We employed parametric mixed-effects models in all analyses. Comparison of the size of the random variance component (i.e., variation not explained by sampling error at each location, σ_{θ}^2) when an explanatory variable is included in the analysis to its size when the predictor is left out provides a measure of the explanatory power (r^2_{MA}) of a parametric mixed effects meta-analytical model (Cooper and Hedges 1994):

$$r^2_{MA} = \frac{\sigma_{\theta}^2(no\ predictor) - \sigma_{\theta}^2(predictor\ included)}{\sigma_{\theta}^2(no\ predictor)} \qquad [1]$$

For comparison, we also report the traditional coefficient of determination (r^2) produced by ordinary regression and analysis of variance, though interpretation of this value is ambiguous in a meta-analysis since it describes the relationship among mean differences, but ignores sampling error. Since pseudo-replication (Hurlbert 1984) was unavoidable at several of the study sites, we did not employ the meta-analytical convention of weighting individual studies by their variance; all sites were given equal weight.

Results and Discussion

Similar to findings from previous research, results from our investigations unanimously indicate that fuel treatments reduced wildfire severity in treated areas. Crown volume scorch averaged 38% in treated areas across the eight study sites, versus 84.5% in untreated areas. Nonetheless, treatment effects among the study sites were variable in their significance. Meta-analysis suggests that much of the variability in the size of treatment effects can be explained by site characteristics, particularly the differences in mean tree diameter between treated and untreated areas (table 3). Mean tree diameter in treated areas was 33.0 cm compared to 23.8 cm in untreated areas. Treatments that increase the average diameter of residual trees through removal of the smallest

Table 3—Variation in fuel treatment effect sizes explained by various study site characteristics.

Explanatory variable	P-value	$R^{2\,a}$	$R^2_{MA}{}^{b}$
Treatment type	0.45	0.18	0
Treatment age	0.50	0.13	0
Density difference	0.17	0.24	0.20
Diameter difference	<0.001	0.71	1.0
Historic fire frequency	0.08	0.34	0.41

[a] R^2 indicates the amount of variation in mean effect sizes explained by the explanatory variable, but ignores sampling error.
[b] R^2_{MA} indicates the amount of reduction in the random variance component (i.e., variation not explained by sampling error) after inclusion of the explanatory variable.

stems appear most effective. This result illustrates the importance of distinguishing fuel treatments from those silvicultural activities that "thin from above" through removal of the largest trees from a stand (Graham et al. 1999).

Vegetation in untreated areas was denser, on average, than in treated areas: 931 versus 319 trees/ha. But tree density differences between treated and untreated areas were insignificant as a predictor of fire severity differences among our study sites. This could be an artifact of the sampling method that we employed, since variable radius plots may provide inaccurate density estimates for small trees (Stage and Rennie 1994). However, they are more efficient than fixed area plots for sampling the larger trees that are more informative recorders of fire intensity. Nonetheless, the relative insignificance of tree density in our analysis suggests that treatment prescriptions based only on density (or basal area) without diameter specifications may be insufficient from a fuels management perspective. Further efforts to increase small diameter wood utilization are needed.

Though our study sites were limited to ecosystems where historic fires were probably fairly frequent (table 2), our synthesis suggests that historic fire regimes may be an important consideration in fuel treatment applications. Among our study sites, fuel treatments were most effective in those ecosystems where fires were historically most frequent. This result might be expected, since these are the ecosystems where fuel hazard has likely increased the most in the 20th Century (Martinson and Omi 2002). Fuel treatment efficacy in ecosystems where fires were historically less frequent than at our study sites is questionable and remains to be investigated.

The insignificance of treatment type and age as predictors of effectiveness is surprising but primarily indicates a need for additional studies. Particularly scarce is information for treatments more than 5 years old. Currently, variability is too great to distinguish the relative effectiveness of treating surface fuels (e.g., broadcast burning) or canopy fuels (e.g., mechanical thinning) versus combining treatments, but results from individual sites suggest that the safest bet is to treat fuel profiles in their entirety.

For example, little difference in crown fuel conditions was found between treated and untreated areas of the Hi Meadow fire, despite a significant treatment effect on fire severity (Omi and Martinson 2002). Though we were unable to assess pre-fire surface fuel conditions, presumably the treatments sufficiently modified surface fuels to reduce wildfire intensity and effects.

In contrast, thinning treatments in the Cerro Grande fire were equally effective in reducing wildfire severity regardless of whether or not the slash was disposed. We speculate that under the extremely windy conditions during this

fire, surface fuels may have had less influence on fire behavior than canopy fuels. Explicit inclusion of weather variables as predictors of fuel treatment effectiveness will be explored in future analyses.

Conclusions

The 20th Century has demonstrated the futility of attempts to eliminate fire from natural landscapes. Society must learn to live with fire and the détente will be realized most appropriately through the medium of fuel treatments. Fuel treatments provide options for landscape management that balance societal preferences with the unavoidable recurrence of wildland fires.

Where fire threatens societal values, fuel treatments can facilitate suppression by providing safe access and egress for firefighters, as well as possible counter-firing opportunities. In wildlands managed to include natural processes, fuel treatments may help restore fire to its historic regime, either by restoring fuel profiles that facilitate safe management ignitions or by buffering the border between values-at-risk and extensively managed areas where natural ignitions are allowed to play themselves out. Results from this synthesis suggest that historic fire regimes are an important consideration in fuel treatment placement and treatments may be most effective when they complement the objectives of ecological restoration.

Acknowledgments

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