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Effects of fuel treatments on fire severity in an area of wildland–urban interface, Angora Fire, Lake Tahoe Basin, California

Hugh D. Safford [a,b,*], David A. Schmidt [c], Chris H. Carlson [d]

[a] USDA-Forest Service, Pacific Southwest Region, Vallejo, CA 94592, USA
[b] Department of Environmental Science and Policy, University of California, Davis, CA 95616, USA
[c] The Nature Conservancy, 2135 Wickson Hall, University of California, Davis, CA 95616 USA
[d] Department of Forestry and Conservation, University of Montana, Missoula, MT 59812 USA

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A B S T R A C T

The Angora Fire burned 1243 ha of Jeffrey pine and mixed conifer forest in the Lake Tahoe Basin between June 24 and July 2, 2007. The Angora Fire burned at unusually high severity due to heavy fuels; strong winds; warm, dry weather; and unseasonably low fuel moistures. The fire destroyed 254 homes, and final loss and suppression cost estimates of $160,000,000 make the Angora Fire one of the ten costliest wildfires in US history. The Angora Fire burned into 194 ha of fuel treatments intended to modify fire behavior and protect private and public assets in the Angora Creek watershed. The fire thus provides a unique opportunity to quantitatively assess the effects of fuel treatments on wildfire severity in an area of wildland–urban interface. We measured fire effects on vegetation in treated and adjacent untreated areas within the Angora Fire perimeter, immediately after and one year after the fire. Our measures of fire severity included tree mortality; height of bole char, crown scorch, and crown torch; and percent crown scorch and torch. Unlike most studies of fuel treatment effectiveness, our study design included replication and implicitly controlled for variation in topography and weather. Our results show that fuel treatments generally performed as designed and substantially changed fire behavior and subsequent fire effects to forest vegetation. Exceptions include two treatment units where slope steepness led to lower levels of fuels removal due to local standards for erosion prevention. Hand-piled fuels in one of these two units had also not yet been burned. Excepting these units, bole char height and fire effects to the forest canopy (measured by crown scorching and torching) were significantly lower, and tree survival significantly higher, within sampled treatments than outside them. In most cases, crown fire behavior changed to surface fire within 50 m of encountering a fuel treatment. The Angora Fire underlines the important role that properly implemented fuel treatments can play in protecting assets, reducing fire severity and increasing forest resilience.

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1. Introduction

Although wildfire behavior is driven by fuels, weather, and topography, human influences on wildfire are largely restricted to intentional or unintentional effects on fuels. As a prime example of the law of unintended consequences, more than 70 years of fire suppression policies in the western United States have led to accumulations of forest fuels that are playing a major role in increasing wildfire size and severity in many semiarid forest types, especially where management practices such as timber harvest have increased surface fuels and homogenized forest structure (Skinner and Chang, 1996; Allen et al., 2002; Graham et al., 2004; Keeley et al., 2009; Miller et al., 2009b). Increased temperatures and changing patterns of precipitation due to climate change greatly exacerbate the problem. Recent data have shown that western fire seasons are beginning earlier and lasting longer than in the past (Brown et al., 2004; Westerling et al., 2006). Extreme fire weather is becoming more frequent, and forest fires are predicted to continue to grow larger, more severe, and more difficult to suppress (Flannigan et al., 2000; Fried et al., 2004; McKenzie et al., 2004; Miller et al., 2009b). Changing fire regimes will influence vegetation distributions in California, which in turn will further alter fire regimes (Lenihan et al., 2003; McKenzie et al., 2004).

These disquieting developments are further complicated by trends in human geography. The density of houses and other private structures in formerly "wildland" landscapes of the West is increasing rapidly (Field and Jensen, 2005). The extent of California's wildland–urban interface (WUI), that area where homes are located in or near undeveloped wildland vegetation (WUI definitions vary; see Stewart et al., 2007), grew almost 9%

* Corresponding author. Tel.: +1 707 562 8934; fax: +1 707 562 9050.
E-mail address: hughsafford@fs.fed.us (H.D. Safford).

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from 1990 to 2000 while the number of houses in new WUI grew by almost 700% over the same period (Hammer et al., 2007). Development in the WUI is leading both to increasing fire ignitions and to increasing losses of property and life. With 5.1 million houses in a roughly 29,000 km^2 WUI of highly fire-prone vegetation, California is the focus of much of the nation's WUI issues (Radeloff et al., 2005). Hammer et al. (2007) point out that 25 people were killed and 3533 structures were destroyed by wildfires in California in the thirty years from 1955 to 1985, while 32 people were killed and 7467 structures lost in fifteen years between 1985 and 2000. Since 2000, this pattern has continued, with 2003 and 2007 alone combining for more than 8500 destroyed structures and 30 deaths. Annual wildfire suppression costs have been averaging US$ 1 billion since 2001, with the value of threatened structures and the presence of private land playing major roles in the rising costs (Liang et al., 2008).

These alarming ecological and socioeconomic patterns have led land management agencies to embark on a large-scale effort to reduce fuel availability in many western forests by the emplacement of strategically located "fuel treatments" (USDA-USDI, 2000; WGA, 2001; USDA, 2004). In a fuel treatment, reduction of forest fuels is carried out in order to ameliorate fire behavior, with a primary focus on enabling more effective fire control, but with other secondary purposes identified depending on the project in question (Husari et al., 2006; Reinhardt et al., 2008). Theoretical considerations and modeling studies provide strong support for the efficacy of properly implemented fuel treatments in modifying wildfire behavior (e.g., Stephens, 1998; Finney, 2001; Graham et al., 2004; Stephens and Moghaddas, 2005; Schmidt et al., 2008). However, controlled empirical investigations of fuel treatment effectiveness in wildfire conditions remain rare. Martinson and Omi (2008) cited approximately two-dozen empirical tests of fuel treatment effectiveness, but aside from their own could find only four studies which combined statistical tests with adequate controls for topography and weather to be able to unambiguously discern a fuel treatment effect in a real wildfire. These studies (Pollet and Omi, 2002; Skinner et al., 2004; Raymond and Peterson, 2005; Cram et al., 2006; Martinson and Omi, 2008) plus another recent study (Strom and Fulé, 2007) all found significant reductions in fire severity in treatments which had explicitly included reduction of surface fuels (e.g., thinning followed by prescribed fire, or prescribed fire alone). In addition, two Canadian studies investigated effectiveness of fuel treatments in jack pine (*Pinus banksiana*) using experimental crown fires, but sample size in both cases was one. In one of the studies (Stocks et al., 2004) fuel treatment without surface fuel reduction had little effect on fire severity. In the other study (Schroeder, 2006), treatment of both canopy and surface fuels strongly reduced fire severity.

Although plans have been developed for networks of wildland fuel treatments across large areas of the West, most work completed to this point in California has occurred in or near the WUI (USDA, 2004, 2005). National Forest management in the Sierra Nevada is guided by the Sierra Nevada Forest Plan Amendment (SNFPA; USDA, 2004), which mandates that at least 50% of initial fuel treatment work in the Sierra Nevada should take place in the WUI until the WUI is sufficiently treated. There are several key differences between fuel treatment priorities and outcomes in the WUI versus in wildlands. WUI fuel treatments are intended primarily to protect private property and to create safe zones for direct attack tactics based on mechanized support, while wildland treatments are typically meant to slow fire spread so as to provide time for indirect efforts to succeed in creating conditions ahead of the fire that are more likely to result in its control; treatment goals may also include reducing fire severity for forest retention and other resource benefits (Husari et al., 2006; Reinhardt et al., 2008). Since WUI treatments are the last line of defense for asset protection, they are often subject to more intense levels of fuel removal. Because of this and their proximity to private property, WUI treatments are typically more expensive than wildland fuel treatments. Furthermore, fuel treatment in the WUI requires collaboration with the public and other agencies, and the ultimate success of WUI fuel treatments can depend heavily on fire preparations made by neighboring property owners (Cohen, 1999; Reinhardt et al., 2008).

Although much effort has been spent in constructing fuel treatments in the WUI, opportunities to empirically assess the effectiveness of WUI treatments have been few. Indeed, almost all statistical evidence for fuel treatment effectiveness at modifying fire behavior or severity has come from wildland settings, far from areas of human habitation. In this contribution we assess the performance of a set of WUI fuel treatments that encountered a highly severe, wind-driven wildfire in the Lake Tahoe Basin, California in June, 2007. Our focus was on treatments in the WUI-defense zone, that part of the WUI that is immediately adjacent to private property. A previous study of WUI treatment performance in the Angora Fire found that efforts at structure protection were strongly abetted by the fuel treatment network (Murphy et al., 2007). We used replicated transect and plot sampling in adjacent treated and untreated stands to assess performance of the same fuel treatment network with respect to its influence on forest fire severity and tree mortality. Although we sought principally to identify general patterns in fuel treatment performance, we were also interested in distinguishing the causes of variability in performance among treatments.

2. Study site

The study site is found within the Lake Tahoe Basin (LTB), in the northern Sierra Nevada of California and Nevada, USA (Fig. 1). The LTB is located 240 km ENE of San Francisco, and includes 83,000 ha of terrestrial habitats and urban areas and Lake Tahoe itself (49,600 ha). Elevations range from less than 1800 m along the Truckee River below Lake Tahoe to 3315 m at Freel Peak. Climate is Mediterranean-type, with warm, dry summers, and cold, wet winters. At the South Lake Tahoe, CA airport (1900 m, 3 km due east of the Angora Fire perimeter), the January mean minimum temperature is −10.4 °C, the July mean maximum is 23.5 °C; extreme recorded temperatures are −25.9 and 37.3 °C. Precipitation averages 784 mm per year, with 86% of precipitation falling as snow between November and April (Murphy and Knopp, 2000; WRCC, 2008). The Lake Tahoe Basin Management Unit (LTBMU) of the USDA-Forest Service (USFS) manages about 72% (59,800 ha) of the LTB. Other land managers include California and Nevada State Parks, the California Tahoe Conservancy, and county governments.

2.1. Forest fires in the Lake Tahoe Basin

Presettlement fire return intervals in the LTB probably averaged 5–20 years in Jeffrey pine-dominated forests (Stephens, 2001; Taylor and Beaty, 2005). As in much of the Sierra Nevada, active fire exclusion in the LTB has nearly completely eliminated fire as a natural ecological process. In addition, a large proportion of the Lake Tahoe Basin (including much of the Angora Fire area) was heavily logged in the late 19th and early 20th centuries. Together these factors have resulted in increases in tree density, canopy cover, and surface fuels (Murphy and Knopp, 2000; Taylor, 2004), and many areas within the LTB support very high fuel loadings (see below). Over the last two decades, there has been an annual average of 62 fire starts on National Forest System lands within the LTB, with 79% ascribed to humans and 21% to natural ignitions (Murphy et al., 2007). Fire suppression is extremely efficient in the LTB, with fire response times averaging 5–10 min (B. Brady,