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Surface fuel treatments in young, regenerating stands affect wildfire severity in a mixed conifer forest, eastside Cascade Range, Washington, USA

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ABSTRACT

Previous studies have debated the flammability of young regenerating stands, especially those in a matrix of mature forest, and no consensus has emerged as to whether young stands are inherently prone to high-severity wildfire. This topic has recently been addressed using spatial imagery, and weak inferences were made given the scale mismatch between the coarse resolution of spatial imagery and the fine resolution of mechanisms driving fire severity. We collected empirical stand and fire-severity data from 44 regenerating stands that are interspersed in mature, mid-elevation forests in the Okanogan-Wenatchee National Forest (OWNF) on the eastside of the Cascade Range in Washington, USA. These stands are mixed-species plantations that were established to promote regeneration of seral to late-seral tree species (Douglas-fir, subalpine fir, Engelmann spruce, western larch) in small patches within a larger lodgepole pine forest. In 2006, the 70,925 ha Tripod Fire burned through all the plantations and the surrounding lodgepole pine matrix. To understand what drives fire effects in plantations, especially those that exist in spatially heterogeneous forests, we compared fire severity in plantations with and without fuels-reducing site preparation (i.e., fuel treatments), using three metrics to quantify severity: mortality (%), exposed mineral soil (%), and char height (m). We built generalized linear models for each severity metric and tested for a difference in all severity metrics between treated and untreated units using Permutational Multivariate Analysis of Variance. Units without fuel treatments have more severe fire effects: mortality is 77% in untreated units and 37% in treated units ($p = 0.0005$). Other variables contribute to differences in fire severity, including species composition, canopy closure, and canopy base height. Canopy base height and canopy closure both exhibit a reverse relationship with mortality from what was expected: the higher the canopy closure and the lower the canopy base height, the lower the mortality. In other words, stands that have trees closer together with crowns near the ground are more likely to have lower mortality. Overall, the results suggest that young stands in some dry mixed conifer forests can be resilient to wildfire if surface fuel loading is low upon stand establishment.

1. Introduction

Interior dry forests in western North America are potentially vulnerable to changes in disturbance regimes due to past land management and a warming climate. Increases in fire frequency and area may occur (McKenzie et al., 2004) as a result of current fuel loadings and changes in spring temperature (Westerling et al., 2006). More regionally specific, forest assessments in the eastern Cascade Range indicate that wildfire hazard on national forests in the United States has increased (USDA FS, 2004). Other forest disturbances, including insect and pathogen outbreaks, are expected to increase in the eastern Cascade region as well, which would further increase fire hazard (Hessburg and Flanagan, 1992). Increased forest disturbance, combined with predicted changes in the distribution and abundance of species, have led to more consideration of how larger landscape (e.g., watersheds, national forests) processes interact with disturbance (Bachelet and Neilson, 2000; Dale et al., 2000). Collaborative assessments of the eastern Cascades suggest active forest management, including thinning and prescribed fire, as an effective way to modify the hazard caused by wildfire, insects, and disease (Everett et al., 1994; USDA FS, 1996). Furthermore, managing forest landscapes at large spatial scales is necessary to adapt to a warmer future climate and potentially new forest structures and conditions (Millar et al., 2007; Joyce et al., 2009). Landscapes with multiple species assemblages, age classes, and structures are expected to be more resilient to increased disturbance than large homogeneous areas (Blate et al., 2009; Joyce et al., 2009).

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Reducing the amount and continuity of surface fuels, both live and dead can decrease fire hazard and the probability of crown fire initiation (e.g., Agee and Skinner, 2005). Initiation of a crown fire is a function of surface fire intensity and canopy base height (Van Wagner, 1977), and fuel treatments decrease crown continuity and fuel loading (Rothermel, 1983; Peterson, 1985). Fuel treatments designed to mitigate fire spread and severity can include a combination of tree harvest and prescribed fire or other means of surface fuel removal. Specifically, effective fuel treatments can (1) reduce the surface spread of fire by removing fine fuels (Agee and Lehmkuhl, 2009), (2) reduce ladder fuels and inhibit vertical spread of fire by thinning from below or whole tree harvesting (Agee and Skinner, 2005; Raymond and Peterson, 2005; Stephens and Moghaddas, 2005), and (3) reduce canopy bulk density and raise canopy height (Peterson et al., 2005; Johnson et al., 2006). In young stands, site preparation conducted upon stand establishment can have long-lasting effects on fuel characteristics and fire severity. Lezberg et al. (2008) found that 21 year old pine plantations that had been scarified burned at lower severity than unscarified stands. In this study, site preparation was more important than harvest regime in determining fire severity. Site preparation broadcast burns are similar to fuel treatments, in that they remove fine surface fuels. These principles of fuel mitigation have been established mostly in forests with low-severity fire regimes, and their application in mixed-severity (Thompson et al., 2007) and high-severity fire regimes is less clear.

Compared to low-severity fire regimes, mixed-severity fire regimes by definition have a wider range of variability in fire severity and frequency, which can complicate management prescriptions (Agee, 1993). Variability in these landscapes is caused by spatial and temporal variations in species composition and forest age, which affect fuel loading, fire behavior, and response to disturbance (Hessburg et al., 2007). The 2002 Biscuit Fire (200,000 ha) in the Klamath-Siskiyou region of Oregon has been studied extensively as a key example of mixed-severity fire regimes. Raymond and Peterson (2005) examined fire effects in mature mixed-evergreen hardwood stands in the Biscuit Fire and found that (1) forest thinning followed by surface fuel removal with prescribed fire was effective in reducing fire severity, and (2) thinning without fuel reduction increased fire severity. One study suggested that the lack of vertical diversification in young stands makes them inherently vulnerable to fire, and that forest management may cause these young stands to burn at higher severity (Thompson et al., 2007). Variability in species composition, fuels, and fire effects in the Biscuit Fire has raised questions regarding mechanistic controls on patterns of fire behavior in mixed-severity fire regimes.

To understand fire patterns in complex landscapes, more empirical data are needed to address fire severity in young stands, especially because of their prevalence in forests of western North America. Spatial imagery has been used to investigate fire in young stands, but the resolution of the data has made it difficult to describe stand structure or surface fuels because of the difference in spatial scale between coarse-resolution imagery and fine-resolution surface fuels (Thompson et al., 2007). In young stands, surface fuels are a combination of downed woody fuels and live fuels (shrub or canopy), and existing live fuel layers can provide connectivity between surface fuels and the canopy. Without pre-fire fuel data, it is difficult to address the role of down woody fuels and shrubs on fire behavior, but the live fuel component can be addressed through *post hoc* reconstructions of live tree structure. Live fuel reconstructions are most easily done in ecosystems that do not have a significant shrub layer (e.g., high elevation forests). Absence of fuels information limits inferences from data collected following wildfires, but information on presence or absence of surface fuel treatments offers some insight regarding fuels.

Fig. 1. Green areas are patches of regenerating forest in a high- severity area of the Tripod Fire.

In this study, we quantified fire effects in mixed species plantations of the eastern Cascade Range of Washington, USA. These plantations burned in the Tripod Complex Fire (hereafter Tripod Fire) in 2006. Fire behavior was not uniform across the landscape, leaving green "islands" where vegetation was almost entirely unburned (Fig. 1). In high-severity areas, green patches often coincided with harvested areas including diverse fuel treatments and regeneration cuts (i.e., small clearcuts with young regenerating forests) that were conducted before the Tripod Fire; some of the plantations contained fuel treatments with prescribed fire that were also done before the wildfire. The contrast between the green islands and the surrounding burned areas exhibited a difference in fire effects that may have been influenced by management practices (Fig. 1).

We were interested in examining the mechanisms that controlled fire severity in the plantations. To test these observations we posed two questions to explain fire effects in young stands: (1) do fuel treatments reduce the severity of fire effects in regenerating stands? and (2) do species composition and stand structure influence fire severity? These questions were investigated in plantations across a large extent of the Tripod Fire, thus capturing variability in site characteristics, fire weather, and fire behavior during the fire.

2. Methods

2.1. Site description

The study was conducted in post-harvest mixed conifer stands in the Okanogan-Wenatchee National Forest (OWNF) on the eastern slope of the Cascade Range, Washington (Fig. 2). This region is characterized by cold winters and warm, dry summers with summer droughts. The nearest Remote Automated Weather Station, First Butte (48 °N, 120 °W, elevation 1674 m), has recorded a mean annual temperature of 15.1 °C, with a January minimum temperature of −11.6 °C and a July maximum temperature of 30.1 °C (Western Regional Climate Center, http://www.wrcc.dri.edu, data recorded between 1931 and 2005). Mean annual precipitation is 3600 mm, with 70% of precipitation falling between October and March, predominantly as snow.

In these watersheds, active land management has affected the spatial and temporal distribution of species assemblages and disturbance regimes on the landscape. Current management