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Vegetation and weather explain variation in crown damage within a large mixed-severity wildfire

Jonathan R. Thompson [a,*], Thomas A. Spies [b,1]

[a] Department of Forest Science, Oregon State University, Corvallis, OR 97331, United States
[b] USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR 97330, United States

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ABSTRACT

The 2002 Biscuit Fire burned through more than 200,000 ha of mixed-conifer/evergreen hardwood forests in southwestern Oregon and northwestern California. The size of the fire and the diversity of conditions through which it burned provided an opportunity to analyze relationships between crown damage and vegetation type, recent fire history, geology, topography, and regional weather conditions on the day of burning. We measured pre- and post-fire vegetation cover and crown damage on 761 digital aerial photo-plots (6.25 ha) within the unmanaged portion of the burn and used random forest and regression tree models to relate patterns of damage to a suite of 20 predictor variables. Ninety-eight percent of plots experienced some level of crown damage, but only 10% experienced complete crown damage. The median level of total crown damage was 74%; median damage to conifer crowns was 52%. The most important predictors of total crown damage were the percentage of pre-fire shrub-stratum vegetation cover and average daily temperature. The most important predictors of conifer damage were average daily temperature and "burn period," an index of fire weather and fire suppression effort. The median level of damage was 32% within large conifer cover and 62% within small conifer cover. Open tree canopies with high levels of shrub-stratum cover were associated with the highest levels of tree crown damage, while closed canopy forests with high levels of large conifer cover were associated with the lowest levels of tree crown damage. Patterns of damage were similar within the area that burned previously in the 1987 Silver Fire and edaphically similar areas without a recent history of fire. Low-productivity sites on ultramafic soils had 92% median crown damage compared to 59% on non-ultramafic sites; the proportion of conifer cover damaged was also higher on ultramafic sites. We conclude that weather and vegetation conditions — not topography — were the primary determinants of Biscuit Fire crown damage.

1. Introduction

Mixed-severity fire regimes — characterized by variable fire frequencies and heterogeneous effects within and between fires — structure temperate forest ecosystems worldwide. Despite their prevalence, the dominant controls over fire effects within mixed-severity regimes remain poorly understood (Agee, 2005). Unlike high severity regimes, where extreme weather tends to override other influences on fire behavior (Bessie and Johnson, 1995; Turner et al., 1997), and low severity regimes where fuels are a primary determinant of fire behavior even during extreme weather (Agee, 1997; Finney et al., 2005), few generalities have been made about the relative importance of weather, fuel, and topography (i.e. the fire environment) for determining fire effects in mixed-severity regimes (Schoennagel et al., 2004). We examined the pattern of crown damage created by the 2002 Oregon Biscuit Fire in relation to its fire environment. The Biscuit Fire encompassed more than 200,000 ha of mixed-conifer/evergreen hardwood forests, whose structure and composition have been strongly influenced by a historically mixed-severity regime (Agee, 1993). The remarkable size of the fire and the diversity of conditions through which it burned provided an opportunity to assess the factors that gave rise to the mosaic of crown damage. Using pre- and post-fire digital aerial photography, we measured patterns of crown damage among several vegetation cover classes in relation to daily weather conditions, topography, vegetation cover, edaphic setting, and recent fire history. We structured our study around three research questions.

* Corresponding author. Current address: Harvard Forest, Harvard University, 324 N. Main Street, Petersham, MA 01366, United States. Tel.: +1 978 756 6159; fax: +1 978 724 3595.
E-mail addresses: jthomps@fas.harvard.edu (J.R. Thompson), tspies@fs.fed.us (T.A. Spies).
[1] Tel.: +1 541 750 7354; fax: +1 541 750 7329.

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Question 1: What was the relative importance of daily regional weather conditions, topography, and vegetation cover for predicting patterns of crown damage?

Variation in regional weather conditions can have a dramatic influence on fire behavior, but quantifying its relationship to fire effects can be difficult post hoc. By consuming oxygen and releasing heat, combustion circulates air and creates its own weather that is site-specific and impossible to reconstruct (Pyne et al., 1996). Consequently, most retrospective studies of fire effects exclude the influence of weather (e.g. Weatherspoon and Skinner, 1995; Lentile et al., 2006). However, the few studies that have related variation in regional weather to patterns fire effects have found average daily temperature and wind speed to be important predictors (Collins et al., 2007, 2009).

Topographic variation can impose important direct and indirect controls on patterns of fire effects. For example, greater solar radiation on southwesterly aspects can result in drier conditions and smaller vegetation, which can lead to higher levels of fire damage (Kushla and Ripple, 1997; Taylor and Skinner, 2003). The relationship between fire effects and elevation is more variable. Higher elevations have been associated with lower severity in some fires, presumably due to cooler temperature and higher humidity (Weatherspoon and Skinner, 1995); however, this pattern may be reversed when vegetation found at higher elevations is more susceptible to damage either due to the species' vulnerability or greater fuel accumulation associated with lower fire frequency (Agee, 1991). Finally, dendrochronological research has linked increasing fire effects with upper topographical positions (Taylor and Skinner, 1998), which have a higher probability of being burned by an intense heading fire.

Vegetation cover type (e.g. evergreen hardwood, conifer, low stature shrub, etc.), while not a direct measure of fuel conditions, is often related to patterns of fire damage (Weatherspoon and Skinner, 1995). Further, because vegetation is the only component of the fire environment that can be managed, and because crown cover is often all that is known over broad regions, understanding its relationship to fire effects is of particular importance. The role of vegetation cover in controlling fire effects varies widely. Clearly, some cover types, such as low-stature shrub vegetation are vulnerable to fire damage regardless of the weather and topographical conditions. Within forested areas, however, the importance of cover type on patterns of fire effects, relative to the rest of the fire environment, is not well understood, particularly in mixed-severity regimes. We measured crown damage within four forested cover types (small, large, and mixed-sized conifers, and evergreen hardwood) and one non-forested cover types (low "shrub-stature" vegetation). Not surprisingly, several studies have found lower rates of damage in large conifers compared to small (Alexander et al., 2006; Lentile et al., 2006). But, whether mixed-sized conifers are at an intermediate level of vulnerability is not clear. There has been concern that large trees in fire-dependent forests may be at increased risk of damage due to the encroachment of small conifers in the understory resulting from decades of fire suppression (Spies et al., 2006). Patterns of fire damage within evergreen hardwood forests have received little attention. However, Raymond and Peterson (2005) did report high levels of overstory mortality of tanoak (*Lithocarpus densiflora*) within field plots in the Biscuit Fire, apparently owing to their low crown-base-heights, relatively thin bark, and flammable leaves.

Question 2: Did the pattern of crown damage differ between areas with and without a recent history of fire?

The 2002 Biscuit Fire re-burned a large area (>38,000 ha) that had burned previously during the 1987 Silver Fire, which provided a unique opportunity to compare fire effects in an area with a recent history of mixed-severity fire to one where fire has been removed for many decades. Prolonged periods of fire exclusion has elevated the hazard within many dry forests types and prompted calls for widespread landscape restoration (Stephens and Ruth, 2005; Spies et al., 2006). It is unclear whether this strategy is appropriate for mixed-severity regime forests, particularly those in the Biscuit Fire region, which are seasonally dry but have relatively high forest productivity and, thus, do not fit the idealized model for restoring fuel-limited forests (e.g. Covington, 2000). Nevertheless, several studies have shown that fire frequency has decreased from historical levels within the region (Agee, 1991; Taylor and Skinner, 1998, 2003), which has coincided with increased forest density and decreased spatial complexity (Skinner, 1995; Taylor and Skinner, 1998). An earlier study that examined fire effects exclusively within the reburn area showed that places where overstory crown damage was severe during the Silver Fire — and had regenerated to low shrubs and young trees — experienced severe crown damage during the Biscuit Fire (Thompson et al., 2007). In contrast, places with low levels of overstory crown damage during the Silver Fire were the least likely to experience overstory damage in the Biscuit Fire. Based on these findings, one might expect that the twice-burned landscape would have more abundant shrubs and regenerating trees, and thus, higher levels of overall Biscuit Fire crown damage than the area outside the Silver Fire. Alternatively, the Silver Fire may have decreased surface fuels and vertical continuity within the bulk of the landscape that burned as a surface fire in 1987, thereby resulting in lower levels of crown damage, which is consistent with the conventional wisdom that fire suppression has increased the fire hazard (Taylor and Skinner, 2003).

Question 3: Did the pattern of crown damage differ between ultramafic and non-ultramafic soils?

Vegetation patterns within the Biscuit Fire region are heavily influenced by largest exposure of ultramafic soils in North America (Kruckeberg, 1984). Approximately one-third of the fire burned over unproductive soils formed on peridotite and serpentinite parent materials. Sparse vegetation on these sites is commonly juxtaposed by dense stands of conifers and evergreen hardwoods on highly productive metamorphic and igneous parent materials (Whittaker, 1960). We are not aware of any studies that have quantified fire effects in serpentine forest vegetation. Conventional wisdom suggests that ultramafic sites do not readily carry fire owing to their low fuel loads (Whittaker, 1960; Taylor and Skinner, 2003). That notwithstanding, these areas tend to support more low shrub-stature vegetation and small trees, which may be more susceptible to fire damage.

2. Methods

2.1. Study area

The study area was the region burned by the 2002 Biscuit Fire, centered at 123°91′W, 42°29′N (Fig. 1). The fire began as five separate lightning ignitions between July 13th and 15th, 2002, which combined to become the Biscuit Fire (GAO, 2004). On September 6th, the fire was contained at 202,168 ha. Ninety four percent of the fire was on land managed by the Rogue Siskiyou National Forest (RSNF) in southwestern Oregon, 5% was on the Six Rivers National Forest in northwestern California, and 1% was on Bureau of Land Management land (USDA-USDI, 2004). The area contains a range of management histories and designations, including the 73,000 ha Kalmiopsis Wilderness as well as roaded and logged areas. Even-aged conifer plantations make up ∼5% of the Biscuit Fire region and those areas were excluded from this