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Mixed severity fire effects within the Rim fire: Relative importance of local climate, fire weather, topography, and forest structure

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ABSTRACT

Recent and projected increases in the frequency and severity of large wildfires in the western U.S. makes understanding the factors that strongly affect landscape fire patterns a management priority for optimizing treatment location. We compared the influence of variations in the local environment on burn severity patterns on the large 2013 Rim fire that burned under extreme drought with those of previous smaller fires for a study area in the Sierra Nevada, California, USA. Although much of the Rim fire burned during plume-dominated conditions resulting in large high-severity patches, our study area burned under milder fire weather resulting in a mix of fire severities. In our study area the Rim fire produced a higher proportion of moderate- and high-severity effects than occurred in previous fires. Random forest modeling explained up to 63% of the Rim fire burn variance using seven predictors: time since previous fire, actual evapotranspiration (AET), climatic water deficit (Deficit), previous maximum burn severity, burning index, slope position, and solar radiation. Models using only a subset of biophysical predictors (AET, Deficit, slope position and steepness, and solar radiation) explained 55% of the Rim fire and 58% of the maximum fire burn severity of previous fires. The relationship of burn severity to patterns of AET, however, reversed for the Rim fire (positive) compared to earlier fires (negative). Measurements of pre-Rim fire forest structure from LiDAR did not improve our ability to explain burn severity patterns. We found that accounting for spatial autocorrelation in burn severity and biophysical environment was important to model quality and stability. Our results suggest water balance and topography can help predict likely burn severity patterns under moderate climate and fire weather conditions, providing managers with general guidance for prioritizing fuel treatments and identifying where fire is less likely to burn with higher severities even for locations with higher forest density and canopy cover.

1. Introduction

In western North America, the frequency and severity of large wildfires is increasing (Gillett et al., 2004; Miller and Safford, 2012; Morgan et al., 2008; Westerling et al., 2006). In an effort to reduce the effects of this trend on fire-prone forests, managers prioritize areas for treatment (North et al., 2009; Hessburg et al., 2015), often based on fire model outputs (i.e., Finney, 2005). While management activities may have limited effect on large wildfires occurring during extreme fire weather, wildfires burning under more moderate weather conditions often produce a mix of burn severities where pre-fire management treatments may affect burn patterns. Previous work has shown that mixed-severity burn patterns are influenced by the local biophysical environment (Holden et al., 2009; Kane et al., 2015; Miller and Urban, 1999, 2000), but few studies have examined this in combination with pre-burn forest structure and previous fire events.

Historical reconstructions of fires (Heyerdahl et al., 2001; Taylor and Skinner, 1998) and analyses of recent fires (Cansler and McKenzie, 2014; Dillon et al., 2011; Falk et al., 2007; Kane et al., 2015; Parks et al., 2015, 2011; Prichard and Kennedy, 2014) have demonstrated the importance of both top-down and bottom-up controls (Falk et al., 2007; Heyerdahl et al., 2001; Lertzman and Fall, 1998; Perry et al., 2011). Top-down controls such as decadal,

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annual, and daily variation in precipitation and temperature influence fire similarly over large areas (Turner and Romme, 1994; McKenzie and Kennedy, 2011). Bottom-up controls such as topography create local patterns of climate and vegetation structure that influence fire by affecting fuel loading, moisture, and fire behavior (Turner and Romme, 1994; McKenzie and Kennedy, 2011). Past fires also create bottom-up controls by locally altering fuels and forest composition and structure (Collins et al., 2009; Larson et al., 2013; Peterson, 2002).

In general, bottom-up controls exert stronger influence during cooler and wetter years when fires generally burn at lower severities, while top-down controls may exert stronger influence during hotter and dryer years (Bessie and Johnson, 1995; Dillon et al., 2011; Parks et al., 2014a, 2014b; Turner and Romme, 1994). However, even in years with strong drought and warmer temperatures, the influence of bottom up controls can still be seen in some landscape burn patterns (Bigler et al., 2005; Cansler and McKenzie, 2014; Lee et al., 2009; Prichard and Kennedy, 2014; Wimberly et al., 2009).

Recent large fires in Sierra Nevada mixed conifer forests have resulted in larger patches and a higher proportion of high-severity effects than occurred historically or in contemporary smaller fires (Mallek et al., 2013; Miller and Safford, 2012; Miller et al., 2009a; van de Water and Safford, 2011). The large 2013 Rim fire (104,131 ha) occurred during an extreme drought and burned partially under extreme (>98 percentile) fire weather. However, portions of the fire burned under milder weather producing mixed-severity burn patterns for an area that also had been subject to a number of previous smaller fires. These previous fires allowed us to compare the controls on these fires to see if the controls for a large fire (the Rim fire) differed. The availability of pre-fire airborne LiDAR data over a portion of the fire allowed us to examine whether high-fidelity forest structure measurements from LiDAR would improve our ability to explain burn severity patterns.

Specifically, we examined three questions for our study area:

1. How well do local variations in climate, topography, and prior fire history explain mixed-severity burn patterns?
2. How do the effects of these controls differ for the pre-Rim fires and for the Rim fire?
3. Do pre-fire LiDAR measurements improve our ability to explain the variation?

2. Methods

2.1. Study area

Yosemite National Park (3027 km^2) lies in the central Sierra Nevada, California, USA (Fig. 1). This area has a Mediterranean climate with precipitation ranging from 800 mm to 1720 mm (Lutz et al., 2010) mostly occurring as snow during the winter. As elevation increases, mean precipitation increases, mean temperature

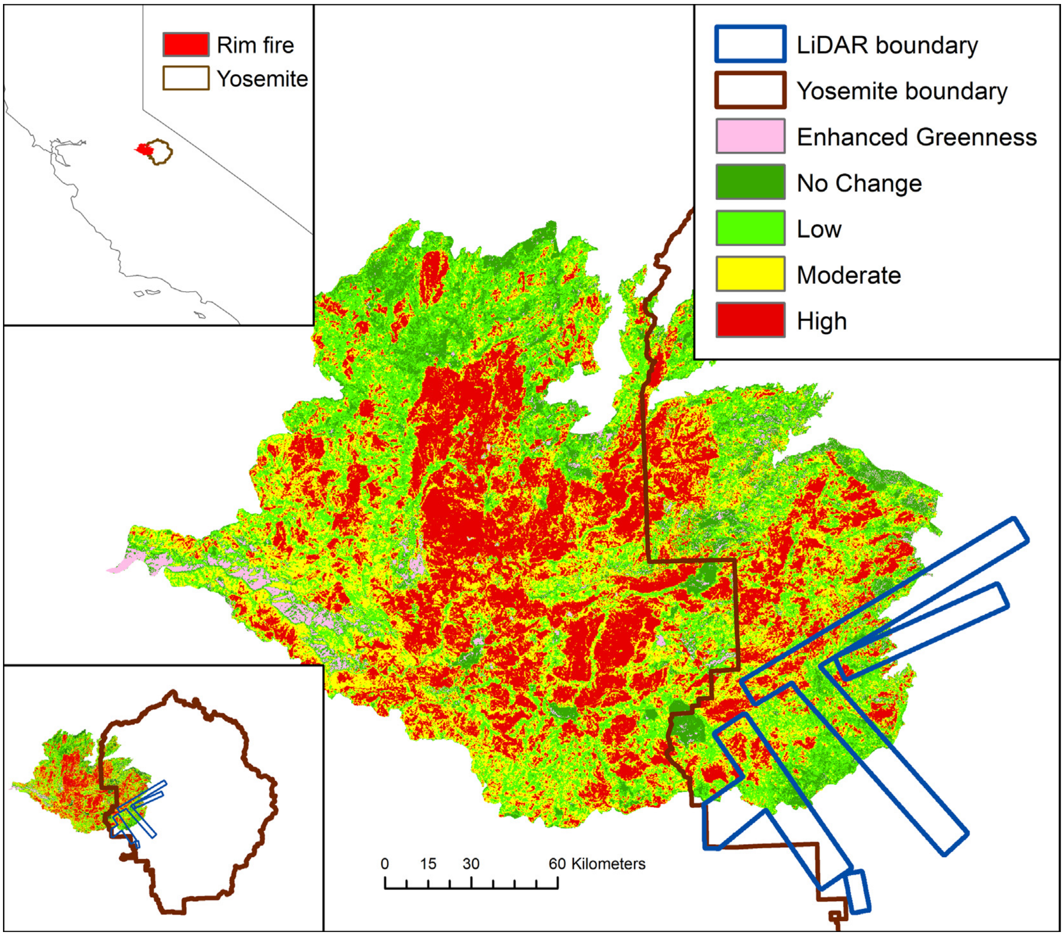

Fig. 1. Map of study area showing location within the state of California, USA (top insert) and within Yosemite National Park (bottom insert). Our study area consists of locations within the LiDAR acquisition boundary that were burned in the Rim fire. Burn severity for the Rim fire shown using classified RdNBR values with breakpoints from Miller and Thode (2007): Enhanced greenness, $\leqslant -150$; no change detected, -150 to 68; low severity, 69–315; moderate severity, 316–640; high severity, $\geqslant 641$.