Forest Ecology and Management 362 (2016) 29–37

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Examining alternative fuel management strategies and the relative contribution of National Forest System land to wildfire risk to adjacent homes – A pilot assessment on the Sierra National Forest, California, USA

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ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 20 November 2015
Accepted 21 November 2015
Available online 9 December 2015

Keywords:
Exposure and effects analysis
Fuel management
Risk source
Risk transmission
WUI

ABSTRACT

Determining the degree of risk that wildfires pose to homes, where across the landscape the risk originates, and who can best mitigate risk are integral elements of effective co-management of wildfire risk. Developing assessments and tools to help provide this information is a high priority for federal land management agencies such as the US Forest Service (USFS) that have limited resources to invest in hazardous fuel reduction and other mitigation activities. In this manuscript we investigate the degree to which fuel management practices on USFS land can reduce wildfire exposure to human communities. We leverage wildfire simulation with spatial risk analysis techniques and examine a range of hypothetical fuel treatment scenarios on a landscape encompassing the Sierra National Forest in California, USA. Results suggest that treating USFS land does little to reduce overall wildland urban interface (WUI) exposure across the landscape. A treatment scenario that focused on treating defensible space near homes was by far the most efficient at reducing WUI exposure, including exposure transmitted from USFS lands. Findings highlight potential tradeoffs and raise questions as to what other land management objectives fuel treatments on federal lands might be able to more cost-effectively achieve relative to WUI protection. Site-specific risk-based analyses can help elucidate these tradeoffs and opportunities.

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1. Introduction

Managing wildland vegetation and fuels to reduce potential threats to the wildland urban interface (WUI) remains a high priority for the US Forest Service (USFS) and other federal land management agencies in the United States. As a result, landscape assessments and budgetary allocation processes typically have a strong emphasis on WUI risk proximal to USFS land (e.g., Thompson et al., 2015a). However, the question of whether implementing fuel treatments on federal lands to protect the WUI is effective, efficient, or the most appropriate investment of taxpayer dollars remains unanswered (Calkin et al., 2014; Omi, 2015; Reinhardt et al., 2008).

Difficulties in answering this question stem from a limited empirical basis to evaluate fuel treatment effectiveness as well as uncertainty over the relative efficacy of alternative treatment strategies (Collins et al., 2010; Hudak et al., 2011). On some landscapes, where specific conditions align, modeling efforts suggest that strategically locating treatments in the wildlands may be an effective option for interrupting fire spread pathways and mitigating WUI risk (Ager et al., 2010). Other analyses however suggest that a shift in emphasis away from broad-scale fuel treatments to intensive fuel management near homes is a more efficient way to mitigate wildfire impacts to human communities (Gibbons et al., 2012; Price and Bradstock, 2012, 2014; Syphard et al., 2014). Managing fuels directly within the interface, while costly, may require smaller areas of treatment to achieve comparable reductions in risk leading to higher overall cost-effectiveness relative to managing fuels in wildlands (Penman et al., 2014).

In the context of federal land management and the WUI, a requisite first step in mitigation planning is determining the relative contribution of federal lands to WUI risk. Wildfires often start outside of the WUI and can spread far from the ignition location to cause damage to other landowners and homeowners. This phenomenon has been termed "risk transmission," and spatial fire spread models are increasingly used to characterize risk transmission potential and to identify potential sources of exposure and risk (Ager et al., 2014a, 2014b, 2015; Scott and Thompson, 2015; Scott et al., 2015; Thompson et al., 2015b). Haas et al. (2015), for

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http://dx.doi.org/10.1016/j.foreco.2015.11.038
0378-1127/Published by Elsevier B.V.

instance, identified areas along the Front Range of Colorado, USA, where ignitions could result in the greatest population impacts, and further partitioned results according to whether ignitions occurred on federal or privately owned land.

While the attribution of potential fire impacts back to ignition locations is intuitive and relatively easy to accomplish for both historical and simulated wildfires, it may present an incomplete picture of risk transmission. Here we expand the transmission concept to consider how landscape-scale vegetation and fuel conditions contribute to fire spread and WUI exposure. Specifically, we focus on quantifying how fuel management practices on federal land could reduce transmission of risk to the WUI. We use stochastic wildfire simulation to characterize the exposure of human communities to wildfire using simulated fire perimeters and ignition locations, and apply these methods on a case study landscape encompassing the Sierra National Forest in California, USA. Related studies using the same simulation approach have been applied to characterize the exposure of human communities, municipal watersheds, and critical wildlife habitat to wildfire (Scott et al., 2012; Thompson et al., 2013a, 2015a, 2015b).

In this study we use simulated perimeters to further explore how WUI exposure levels vary under alternative "fuelscapes", i.e., hypothetically treated landscapes. Our treatment scenarios are based on the "ideal landscape" concept (Finney, 2002, 2006), and range in scope from strictly infeasible – designed to provide a benchmark against which to compare results – to plausibly feasible – grounded in realistic treatment rates and spatially identified treatment constraints (North et al., 2015). Relative to other WUI risk analyses that consider alternative fuelscapes and use spatial fire spread modeling (e.g., Ager et al., 2010), our simulation approach captures a broader range of fire weather conditions under which fuel treatments may be tested by wildfire, and explicitly incorporates the probability of large fire ignition rather than assuming large fire occurrence. We compare simulated exposure levels under current conditions with those from alternative fuelscapes, and attribute exposure according to fires that ignite within and outside of USFS ownership. In the subsequent sections we describe our fire modeling approach and generation of landscape fuel treatment alternatives, present exposure analysis results, and discuss policy and management implications of our findings.

2. Methods

Our modeling approach was built around four main elements, which are described in more detail in subsequent sub-sections. First, we describe how we mapped human communities (i.e., the WUI), which are the ultimate endpoint of our assessment. Stochastic wildfire simulation formed the backbone of our entire analysis, and is presented second. We describe our use of the fire modeling system FSim (Finney et al., 2011) to simulate the occurrence and spread of wildfire. Third, we describe how we generated landscape conditions under current and hypothetical post-treatment scenarios, all of which were used as inputs for simulations with FSim. We compare alternative scenarios in terms of the extent and location of treated areas. Fourth, we describe how we quantified WUI exposure to wildfire under the various treatment scenarios. To begin, we introduce the study area for our analysis.

2.1. Study area

The study area consisted of the Sierra National Forest and surrounding land ownerships, located on the western slope of the southern Sierra Nevada Mountains, California (Fig. 1). The analysis area was a 30-km buffer around the north, west and south sides of the Sierra NF. A buffer was not added to the east because the forest boundary at that location is the Sierra Crest, a high-elevation, sparsely vegetated area that fires do not historically cross from the east to the west. To account for fires that could affect the analysis area from an ignition outside of it, we also identified a fire occurrence area (FOA) and used that to simulate fire starts and summarize historical fire occurrence. The FOA included a 30-km buffer around to the north and south of the analysis area. The FOA did not extend to the west of the analysis area because that is primarily agricultural land with little potential to influence the analysis area.

Vegetation and topography varied widely across the FOA. At the foot of the mountains to the west, elevation is only 100 m above sea level; the vegetation there consists of orchards, row crops and grasslands. The eastern edge of the study area is the Sierra Crest at nearly 4000 m elevation.

2.2. Characterizing the human community

We used the West-wide Wildfire Risk Assessment Where People Live (WPL) raster—representing the density of residential structures (houses per km^2)—to characterize the human community across the study area (Fig. 1). WPL was based on the LandScan population database from the Oakridge National Laboratory. LandScan, and uses advanced modeling approaches to incorporate remotely sensed data such as nighttime lights and high-resolution imagery, along with local spatial data to spatially distribute 2010 U.S. Census population counts within census blocks polygons (Oregon Department of Forestry, 2013). The native WPL raster cell size is 30 m, so each cell covers 900 m^2, or 0.0009 km^2. We multiplied the WPL density value by 0.0009 to estimate the expected number of houses per pixel.

2.3. Wildfire simulations

We used the FSim large-fire simulator (Finney et al., 2011) to simulate 10,000 complete fire seasons. The result was an event set—a set of hundreds of thousands of simulated wildfire perimeters that collectively represent possible outcomes of the 10,000 simulated wildfire seasons; each simulated wildfire in the event set has a known probability of occurrence (Scott and Thompson, 2015). FSim is a comprehensive wildfire occurrence, growth and suppression simulation system that pairs a wildfire growth model (Finney, 1998, 2002) and spatial and temporal models of ignition probability with simulated weather streams in order to simulate wildfire ignition and growth for thousands of fire seasons. FSim's temporal ignition probability model is a logistic regression of historical large-fire occurrence in relation to the historical Energy Release Component (ERC) of the National Fire Danger Rating System for the period 1992–2013. The spatial ignition model is a raster representing the relative density of large-fire ignitions across the landscape.

FSim generates raster values of annual burn probability (*BP*) and conditional flame length probabilities. FSim also generates polygons, in ESRI Shapefile format, representing the final perimeter of each simulated wildfire. An attribute table specifying certain characteristics of each simulated wildfire—its start location and date, duration, final size, and other characteristics—is included with the shapefile.

After calibrating FSim for the current condition (Scott et al., 2015), we then ran FSim on each of the hypothetical fuelscapes (described below). We used the feature of FSim whereby these subsequent simulations on hypothetical fuelscapes use the same simulated fire occurrences (locations, dates, weather conditions, etc.) so that differences among the simulations can be attributed to the factors that changed between simulations rather than to stochasticity (see Thompson et al., 2013b). In this analysis, the only factor that we changed between runs was the fuelscape. More