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Fire severity and cumulative disturbance effects in the post-mountain pine beetle lodgepole pine forests of the Pole Creek Fire

Michelle C. Agne *, Travis Woolley [1], Stephen Fitzgerald

Department of Forest Engineering, Resources, and Management, Oregon State University, 280 Peavy Hall, Corvallis, OR 97331-5704, United States

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ABSTRACT

Recent large scale mountain pine beetle (*Dendroctonus ponderosae* Hopkins, MPB) outbreaks have created concern regarding increased fuel loadings and exacerbated fire behavior and have prompted a desire to understand the effects of sequential disturbances on the landscape. However, previous research has focused on quantifying fuel loadings and using operational fire behavior models, rather than direct field measurements, to understand changes in fire severity following MPB. The 2012 Pole Creek Fire in central Oregon partially occurred in gray stage (8–15 years post-MPB epidemic) lodgepole pine forests. We examined the combined effects of MPB and fire disturbances on stand structure, and investigated the influence of previous MPB severity and fire weather on subsequent fire severity and cumulative disturbance severity. We randomly selected and installed 52 plots over a gradient of MPB and fire severity combinations and measured stand structure and fire severity characteristics. Fire severity metrics representing both crown and surface fire decreased with increased MPB severity under extreme burning conditions, following expected trends for crown fire severity, but not surface fire severity. Cumulative basal area mortality increased with MPB severity under moderate burning conditions, while other cumulative disturbance severity metrics were unrelated or weakly related to MPB severity. High severity crown fire was common despite hypothesized low canopy fuel loadings during the gray stage, indicating the importance of understanding variable mortality density of MPB outbreaks. Although long-term studies are needed to understand ecosystem recovery trajectories over time, there was no indication that a loss of ecosystem resilience occurred as a result of two sequential disturbances in this landscape.

1. Introduction

Bark beetles are important drivers of tree mortality and forest structure in North American coniferous forests (Jenkins et al., 2008). Large scale bark beetle outbreaks of recent decades (Meddens et al., 2012; Raffa et al., 2008) have created concern regarding elevated fuel loadings and exacerbated fire behavior (Jenkins et al., 2012), prompting a desire to understand the effects of multiple sequential disturbances on the landscape. The influence of mountain pine beetle (*Dendroctonus ponderosae* Hopkins, MPB[2]) on fuels succession and potential fire behavior in lodgepole pine (*Pinus contorta* Douglas ex Loudon) forests following an epidemic is of particular interest (Hicke et al., 2012; Jenkins et al., 2014). Large-scale assessments have not noted a consistent, region-wide relationship between MPB activity and wildfire occurrence (Hart et al., 2015; Kulakowski and Jarvis, 2011; Meigs et al., 2015). However, when disturbances do overlap spatially and temporally, there is evidence that fire behaves differently than predicted by currently used models. Perrakis et al. (2014) found higher rates of crown fire spread and more frequent active crown fire in post-MPB red and gray stage lodgepole pine stands in British Columbia as compared with fire behavior model predictions. Fire severity also can vary with the magnitude of previous MPB epidemics in the Rocky Mountains (Harvey et al., 2014a,b). Although the co-occurrence of these disturbances on the landscape is relatively rare in a given year (Meigs et al., 2015), it is important to understand their combined effects on fire behavior, which influences firefighter safety (Page et al., 2013), and fire severity, which may influence rates of ecosystem recovery (Harvey et al., 2014a). At localized scales, there is some evidence of a relationship between fire hazard and previous MPB activity, but this relationship varies with time since beetle attack (TSB[3]) and other factors like topography, drought, fire weather, and previous fire management (Harvey et al., 2014a,b; Lynch et al., 2006).

* Corresponding author.
E-mail address: Michelle.Agne@oregonstate.edu (M.C. Agne).
[1] Present address: The Nature Conservancy, 114 N. San Francisco Street #205, Flagstaff, AZ 86001-5252, United States.
[2] Mountain pine beetle.

[3] Time since beetle.

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Mountain pine beetle has been a part of the disturbance regime in lodgepole pine forests for as long records exist (Roe and Amman, 1970), and has the ability to cause mortality at a landscape scale in lodgepole pine forests when epidemics occur (Cole and Amman, 1980; Hansen, 2014). Mountain pine beetle outbreaks often occur in high density lodgepole pine stands, typically targeting large diameter (>23 cm) trees, and lasting from several years to a decade (Cole and Amman, 1980). Outbreaks collapse once most preferred host trees are killed, leaving smaller diameter lodgepole pine and non-host species (Hansen, 2014). This is followed by the release of advance regeneration and suppressed lodgepole pine, or forest type conversion where lodgepole pine is seral (Diskin et al., 2011; Kayes and Tinker, 2012; Pelz et al., 2015; Pelz and Smith, 2012). Fuels characteristics following a MPB epidemic are highly dependent on TSB and have been well studied (e.g., Klutsch et al., 2011; Page and Jenkins, 2007a; Schoennagel et al., 2012; Simard et al., 2011; Woolley et al., submitted for publication). The 2–4 years following epidemic initiation (i.e., the red stage) are characterized by substantial decreases in foliar moisture which is hypothesized to exacerbate crown fire behavior (Jolly et al., 2012; Page et al., 2012), although much uncertainty remains surrounding the importance of the proportion of green attacked trees in this relationship (Hoffman et al., 2012). Throughout this stage, canopy bulk density decreases as foliage senescence occurs, while litter and fine woody fuels may begin to increase (Page and Jenkins, 2007a; Simard et al., 2011; Woolley et al., submitted for publication). The gray stage (4–15 years TSB) begins when dead foliage is absent from the canopy. During this time, active crown fire potential is hypothesized to decrease considerably due to low canopy bulk density (Hicke et al., 2012). Live woody fuels (i.e., seedlings, saplings, and shrubs), coarse woody fuel load, and fine woody fuel load increase, but there is disagreement among studies regarding the effect on surface fire potential (Klutsch et al., 2011; Page and Jenkins, 2007b; Schoennagel et al., 2012; Simard et al., 2011). During the old stage (15–30+ years TSB), seedling and sapling densities continue to increase (Pelz and Smith, 2012; Simard et al., 2011), and continued snag fall adds to the coarse woody fuel load (Page and Jenkins, 2007a; Schoennagel et al., 2012). Crown fire potential may increase with increased canopy bulk density driven by the release and ascension of advanced regeneration and suppressed trees to the overstory (Hicke et al., 2012).

Although the relationship between MPB and fire has been well-studied, the lodgepole pine forests of central Oregon are ecologically distinct from those of the Intermountain West, where much of the previous research was based. In central Oregon, lodgepole pine is typically a climax species, forming uneven-aged, single-species stands (Simpson, 2007; Stuart et al., 1989), rather than a seral species as in Rocky Mountain lodgepole pine forests (Lotan et al., 1985). While the fire regime of seral lodgepole pine forests is typically considered to be high-severity and stand replacing, central Oregon lodgepole pine is characterized as having a mixed-severity fire regime (Agee, 1993; Heyerdahl et al., 2014). This may have a strong influence on the relationship between MPB severity and fire severity. Furthermore, central Oregon lodgepole pine forests exhibit low levels of cone serotiny as compared with Rocky Mountain lodgepole pine forests (Lotan and Critchfield, 1990; Mowat, 1960), which could lead to a significantly different post-fire stand development trajectory.

Previous research has largely focused on quantifying fuel loadings and using operational fire behavior models to investigate changes to potential fire behavior following MPB outbreaks (Hicke et al., 2012). Although these studies provide useful information regarding changes in fuel structure over time, the accuracy of fire behavior models using fuel loadings from MPB-affected stands is unknown due to limitations of currently available operational fire behavior models (Affleck et al., 2012; Cruz and Alexander, 2010). Additionally, effects on the ecosystem following multiple disturbances cannot be obtained from fire behavior models, thus, direct pre- and post-fire field measurements and observations are needed. Incorporation of fire weather data is also informative as previous studies have found variability around the relationship between previous MPB and fire severity to be partially explained by burning conditions (Harvey et al., 2014a,b; Prichard and Kennedy, 2014). Some recent studies have aimed to address the issue of fire behavior and fire severity following MPB by investigating fires which burned through post-MPB stands in the Rocky Mountains (Harvey et al., 2014a,b). However, the relationship between fire severity and MPB severity is not fully understood; the study of additional fires in other regions and in later TSB stages would benefit the understanding of this disturbance interaction (Harvey et al., 2014b).

Predicted increases in disturbance magnitude and frequency under changing climate conditions (Dale et al., 2001) necessitate the investigation of interactions between successive forest disturbances. Understanding the effect of one disturbance on the severity of the next disturbance (i.e., linked disturbance effects; Simard et al., 2011), is instructive for management objectives such as the allocation of fuels treatments in stands with increased fire hazard and the identification of areas which may pose additional difficulties during firefighting operations (Page et al., 2013). In contrast, predictions of stand development trajectories and ecosystem reorganization are strongly influenced by compound disturbance effects, in which disturbance effects on the ecosystem combine in a non-additive manner (Paine et al., 1998; Turner, 2010). Compound disturbance effects in various forested ecosystems can lead to alteration of forest successional patterns and may result in a state change if the ecosystem is not resilient to these effects (Buma, 2015). Compound disturbance effects are unique because they cannot be predicted by observing each disturbance individually; they must be observed where they overlap to be understood (Paine et al., 1998). Therefore, in addition to investigating the effect of previous MPB severity on fire severity (linked disturbance effect), it is imperative to address the relationship of combined disturbance severity on ecosystem response to determine the possibility of compound disturbance effects.

A large portion of the 2012 Pole Creek Fire in central Oregon's Eastern Cascade Mountains burned in lodgepole pine forests which had experienced a MPB epidemic 8–15 years prior to fire. The Pole Creek Fire burned with mixed-severity, providing an opportunity to examine the combined effects of a single MPB outbreak and fire event at various intensities in lodgepole pine forests of central Oregon. The objectives of this case study were: (1) to quantify changes in stand structure over time following both MPB and fire, and (2) to determine the effect of prior MPB severity and fire weather on subsequent surface fire severity, crown fire severity, and cumulative disturbance severity. We expected that changes to stand structure would occur at similar magnitudes over both disturbances and that lodgepole pine would remain the dominant tree species. We hypothesized that surface fire severity would increase with MPB severity due to increased surface fuel loadings (Page and Jenkins, 2007a; Schoennagel et al., 2012), while we anticipated that crown fire severity would decrease as a result of decreased canopy bulk density (Klutsch et al., 2011; Simard et al., 2011; Woolley et al., submitted for publication). We hypothesized that cumulative disturbance severity would not vary with MPB severity because of the expected inverse relationship between MPB severity and fire severity.