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Review

Effects of bark beetle-caused tree mortality on wildfire

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ABSTRACT

Millions of trees killed by bark beetles in western North America have raised concerns about subsequent wildfire, but studies have reported a range of conclusions, often seemingly contradictory, about effects on fuels and wildfire. In this study, we reviewed and synthesized the published literature on modifications to fuels and fire characteristics following beetle-caused tree mortality. We found 39 studies addressing this topic with a variety of methods including fuels measurements, fire behavior simulations, an experiment, and observations of fire occurrence, severity, or frequency. From these publications, we developed a conceptual framework describing expected changes of fuels and fire behavior. Some characteristics of fuels and fire are enhanced following outbreaks and others are unchanged or diminished, with time since outbreak a key factor influencing changes. We also quantified areas of higher and lower confidence in our framework based on the number of studies addressing a particular area as well as agreement among studies. The published literature agrees about responses in many conditions, including fuels measurements and changes in stands with longer times since outbreak, and so we assigned higher confidence to our conceptual framework for these conditions. Disagreement or gaps in knowledge exist in several conditions, particularly in early postoutbreak phases and crown fire behavior responses, leading to low confidence in our framework in these areas and highlighting the need for future research. Our findings resolved some of the controversy about effects of bark beetles on fire through more specificity about time since outbreak and fuels or fire characteristic. Recognition of the type of study question was also important in resolving controversy: some publications assessed whether beetle-caused tree mortality caused differences relative to unattacked locations, whereas other publications assessed differences relative to other drivers of wildfire such as climate. However, some disagreement among studies remained. Given the large areas of recent bark beetle and wildfire disturbances and expected effects of climate change, land and fire managers need more confidence in key areas when making decisions about treatments to reduce future fire hazard and when fighting fires.

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1. Introduction

Wildfire and bark beetle outbreaks are major disturbances in the conifer forests of North America. Wildfires have burned millions of hectares in recent decades (Littell et al., 2009), and bark beetle outbreaks have affected tens of millions of hectares in western North America since 1990 (Raffa et al., 2008). Both disturbances are influenced by climate (e.g., Westerling et al., 2006; Bentz et al., 2010) as well as stand conditions (Fettig et al., 2007), and projected future changes in climate are expected to increase wildfire and beetle outbreaks (Bentz et al., 2010; Pechony and Shindell, 2010).

In addition to effects on many resources such as timber production, water quantity, recreation, and wildlife habitat, bark beetle-caused tree mortality may alter fuels and therefore wildfire characteristics (Table 1). Potential modifications to forest fire behavior following beetle outbreaks could have multiple critical effects. The possibility of more extreme crown fire behavior in beetle-killed stands has led to concern about public safety and structure loss. Firefighting operations may be affected in areas with beetle-killed trees, with the increase in downed woody debris posing challenges for suppression and control, and more extreme fire behavior affecting firefighter safety (Cahill, 1977; Alexander and Stam, 2003). Altered fuels and fire characteristics following beetle outbreaks are of interest to water and wildlife managers because of possible changes in water quality and habitat that may occur following wildfire.

Despite these potential influences, there is a lack of consensus in the published literature about responses, with some publications reporting large effects of beetle-killed trees on fuels and fire (e.g., Jenkins et al., 2008) and other studies reporting no effect or a reduced impact (e.g., Berg and Anderson, 2006; Bond et al., 2009). This range of responses leads to confusion among scientists, resource managers, and the public, increasing uncertainty about decisions during firefighting operations and treatments to reduce wildfire impacts.

Here we report on a synthesis of the effects of bark beetle outbreaks on different fuels and fire characteristics. Past publications have reviewed the literature on this topic (Parker et al., 2006; Romme et al., 2006; Jenkins et al., 2008; Kaufmann et al., 2008; Simard et al., 2008; Gibson and Negron, 2009; Black et al., 2010); we provide an updated and more detailed review, critically evaluating each publication and identifying key characteristics for synthesis. We developed a conceptual framework from the published literature describing expected changes to characteristics following outbreaks, quantified agreement and disagreement among published studies, and assessed confidence in the developed framework. Our synthesis describes issues and challenges for studies of this topic and identifies gaps in knowledge.

2. Methods

We first identified aspects of studies that permitted valid comparisons. Key among these were (a) forest type and insect species; (b) fuels or wildfire characteristic studied (Table 1); (c) types of study (observational, experimental, simulation modeling); (d) consideration and type of study control that allowed comparisons with uninfested locations; (e) sources of infestation and fire data; (f) mortality rate following bark beetle outbreak (number of attacked trees); (g) time since outbreak; and (h) question addressed by study (does beetle-caused tree mortality alter fuels or fire characteristics relative to unattacked locations versus relative to influences of other drivers such as climate?).

Using standard search methods that included reference databases, the Internet, and personal inquiry, we identified all publications that reported new results on the effects of bark beetle outbreaks on fuels or wildfire characteristics. For each study, we identified the reported response of one or more combinations of fuels or fire characteristic in one or more postoutbreak phases for subsequent grouping and analysis. We also rated fuels or fire behavior characteristic/phase/study combinations for use in our conceptual framework; using such combinations allowed us to separate findings within one study that may have been obtained with different methods (e.g., findings from observations versus modeling results that were reported in one publication). Combinations were rated from low (1) to high (3) according to an established set of criteria that considered several factors (Table 2). The type of publication influenced the ratings: briefing papers or reports that did not undergo peer review received lower ratings, whereas articles in peer-reviewed refereed journals received higher ratings, and government publications received intermediate ratings. Publications describing qualitative observations were rated lower, and scientific studies with hypotheses or objectives and quantitative measurements or modeling were rated higher. We gave studies that relied on simulation modeling lower ratings than studies based on ground-based observations. Studies that included appropriate control sites or preoutbreak times for comparison with infested sites and times were rated higher than those without controls. Because multiple factors influence wildfire behavior (weather, fuels, topography), higher ratings were assigned to studies that included consideration of important explanatory variables representing these factors, and lower ratings were assigned to studies that considered only one or a few explanatory variables and did not include some major factors. Finally, we rated studies that lacked sufficient details on key aspects (as discussed above) lower.

Guided by the scientific literature, we developed a conceptual framework that describes expected patterns of fuels and fire characteristics as a function of time since outbreak. In conditions where knowledge gaps or disagreement occurred, we used scientific understanding about bark beetle outbreaks and fuels and fire behavior to suggest responses. Following bark beetle attack, stands move through several phases as time progresses (Hopkins, 1909; Amman et al., 1990; Wulder et al., 2006; Simard et al., 2011). After trees are killed, foliar moisture content decreases (Gibson and Negron, 2009; Jolly et al., in press) and in many bark beetle-attacked conifer species such as pines, needles fade to red within a year (“red phase”). Other conifers such as some spruce may fade to yellowish or remain green instead of turning red (Holsten et al., 1999). Following needledrop in 3–5 years (typical for lodgepole pine, *Pinus contorta*; other forest types have different timing (Clifford et al., 2008)), killed trees turn gray (“gray phase”). Within one to several decades, snags fall (Keen, 1955; Schmid et al., 1985; Mitchell and Preisler, 1998), understory vegetation increases (McCambridge et al., 1982; McMillin et al., 2003), and new tree