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Fire and Bark Beetle Interactions

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Synonyms

Fire and insect interactions

Definition

Interactions between wildland fire and bark beetles such that one disturbance impacts the other

Introduction

Wildland fire and bark beetle outbreaks are both large disturbances in North American forests with the potential to interact over spatial and temporal scales (Hicke et al. 2016; Raffa et al. 2008). The order of the disturbances, fire before bark beetles or fire after bark beetles, influences the outcome of the interaction. Fire and bark beetles are similar in that both can cause massive amounts of tree mortality, alter nutrient cycling, and alter forest structure and species composition, but these disturbances, in isolation and together, also have distinct effects on ecosystems. Several reviews of fire-bark beetle interactions exist with more detailed information (Hicke et al. 2012; Jenkins et al. 2008, 2012, 2014; Kane et al. 2017).

A basic background of bark beetle biology is necessary to understand fire-bark beetle interactions. Numerous bark beetles (Coleoptera: Curculionidae, Scolytinae) species are native insects to North America that are capable of irrupting in population to kill mature trees (Wood 1982). Host tree species is specific to the bark beetle species. Bark beetles require living phloem to successfully reproduce; therefore, they only attack live trees. Life cycle varies by geographic region and bark beetle species, but generally, beetles communicate via pheromones to mass attack a live tree by boring through the bark on the tree's main stem. The coordinated mass attack overwhelms a tree's defenses to allow mating and reproducing (Raffa and Berryman 1983). Females construct galleries in the phloem and deposit eggs. As eggs develop into larvae and then pupae, they feed on phloem. When mature, the new generation of beetles bore out of the tree through the bark to attack other trees.

Fire Before Bark Beetles

Fire severity, bark beetle populations, and forest structure and composition determine if a burn area is susceptible to bark beetles (Fettig et al. 2014; Parker et al. 2006). If an area burns intensely and kills most trees (i.e., high severity), then there is not suitable host material for bark beetles. The fire must also be within a bark beetle's dispersal range and contain host

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species of suitable size. If these conditions are met, then bark beetles are capable of attacking trees weakened by fire that may have otherwise survived to cause additional tree mortality. Levels of bark beetle-caused mortality after fire also vary with tree injury, postfire environment, and other factors such as beetle predation (Jenkins et al. 2014). While bark beetles routinely cause additional tree mortality after fire, outbreaks into adjacent unburned areas are uncommon (Davis et al. 2012; Lerch et al. 2016; Lombardero and Ayres 2011; Powell et al. 2012).

Tree injury level influences bark beetle attraction, with moderately injured trees generally being more susceptible to attack (Hood and Bentz 2007; Lerch et al. 2016; McHugh et al. 2003; Powell et al. 2012; Santoro et al. 2001). Red turpentine beetle (*Dendroctonus valens* LeConte) attacks were positively related to bark char height in ponderosa pine (Westlind and Kelsey 2019) and correlated with increased tree mortality after fire (Hood et al. 2010; Westlind and Kelsey 2019).

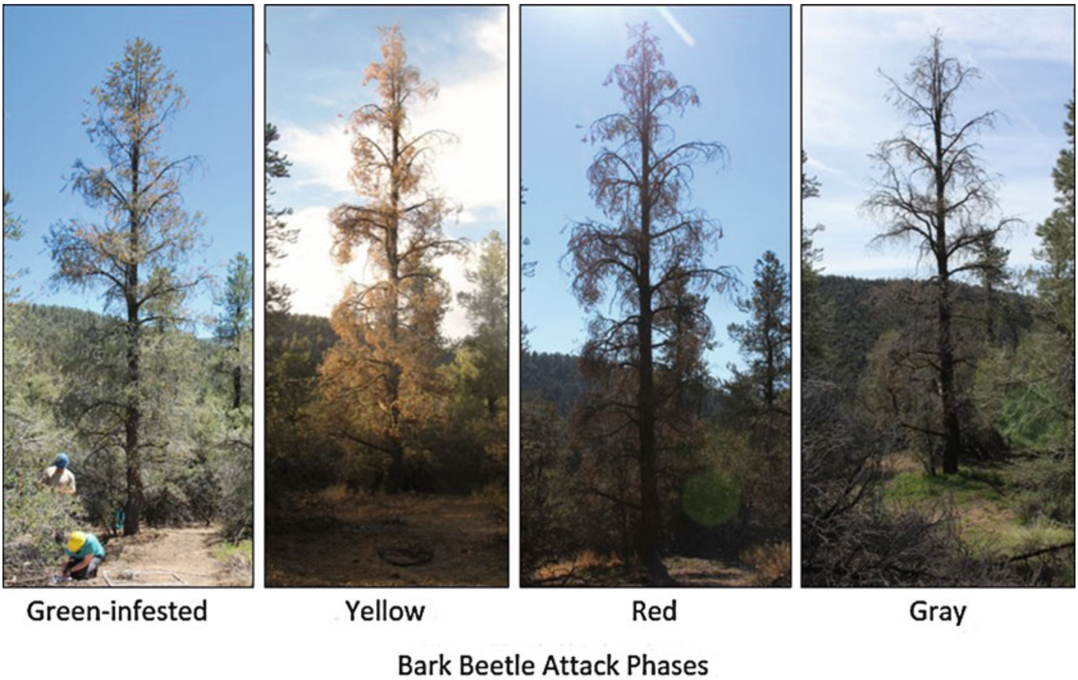
Fire severity influences both individual tree physiology and stand-to-landscape-level patterns of forest structure, thereby influencing forest susceptibility to bark beetles. Low-severity fire can induce tree defenses, which increases resistance to bark beetles (Hood et al. 2015; Lombardero and Ayres 2011; Lombardero et al. 2006). Resin duct-related induced defenses take approximately 1 year after fire to form, and fire-injured trees may be more susceptible to bark beetle attacks during this time. In this way, frequent, low-severity fire in dry conifer forests may foster both high tree level defenses and forest structure that confers resistance to subsequent bark beetle outbreaks, but there is a window of increased susceptibility to beetles after fire before induced defenses form (Hood et al. 2015, 2016). High-severity fire also reduces susceptibility to bark beetles by killing host tree species of sufficient size to support a developing beetle brood. Work in subalpine forests has shown spruce beetle outbreaks are reduced for decades after high-severity fire because host trees are too small to be attacked (Bakaj et al. 2016; Bebi et al. 2003).

Fire After Bark Beetles

Wildland fire behavior and effects after a bark beetle outbreak is dependent on the outbreak severity and time since outbreak (Hicke et al. 2012). The course of an outbreak has been called a "bark beetle rotation" by Jenkins et al. (2008, 2014) to describe the phases of time since attack and changes to tree crown condition (Fig. 1). Attacked trees are first "green-infested," then needles fade, and tree enters the "yellow" phase. In the "red" phase, the tree is dead, and needles turn red. The final phase is the "gray" phase when needles fall off the tree. It is important to note that during the course of an outbreak, trees are attacked and killed often over a period of several years, and cumulative mortality varies considerably by attack severity. Therefore, a forest can contain trees in multiple phases of the bark beetle rotation at the same time.

Outbreaks alter fuel loading, arrangement, and moisture as bark beetle-killed trees deteriorate and fall to the ground (Jenkins et al. 2014). Figure 2a from Hicke et al. (2012) describes the generalized expected change in fuels by type with time since outbreak. The exact timing will vary by tree species, beetle species, and geographic location. As successfully attacked trees move from the red to gray phase, needles and fine branches drop to the ground and litter, 1, and 10 h fuels increase. This causes a concomitant decrease in canopy fuels. In the gray phase, 100 and 1000 h fuels gradually increase over time as the dead trees deteriorate. Increased light and moisture availability from overstory tree mortality releases smaller, surviving trees that were not suitable hosts to the beetles, causing an increase in ladder fuels.

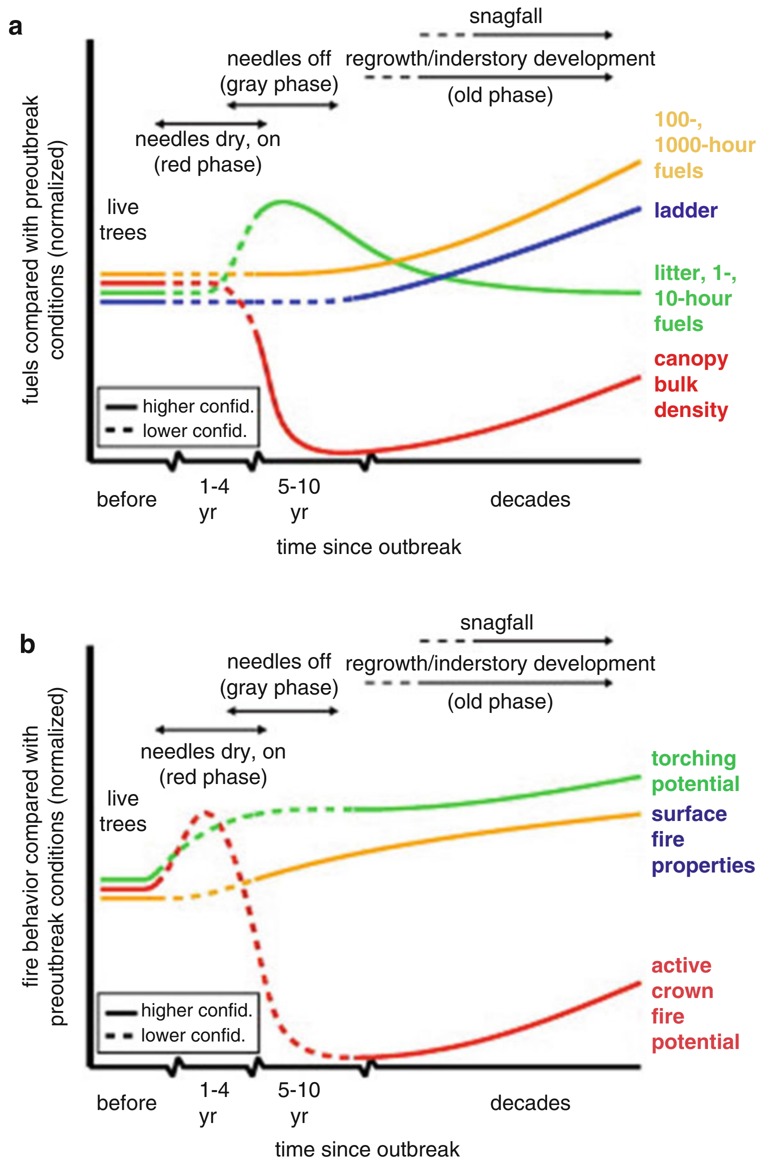
The changes to fuels from a bark beetle outbreak also lead to changes in forest flammability and potential fire behavior (Figure 2b; Hicke et al. 2012; Jenkins et al. 2012). There are many challenges with modeling fire behavior in beetle-impacted forests, largely because fire behavior model assumptions are violated (Jenkins et al. 2012; Page et al. 2014). These challenges and the limited ability to evaluate model predictions with empirical data (Alexander and Cruz 2013) have led to inconsistencies and debate in the



Fire and Bark Beetle Interactions, Fig. 1 An individual tree as it goes through the bark beetle attack phases or bark beetle rotation

literature about if bark beetle-impacted forests increase fire behavior relative to unattacked, green forests (Jolly et al. 2012a; Simard et al. 2011; 2012). Efforts using physics-based models suggest bark beetle-caused mortality increases fire rate of spread above unattacked forests, with spread rates peaking during the red phase, but remaining faster than in green forests even as canopy fuels decrease (Hoffman et al. 2015). In an experiment of needle flammability, red needles from attacked trees ignited faster than green needles, which could lead to increased crown fire potential (Jolly et al. 2012b). Schoennagel et al. (2012) also show the importance of accounting for reduced foliar moisture content during the red phase when predicting crown fire behavior in beetle-impacted forests. However, once a crown fire is initiated, fire behavior in lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson) forests that occurs under dry, windy weather conditions is likely to be similar regardless of bark beetle activity (Schoennagel et al. 2012).

Whether fire severity, measured as either tree mortality, vegetation change, or soil heating, changes in beetle-impacted forests compared to green, unattacked forests depends on the phase of the bark beetle rotation, weather at the time of fire, and forest type. Using a physics-based model, Sieg et al. (2017) found fire severity (i.e., tree mortality) increased in ponderosa pine-dominated (*Pinus ponderosa* Lawson & C. Lawson) beetle-impacted forests during the red phase, but was unchanged or decreased in the gray phase compared to green forests. The interactions between fire and bark beetles on resulting severity were weakened under high wind conditions (Sieg et al. 2017). Fire severity, measured as change in vegetation, decreased with time since mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak in Washington and Oregon, USA (Meigs et al. 2016). In contrast, Prichard and Kennedy (2014) also measured severity by change in vegetation in Washington, USA but found higher fire severity in red phase mountain pine beetle-impacted forests. Harvey et al. (2014) reported mountain pine beetle attack



Fire and Bark Beetle Interactions, Fig. 2 Conceptual framework of (**a**) fuels characteristics and (**b**) fire behavior relative to preoutbreak conditions for red, gray, and old (snagfall and regrowth) phases. Surface fire properties include reaction intensity, rate of spread, and flame length. For postoutbreak phases, solid lines indicate higher confidence, and dashed lines indicate lower confidence (more disagreement, fewer studies, or knowledge gaps). (Reprinted from Forest Ecology and Management, 271, Hicke JA, Johnson MC, Hayes JL, Preisler HK, Effects of bark beetle-caused tree mortality on wildfire, 8190, Copyright (2012), with permission from Elsevier)

severity in both red and gray phase lodgepole pine forests was largely unrelated to subsequent fire severity in the Northern Rocky Mountains, USA. Several metrics of fire severity were evaluated, and it was only under extreme weather conditions that mountain pine beetle outbreaks increased fire severity, as measured by deep charring (Harvey et al. 2014).

While bark beetles outbreaks can influence fire behavior and severity, outbreaks typically do not greatly influence the amount of area burned. Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks were not shown to influence the area burned in the Western United States (Hart et al. 2015) or the likelihood of fire (Meigs et al. 2015). No difference in fire frequency was found between areas impacted by spruce beetle (*Dendroctonus rufipennis* Kirby) compared to unattacked areas (Bebi et al. 2003).

The changes in fuels, fire behavior, and fire severity due to bark beetles impact fire suppression efforts and firefighter safety. Snags created from beetle-killed trees are a safety concern and increase fireline construction times. Page et al. (2013) describe these impacts in detail. A compilation of firefighter observations reported unexpectedly active fire behavior in mountain pine beetle-killed lodgepole pine forests (Moriarty et al. 2019). These considerations highlight the important distinction between understanding the effects of fire in beetle-impacted forests for planning and management purposes and the caution needed to safely manage wildland fire for firefighters and the public.

Cross-References

- ▶ First and Second Order Fire Effects
- ▶ First-Order Fire Effects Model (FOFEM)
- ▶ Post-fire Tree Mortality

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