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Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest

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Abstract

Over the last century, fire exclusion in the forests of the Sierra Nevada has allowed surface fuels to accumulate and has led to increased tree density. Stand composition has also been altered as shade tolerant tree species crowd out shade intolerant species. To restore forest structure and reduce the risk of large, intense fires, managers have increasingly used prescription burning. Most fires prior to EuroAmerican settlement occurred during the late summer and early fall and most prescribed burning has taken place during the latter part of this period. Poor air quality and lack of suitable burn windows during the fall, however, have resulted in a need to conduct more prescription burning earlier in the season. Previous reports have suggested that burning during the time when trees are actively growing may increase mortality rates due to fine root damage and/or bark beetle activity. This study examines the effects of fire on tree mortality and bark beetle attacks under prescription burning during early and late season. Replicated early season burn, late season burn and unburned control plots were established in an old-growth mixed conifer forest in the Sierra Nevada that had not experienced a fire in over 120 years. Although prescribed burns resulted in significant mortality of particularly the smallest tree size classes, no difference between early and late season burns was detected. Direct mortality due to fire was associated with fire intensity. Secondary mortality due to bark beetles was not significantly correlated with fire intensity. The probability of bark beetle attack on pines did not differ between early and late season burns, while the probability of bark beetle attack on firs was greater following early season burns. Overall tree mortality appeared to be primarily the result of fire intensity rather than tree phenology at the time of the burns. Early season burns are generally conducted under higher fuel moisture conditions, leading to less fuel consumption and potentially less injury to trees. This reduction in fire severity may compensate for relatively modest increases in bark beetle attack probabilities on some tree species, ultimately resulting in a forest structure that differs little between early and late season prescribed burning treatments.

Keywords: *Abies*; *Pinus*; *Dendroctonus*; *Scolytus*; Bark beetle; Prescribed fire

1. Introduction

Prior to the past century of fire exclusion, frequent fire had long been a major ecosystem influence in California's Sierra Nevada mixed-conifer forests (Swetnam and Baisan, 2003). The introduction of grazing, decimation of the Native American population, and more recent fire suppression policies however, resulted in fire exclusion and increased tree density, fuel accumulation, and fuel continuity on the forest floor (Skinner and Chang, 1996; McKelvey and Busse, 1996; Bradley and Tueller, 2001). Fire exclusion has promoted uniform tree age and structural distributions, and has altered stand composition by allowing shade tolerant species such as firs (*Abies*) to crowd out shade intolerant species such as pines (*Pinus*) (Parsons and DeBennedetti, 1979; Barbour et al., 2002). The unnatural accumulation of fuels and changes to stand structure are feared to have detrimental effects on the ecosystem while also greatly increasing the risk of high intensity crown fires.

As knowledge of the negative effects of fire suppression has grown, managers have increasingly relied on prescribed fire to reduce fuel loads and restore natural ecosystem processes

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(Kilgore, 1973; Kilgore and Sando, 1975; Keeley and Stephenson, 2000; Stephens and Ruth, 2005). Historically, wildfires in the Sierra Nevada occurred most frequently in the late summer and early fall (Caprio and Swetnam, 1995) when fuels are driest and trees dormant or nearly so. Late season prescribed burning has been favored by some managers because it approximated the historical fire season and the onset of fall precipitation can reduced post-fire monitoring for escapes. However, the fall burning season often coincides with stable atmospheric conditions when smoke dispersal is poor (Cahill et al., 1996) and managers face increased legal restrictions on burning. As a result, an increasing number of prescribed burns are being conducted during the early season when atmospheric conditions are more favorable for smoke dispersal.

Most pre-EuroAmerican settlement fires occurred in late season. The potential differences in tree mortality from fires in late spring or early summer rather than in the late summer or fall are still not well understood and reports in the literature have been contradictory. On one hand, early season burns occur at the beginning of the annual growth period and plants have been shown to be more susceptible to heat damage when carbohydrate reserves are at their lowest levels (Hough, 1968; Garrison, 1972). For example, growing season prescribed burns have resulted in greater ponderosa pine (*Pinus ponderosa*) mortality than dormant season burns (Swezy and Agee, 1991; Harrington, 1993). Damage to fine roots that are abundant in the litter and duff layers, particularly during the early season period of tree growth, may be an explanation (Swezy and Agee, 1991). On the other hand, late season burns are likely to be of greater intensity because fuels are typically drier (Skinner and Chang, 1996), and a recent replicated experiment in eastern Oregon ponderosa pine forests revealed greater mortality following late season burns (Thies et al., 2005).

Trees weakened by fire are susceptible to attack by insects such as bark beetles. Season of fire might influence tree mortality by affecting this susceptibility according to the time of year when the damage occurs—trees damaged when carbohydrate reserves are low may be unable to defend against attack (McCullough et al., 1998; Goyer et al., 1998; McHugh et al., 2003). In the Sierra Nevada, bark beetles (Coleoptera: Scolytidae) are common pests that kill firs and pines, and are capable of large-scale population increases following disturbances such as droughts or fires (Miller and Keen, 1960; Bradley and Tueller, 2001). Such outbreaks can be in response to tree physiological conditions that enable insects to circumvent tree defenses (Berryman, 1982; Mattson and Haack, 1987; Logan et al., 2003; Wallin et al., 2004), or in response to physical and structural attributes of conifer stands that favor bark beetle populations (Sanchez-Martinez and Wagner, 2002; Sartwell and Stevens, 1975; Mitchell et al., 1983; Powers et al., 1999). Dense forests subject to fire exclusion are feared particularly susceptible to insect attack (Wallin et al., 2004; Sala et al., 2005).

Bark beetle attacks are expected to increase in response to weakened tree defenses following fires (Ryan and Amman, 1994; McHugh et al., 2003), and one prediction is that fires resulting in more severe effects on trees will produce more resources for bark beetles. However, individual trees within a species vary in their suitability as hosts (Rudinsky, 1962; Wright et al., 1979; Wallin et al., 2004) and some previous work has suggested that bark beetle preference for trees may be a ‘‘humped-shaped’’ response to tree health: vigorous trees and very damaged trees both provide poor resources (Mitchell et al., 1983). An open question is the extent to which bark beetle attacks and resulting secondary mortality follow or differ from the pattern of primary fire-caused mortality. Differences in fire behavior due to environmental conditions at the time of burning may result in different effects on tree defenses against bark beetles with fire season. The timing of fires might also influence bark beetle activity through direct effects on beetle populations and phenology: late season burns occur after bark beetle activity has ceased for the season and may provide fewer wounded but suitable trees available for bark beetles the following spring.

The purpose of this study was to evaluate the differences in direct and secondary tree mortality with early season and late season prescribed fires. This study was intended to provide managers with information to tailor prescribed burning operations so that both fuel reduction and forest stand structure and composition restoration goals are met.

2. Methods

2.1. Study sites and system

This study was located in an old growth mixed conifer forest within the Marble Fork watershed of the Kaweah River, Sequoia National Park, CA, USA. To test for the effects of fire season on tree mortality and bark beetle activity, three treatments (early season, late season, and unburned control) were applied to nine experimental units in a completely randomized design. Each treatment was replicated three times. The experimental units were each 15–20 ha in size and were located on west to northwest facing aspects of variable slope at elevations ranging from 1900 to 2150 m above sea level. Prior to the burns, the most common tree species were white fir (*Abies concolor* Gordon and Glend.), sugar pine (*Pinus lambertiana* Douglas), and incense cedar (*Calocedrus decurrens* Torrey). Red fir (*A. magnifica* Murray), Jeffrey pine (*P. jeffreyi* Grev and Balf.), ponderosa pine (*P. ponderosa* Lawson), mountain dogwood (*Cornus nuttallii* Audobon), and black oak (*Quercus kelloggii* Newb.) were also present at low densities.

2.2. Fire history

To establish the historical fire return interval and season during which fires burned, we collected cross sections of snags and logs containing fire scars at four locations within or adjacent to the study area. Each collection location was approximately 2 ha in size, and between five and nine fire scarred snags or down logs were sampled per location. The majority of cross sections were from *P. lambertiana*, but some *P. jeffreyi* and *C. decurrens* sections were also used. Cross sections were sanded to improve visibility of the annual rings. Fire scars were identified and fire years determined by cross-dating, using standard