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Forest thinning and subsequent bark beetle-caused mortality in Northeastern California☆

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ABSTRACT

The Warner Mountains of northeastern California on the Modoc National Forest experienced a high incidence of tree mortality (2001–2007) that was associated with drought and bark beetle (Coleoptera: Curculionidae, Scolytinae) attack. Various silvicultural thinning treatments were implemented prior to this period of tree mortality to reduce stand density and increase residual tree growth and vigor. Our study: (1) compared bark beetle-caused conifer mortality in forested areas thinned from 1985 to 1998 to similar, non-thinned areas and (2) identified site, stand and individual tree characteristics associated with conifer mortality. We sampled ponderosa pine (*Pinus ponderosa* var *ponderosa* Dougl. ex Laws.) and Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) trees in pre-commercially thinned and non-thinned plantations and ponderosa pine and white fir (*Abies concolor* var *lowiana* Gordon) in mixed conifer forests that were commercially thinned, salvage-thinned, and non-thinned. Clusters of five plots (1/50th ha) and four transects (20.1×100.6 m) were sampled to estimate stand, site and tree mortality characteristics. A total of 20 pre-commercially thinned and 13 non-thinned plantation plot clusters as well as 20 commercially thinned, 20 salvage-thinned and 20 non-thinned mixed conifer plot clusters were established. Plantation and mixed conifer data were analyzed separately. In ponderosa pine plantations, mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) caused greater density of mortality (trees ha^{-1} killed) in non-thinned (median 16.1 trees ha^{-1}) compared to the pre-commercially thinned (1.2 trees ha^{-1}) stands. Percent mortality (trees ha^{-1} killed/trees ha^{-1} host available) was less in the pre-commercially thinned (median 0.5%) compared to the non-thinned (5.0%) plantation stands. In mixed conifer areas, fir engraver beetles (*Scolytus ventralis* LeConte) (FEN) caused greater density of white fir mortality in non-thinned (least square mean 44.5 trees ha^{-1}) compared to the commercially thinned (23.8 trees ha^{-1}) and salvage-thinned stands (16.4 trees ha^{-1}). Percent mortality did not differ between commercially thinned (least square mean 12.6%), salvage-thinned (11.0%), and non-thinned (13.1%) mixed conifer stands. Thus, FEN-caused mortality occurred in direct proportion to the density of available white fir. In plantations, density of MPB-caused mortality was associated with treatment and tree density of all species. In mixed conifer areas, density of FEN-caused mortality had a positive association with white fir density and a curvilinear association with elevation.

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1. Introduction

In Western North America, bark beetles (Coleoptera: Curculionidae, Scolytinae) are native forest insects whose endemic populations create canopy gaps for new growth by colonizing and killing older, diseased or declining trees (Cole and McGregor, 1988; Lundquist and Negron, 2000). Bark beetles play a crucial role in forest nutrient cycling and promote biodiversity by providing forage for avian and other species (Furniss and Carolin, 1977; Martin et al., 2006). At outbreak population levels, beetles can cause extensive tree mortality altering forest structure, reducing fiber productive capacity, and diminishing stand aesthetics (Cole and McGregor, 1988; Fiddler et al., 1989; Cochran and Barrett, 1998). Increases in surface fuel loadings also follow bark beetle-caused mortality (Jenkins et al., 2008; Klutsch et al., 2009).

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) and fir engraver (*Scolytus ventralis* LeConte) (FEN) are economically important species whose outbreaks have led to extensive

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mortality in ponderosa pine (*Pinus ponderosa* var *ponderosa* Dougl. ex Laws.) and white fir (*Abies concolor* var *lowiana* Gordon) forests. For example, MPBs caused mortality of 870,000 trees from 1999 to 2003 in California and FENs contributed to the death of over 1.2 million trees in the forests of northern California from 1977 to 1978 (Ferrell, 1986; USDA, 2004).

Land managers and researchers have sought ways to reduce tree mortality caused by bark beetles since the early 1900s when direct control techniques to eliminate pre-flight bark beetle brood were extensively tested (Miller and Keen, 1960). While many methods of direct control are effective in causing brood mortality, application on a landscape-scale is ineffective or impractical for outbreak mitigation (Miller and Keen, 1960; Amman and Baker, 1972; Sartwell and Stevens, 1975). However, silvicultural treatments that manipulate stand density have been shown effective in reducing bark beetle-caused mortality in multiple forest types (Fettig et al., 2007).

Thinning is the reduction of stand density to reallocate growing space and increase vigor in residual trees (Oliver and Larson, 1990). Trees with low vigor can have greater risk of bark beetle attack and subsequent mortality after being attacked (Sartwell, 1971; Larsson et al., 1983). Thinning ponderosa pine can reduce competition leading to immediate decreases in water stress that can last from 8 to 16 years and contribute to increases in phloem thickness, net photosynthetic rates, and annual or periodic basal area increment growth rates (Kolb et al., 1998; Zausen et al., 2005). In true fir stands, thinning can increase residual tree vigor by 60% within two years of treatment while increasing diameter growth and net volume production (Oliver, 1988). Therefore, thinning may reduce bark beetle-caused mortality by alleviating inter-tree competition for scarce resources and increasing residual tree vigor.

Thinning can immediately influence stand microclimate while increases in tree vigor can have a multi-year lag period as trees respond to increased growing space (McGregor et al., 1987; Bartos and Amman, 1989; Amman and Logan, 1998). Benefits of thinning on bark beetle-caused tree mortality can be observed prior this lag period; thus, microclimate may be a mechanism by which thinning can reduce tree mortality (Hall and Davies, 1968; Amman and Logan, 1998). Microclimate variables that may influence MPB behavior or reproductive success after thinning include air temperature, solar radiation exposure, wind speed, and pheromone plume stability (Schmid et al., 1995; Amman and Logan, 1998; Thistle et al., 2004).

Evaluations of thinning in various forest types support this treatment as a means to reduce bark beetle-caused mortality. Thinning studies in ponderosa pine forests consistently report that thinning reduced the density of bark beetle-caused mortality (trees ha^{-1} killed) or, where different thinning intensities were tested, areas with lower density had less percent mortality (trees ha^{-1} killed/trees ha^{-1} host available) compared to areas with higher density (Cole and McGregor, 1988; Fiddler et al., 1989; Schmid et al., 1994). Other studies, while not testing thinning practices directly, lend support to the thinning hypothesis by illustrating positive linear relationships found between ponderosa pine density and the density of MPB-caused mortality (Cole and McGregor, 1988; Fiddler et al., 1989; Oliver and Uzoh, 1997; Amman and Logan, 1998; Negron and Popp, 2004). Few studies have evaluated thinning efficacy in true fir forests. Cochran (1998) reported high levels of FEN-caused mortality in thinned and non-thinned true fir forests during drought conditions. In ponderosa pine/white fir and other mixed-species forests the efficacy of thinning has not been tested in experimental studies to-date (Fettig et al., 2007).

Our study was conducted in the Warner Mountains of northeastern California after a period of below average precipitation coincided with a high occurrence of bark beetle-caused tree mortality from 2001 to 2007 (CFPC, 2001–2007). The goal of this research was to determine if thinning treatments are a viable tool to reduce bark beetle-caused mortality in mixed-species ponderosa pine/white fir stands and ponderosa/Jeffrey pine plantations during drought conditions. Our objectives were to: (1) compare the density and percent of bark beetle-caused tree mortality that occurred from 2001 to 2007 in thinned and non-thinned areas and (2) identify site, forest or individual tree characteristics associated with differing densities of bark beetle-caused mortality.

2. Methods

2.1. Study area

Our study area was the western slope of the Warner Mountains, Modoc National Forest, in northeastern California (Fig. 1). The Warner Mountains are an isolated range with a Mediterranean climate where most of the 38–76 cm of average annual precipitation falls as snow between November and April (PRISM 1961–1990; NRCS, 2010). Forests are primarily located on north-facing slopes that have deep molisol and alfisol soils (Peace, 1965; Vasek, 1978).

The study area was between 1620 and 2230 m and contained primarily ponderosa and Jeffrey pines (*Pinus jeffreyi* Grev. and Balf.) plantations and mixed ponderosa pine and white fir forests. Other tree species in the study area included western juniper (*Juniperus occidentalis* Hook.), incense cedar (*Calocedrus decurrens* Torrey), quaking aspen (*Populus tremuloides* Michx.), and western white pine (*Pinus monticola* Dougl. ex D. Don). Ecological plant association habitats (Smith, 1994) included ponderosa-white fir/serviceberry-oregongrape (*P. ponderosa-A. concolor/Amelanchier alnifolia* Nutt. ex M. Roem.-*Mahonia aquifolium* Pursh Nutt.), yellow pine-white fir/serviceberry-oregongrape (*P. ponderosa* and *P. jeffreyi-A. concolor/A. alnifolia-M. aquifolium*), and ponderosa-white fir/spreading snowberry (*P. ponderosa-A. concolor/Symphoricarpos mollis* Nutt.).

2.2. Silvicultural treatments surveyed

Forest management practices assessed included pre-commercial, commercial, and insect salvage thinning. Forest areas that were pre-commercially thinned (hereafter referred to as plantations) were planted at 1.2 m × 1.2 m spacing with ponderosa and Jeffrey pine seedlings as pure or mixed-species in the late 1930s and early 1940s after a stand-replacing fire in 1929 (Oliver and Uzoh, 1997). Plantations were pre-commercially thinned in the early 1990s to an average of 6.1 × 6.1 (range 4.3 × 4.3–7.0 × 7.0) m spacing and 274 (247–408) trees ha^{-1}. Areas that were commercially thinned or salvage-thinned (hereafter referred to as mixed conifer) were naturally regenerated stands of mixed-species dominated by ponderosa pine or white fir. Commercial thinning treatments took place at an average of 12 (7–13) years before the onset of tree mortality in 2001 with a mean residual basal area (BA) target of 37 (31–49) $m^2\,ha^{-1}$. Salvage-thinning treatments occurred on average 5 (3–8) years prior to 2001 and combined salvage harvesting of bark beetle-killed trees with live-tree thinning to reduce BA to 25 (18–39) $m^2\,ha^{-1}$.

Historical disturbances in the mixed conifer forests included grazing since the late 1800s, fire suppression since around 1910 and harvesting (primarily of pines) since the early 1900s. These disturbances, as well as MPB and western pine beetle (*Dendroctonus brevicomis* LeConte)-caused ponderosa pine mortality, likely contributed to an increase in the number and proportion of white fir trees in forested areas and grass-dominated meadows (Eaton, 1941; Vale, 1977).

Stands thinned from 1985 to 1998 were identified using the Forest Service Activity Tracking System (FACTS) geospatial database (Modoc National Forest), research of stand record cards, and field