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Long-term impacts of stand management on ponderosa pine physiology and bark beetle abundance in northern Arizona: A replicated landscape study

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Abstract

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forests in northern Arizona have degraded due to overgrazing, logging, and fire suppression that accompanied Euro-American settlement in the late 1800s. Overstocked stands of suppressed trees with low structural diversity dominate the landscape. These conditions create high risk of catastrophic fires and insect outbreaks. We investigated long-term effects (8–16 years post-treatment) of thinning and thinning + prescribed burning on ponderosa pine water stress, leaf carbon isotope discrimination and nitrogen concentration, oleoresin exudation flow, phloem thickness, radial growth, and bark beetle abundance relative to unmanaged control stands over 2 years of measurement in 12 stands replicated across the landscape. Predawn water potential in late June, phloem thickness, and basal area increment were lower in unmanaged than managed stands. Oleoresin exudation flow in July was greater in unmanaged and thinned + burned stands than thinned stands, and greater in a warm year than a cooler year. Leaf nitrogen concentration differed between years, but not among treatments. Tree competition and water stress were positively correlated, and tree competition was negatively correlated with radial growth and phloem thickness. Pheromone-baited trap catches of *Dendroctonus* spp. (*D. brevicomis* Leconte pooled with *D. frontalis* Zimmerman) were higher in unmanaged than managed stands, whereas catches of *Ips* spp. did not differ among treatments. We conclude that thinning with and without prescribed burning can have long-term effects on ponderosa pine water stress, growth, phloem thickness, resin flow, and bark beetle abundance. Low levels of tree mortality from bark beetles at our study sites suggest remarkable resistance of ponderosa pine in mid-elevation forests in northern Arizona, even at high tree densities.

Keywords: Competition; *Dendroctonus brevicomis*; *Dendroctonus frontalis*; Fire; *Ips pini*; *Pinus ponderosa*; Prescribed burning; Resin defense; Thinning

1. Introduction

Many experts agree that current forest conditions in northern Arizona are unsustainable due to increases in

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tree density that have occurred since Euro-American settlement in the late 1800s (Covington et al., 1997; Dahms and Geils, 1997; Allen et al., 2002). Current, undesirable conditions include overstocked stands of suppressed trees, high fuel loads, low understory diversity, and homogeneity of tree size and age classes (Covington and Moore, 1994a; Covington et al., 1997; Stone et al., 1999). With these conditions come high risk of epidemic insect outbreaks and catastrophic wildfire (Olsen et al., 1996; Feeney et al., 1998; Kolb et al., 1998; Fulé et al., 2001; Sanchez-Martinez and Wagner, 2002). The current state of the Arizona ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest is a result of overgrazing, logging, and fire suppression that accompanied Euro-American settlement, in addition to favorable conditions for tree establishment in the early 20th century (Cooper, 1960; Covington and Moore, 1994b; Savage et al., 1996). These factors promoted a pulse of tree regeneration resulting in an almost even-aged cohort of trees growing at high density across the landscape (Savage et al., 1996).

Managers and researchers have implemented thinning and prescribed burning treatments to decrease risk of wildfires and improve ponderosa pine forest condition in northern Arizona. Thinning of these forests is effective in increasing individual tree growth (Ronco et al., 1985; Feeney et al., 1998; Skov et al., 2005), decreasing tree water stress (Kolb et al., 1998; Skov et al., 2004; Wallin et al., 2004), increasing tree defense against bark beetles through increased resin production (Kolb et al., 1998), and increasing leaf nitrogen concentration and hence photosynthetic capacity in some cases (Feeney et al., 1998; Wallin et al., 2004). The few long-term studies of prescribed burning in Arizona ponderosa pine forests suggest that frequent burning can impact tree nitrogen and water relations, and growth. For example, Wallin et al. (2004) reported higher predawn water potentials of old-growth ponderosa pine in thinned plots burned twice at 4-year intervals compared to thinned-only plots and decreased leaf nitrogen concentration in thinned + burned plots compared to thinned-only plots. Similarly, Wright and Hart (1997) found that repeated burning over 20 years depleted soil nitrogen in a ponderosa pine stand. Peterson et al. (1994) reported that prescribed burning at 4–6-year intervals increased ponderosa pine growth rate compared with longer or shorter burn intervals. In contrast to these findings in Arizona, ponderosa pines in thinned and thinned + burned treatments in western Montana had similar physiological characteristics 8 and 9 years after treatment (Sala et al., 2005).

Bark beetle populations in northern Arizona region were endemic prior to 2002 for almost a century (Sanchez-Martinez and Wagner, 2002). However, mortality of ponderosa pine from drought and bark beetles in this region increased dramatically between 2000 and 2003 (http://www.fs.fed.us/r3/resources/health/beetle/index.shtml). Biotic and abiotic stresses such as high inter-tree competition, defoliation, drought, lightning strikes, and fire damage are thought to influence tree susceptibility to bark beetle attack (Berryman, 1976; Christiansen et al., 1987; Ruel et al., 1998; Bradley and Tueller, 2001; Wallin et al., 2003). Thinned stands of several pine species have been reported to be less susceptible to tree-killing bark beetles (e.g., Sartwell and Stevens, 1975; Mitchell et al., 1983; Brown et al., 1987; Amman et al., 1988; Schowalter and Turchin, 1993). Research in northern Arizona has suggested greater ponderosa pine resistance to bark beetles, based on higher resin flow, in thinned or thinned + burned stands compared to unthinned stands (Feeney et al., 1998; Kolb et al., 1998; Wallin et al., 2004). Higher resin flow in thinned stands may result from greater tree resource uptake and greater carbon allocation to constituitive, or preformed resin, and increased resin flow has been associated with an induced resin synthesis response to stem tissue damage from fire or physical wounding, or inoculation by blue stain fungi (Feeney et al., 1998; Ruel et al., 1998; Klepzig et al., 2005). In contrast, severe defoliation because of crown scorch during fire decreases ponderosa pine resin production and increases bark beetle attacks and success (Wallin et al., 2003). In loblolly pine (*Pinus taeda* L.) moderate water stress has been shown to increase carbon allocation to resin production (Lorio, 1986; Lorio et al., 1995; Reeve et al., 1995), but the influence of water stress on resin defenses of other pines is poorly understood.

Our objectives were to compare ponderosa pine water and carbon relations, growth, resin defenses, and bark beetle occurrence among different forest conditions produced by silvicultural treatments in northern Arizona. The conditions are unmanaged stands, stands