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The response of light, water, and nutrient availability to pre-commercial thinning in dry inland Douglas-fir forests

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ABSTRACT

Fire suppression and limited forest management have caused overstocking in many forests across the western United States. Overstocked stands have higher competition for limiting resources and causes tree stress. The amount of stress a tree experiences is related to the current availability of resources (site productivity), and the competition for those resources (stand density). Stressed trees are more susceptible to insects, disease, and mortality, which cause fuel buildup and increase wildfire risk. Pre-commercial thinning (PCT) can alleviate stress by decreasing the amount of competition in younger stands. The objective of this study was to determine how reducing competition through PCT might improve resource availability to trees at a range of initial stand conditions.

We used a triplet-plot approach including 4.3 m and 5.5 m spacing and compared those to unthinned controls in stands varying in site productivity (height growth) and density (initial stand basal area) throughout northern Idaho and northeastern Washington. Stands were dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Douglas ex D. Don) Lindley), and western red cedar (*Thuja plicata* Donn ex D. Don). As expected, higher density stands intercepted greater amounts of light. Thinned stands intercepted 33–58% less light than controls, depending on tree spacing. Site productivity was positively correlated with soil moisture in the spring and soil temperature in both the spring and summer. Pre-commercial thinning increased soil moisture by 6% in the spring and 10% in the summer, and soil temperature increased by 0.5 °C in spring and 1 °C in summer. Douglas-fir foliar N, Ca, Zn concentration decreased after thinning, while P and B increased and S, K, and Cu were unchanged. Thinning had the greatest relative impact on summer soil moisture, followed by soil N availability, and light interception. Thinning response studies frequently focus on light availability; our results demonstrate that the response of soil moisture and nutrient availability exceeded that of light availability for the studied forest types.

1. Introduction

Fire suppression and lack of adequate density management in the Pacific Northwest cause many forest stands to be overstocked. Overstocked stands experience greater competition for growth-limiting resources, including light, water, and nutrients, causing tree stress within the stand (Cole and Newton, 1986; Nambiar and Sands, 1993). In addition to greater competition, changing climatic conditions are putting further stress on trees (Chmura et al., 2011; Elkin et al., 2015). Stress reduces the ability of trees to resist insects and disease and increases the likelihood of mortality (Stoszek et al., 1981; Louda and Collinge, 1992). Overstocking and greater amounts of mortality lead to fuel buildup, creating higher wildfire hazard (Schoennagel et al., 2004). Thus, understanding or estimating the amount of stress or competition a tree is experiencing is critical for prioritizing forest management decisions.

How much stress a tree experiences is largely a function of the availability of the resources essential for tree growth and development (light, water, nutrients), and the amount of competition for those resources (Dobbertin, 2005; He and Duncan, 2000). However, it is easier to measure and quantify the forest growth or productivity than it is to directly measure resource availability. A common indirect measure for the availability of resources or "site quality" at a location is forest productivity or site index. Site index is commonly expressed as the amount of height growth over a given amount of time for the largest or "dominant" trees of a certain species (Monserud, 1984). Higher site index at one location indicates better site quality than lower site index at a different location.

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How resource availability changes with differences in site quality is largely unknown, thus making site quality manipulations difficult and costly. Consequently, forest managers commonly focus efforts on decreasing competition for limiting resources by lowering stand density.

Forest stand density characterizes the amount of competition among trees. The most common metrics of density combine the number of trees per area, and the size of those trees (Reineke, 1933; Curtis, 1982). Higher densities suggest greater competition for resources and therefore, more stress. Suppressed trees, or those with the least competitive advantage, suffer the highest stress levels and will likely die without relief from competition (Dobbertin, 2005). Lowering stand density by removing trees will decrease competition, relieve stress, and improve forest resource availability. Lower competition after thinning also provides residual trees a better chance to cope with changing climatic conditions (Chmura et al., 2011; Giuggiola et al., 2013; Sohn et al., 2013). A common silvicultural practice that reduces the density of forests is pre-commercial thinning.

Pre-commercial thinning (PCT) reduces the density of a forest by felling undesirable trees at a young age to achieve a preferred species composition and spacing. Lower competition resulting from thinning allows for better crown development and growth of residual or "crop" trees (Ferguson et al., 2011), decreased rotation lengths, and better product dimensions (Curtis, 2006). Thinning also increases crop tree resistance to insect attack (Waring and Pitman, 1985) and can decrease the risk of wildfire (Moghaddas and Stephens, 2007). The amount of competition or stress relief depends on both pre- and post-thinning stand conditions. After thinning, limiting resources become more available for both forest and tree growth because of lower competition (Thibodeau et al., 2000; Sterba, 1988).

Resources that initially respond to PCT are either physical resources, such as light, water, and temperature, or chemical resources, such as soil nutrients. Such resources are available immediately after thinning, and continue to respond dynamically as the trees reoccupy the available growing space. More light penetrates tree crowns after PCT, which results in greater photosynthetic capacity for the residual trees (Brockley, 2005; Ferguson et al., 2011). Soil moisture increases after PCT by greater throughfall, less stand water use, and decreased evaporation from higher slash loads (Stogsdill et al., 1992; Smethurst and Nambiar, 1990). Higher soil and pre-dawn shoot water potentials indicate lower post-thinning water stress (Brix and Mitchell, 1986; Laurent et al., 2003). Reduced tree water stress by thinning is a viable option for improving forest resiliency to drought induced by climate change (D'Amato et al., 2013; Elkin et al., 2015; Sohn et al., 2013). Soil temperatures after thinning increase by as much as 2 °C (Thibodeau et al., 2000), which provides a more suitable environment for soil biota and nutrient mineralization processes (Powers, 1990).

Chemical or nutrient resources also respond to PCT and are just as important for tree growth as physical resources. Yet the thinning response to nutrients is not well understood because it is difficult to monitor changes in nutrient availability over time given the high spatial variation that is commonly observed (Binkley, 1986). Nutrient limitations are common in forest ecosystems (Bergh et al., 1999; Davidson et al., 2004; Valentine and Allen, 1990; Webster and Dobkowski, 1983). Foliar nitrogen (N) is commonly beneath critical levels for Douglas-fir, ponderosa pine, and grand fir within the Inland Pacific Northwest of the United States (Moore et al., 2004). Additional nutrient deficiencies in sulfur (S), potassium (K), and boron (B) are often regionally found in Douglas-fir foliage (Coleman et al., 2014). Thinning may alleviate competition for these limiting nutrients. A majority of the nutrients acquired by trees reside in the foliage (Garrison and Moore, 1998), which PCT operations leave on site. Nutrients and organic matter from trees felled after PCT incorporate into the soils, providing greater availability of nutrients to residual trees (Sterba, 1988). Increased foliar N, phosphorous (P), and K concentrations occur after PCT (Carlyle, 1995; Thibodeau et al., 2000), although these results are not consistent across species and regions (Ginn et al., 1991; Velazquez-Martinez et al., 1992). Changes in foliar nutrient concentration dissipate as the canopy responds to changes in nutrient availability (Hokka et al., 1996; Gower et al., 1992). The dynamic nature of nutrient pools and their relationships with other resources (water, temperature) make them difficult to measure (Sands and Mulligan, 1990). Furthermore, how well residual trees are able to acquire these nutrients is uncertain. There is little information about how resources respond to thinning at various initial site conditions. The objective of this experiment was to determine how reducing competition through PCT affected relative resource availability at a range of site productivity and initial stand density with respect to tree and stand growth response.

2. Material and methods

2.1. Study design

We selected 14 sites across northern Idaho and northeastern Washington to represent the range of forest site productivity and stand density commonly found across the region (Fig. 1). Site productivity was determined by measuring dominant Douglas-fir height growth for the last 10 distinct growth whorls (Table 1). If 10 whorls were not well distinguished, height growth for the last five whorls was measured and doubled for comparing to 10-year growth measurements. All measurements were taken after thinning treatments were established. Therefore, control plot basal area during year zero (2013) defined initial stand density prior to thinning.

At each location, three comparable 0.04 hectare (tenth acre) measurement plots were established. Each 0.04 hectare measurement plot was located within a 0.2 hectare (half acre) treatment plot which acted as a buffer. Treatments were randomly applied to each plot conducted during the summer of 2013, including a control (no thinning), 544 trees per hectare (4.3 m spacing), and 321 trees per hectare (5.5 m spacing). The 4.3 m spacing treatment was selected to represent "operational" spacing, and the 5.5 m spacing was selected to determine how the additional removal of competition impacted resource availability. Thinning favored dominant and healthy Douglas-fir trees at approximately equal interval spacing. Study locations were mixed species forests, of which Douglas-fir was dominant, representing from 48% to 98% of the total plot basal area (Table 1). Other common species present at study locations included grand fir, western red cedar, western larch (*Larix occidentalis* Nutt.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and lodgepole pine (*Pinus contorta* Dougl. ex. Loud.), none of which represented more than 36% of the total basal area.

2.2. Site characteristics

Site characteristics were determined using a combination of topographic, soil, and climate variables. We measured soil properties at three random locations in each plot using a bulk density sampler and soil auger. Measurements included bulk density, depth of Mount Mazama volcanic ash (McDaniel et al., 2005), duff layer depth, and soil classification. Parent materials and soil classification were determined through site observations and verified using United States Geological Survey (USGS) maps and Natural Resource Conservation Service (NRCS) soil surveys (USDA NRCS,