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Ten-year responses of ponderosa pine growth, vigor, and recruitment to restoration treatments in the Bitterroot Mountains, Montana, USA

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Abstract

Little is known about ponderosa pine forest ecosystem responses to restoration practices in the Northern Rocky Mountains, USA. In this study, restoration treatments aimed at approximating historical forest structure and disturbances included modified single-tree selection cutting, with and without prescribed burning. We compared the effectiveness of restoration treatments on growth, vigor, and composition of recruitment responses with untreated controls. We used a randomized block design to detect treatment differences in mean individual tree basal area increment (BAInc10), growth efficiency (GE), and recruitment abundance between two restoration treatments (Cut-only and Cut-burn) and a Control. We further examined treatment effects by tree age-class (Young, Mature, Presettlement) using a spatial ANOVA model that incorporates the spatial autocorrelation among trees within experimental units. Ten years after implementing restoration treatments, mean individual tree BAInc10 and GE were significantly higher for treated units relative to Control units; all three age-classes benefited similarly from restoration treatments relative to the Control, with the greatest response in the Cut-only and moderate response in the Cut-burn. When treated units were compared, Cut-burn negatively affected BAInc10 and GE relative to Cut-only. Presettlement trees responded positively to treatment relative to the Control, particularly for BAInc10, demonstrating the potential of these old trees to respond to reduced competition. The Cut-burn treatment, in contrast, negatively affected the BAInc10 and GE response of postsettlement trees when compared to Cut-only. Restoration treatments did not reduce the amount of Douglas-fir recruits. In addition, the recruitment of both ponderosa pine and Douglas-fir species was associated with the proximate cover of woody debris in Cut-only and Control treatments. Finally, special consideration needs to be taken for spring Cut-burn treatments, which appeared to dampen growth and vigor, relative to Cut-only, particularly for Young and Mature trees, and increased recruitment of ponderosa pine and particularly Douglas-fir.

Keywords: Growth efficiency; Prescribed burning; Regeneration; Restoration; Semivariograms; Spatial ANOVA

1. Introduction

Over the last decade, restoration efforts have generally aimed to reintroduce disturbance and re-establish historical abiotic conditions to promote return of the original plant community (Suding et al., 2004; Young et al., 2005). This is particularly true for lower elevation ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forests in the Rocky Mountains, where prior to Euro-American settlement, natural disturbance dynamics were primarily driven by frequent but low intensity surface fires that tended to maintain open, multi-aged, and biologically diverse stands (Agee, 1993; Arno, 1988; Covington and Moore, 1994; Mast et al., 1999). In the northern Rockies, understory burns limited more relatively shade-tolerant competitors, particularly Douglas-fir (*Pseudotsuga menziesii* var. glauca (Mirbel) Franco), from developing in the understory and eventually replacing ponderosa pine (Fiedler, 2000; Thomas and Agee, 1986). In the last century, however, fire exclusion practices have changed the dynamics of these forest ecosystems (Arno and Fiedler, 2005). An increase in understory biomass dominated by shade-tolerant species, along with a decrease of ground flora structure and diversity have been cited as the most striking changes (Arno et al., 1995; Mast et al., 1999; Moore et al., 1999). The increased stocking levels (particularly in the understory) have increased competition for resources, the risk of insect and disease outbreaks, and the potential for stand replacing fires (Arno

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and Fiedler, 2005; Keane et al., 2002). Thinning and prescribed burning are increasingly used to initiate restoration of historical conditions and reduce the risk of stand replacing fires in these forests (Arno et al., 1995; Fiedler et al., 2003; Powers and Reynolds, 2000; Smith et al., 2005). Managers have justified this decision by assuming that presettlement conditions and processes may best represent factors that shaped the evolution of these forest communities (Covington et al., 1997; Moore et al., 1999). However, how these ponderosa pine forests in the Northern Rockies will respond to restoration treatments is not well known.

Studies of ecosystem responses to restoration treatments have led to somewhat contradictory conclusions (Byers et al., 2006; Suding et al., 2004). In Southwest ponderosa pine forests (where fire frequencies are higher than elsewhere) and in the Northern Rockies, treatments such as thinning and prescribed burning have been evaluated based on tree growth and mortality (Feeney et al., 1998; Fiedler, 2000; Skov et al., 2005), as well as on changes in soil nutrient status (Busse et al., 2000; DeLuca and Zouhar, 2000; Gundale et al., 2005; Kaye and Hart, 1998; Monleon et al., 1997; Sala et al., 2005) and understory vegetation composition and structure (Gundale et al., 2006; Metlen and Fiedler, 2006). In some studies, thinning followed by burning has increased soil water availability and improved physiological performance of second-growth (Sala et al., 2005; Skov et al., 2004) and old-growth ponderosa pine (Feeney et al., 1998; Stone et al., 1999). However, in other studies reduced growth and increased mortality have also been reported following prescribed burns (Busse et al., 2000; Landsberg, 1994; Swezy and Agee, 1991). Most of these studies were conducted in second-growth stands or old-growth forest where the focus was on younger trees (Sala et al., 2005) or on presettlement trees only (McDowell et al., 2003), and therefore did not specifically evaluate the response of different age cohorts to restoration treatments (but see Skov et al., 2005).

Ponderosa pine restoration treatments are conducted in part to reduce catastrophic wildfire hazard, but also to improve individual tree vigor, particularly for the conservation of older trees left in the stand (McDowell et al., 2003; Skov et al., 2005; Stone et al., 1999). Improvement in vigor can potentially decrease the vulnerability of these older trees to attacks by insects and pathogens (Coyea and Margolis, 1994; Mitchell et al., 1983). One useful index of tree vigor is the physiologically based measure of growth efficiency, which is the amount of stemwood production per unit leaf area (Coyea and Margolis, 1994; Waring, 1983). Growth efficiency (GE) reflects the average capacity of a tree crown to assimilate carbon, assuming that allocation to stemwood occurs as a lower priority than allocations to defensive compounds and starch storage (Waring and Running, 1998). Growth efficiency has also been examined to measure intensity of competition among individual trees (Mitchell et al., 1983; Waring and Running, 1998), and has increasingly been applied in studies related to tree and stand growth (O'Hara, 1996; Seymour and Kenefic, 2002; Smith and Long, 1989). It has generally been found that GE decreases with increasing tree size and age (Maguire et al., 1998; Seymour and Kenefic, 2002; Waring and Running, 1998), but this also varies with stand structure and the crown class of individual trees (Maguire et al., 1998; Woodall et al., 2003). Little is known, however, regarding the potential for restoration treatments to promote tree growth and vigor, particularly of older individuals in the Northern Rockies (Latham and Tappeiner, 2002; Skov et al., 2005).

Because old trees are scarce in present-day ponderosa pine forests, and restoration efforts have aimed to conserve them and reinvigorate their growth (Skov et al., 2005). Multi-aged silvicultural practices (i.e., selection cutting) aim to maintain vigorous growth on the reserve growing stock (e.g., older trees) and recruit a new age-class (O'Hara, 1996; Smith et al., 1997). Few studies have examined how individual tree selection cutting and subsequent prescribed burning affect the species composition of regeneration (Bailey and Covington, 2002; Fiedler, 2000). Assuming that one of the goals is to restore presettlement forest composition, we must expect a change in the ratio of recruitment composition. In other words, we expect the application of restoration treatments to dampen the recruitment of the relatively more shade-tolerant Douglas-fir when compared to the seral ponderosa pine. Quantitative data on recruitment of desirable regeneration would improve evaluation of alternative treatments (i.e., the assessment of progress or success of restoration efforts), and promote the adoption of effective restoration practices.

In this study, our general aim was to examine the effects of restoration treatments on the mid-term responses of growth, tree vigor, and post-treatment seedling recruitment in a western Montana ponderosa pine forest. Specifically, we compared basal area increment and growth efficiency of overstory trees, as well as the abundance and composition of recruited seedlings 10 years after the implementation of two restoration treatments, relative to an untreated control. Restoration treatments were conducted using modified selection cutting with and without prescribed broadcast burning. Furthermore, we evaluated the response of different tree age-classes to restoration treatments, for which we conducted a spatial ANOVA model that incorporated the spatial autocorrelation among trees. We addressed the following specific questions: (1) is there a significant growth response of reserve trees following restoration treatments, both in terms of increased basal area increment and improved tree vigor (as indexed by growth efficiency)? (2) Do restoration treatments differ in their effects on growth rate and vigor of reserve trees, as well as on the relative abundance of recruitment composition? (3) Do young, mature, and old (presettlement) trees respond differently to restoration treatments? (4) Is seedling abundance spatially associated with local stand characteristics?

2. Study area and methods

2.1. Study site and restoration experimental design

The study area is located at the Lick Creek Research/Demonstration Forest in the Bitterroot Mountains of western Montana (46°5′N, 114°15′W), at an elevation of about 1500 m. The mean annual temperature is 7 °C and the mean annual