

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 BAI_{nc10} 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 BAI_{nc10} and GE relative to Cut-only. Presettlement trees responded positively to treatment relative to the Control, particularly for BAI_{nc10}, demonstrating the potential of these old trees to respond to reduced competition. The Cut-burn treatment, in contrast, negatively affected the BAI_{nc10} 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.

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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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