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Restoration treatments in a Montana ponderosa pine forest: Effects on soil physical, chemical and biological properties

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Abstract

Low-elevation ponderosa pine ecosystems of the inland northwestern United States experienced frequent, low-severity fire that promoted open stands dominated by large diameter ponderosa pine (*Pinus ponderosa*). Fire exclusion has led to increased stand densities, often due to proliferation of less fire-tolerant species and an increased risk of stand-replacing wildfire. These fundamental changes have spurred interest in forest restoration treatments, including thinning, prescribed burning and thinning combined with prescribed burning. We examined the response of numerous soil physical, chemical and biological parameters to these treatments 1 and 3 years post-treatment, using a replicated field experiment. Individual restoration treatments were implemented in 9 ha units. We observed significantly lower C:N in the O horizon and higher O horizon and mineral soil NH_4^+ concentrations in both BURN and THIN/BURN treatments during year 1. Soil NH_4^+ remained elevated through year 3 in the THIN/BURN treatment. Net N mineralization, nitrification and NO_3^- concentration were significantly greater in the THIN/BURN than all other treatments during year 1 and net nitrification rates remained elevated through year 3. A high C:N substrate decomposed more rapidly in both BURN treatments relative to the unburned treatments. Treatments had no immediate effect on the soil microbial community; however, phospholipid fatty acid profiles differed 16–18 weeks following treatments due to higher actinomycetes in the THIN/BURN treatment. The large scale of our treatment units resulted in significant variation in fire severity among prescribed burns as a function of variation in fuel quantity and distribution, and weather conditions during burn days. Correlation analysis revealed that variation in fine fuel consumed was tightly correlated with net N mineralization and net nitrification. These differences in soil characteristics may influence stand productivity and understory species composition in the future.

Keywords: Ponderosa pine; Fuels management; Nitrogen cycling; Microbial community; Prescribed fire; Thinning; Restoration

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1. Introduction

Lower elevation ponderosa pine ecosystems of the Rocky Mountain West (US) historically experienced a frequent, low-intensity fire regime that promoted dominance of large diameter ponderosa pine (*Pinus ponderosa*) (Arno, 1980; Barrett and Arno, 1982; Arno et al., 1995a; Fule et al., 1997; Mast et al., 1999; Moore et al., 1999). The historical fire regime likely maintained more rapid nutrient cycling that corresponded with a diverse understory community of grasses and forbs (Hall, 1977; Mutch et al., 1993; Kaye and Hart, 1998; Moore et al., 1999; Smith and Arno, 1999). An abrupt change in this historical disturbance regime occurred upon Euro-American settlement of the West in the late 1800s and early 1900s (Arno, 1980; Barrett and Arno, 1982; Arno et al., 1995a; Fule et al., 1997; Mast et al., 1999; Moore et al., 1999). A century of fire exclusion may have allowed less fire-tolerant species to become more dominant and C rich organic matter to accumulate (MacKenzie et al., 2004). Some investigators hypothesize that these changes in forest structure and composition have resulted in reduced nutrient turnover relative to historical conditions (Covington and Sackett, 1984; Kaye and Hart, 1998; MacKenzie et al., 2004).

Land managers throughout the West are introducing surrogates of natural disturbance into the ponderosa pine community in an effort to reduce the risk of stand-replacing wildfire. Management strategies to accomplish these goals often include silvicultural thinning or thinning followed by prescribed burning. A third option, less often employed, is the use of prescribed fire by itself. These restoration treatments likely affect ecosystem function in dramatically different ways (Moore et al., 1999). Central to ecosystem function are the numerous processes that occur within the soil that determine resource availability to the plant community. These belowground processes may ultimately influence site productivity, and initial composition and successional trajectory of the understory community. Thus, understanding these belowground responses to alternative restoration treatments may lead to more informed management decisions that may ultimately determine the success of restoration efforts.

Several studies focused on N cycling suggest that important belowground differences exist following these restoration treatments. Comparisons of prescribed fire with unburned controls (White, 1986; Covington and Sackett, 1992; Monleon et al., 1997) consistently show that prescribed fire results in a substantial short-term increase in N mineralization and the availability of inorganic N. Additional studies (Kaye and Hart, 1998; DeLuca and Zouhar, 2000) have also included thinning treatments among these comparisons. Kaye and Hart (1998) found that both thinning and prescribed burning increased N mineralization and inorganic N availability relative to the control in the southwestern US, whereas DeLuca and Zouhar (2000) found that only prescribed fire increased inorganic N pools in western Montana. Few studies have reported how other soil nutrient pools respond to restoration treatments.

The objective of our research was to determine how the initial application of restoration treatments, in a long-term restoration process, affect an array of soil physical, chemical and biological properties. These treatments included silvicultural cutting, cutting followed by prescribed burning, prescribed burning alone and an untreated control. To our knowledge, no published studies have simultaneously examined these restoration treatments under an experimental design where treatments are both replicated and implemented at a scale representative of operational restoration projects. Most studies evaluating fuel management and restoration in ponderosa pine have been conducted at the scale of 1 ha or smaller (Covington and Sackett, 1984, 1992; White, 1986; Monleon et al., 1997; Kaye and Hart, 1998). Larger treatment units allow a more natural spread of fire through stands and better reflect the heterogeneous effects of harvesting activities on fuel distributions compared to studies conducted at smaller scales. This experimental design allows us to examine differences among restoration treatments as well as examine within-treatment variation, variation that is likely to occur in operational-sized restoration projects. Finally, this study provides an analysis of ponderosa pine restoration in the northern half of its range, where far less research has been conducted.

2. Materials and methods

Our study is part of the Fire and Fire Surrogates (FFS) national study network, which includes 13 research sites utilizing similar experimental designs