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Short-term effects of forest restoration management on non-symbiotic nitrogen-fixation in western Montana

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ABSTRACT

Forest restoration treatments involving selection harvest and prescribed fire have been applied throughout the Rocky Mountain West with only a limited understanding of how these treatments influence plant community composition and soil processes. Forest restoration treatments, especially those involving fire, have the potential to reduce N capital on site. Unfortunately there has been only limited effort to investigate the effects of forest restoration treatments on forest ecosystem N inputs, especially free living N-fixation in soil and woody residues. Recent studies have highlighted the potential for decaying woody roots to serve as hot spots for N-fixation. The fire and fire surrogates (FFS) study site at Lubrecht Experimental Forest in Western Montana provided a unique opportunity to investigate the effect of restoration treatments on N-fixation. We set out to examine how prescribed fire, selection harvest, and a combination of both influence free living N-fixing bacteria that colonize decomposing woody roots, mineral soil, and soil crusts. Soil, root, and soil crust samples were collected from replicated treatment plots in August 2005 and soil samples were recollected in May 2006 just following snowmelt. Acetylene reduction assays were run on all samples, and extractable inorganic N and potentially mineralizable N (PMN) were measured in mineral soil. While restoration treatments caused an increase in dead roots associated with stumps and fire killed trees, N-fixation rates were nearly non-existent in these root systems. Nitrogen-fixation rates were not significantly influenced by treatments in decomposing woody roots or in mineral soil, but were slightly greater ($P < 0.10$) in soil crusts when the control stand was compared to treated plots. Nitrogen-fixation rates were also greater in mineral soil than in roots. Soil collected in August exhibited greater rates of N-fixation than soil collected in May which we attributed to higher moisture and an increase in available N following spring thaw. Average rates of free living N-fixation across the treatment plots at Lubrecht were low (0.26 kg N ha^{-1} $year^{-1}$), but over time we estimate that these sources, along with the sparse population of symbiotic N-fixing plants and wet N deposition, would replenish soil N lost through fire or harvesting in approximately 40–100 years.

1. Introduction

Forest managers in western Montana have recently begun implementing restoration treatments in an attempt to reduce fuel loading and reduce the likelihood of stand replacing wildfires in forests that were historically characterized by mixed and low severity fire regimes (Arno and Fiedler, 2005; Gundale et al., 2005). Yet there is limited understanding of the long-term effects of these treatments on various ecosystem processes (DeLuca et al., 2008a). Western ponderosa pine (*Pinus ponderosa*)/interior Douglas-fir (*Pseudotsuga mensziesi* var. *glauca*) forests of western Montana historically experienced low severity, frequent wildfire (Heyerdahl et al., 2008), but past forest management activities have led to high stand densities and greater potential for stand replacing fires, leading forest managers to implement restoration treatments. Forest restoration treatments that include prescribed fire have the potential to temporarily increase N availability, but are likely to reduce total N capital on site (DeLuca and Zouhar, 2000; Gundale et al., 2005; Neary et al., 2005; Smithwick et al., 2005). Historically soil N losses after fire were likely replenished by light loving N-fixing plant communities (Johnson et al., 2005; Newland and DeLuca, 2000).

Treatments including prescribed fires, thinning operations or both techniques have been implemented at a large scale in the Fire, Fire Surrogates (FFS) study at Lubrecht Experimental Forest in western Montana and have been found to affect soil properties and vegetation dynamics (Gundale et al., 2005; Metlen and Fiedler,

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2006). Gundale et al. (2005) reported that forest restoration treatments that included prescribed fire greatly increased N availability during the first year after fire. The fire induced increase in inorganic N was lost by 3 years after fire, however, net nitrification remained elevated through the 3-year study period (Gundale et al., 2005). These findings are consistent with other studies from this region that demonstrate a short-term effect of fire on extractable inorganic N (DeLuca and Zouhar, 2000; Monleon et al., 1997; Smithwick et al., 2005), but that nitrification rates may remain elevated for extended periods of time (DeLuca et al., 2006; DeLuca and Sala, 2006). Although total N in the mineral soil and the forest floor were not significantly altered by fire at the FFS study in Montana, decreases in total N in the forest floor have commonly been observed with prescribed fire as a portion of the organic N in the forest floor is consumed during the fire event (Smithwick et al., 2005).

Nitrogen is the primary limiting nutrient in western forest ecosystems (Mandzak and Moore, 1994; Vitousek and Howarth, 1991) and is partially lost from the ecosystem during timber harvest and fire events. The question of how N is replenished following fire or timber harvest is poorly understood. Symbiotic N-fixing plant species are thought to be the main source of N following disturbance in temperate forest and grassland ecosystems; however, with extended periods of time without fire, the seedbanks of these species may be lost (Leach and Givnish, 1996; Newland and DeLuca, 2000) and many of these species rely on fire for regeneration (Casals et al., 2005; Hainds et al., 1999; Hendricks and Boring, 1999; Johnson et al., 2005; LaJeunesse et al., 2006; Towne and Knapp, 1996). The exclusion of fire from low elevation, dry montane forests in the western US may have increased the importance of free living N-fixing organisms colonizing mineral soil or decomposing woody roots (Chen and Hicks, 2003; Wei and Kimmins, 1998) in replenishing N losses following fire or harvest. In N limited ecosystems, more C is allocated to roots and a great deal of biomass and nutrients are stored belowground, so woody roots could be a significant C source for N-fixing bacteria (Wei and Kimmins, 1998).

The purpose of this research was to investigate how forest restoration treatments impact free living N-fixing bacteria colonizing decaying roots, surrounding soil and soil crusts. The specific objectives of the research were: (1) determine how selection harvest, prescribed fire, and lack of fire influence the abundance and ability of free living N-fixing bacteria in decaying roots, soil, and soil crusts; (2) estimate the approximate N contribution of these organisms to the ecosystems; (3) discuss the relationship between forest management, N export, and the role of these organisms in replenishing N capital. The FFS study site at Lubrecht Experimental Forest provides a unique opportunity to examine the effects of restoration treatments on free living N-fixing organisms at a location that has had intensive data collection on soils, nutrients, weeds, and stand characteristics (Dodson and Fiedler, 2006; Gundale et al., 2005, 2006; Metlen and Fiedler, 2006).

2. Methods and materials

The FFS Montana site is located at the University of Montana's Lubrecht Experimental Forest (Gundale et al., 2005; Metlen and Fiedler, 2006). The mean annual air temperature at the site is 7 °C and the mean annual precipitation is 50 cm, with almost half falling as snow (Nimlos, 1986). The sites were located in approximately 100 years old stands of ponderosa pine and Douglas-fir. Site characteristics and Soil Taxonomy for individual plots are provided in Table 1, detailed soil physical and chemical characteristics are provided in Gundale et al. (2005). Harvesting treatments were implemented in the winter of 2000/2001, and burn treatments were implemented in the spring of 2002. Harvesting was done on frozen, snow-covered soils using a single-grip harvester which cut, limbed, and bucked timber into logs. Logging residues was left in place and trampled by harvest machinery. Logs were yarded at a landing area by a self-loading forwarder. Selection harvest treatments reduced stand basal area from approximately 22 m^2 ha^{-1} down to 11 m^2 ha^{-1} and establish ponderosa pine as the dominant component of the treated stands.

Table 1
Site characteristics for the FFS plots at Lubrecht Experimental Forest, western Montana.[a]

Treatment	Block	Elevation (m)[a]	Aspect (°)[b]	Slope (°)[b]	Soil classification
Control	1	1319	125	13	Eutric Haplocryalfs
Control	2	1265	75	5	Typic Dystrocrepts
Control	3	1253	59	5	Eutric Haplocryalfs
Burn	1	1350	127	10	Eutric Haplocryalfs
Burn	2	1289	336	5	Typic Dystrocrepts
Burn	3	1268	303	5	Eutric Haplocryalfs
Thin/burn	1	1363	123	10	Eutric Haplocryalfs
Thin/burn	2	1307	11	8	Typic Dystrocrepts
Thin/burn	3	1249	263	7	Eutric Haplocryalfs
Thin	1	1306	138	9	Eutric Haplocryalfs
Thin	2	1271	3	8	Typic Dystrocrepts
Thin	3	1262	98	8	Eutric Haplocryalfs

[a] Data from Gundale et al. (2005, 2006) and Metlen and Fiedler (2006).
[b] Mean value derived from 10 plots.

The FFS study is part of a nationwide effort wherein similar restoration treatments were applied at 11 individual locations across the nation (Youngblood et al., 2007). The purpose of the national FFS study was to examine the effects of fuel reduction treatments on vegetation, soils (physical, chemical, biological), fuels, wildlife, insects, and diseases. The study compared four possible restoration treatments: selection harvest (thin-only), prescribed fire alone (burn-only), and selection harvest with prescribed fire (thin + burn), and a no-treatment control in a randomized complete block. Each block was divided into four, 9 ha units, with each unit receiving a different treatment.

Prescribed fires were conducted in May to June 25, 2002 and resulted in 11% duff consumption and 10% mortality on the burn-only treatment plots and 13% duff consumption and 15% mortality on the thin + burn treatment plots. A detailed discussion of the nature of these treatments can be found in Gundale et al. (2005) and in Metlen and Fiedler (2006).

Within each unit, there were 36 reference points established and 10 of these were randomly selected as permanent Whitaker plots. From these 10, five were chosen randomly for the current study. In the summer of 2005 (4 years after timber harvest and 3 years after prescribed fire treatments), at each Whitaker plot within the burn-only and control treatments, a dead tree just outside the Whitaker plot, nearest to the west corner of blocks two and three and the southeast corner of block one was selected.

Two decaying root samples were collected by digging a trench along a main root of a dead tree or stump and then sawing off the smaller root parts. At each Whitaker plot within the thin-only and thin + burn treatments, stumps were almost always selected for root sampling as they were the most abundant dead trees. A total of five samples (of two root segments) were collected per plot, 20 samples per block, yielding a total of 60 samples per treatment. Only large woody roots (>2 mm diameter) were collected as these have been identified as harboring the highest rates of N-fixation (Chen and Hicks, 2003).

Composite soil samples were collected next to each dead tree or stump where root samples were taken. Soil samples were collected using a 2.5 cm diameter stainless steel soil probe and were collected from a depth of 0–10 cm. The O horizon material was