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Recovering lost ground: Effects of soil burn intensity on nutrients and ectomycorrhiza communities of ponderosa pine seedlings

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A B S T R A C T

Fuel accumulation and climate shifts are predicted to increase the frequency of high-severity fires in ponderosa pine (*Pinus ponderosa*) forests of central Oregon. The combustion of fuels containing large downed wood can result in intense soil heating, alteration of soil properties, and mortality of microbes. Previous studies show ectomycorrhizal fungi (EMF) improve ponderosa seedling establishment after fire but did not compare EMF communities at different levels of soil burn intensity in a field setting. For this study, soil burn intensity effects on nutrients and EMF communities were compared at Pringle Falls Experimental Forest, La Pine, Oregon. Twelve replicate sites were used, each with three treatments: high intensity soil burn from large downed wood combustion (HB), low intensity soil burn (LB), and unburned control (UB). Temperatures lethal to fungi were detected at 0-cm, 5-cm, and 10-cm depths in HB soils and 0-cm depth in LB soils. Ponderosa pine seedlings planted post-burn were harvested after four months for EMF root tip analysis. We found: (a) greater differences in soil properties and nutrients in HB soils compared to LB and UB soils; (b) no differences in EMF richness and diversity among treatments; (c) weak differences in community composition based on relative abundance between UB and either burn treatments; and (d) EMF composition in HB and LB treatments correlated with soil carbon and organic matter contents. These results support the hypothesis that the combustion of large downed wood can alter the soil environment directly beneath it. However, an EMF community similar to LB soils recolonized HB soils within one growing season. Community results from both burn treatments suggest an increase in patchy spatial distribution of EMF. We hypothesize that quick initiation of EMF recolonization is possible depending on the size of high intensity burn patches, proximity of low and unburned soil, and survival of nearby hosts. The importance of incorporating mixed fire effects in fuel management practices will help to provide EMF refugia for ponderosa pine forest regeneration.

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1. Introduction

Fire provides many benefits to forest ecosystems by consuming accumulated vegetation and releasing nutrients into the soil. Over the past century, humans have actively suppressed wildfires to prevent damage to human infrastructure and natural resources. As a result, fire exclusion has led to an unprecedented overgrowth of vegetation (Fulé et al., 1997; Safford et al., 2012). The accumulated vegetation acts as fuel when fire returns to a forest, resulting in hotter and more destructive fires (Kaufmann et al., 2005). Climate shifts in conjunction with fuel accumulation are contributing to an increase in the frequency and size of high severity fires and length of fire season in the ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forests of central Oregon (Covington, 2000; Hessburg et al., 2005; Westerling et al., 2005; Millar and Stephenson, 2015). This outlook has created a need for an increased comprehension of the effects of fire on soil ecosystems and their implications for post-fire ponderosa pine regeneration.

The impact of a fire can be classified by burn severity, the "degree to which a site has been altered or disrupted by fire" (NWCG, 2003). The degree of severity can be determined by assessing the physical, chemical, and ecological changes observed post-fire that occur as a direct result of combustion (Keeley, 2009). Burn severity is a product of burn intensity, i.e., the amount of heat energy measured by temperature and duration of heating (NWCG, 2003; Keeley, 2009). The term *soil burn intensity* directly refers to the heat absorbed by the ground during a fire. The size, quantity, arrangement, and quality of the fuel in contact with the

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forest floor influence the depth and degree of soil burn intensity (Busse et al., 2013).

Large downed wood increases soil burn intensity (Busse et al., 2013)—but what role does it play in the post-fire effects and recovery of ponderosa pine forests? In many forest ecosystems decaying downed wood can provide habitat for organisms as well as shade, water, and growing substrate for plants (Maser and Trappe, 1984; Franklin et al., 1987; Fukasawa, 2012). The natural accumulation of large downed wood in ponderosa pine forests was historically managed and maintained by periodic fire (Fitzgerald, 2005). In the environment created post-fire, the combustion of large downed wood can form a mineral soil seedbed temporarily void of competing vegetation for ponderosa pine seedlings (White, 1985). However, large downed wood may also have negative effects on soil. Greater belowground degradation of some soil properties occurs as a result of high intensity soil burning (Neary et al., 1999). Soil nutrients may be volatized or leached at higher temperatures, making them less accessible for plants and microbes (Neary et al., 1999; Bormann et al., 2008). Water repellant layers form during intense soil heating and can contribute to soil erosion (DeBano, 2000). High soil burn intensity can also reduce water content and elevate soil pH (Certini, 2005; Neary et al., 2005), creating a less favorable environment for some plants and microbes.

High soil burn intensity can also directly affect soil microbes, including ectomycorrhizal fungi (EMF) (Holden et al., 2013). Ectomycorrhizal fungi form symbiotic relationships with the roots of host trees and shrubs where water and nutrients are exchanged for the tree's carbohydrates. Through hyphal networks, EMF expand the area of soil from which a tree can attain resources. Ectomycorrhizal fungi can also prevent post-disturbance nutrient leaching, aid in soil stabilization, and supply host trees in depleted soils (Claridge et al., 2009; van der Heijden et al., 2015). In the absence of an EMF symbiont, some conifer species are unable to establish and thrive (Miller et al., 1998).

Ectomycorrhizal fungi can be sensitive to heating by fire. Fungal mortality occurs at temperatures around 60 °C and above (Neary et al., 1999). While the insulating properties of soil help to buffer heat penetration from fire (Neary et al., 2005), the depth can vary depending on soil type, moisture, and other factors (Agee, 1996; Smith et al., 2004). Some EMF produce spores that can withstand higher temperatures (Baar et al., 1999; Peay et al., 2009). Whereas these spores can serve as sources of post-fire inoculum (Cairney and Bastias, 2007), successional dynamics and the length of time needed for recovery are poorly understood. Measures of EMF diversity such as species richness and relative abundance have been used as indicators for recovery of an EMF community (Taylor, 2002). The presence of a diverse EMF community can support the growth and survival of the host plants with which they associate (Barker et al., 2013).

Ectomycorrhizal fungi form an obligate association with ponderosa pine roots that assists trees during drought and provides protection from root pathogens (Read, 1998; Peterson et al., 2004). The first growing season is critical for pine seedlings; EMF colonization during this time can determine seedling success (Horton et al., 1998; Baar et al., 1999; Barker et al., 2013). Previous observational and greenhouse studies have shown EMF also improve ponderosa seedling growth and survival after fire but did not investigate community composition among different levels of soil burn intensity in a field setting (Miller et al., 1998).

Current research gaps expose the question: Does soil burn intensity alter early EMF recruitment on ponderosa pine seedlings? The goal of this study was to investigate first-growing season effects of high intensity soil burning from the combustion of large downed wood in ponderosa forests. To do this, we conducted an *in-situ* experiment with three treatments: high soil burn intensity (HB), low soil burn intensity (LB), and unburned control (UB). We expected to find (a) greater differences in soil properties and nutrient contents in soils subjected to HB treatment in comparison with LB and UB treatments; (b) lower EMF richness and diversity on ponderosa pine seedlings grown in HB soils compared to LB and UB soils; (c) greater differences in EMF constancy and relative abundance in HB soils in comparison with LB and UB soils; and (d) differences in EMF composition in HB plots that would correlate with differences in HB soil properties and nutrient contents.

2. Materials and methods

2.1. Study area

We conducted our research at the Pringle Falls Experimental Forest on the eastern slope of the Cascade Range in Central Oregon (43°42′N, 121°37′W). Pringle Falls is located about 48 km southwest of the city of Bend, in the Deschutes National Forest. Operated by the United States Department of Agriculture-United States Forest Service, the Experimental Forest is part of a national network of outdoor laboratories dedicated for silviculture, insect, disease, fire, and climate change research. Originating from a stand-replacing fire in 1845, the Pringle Falls Experimental Forest has experienced over a century of fire exclusion and infrequent thinning (Youngblood et al., 2004).

A 199 ha area of Lookout Mountain was designated for the study located in a forest stand that was thinned from below (two years prior) to a residual tree density approximating 75% of the maximum recommended stocking level, the site occupancy threshold for competition induced mortality and risk of bark beetle outbreak (Cochran et al., 1994; Youngblood, 2009). The study area ranges from flat to gently sloping terrain (0–20%, southeast aspect) at elevations of 1340–1440 m. Ponderosa pine is the dominant tree species, with a stand density index of 107 and an average basal area of 16.8 m^2 ha^{-1} (Youngblood, 2009). The dominant shrubs of the understory plant communities are bitterbrush (*Purshia tridentata* Pursh) and snowbrush ceanothus (*Ceanothus velutinus* Dougl. ex Hook) typical of a ponderosa pine/bitterbrush/Idaho fescue (*Festuca idahoensis*) plant association (Simpson, 2007). The forest floor includes pine needle litter and duff averaging about 3 cm in depth. Soils are 62–148 cm in depth (to bedrock) and consist of well- to excessively-drained loamy coarse sands and volcanic ash deposits from the eruption of Mount Mazama 7700 years ago (http://websoilsurvey.nrcs.usda.gov/app/help/citation.htm; Powers and Wilcox, 1964). The soils are classified as Xeric Vitricryands in the La Pine Soil Series (Soil Survey Staff, 2014) and the density of pumice components averages 81% (Klug et al., 2002). Hot, dry summers and cold winters typify the climate of the region. The mean annual precipitation is 519 mm, usually arriving in the form of winter snow, and annual temperatures average 6.4 °C (Youngblood et al., 2004).

2.2. Experimental design

We established 12 sites throughout the study area in the summer of 2011. Sites were non-randomly assigned to areas with open canopies for maneuverability of log-lifting machinery. Parallel stacks of large downed logs ("mega-log") were constructed to simulate large diameter coarse woody debris that can be found in ponderosa pine ecosystems. Mega-logs were covered with plastic tarps and left to cure over the following two years. At each of the 12 replicate sites, we established a site center and three plots: high soil burn intensity (HB), low soil burn intensity (LB), and an unburned control (UB). The three plots were located 10 m from the site center, equidistance from one another in a pinwheel design (Fig. 1). HB plots were assigned to mega-log locations. We