Forest Ecology and Management 422 (2018) 11–22

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

# Recovery of ectomycorrhizal fungus communities fifteen years after fuels reduction treatments in ponderosa pine forests of the Blue Mountains, Oregon

Benjamin T.N. Hart[a], Jane E. Smith[b,*], Daniel L. Luoma[a], Jeff A. Hatten[c]

[a] Department of Forest Ecosystems and Society, College of Forestry, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331, USA
[b] USDA Forest Service Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331, USA
[c] Department of Forest Engineering, Resources & Management, College of Forestry, Oregon State University, 280 Peavy Hall, Corvallis 97331, USA

ARTICLE INFO

*Keywords:*
Ectomycorrhizal fungi
*Pinus ponderosa*
Fire
Soil nutrients
Prescribed thinning and fire
Ecological restoration

ABSTRACT

Managers use restorative fire and thinning for ecological benefits and to convert fuel-heavy forests to fuel-lean landscapes that lessen the threat of stand-replacing wildfire. In this study, we evaluated the long-term impact of thinning and prescribed fire on soil biochemistry and the mycorrhizal fungi associated with ponderosa pine (*Pinus ponderosa)*. Study sites were located in the Blue Mountains of northeastern Oregon where prescribed fire treatments implemented in 1998 and thinning treatments in 2000 included prescribed fire, mechanical thinning of forested areas, a combination of thinning followed by fire, and an untreated control. Soil sampling for this study occurred in 2014 and included four replications of each treatment for a total of 16 experimental units. Differences among treatments in Bray-P, total C and N, and pH were likely driven by the thinning treatments and the resultant deposition of residual slash following harvesting or the consumption of slash by prescribed fire. Similar litter depths across treatments suggest that litter depth stabilizes over time in these forests. After more than a decade of recovery, mycorrhizal fungi in dry inland forests dominated by ponderosa pine that were subjected to fire returned to levels similar to the untreated controls. The results of this study demonstrate the resiliency of these forests to disturbances associated with restoration treatments, providing managers increased flexibility if maintaining abundant and persistent fungal communities for healthy soils is an objective.

## 1. Introduction

Fire suppression, among other factors, has contributed to the alteration of previously fire-adapted ecosystems to those more at risk of stand replacing wildfire (Covington and Moore, 1994). In the last two decades, fire suppression costs have been rising exponentially as the amount of forested land that annually burns has increased (Covington and Vosick, 2016). In effect, fire suppression is producing more severe and larger fires by allowing fuel beds to increase relative to historical levels. In response to the rising cost of suppression at a receding benefit of that effort, the potential benefits of proactive actions to reduce wildfire severity have received increased attention. Increased emphasis on restoring fire adapted forest structure, along with appropriate management response to wildfires (FLAME Act 2009) and public education of the ecological benefits of fire, has facilitated heightened interest about the potential for prescribed fire and manual removal of woody materials from forested areas to decrease fire severity.

Historically, forests dominated by ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) extended throughout much of the western United States (Oliver and Ryker, 1990; Graham and Jain, 2005). These forests were characterized by frequent fires that removed understory vegetation and promoted cohorts of trees clumped in densities as low as 20–57 trees $ha^{-1}$ (Covington and Moore, 1994). This sparse distribution allows increased levels of light to reach the forest floor, and when combined with frequent fire, promotes an understory dominated by grasses and herbaceous plants. Historically, low severity fire consumed fuels on the forest floor ranging from fine fuels and litter on a single fire occurrence to coarse woody debris over multiple fires. Germinating shrubs and shade-tolerant seedlings were also removed this way, creating an open understory. These "janitorial services" were removed with the advent of fire suppression, resulting in a shift in plant community structure from herbaceous and shade intolerant shrub to shade tolerant shrub and fire-susceptible tree species such as grand fir (*Abies grandis* (Dougl. ex. D. Don) Lindl.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr) (Moore et al., 1999). In-growth of this community changed fire interactions within these landscapes, bolstered

* Corresponding author.
*E-mail address:* jsmith01@fed.fs.us (J.E. Smith).

https://doi.org/10.1016/j.foreco.2018.03.050
Received 21 December 2017; Received in revised form 23 March 2018; Accepted 24 March 2018
0378-1127/ Published by Elsevier B.V.

competitive stress for water and nutrient sources, and left trees more susceptible to attack from pathogens such as bark beetles (Youngblood et al., 2004). Fires that were historically confined to the forest floor became able to climb a vegetative "ladder" that allows fire to enter the crown layer of the forest canopy and move quickly through the forest, resulting in tree mortality outside the historic range (Binkley et al., 2007). To mitigate risks of future stand-replacing wildfires, forest managers have accelerated the use of fuel reduction methods (e.g. prescribed fire and thinning), but do so with little comparative knowledge of their short and long-term environmental effects.

In the Blue Mountains of eastern Oregon, at the original site of the nationwide Fire and Fire Surrogate study (FFS) network (http://www.fs.fed.us/ffs/sites.htm), fuels reduction with low-intensity prescribed fire and mechanical thinning/removal treatments were studied at the operations scale, a novel approach at the time. A limitation of previous research was that many studies were conducted at scales relatively easy to measure, but not applicable beyond a single site (McIver et al., 2000). Research at the first FFS project area, known as Hungry Bob, incorporated research considerations including wildlife, insects, economics, forest pathology, vegetation, fuels, soils, and soil microbial communities (Youngblood et al., 2006; McIver et al., 2013).

The objective of the FFS study was to determine the ability of fuels reduction treatments to transition fires from those of high severity and often stand-replacing, to those of low severity. Fire severity is a secondary metric related to fire intensity. Fire intensity relates to the energy released by fire (temperature, flames height, duration of heat pulse), while fire severity relates to the consequences of the fires intensity (amount of vegetation killed, amount of fuels consumed, damage to roots) (Keeley, 2009). High severity fires may burn at soil surface temperatures exceeding 300 °C (Smith et al., 2016) and cause partial to total vegetation mortality aboveground and complete or near complete loss of belowground soil microbes in the top 15 cm of the soil profile (Rundel, 1983; Hebel et al., 2009; Reazin et al., 2016; Smith et al., 2017). In contrast, low severity fires typically experience temperatures below 100 °C at the surface and remove mostly smaller shrubs and small diameter trees, leaving larger trees and soil microbes below the top 5 cm intact (Agee, 1973; Cowan et al., 2016).

Soil microbes tend to congregate in the upper portion of the soil profile where nutrient concentrations are highest (Oliver et al., 2015), decrease in frequency with increasing depth (Anderson et al., 2014), and respond quickly to ecosystem disturbances such as fire (Smith et al., 2004, 2005, 2017; Barker et al., 2013; Kageyama et al., 2013; Reazin et al., 2016). However, their long-term response to restoration treatment disturbances, exacerbated by over a century of fire suppression, is largely unknown. Forests in which low-intensity fire has been excluded have diminished release of nutrients bound in accumulated surface leaf litter, duff, and woody debris (Monleon and Cromack, 1996; Monleon et al., 1997). This pool of nutrients, localized in the upper soil layer and diminishing with depth, creates a gradient that is presumably followed by microbial presence and abundance with higher levels of microbes near the surface and lower levels with increasing depth (Hart et al., 2005b). This accumulated duff and organic layer also contributes to increased soil heating in the event of a fire (Ryan, 2002). In a low-severity fire, flames typically have a low duration in any one place, translating into temperatures that barely penetrate the soil, leaving the microbial community intact. Deep organic layers at the soil surface provide fuel that increase the duration of time heat radiates into the soil (Busse et al., 2013; Smith et al., 2016), and have the potential to heat soil to temperatures lethal to soil microbes, communities of which can remain altered after more than a decade (Klopatek et al., 1990).

Soil microbes are directly responsible for the survival of forest trees. Mycorrhizal fungi expand the functional root network of the tree by growing over an increased surface area, making it possible to access water and nutrients that non-colonized tree roots would be unable to access on their own. In many forested systems, the primary limiting nutrients to tree growth are nitrogen (N) and phosphorus (P). Mineralization (mobilization) of these nutrients is often facilitated by other soil microbes in the interstitial space between soil particles (Binkley and Fisher, 2012) and are then absorbed and transported via the mycelial network to the fungal symbiont's host tree(s). In exchange for soil nutrients, the host tree provides carbon (C) to the ectomycorrhizal fungi (EMF) in the form of sucrose, which is then converted to glycogen by the fungi (Smith and Read, 2010). Additional services of EMF to the host tree include physical and chemical protection from antagonistic/pathogenic fungi (Smith and Read, 2010), and connection and transfer of C among other host trees through *common mycorrhizal networks* (i.e. shared mycelial connections among trees) (Molina and Trappe, 1982; Molina et al., 1992; Simard et al., 2015).

While there is a large pool of research on mycorrhizal fungus responses to experimental changes to their environment, few studies investigate beyond a few growing seasons. Indeed, there is a paucity of long-term research on mycorrhiza responses to fire and fire-mitigation, especially when considering the extent of the fire-prone landscapes of western North America (Bastias et al., 2006; Dooley and Treseder, 2012; Holden et al., 2013; Oliver et al., 2015; Overby et al., 2015). It could be expected that after forestry operations to reduce fire risk (mechanical thinning and prescribed fire), adverse effects on fungal populations could occur. Smith et al. (2005) found this outcome, concluding that following restoration activities, fungal abundance and diversity were significantly decreased two years following thinning and one year following subsequent burning treatments. Some evidence suggests that long-term, short rotation burning can alter the belowground EMF to a depth of up to 10 cm (Bastias et al., 2006; Hart et al., 2005a). What is less well known is the response of mycorrhizal fungi to restoration practices and the length of time for which initial damage to the fungal communities persists.

The objective of this study was to assess the EMF community in the dry-climate region of eastern Oregon where fuels reduction treatments were implemented at the Hungry Bob study site over 15 years ago. Specifically we ask, did the impact of mechanical thinning, prescribed burning, or a combined effect of the two as compared to untreated forest stands have a transient or long-term effect? Additionally, is there a spatial component by depth to the EMF communities' variation in diversity, abundance, and composition within the top 10 cm of soil among each treatment type? Also investigated were differences among treatments in soil nutrients C, N, and P; pH and soil bulk density; as well as the recovery of litter - which contributes to nutrient cycling near the soil surface.

## 2. Materials and methods

### 2.1. Study area

Samples were collected from the Hungry Bob study area located on the Wallowa Valley Ranger District (Wallowa-Whitman NF) within the 12,000 ha "Waipiti Ecosystem Restoration Project" (Matzka, 2003). The Hungry Bob project area (www.fs.fed.us/ffs/docs/hb/pubs.html) is located between the Crow Creek and Davis Creek drainages (45°38′N, 117°13′W), about 45 km north of Enterprise, OR, and was designed as an experimental site for operations-scale harvest units. The area covers approximately 9400 ha (50 $km^2$) and was established for the purpose of evaluating the economic and environmental impacts of restoration timber harvesting and prescribed underburning (Youngblood et al., 2008).

Soils found at the study site are generally derived from ancient Columbia River basalts, which form steep topographies interspersed with numerous plateaus, draws, and ridges. In addition, the soil has received ash from pre-historic eruptions of ancient Mount Mazama and other volcanos in the Cascade Mountains to the west (Powers and Wilcox, 1964). While there was some ash deposition from the Mount St. Helens eruption in 1980, it was less than 1.25 cm (Tilling et al., 1990) and investigation of soil at the time of sampling did not reveal an