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The Forest, the Fire and the Fungi: Studying the Effects of Prescribed Burning on Mycorrhizal Fungi in Crater Lake National Park

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RESEARCH SUPPORTING SOUND DECISIONS


Crater Lake National Park, which is rich in a wide variety of mycorrhizal fungi such as these, presented the perfect site for studying the effects of prescribed burning on mycorrhizal fungi and soil attributes. From left—*Cortinarius caperata* and *Tricholoma equestre*. Credit: Matt Trappe.

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Summary

A first-of-its-kind study, conducted in a forest of old-growth ponderosa pine and white fir in Oregon's Crater Lake National Park, explored the relationships among seasonal prescribed burning, an array of soil attributes, and mycorrhizal fungal fruiting patterns. This three-fold approach not only made the study unique, but also enabled researchers to separate the effects of fire treatment from the effects of soil attributes on fungal fruiting patterns.

The study's site encompassed three different prescribed burn treatments—applied in the early spring, late spring, and fall of 2002—as well as non-burned control plots. Analyzing statistics with multiple variables, the researchers identified how the treatments affected specific soil attributes, which soil attributes affected fungal fruiting patterns, and how the burn treatments affected fungal fruiting patterns.

The study revealed that soil attributes—specifically carbon-to-nitrogen (C:N) ratios—drive fungal fruiting patterns, and that while fungal communities respond more to C:N ratios in the soil than to burn treatments, prescribed fire can reduce soil C:N ratios. Most importantly for forest managers concerned with the effects of prescribed fires, the study determined that mycorrhizal fungal communities can withstand even hot prescribed burns in the forests above them.

Key Findings

- Fungal fruiting patterns seem to be driven primarily by C:N ratios in the soil.
- Fungal communities respond more to C:N ratios in the soil than to burn treatments.
- Mycorrhizal fungal communities can withstand the level of disturbance created by a hot prescribed burn.
- The C:N ratios and mycorrhizal fungal fruiting patterns were remarkably consistent, irrespective of burn treatment or location within the study site.

Introduction

Crater Lake National Park's 100-year anniversary celebration in 2002 featured a variety of activities, including a scientific symposium of people conducting research at the park. In attendance was Matthew J. Trappe, a Ph.D. graduate student at Oregon State University who was studying fungi in park campsites. During lunch on the conference's last day, Matt happened to sit next to Dr. Jim Agee—a Fire Ecologist with the University of Washington who was studying the use of experimental burns to restore and conserve old-growth forests in the panhandle area of the park.

"As we talked about our respective projects, light bulbs came on," says Trappe. "Wouldn't it be interesting to study the effects of prescribed fires on soil attributes and mycorrhizal fungi?"

While several studies have examined the effects of fire on soil attributes, and others have examined the effects of fires or soil attributes on fungal fruiting patterns, no study had yet explored the relationships among all three: seasonal prescribed burning, an array of soil attributes, and mycorrhizal fungal fruiting patterns.

Living within the soil, mycorrhizal fungi form a network of threadlike cells, or hyphae, surrounding and permeating the root tips of trees. These fungi collect energy from the tree in the form of sugars produced by photosynthesis. In return, the fungi help the tree absorb water and nutrients and improve the tree's resistance to soil pathogens. Because of this mutually beneficial, or symbiotic, relationship, mycorrhizal fungi are critical to the survival and growth of all forest tree species in the Pacific Northwest and beyond.

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And, because much of the biomass of mycorrhizal fungi resides in the top 4 inches (10 cm) of soil—a region likely to be affected by forest fire—the implications of fire-induced changes in the mycorrhizal community could be significant to post-fire forest recovery and productivity.

The lunch-hour idea set the course for this groundbreaking study designed to separate the effects of fire treatment from the effects of soil attributes on fungal fruiting patterns.

Prescribed burns at Crater Lake National Park provide the opportunity to study fire's effects on soil attributes and mycorrhizal fungi. Credit: Mary Rasmussen.

Understanding why forests need fire and fungi

Old-growth ponderosa pine forests in the western United States depend on regular, low-intensity fires to thin the understory and prevent dangerous accumulations of flammable litter on the forest floor. When frequent fire is suppressed, the increase in fuel loading puts these dry pine forests at risk of more severe fires.

Prescribed fires—fires set and controlled by forest managers—represent a valuable tool for reducing aboveground forest fuels. But prescribed fires also affect the belowground habitat of soil and the mycorrhizal fungi living within it.

These tree-friendly fungi also enjoy a symbiotic relationship with forest wildlife. Mycorrhizal fungi produce mushrooms and truffles, which, like apples to an apple tree, are the fruit of the fungus (also known among scientists as sporocarps, or fruiting bodies that carry spores). Mushrooms fruit aboveground and spread their spores through the air. Truffles are underground versions of mushrooms. Resembling small potatoes, truffles don't form a prominent stem and their spore-bearing surfaces are enclosed. Instead of depending on air currents like mushrooms, truffles rely on animals eating them to distribute their spores. Truffles have evolved strong scents that, as they mature, can be detected from a distance by hungry animals. The animals dig up and eat the truffles and then distribute the spores in their feces.

In this way, animals help spread mycorrhizal fungi throughout the forest, and the fungi return the favor by providing animals an important source of nutrition.

"Crater Lake is rich with truffles. One of the reasons we chose to study the response of mycorrhizal fungal fruiting patterns to fire was this animal connection—truffles are a significant food source for wildlife," says Trappe. "Another consideration is that several mycorrhizal fungi in southwestern Oregon produce mushrooms and truffles of economic value to humans."

For example, many species of mushrooms, such as chanterelles and morels, and a few species of truffles, are considered culinary delicacies. In fact, truffles are the second most expensive food in the world after saffron (French black truffles, for instance, can cost $1,000 per pound).



These photos reflect the exotic diversity of mycorrhizal fungi found within Crater Lake National Park. (From top left) *Morchella angusticeps*, *Ramaria rasilispora*, and (bottom left) *Sarcodon imbricatus*. Credit: Matt Trappe.

Treading new ground—above and below

Working under the guidance of his major professor and the study's lead investigator, Dr. Kermit Cromack, Jr. of Oregon State University, Trappe began his three-year study. He utilized the prescribed burns already implemented by Dr. Agee and his student, Daniel Perrakis, of the University of Washington.

Trappe and Cromack established two hypotheses for this study:

1. That prescribed burning at different times of the year influences belowground habitat differently.
2. That burning at different times of the year affects the post-fire mycorrhizal fungal fruiting patterns differently.

The timing of a prescribed burn influences fire severity because of fuel moisture—and burn severity can modify soil chemistry, fine roots, litter layer coverage and depth, and levels of coarse woody debris in different ways.

All of these factors have the potential to act upon the mycorrhizal community.

- Soil chemistry and fine root survival influence the availability of energy resources and habitability of the immediate environment;
- Litter coverage and coarse woody debris influence soil moisture retention; and
- Coarse woody debris is an important habitat feature for many small mammals that play a major role in distributing fungal spores.

"The relationship between burn treatments and fungal fruiting patterns is not a simple one," Trappe says. "Not much is known about fungi. Each species has its own preferences and personality. They're difficult to study because they don't come up in the same place every year, the sporocarps last only a short time, and most of what happens is underground."

Trappe explains that if researchers go underground, they disrupt the fungi and alter the conditions they are attempting to study. In addition, mycorrhizal fungi don't grow well in culture because they either die or grow too slowly without their tree hosts. So, this type of fungi must be studied as it exists naturally.

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The research area for the study encompassed 24 units averaging 7.5 acres (about 3 ha) in size in an old-growth ponderosa pine stand with a white fir understory in Crater Lake National Park. This site comprised three prescribed-burn treatments (early spring, late spring, and fall burns), as well as non-burned control areas. All burn treatments were somewhat patchy in their intensity and severity, causing minimal damage to the ponderosa pine overstory and varying reductions to the understory of white fir.

"By the time Dr. Agee and I made our connection over lunch, the fires had been implemented," Trappe says. "This meant we had no pre-burn soils data to work from. So, we could only make inferences about pre-treatment soil conditions."

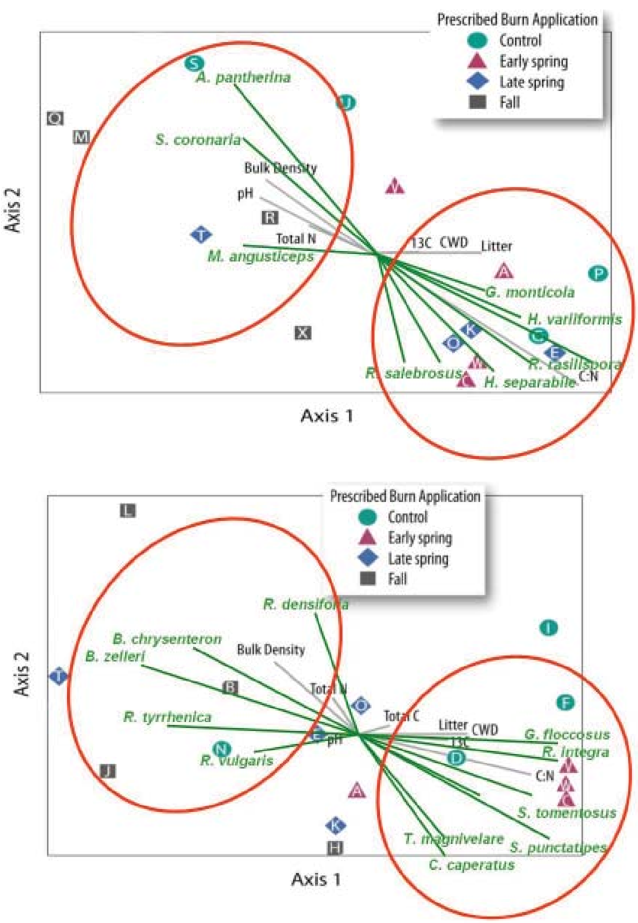
The researchers collected data on ten habitat attributes: mineral soil bulk density, total soil carbon, carbon 13 isotopic depletion, total soil nitrogen, nitrogen 15 isotopic enrichment, C:N ratio, coarse woody debris mass, fine woody debris mass, litter mass, and mineral soil pH.

Some unusual correlations between soil bulk density and burn treatments alerted the researchers to the presence of a pre-existing series of soil property grades across the study area. In addition to soil bulk density, this gradation was also reflected in soil C:N ratios and soil nitrogen levels, and helped to separate the effects of the treatments from the effects of the soil properties on fungal fruiting responses.

Researchers evaluated the 24 units in the study site from three independent perspectives: by treatment, by habitat attributes, and by fungal species. During the three-year study, the researchers identified mycorrhizal fungal sporocarps collected in the spring and fall. They then used a powerful analytical technique called ordination on the fungal and habitat data to:

- Determine the effect of the prescribed burn treatments on the habitat attributes and fungal fruiting patterns,
- Seek relationships within and between the habitat attributes and fungal fruiting patterns, and
- Identify patterns among fungal communities as responses to prescribed burn treatments and habitat attributes.

Ordination analysis produces a scattergram, which can plot species assemblages or environmental variables, and overlay one on the other.



These scattergrams show that fungal species in both spring (top) and fall (bottom) separate into two distinct groups, or "guilds," associated with either high or low C:N ratios.

Uncovering the truth

In addition to revealing that fungal species assemblages in both spring and fall separate into two distinct groups, or "guilds," associated with either high or low C:N ratios, these scattergrams also show that the pattern of C:N ratios at this site was not strictly correlated with burn treatment.

During the study period, researchers identified 566 collections of mycorrhizal fungi, which represented 133 species. Of these 133 species, only 20 were common enough and responded one way or the other consistently enough to be useful as indicator species.

"Although other habitat attributes, such as fuel levels, were correlated with C:N ratios, the single most consistent element corresponding to fungal fruiting patterns was the C:N ratio of the soil—irrespective of burn treatment or location within the study site," Trappe says.

- Overall, the fall burn treatment reduced soil C:N ratios. Most of the fall burned units produced the fungal indicator species associated with lower C:N ratios, but the same fungal indicator species also fruited in the non-burned control units with lower C:N ratios.
- The spring burn treatments did not differ significantly from adjacent non-burned controls in fungal fruiting patterns or C:N ratios.
- Both spring burn treatments produced significantly more fungal species and collections than fall burn units, and slightly more than control units.

In determining treatment effects on habitat attributes, the researchers also discovered that:

- Total soil nitrogen did not vary significantly between treatments, although treatment effects may have been masked by the pre-existing soil property grades.
- Total soil carbon did not differ significantly between treatments, but trended steadily downward from control units to fall burn units.
- Litter mass decreased steadily with burn severity.
- Coarse woody debris responded dramatically to burning, with all treatments differing significantly from each other except controls and early spring burns.
- Fine woody debris levels differed significantly between controls and all burn treatments. Among the burn treatments, only the early spring and fall burns differed.
- Mineral soil pH trended upward from controls to the fall burns, but only those two extremes differed significantly.
- Including all fungal collections with each treatment sampled equally, the total number of collections was significantly lower in fall burns than other treatments. Both spring burns produced more collections than controls but not significantly so.
- With only one exception among 24 units, all units with a C:N ratio below 26 produced a distinct guild of fungal sporocarps, indicated by *Amanita pantherina*, *Boletus chrysenteron*, *Boletus zelleri*, and *Sarcosphaera coronaria*.
- Conversely, all but one unit with a C:N ratio above 26 produced a distinctly different guild of indicator fungal sporocarps: *Cortinarius rigidus*, *Hydnotrya variiformis*, *Hysterangium separabile*, *Lactarius rufus*, *Russula integra*, *R. albonigra*, and *Suillus tomentosus*.

- In no unit or treatment was mycorrhizal fungal fruiting suppressed entirely.

"Within the fungal communities, some like their C:N ratios higher, and some like them lower," Trappe says. "The indicator species rarely intermix. We found that interesting."

These fungi represent members of a distinct guild of fungal sporocarps that prefer a C:N ratio below 26. From left, *Amanita pantherina* and *Boletus zelleri*. Credit: Matt Trappe.

These fungi represent members of a distinct guild of fungal sporocarps that prefer a C:N ratio above 26. From left, *Cortinarius rigidus* and *Hydnotrya variiformis*. Credit: Matt Trappe.

Moving forward

The researchers' first hypothesis was that prescribed burning at different seasons influences belowground habitat differently. This turned out to be true. The fall burns in particular had significant effects on soil C:N ratios, pH, and surface fuel levels.

Their second hypothesis was that prescribed burning at different seasons influences mycorrhizal fungal fruiting patterns differently. This is only partially true. With the exception of Morchella angusticeps, which responded more to the treatment itself than to the effects on soil properties, the timing and consequent intensity of prescribed burn treatments influenced fungal communities only indirectly, as a function of treatment effects on soil attributes.

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"Matt's research met Crater Lake National Park's goal of understanding the effects of fire on mycorrhizal fungi so that park managers can proactively help these forests by restoring fire to the park," says Dr. Cromack. "Having identified the fungal species in each of the treatment units and their relationship to soil attributes and prescribed burn treatments, the strongest course of action going forward would be to continue monitoring this research site for years to come."

Management Implications

- Forest managers weighing the pros and cons of prescribed burns can rest assured that the mycorrhizal fungal community can withstand even a hot prescribed fire.
- Prescribed burns implemented in the spring will have very little effect on fungal communities.
- Fires implemented in the fall significantly reduce fungal productivity and shift fungal fruiting patterns, but do not suppress mycorrhizal fungi entirely.

Further Information: Publications and Web Resources

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Scientist Profiles

Matthew J. Trappe began his career as an electronics engineer, and after ten years in the industry he decided to return to graduate school to study forest and restoration ecology. He received his master's degree in Forest Science in 2001 from Oregon State University by modeling the host and habitat requirements of a record-of-decision (ROD)-listed fungus, *Craterellus tubaeformis*. Matt continued his graduate studies at Oregon State University and received his Ph.D. in Environmental Sciences in 2008, studying the interactions of prescribed fire treatments and recreational activities on forest soils and mycorrhizal and mat-forming fungus communities. He recently completed his Ph.D. thesis as part of this Joint Fire Science Program-funded project. Matt is currently seeking to apply his knowledge of fire and community ecology in western forests.

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Kermit Cromack, Jr. currently is a Professor Emeritus in the Forest Science Department at Oregon State University. He received B.A. and M.A. degrees from the University of Texas in Austin, and a Ph.D. in Botany (Plant Ecology) from the University of Georgia, Athens, Georgia. His research has included studies of forest nutrient cycling, decomposition, and the role of ectomycorrhizal fungi in forest ecosystems. Cromack also has studied the effects of prescribed fire in ponderosa pine forests and in Douglas-fir forests in Oregon.He served as the principal investigator (2003–2007) for this Joint Fire Science Program project at Crater Lake National Park.

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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Joint Fire Science Program
Manager's Viewpoint
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Effects of Prescribed Burning on Mycorrhizal Fungi in Crater Lake National Park

Written By: Lara Durán

Purpose of this opinion piece

Manager's Viewpoint is an opinion piece written by a fire or land manager based on information in a JFSP final report and other supporting documents. This is our way of helping managers interpret science findings. If readers have differing viewpoints, we encourage further dialogue through additional opinions. Please contact Tim Swedberg to submit input (timothy_swedberg@nifc.blm.gov). Our intent is to start conversations about what works and what doesn't.

Problem

White fir (*Abies concolor*) is an undesirable ladder fuel tree species that encroaches into Ponderosa pine (*Pinus ponderosa* var. *ponderosa*) in Pacific Northwest and Sierra Nevada forests that have received active fire suppression/ an absence of fire. Therefore, management objectives in this type of system, even in mature stands, often aim to reduce white fir populations by using prescribed fire.

In these same stands, however, Mycorrhizal fungi also provide an important ecological service. Their fruits have commercial and recreational value as truffles and edible mushrooms. In addition, invertebrates and small mammals have a close relationship with mycorrhizal fungi. It serves as a main food source for many small mammals that disperse the fungal spores.

Mycorrhizal fungi also have an obligatory "win-win" relationship with many green plant and tree species. These fungi gain nutrients from green plants while simultaneously assisting plants with nutrient and water absorption—necessary for plant growth. Conservation of mycorrhizal fungi is therefore a growing concern for Pacific Northwest land managers. Despite the services that mycorrhizal fungi provide, little is known about prescribed fire's effects on the relationship between these fungi's fruiting patterns and the surrounding soil attributes.

Application by Land Managers: Fruiting Patterns and the Suite of Soil Attributes

The information that this study provides on mycorrhizal fungi fruiting patterns, the correlation of fruits with the ratio between carbon and nitrogen (C:N), soil attribute suites, and the effects of fire on fruits is all very useful information for Pacific Northwest forest managers.

Perhaps the most important aspect for managers is the very rich aggregation of mycorrhizal fungi into C:N guilds that can be expected to fruit during different seasons. This information, in combination with the effects on fruiting from fire applied during different seasons, can assist managers with: narrowing the scope of the effects analysis, scheduling inventories, and the monitoring of fruiting bodies.

However, the related, significant questions are: Can soil scientists and botanists easily identify the presence of the C:N guilds in the south central Cascade Range of Oregon? And, how are soil scientists, botanists, and fuels specialists going to quickly know if their project site has the "low" or "high" C:N guild?

Photographic field reference guides of fruiting bodies sorted by guilds would be useful tools to help managers quickly identify guilds in the field. But, at the same time, this information could complicate the workload for Pacific Northwest botanists and soil scientists. Like most green plants, fruiting occurs only during optimal conditions (Hoff et al. 2004). Because season, fire effects, and optimal conditions have influence over fruiting, accurately determining the presence, diversity, and abundance of mycorrhizal fungi and fungal mats could be problematic. While Protocols developed by Pacific Northwest mycologists provide some assistance, the list of species is daunting.

Likewise, the aggregation of soil attributes suggests that the characteristics of Pacific Northwest soils and the effects of fire could be difficult to estimate in the field. While it is important for soil scientists to know these soil attributes are interrelated, managers will focus on compaction, coarse woody and fine woody debris, litter, and erosion hazard.

Even though the soil's chemical components are rarely measured for projects, managers do consider how carbon and nitrogen are cycled relative to the soil's ability to recover from management actions. Managers will be most concerned with short-term versus long-term recovery of soils and mycorrhizal fungi. Thus, the questions managers should ask include: How severe are the impacts? How long do the effects last? What mitigations can we make to mediate the effects?

For the most part, this study focused only on short-term effects.

Coarse Woody Debris Management

The complex link between coarse woody debris, mycorrhizal fungi, small mammals, and C:N cannot be denied. For instance, fungi assist in coarse wood decay and single live tree death, which creates canopy gaps and recycles carbon and nitrogen to soils (Hoff et al. 2004). Additionally, coarse woody debris provides hiding and thermal cover for small mammals.

Mycorrhizal fungi—along with coarse woody debris—is one of the primary habitat characteristics that small mammals require in the Pacific Northwest (Carey and Johnson 1995). This study provides even more evidence for this important relationship. It determined that C:N and coarse woody debris are correlated, and that "high" C:N were connected with above-mean coarse woody debris levels. The study also found that three mycorrhizal fungi (*Gautieria monticola*, *Lepiota magnispora*, and *Piloderma fallax*) were significantly correlated to litter and coarse woody debris abundance. All three also responded poorly to intense burns or soil disturbances.

As a current manager, I am concerned how future managers are going to balance the resource needs of these systems with the changes in fuels and arguments for planning and implementing prescribed fires.

As a current manager, I am concerned how future managers are going to balance the resource needs of these systems with the changes in fuels and arguments for planning and implementing prescribed fires. Certainly, the objectives for prescribed burning in this type of system are paramount to deciding in which season burning should occur. Unfortunately, this study provides little information about the objectives for burning or the burn plan details that influenced fire behavior (such as live and dead fuel moisture).These factors have important consequences for managers who are tailoring fire behavior to fit management objectives.

While no two prescribed fire entries can be exactly alike—even on adjacent plots—these burning conditions/prescribed fire applications are very important to know. Evidently, if managers wish to conserve the three mycorrhizal fungi species correlated with coarse woody debris, fall may *not* be the best window for burning.

Vegetation and Fuel Management

Developing burn plans for fuel reduction in similar stands combined with truffle and fungal mat conservation could be complex. While spring burning appears to yield greater fruiting bodies and fall burns have negative impacts on mycorrhizal fungi and fungal mats, both have negative effects.

The question about meeting burn objectives with spring burning alone becomes a site-specific issue. Spring broadcast burning may not have the same reduction effects on coarse woody debris and over-story and mid-story fuels as fall burning or mechanical thinning.

If mycorrhizal fungi conservation is an issue, would the effects from spring broadcast burning be preferred to thinning and pile burning, chipping, or mastication? When developing fuel prescriptions, these are important questions to consider—with no obvious or easy answers.

A joint demonstration project on the impacts of overstory structure treatments on mycorrhizal fungi, small mammals, and associated physical elements is ongoing and, in combination with this study, may provide managers with options for addressing fuels and conserving mycorrhizal fungi within these systems.

The key question emerges about the role of fire in mycorrhizal fungi ecology compared with prescribed fire effects. Even though Ponderosa pine is generally considered a “fire-adapted species,” an earlier study found that first-entry prescribed fire in nutrient-poor stands in central Oregon can have long-term decreases in available nitrogen (Agee 1993, Monleon et al. 1997). Were the differences in effects between spring and fall burning in Molina’s study the result of changes to soil chemistry that indirectly impacted the mycorrhizal fungi (changes to soil nitrogen and carbon availability, mineralization, volitization)? Or, were they related to direct mortality of mycorrhizal fungi from resident time or soil heating?

Furthermore, it is not clear how summer wildland fires historically differed on their mycorrhizal fungi and fungal mats effects compared to spring and fall prescribed fire. It can be assumed that historic summer wildland fires burned with greater fireline intensity than modern prescribed fire applications. Therefore, is there an evolutionary adaptive relationship between wildland fire and mycorrhizal fungi and fungal mats? Is the frequency and intensity of prescribed fire application in this part of the Pacific Northwest congruent with historic wildland fires? Because soil heating from prescribed and wildland fires during different seasons are bound to have different effects, it really comes down to what effects land managers are comfortable applying.

Not only are the effects of single entries on soil chemistry and mycorrhizal fungi important—what about multiple entries? Perhaps, at some future point, prescribed fire is going to be planned on the same piece of ground as a maintenance burn, or for other reasons. Consequently, how long do managers have to wait until the second entry burn is applied? Should we reenter these sites given the effects to mycorrhizal fungi and the relationships with green trees, spore dispersal, food availability, and predator prey relationships characteristic of the Pacific Northwest forests?

Wildlife Species

The findings from this study have direct relevance on the management and habitat of the northern spotted owl. Mycorrhizal fungi comprise more than 90 percent of the Northern flying squirrel (*Glaucomys sabrinnus*) diet. In turn, this squirrel is a major prey species for the federally listed Northern spotted owl (*Strix occidentalis caurina*). Twenty-three different truffles constitute approximately 88 percent of the northern flying squirrel diet. Complex, tight dependent relationships between mycorrhizal fungi, northern flying squirrels, northern conifer tree species, and the northern spotted owl underlie the importance of the effects from management actions—such as prescribed burning (Weigl 2007).

The negative effects that fall and spring burning have on mycorrhizal fungi highlight the importance of finding a means of meeting management objectives. For instance, reducing white fir ladder fuels while limiting impacts to the fungi. Lehmkul et al. point out: “Management of low-elevation dry forest to maintain or restore stable fire regimes might reduce truffle diversity at stand scales…; but, such management might increase long-term beta and landscape truffle diversity and persistence by reducing the occurrence of high-intensity fires and stabilizing inherent fire disturbance regimes” (2004). Meyer et al. argue for management actions that retain litter depth ≥2 cm for maintaining truffle abundance and canopy cover ≥75 percent for hiding cover to provide northern flying squirrel habitat (2007). Once again, site-specific decisions about whether or not these objectives are in sync with other resource objectives, and whether or not they can be achieved with spring prescribed fire or other tools, remains to be seen.

Forest Structure and Composition

Many Pacific Northwest forest species depend directly on mycorrhizal fungi for nutrient and water uptake. Small mammals’ role in foraging for these fungi and dispersing their spores for future symbiotic relationships with trees is integral to sustaining these forests. It therefore behooves silviculturists to team-up with fuels specialists, wildlife biologists, and soil scientists to ensure the perpetuity of mycorrhizal fungi, small mammals, and northwestern tree species through active forest management. Developing silviculture prescriptions that balance the needs of small mammals (for instance, retaining coarse woody debris, litter depth, and truffles) is not only difficult, but apparently necessary. The application of prescribed fire should be used judiciously in systems where mycorrhizal fungi and fungal mats provide such profound ecological services.

Mushroom and Truffle Collection

Managers concerned with providing harvesting opportunities might be interested to know the fuels management history of these sites. Sites burned in the fall might not produce the quantities of fruits that are produced by unburned or spring burned sites. Thus, this study can influence how managers partition multiple-use objectives that include mycorrhizal fungi collection for commercial or recreational pursuits.

Nutrient Cycling: Carbon and Nitrogen

While few studies have been implemented, the literature suggests that mycorrhizal fungi could act as a carbon sink for elevated levels of CO_2 from fossil fuel emissions (Treseder and Allen 2000). If mycorrhizal fungi and fungal mats do store vast amounts of atmospheric carbon, then more emphasis may be placed on their conservation. This may also make managers think twice about running prescribed fire through mycorrhizal fungi in the fall and, perhaps, even during the spring. Some argue, however, that mycorrhizal fungi fruiting is declining due to increases in nitrogen deposition from air pollution (Arnolds 1991). Given this, if nitrogen deposition rates continue to increase, our efforts at conserving mycorrhizal fungi or using it as a future carbon sink may be in vein.

Scale of Management

This study highlights the complexity of managing Pacific Northwest forests. In doing so, it raises important questions about appropriate management scales and values. While many fire and fuels managers may be unaware of the importance of soil ecology in forest management, the results from this study illustrate how soil microhabitats—mycorrhizal fungi in particular—are strongly influenced by our management actions.

While it is doubtful that truffle and fungal mat abundance will be the driving factor that influences management decisions, the effects to these species is obviously an ecological concern. This is especially true when threatened or endangered species, such as the northern spotted owl, are involved. In such cases, the Endangered Species Act requires consideration and protection of all essential elements of these species' habitats. The related "trickle effect" means including mycorrhizal fungi in our fuels effects descriptions, even when their presence may be hidden below the litter layer. Hence, not only are the findings from this study important on a local and regional scale, they are also important for the value and services that mycorrhizal fungi provide for sustaining native or federally listed trees, plants, and animals of Pacific Northwest forests.

Hence, not only are the findings from this study important on a local and regional scale, they are also important for the value and services that mycorrhizal fungi provide for sustaining native or federally listed trees, plants, and animals of Pacific Northwest forests.

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Manager Profile

Lara Durán is a Fire Planner for the Sawtooth National Forest in Idaho. Her previous positions included Fuels Specialist, Fire Prevention, and Wildlife Technician for the U.S. Forest Service in Colorado. Lara contributed to the JFSP Risk Roundtable, Manager's Reviews, and participated in the national pilot program Integrated Landscape Design to Maximize Fuel Reduction Effectiveness.

She earned a BA in Ecology from the University of Colorado at Boulder where she earned a National Science Foundation grant for undergraduate research in alpine plant development. She was a Wildlife and Plant Ecology Research Assistant at the University of Colorado, contributing to long-term studies on ponderosa pine, Abert squirrels, dwarf mistletoe, elk, American marten, and yucca plants. Since then, she's completed graduate courses in wildlife and plant ecology, law, and administration. She is interested in disturbance ecology and the effects to wildlife.

The information in this Manager's Viewpoint is based on JFSP Project 03-3-2-05, Effects of Prescribed Burning on Mycorrhizal Fungi in Crater Lake National Park; Principal Investigator was Randolph J. Molina.