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Science FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

The Recovery of Soil Fungi Following a Fire

Ariel Cowan

An experiment involving a controlled burn and "mega-logs" constructed to serve as proxies for large downed wood reveals new information about the effects of intense soil heating on soil fungi and subsequent pine regeneration. Chemical changes in the soil, triggered by intense heat, result in the distinctive reddish-tan color and mark the placement of the burned mega-log.

IN SUMMARY

Although burned trees are the most visible damage following a wildfire, a forest's soil can also be damaged. The heat generated by a wildfire can alter the soil's physical properties and kill the fungi and bacteria that are responsible for nutrient cycling and other ecosystem services. What isn't well understood is the extent of the heating within the soil and how quickly the soil recovers.

In the Pringle Falls Experimental Forest in the Deschutes National Forest, researchers with the U.S. Forest Service Pacific Northwest Research Station, Oregon State University, and Kansas State University conducted a study to compare the effects of low-intensity and high-intensity burns on soil organisms and nutrients. The high-intensity burns were simulated by burning "mega-logs," a proxy for naturally occurring large downed wood. They established 12 sites and collected pre- and postburn soil samples and continuous temperature recordings during the fire.

As expected, the soil on the mega-log sites experienced intense heating. High temperatures penetrated 4 inches below the surface but no farther than 12 inches, and soil carbon and organic matter-derived nutrients were volatized. There was also a substantial loss of nearly all the existing microbial communities. Within one week, however, fungi had returned; ascomycete fungi, such as morels, dominated the sites. Ponderosa pine seedlings were colonized by ectomycorrhizal fungi within four months.

"The world depends on fungi, because they are major players in the cycling of materials and energy around the world."

—E. O. Wilson, biologist

If all the fungi within a half gram of forest soil were lined up, they would form a line that's half a mile long. That same half gram of soil includes bacteria that number in the hundreds of thousands. These fungi and bacteria, through their nutrient cycling and other valuable ecosystem services, sustain the forests that dominate the Pacific Northwest. It's why mycologists joke that trees are the photosynthetic appendages of fungi.

"Fungi play so many critical roles in the soils and for the trees," explains Jane Smith, a research botanist with the U.S. Forest Service Pacific Northwest Research Station. "For example, saprobic fungi decompose plant materials and cycle nutrients that the plants can absorb, and ectomycorrhizal fungi, which colonize roots of trees and shrubs, bring nutrients to the plants in exchange for the carbon produced during photosynthesis."

For most of her 31-year research career with the Forest Service, Smith has studied fungal communities within forests. She has witnessed the technological advances that enable researchers to identify specific species within a soil sample and better understand the fungal communities in the drier forests east of the Cascade Range, where the fungi don't fruit as often compared to the fungi found in moist forests.

With the availability of these new analysis methods, coupled with the increasing occurrence of high-severity wildfires, Smith has researched the effects that these wildfires have on forest soils. Although soil has insulating properties, when soil burn temperatures exceed 140 °F, fungi and a tree's fine roots are destroyed. "Nutrients are largely depleted where soils experience a high-severity fire, and vegetation is slow to recover," she says. "Although these high-severity burn areas create diversity on a landscape, it becomes a concern when there is a high percentage of these burned areas."

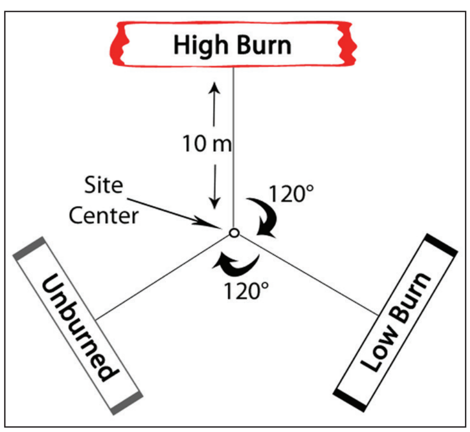
In a study conducted following the Booth and Bear Butte (B&B) Fire that burned 90,770 acres in the Deschutes National Forest in 2003, Smith found that "red" soils, whose distinct reddish color is the result of intense temperatures, aren't sterile as was previously thought. These soils do recover following a high-severity wildfire. However, as significant as those findings were, there were still outstanding questions that Smith hadn't answered. "It always bothered me that we didn't have the preburn information about the soils," she explains. "We couldn't understand fully how deeply the soil was affected by the heat."

KEY FINDINGS

- On the high-intensity burn plots, the complete combustion of logs stacked to simulate naturally occurring large downed wood resulted in surface temperatures up to 2,134 °F. Temperatures greater than 140 °F (lethal to fine roots and soil organisms) penetrated the soil to at least 4 inches but were not recorded at 12 inches.
- Lethal temperatures beneath the stacked logs persisted for 4 to 13 hours. Soil in adjacent low-intensity plots where fuels had been shredded (mechanically masticated) and then broadcast burned experienced lethal temperatures at the surface for about an hour but were not recorded 2 inches below the surface
- When exposed to high temperatures, soil carbon and organic matter volatized to a depth of 4 inches. Although the resulting loss deprived the fungal communities of important sources of nutrients, the high temperatures also released other nutrients, such as calcium and magnesium.
- On the high-intensity burn plots, a substantial change in the soil microbial community occurred within one week. The initially dominant basidiomycete fungi (e.g., mushrooms, chanterelles, and puffballs) were replaced by ascomycete fungi (e.g., morels).
- Ponderosa pine seedlings planted after the burn were colonized by ectomycorrhizal fungi (basidiomycete and ascomycete) within four months.

Creating a Controlled Wildfire

In 2011, Stephen Fitzgerald, the extension silviculture specialist director with Oregon State College of Forestry, was proposing a study at the Pringle Falls Experimental Forest in the Deschutes National Forest and presented Smith with the opportunity to explore these questions. A 490-acre thinning project in the ponderosa pine forest on Lookout Mountain was underway, resulting in large downed wood.



To fully capture the effects of burning upon the forest soil and its fungi, each of the 12 study sites contained three plots with different burn intensities: high intensity, low intensity, and unburned. These different burn intensities represent high- and low-severity wildfires that were once common in the ponderosa pine forests east of the Cascade Range.

Because the burning of large downed wood is responsible for the high-intensity heating that creates red soils, Smith saw a way to burn large downed wood within a controlled setting and capture the missing preburn data.

With considerable help, the researchers established 12 sites throughout the study area. Each site contained three plots representing different burn intensities: high, low, and an unburned control. The low-burn intensity represented the historic wildfire regime of the ponderosa pine forests east of the Cascades.

On the high-intensity burn plots, mega-logs were constructed with parallel stacks of large logs to simulate the naturally occurring large downed wood that would burn during a wildfire. These mega-logs were covered with plastic tarps and allowed to cure for 2 years. This was done to help simulate naturally occurring conditions. "In a forest where you would find a large old-growth log or large woody debris, it would have been in contact with the ground for a while and would have decayed to some extent," Smith explains.

While waiting for the logs to cure, Smith secured funding for Ariel Cowan to join the project while a master's student at Oregon State University.

Cowan was attracted to the project because it not only focused on fungi but also had the fire ecology element. "I had learned a little bit about fire ecology in undergrad, but I didn't know a whole lot about it. Fire plays such a large role in ecosystems of the West," she explains.

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Ariel Cowan

Hotshot fire crews from the Deschutes National Forest Bend-Fort Rock Ranger District conducted the prescribed burning in the Pringle Falls Experimental Forest. Care was taken to ensure that the controlled portion of the plots did not burn.

Smith also reached out to Ari Jumpponen, with whom she worked when he was a doctoral student at Oregon State University. Now a professor in biology at Kansas State University, Jumpponen oversees the Fungal Ecology Lab where he uses high-throughput DNA sequencing to analyze soil fungal communities. For Jumpponen, it was also the intersection of wildfire and fungi that interested him. "There's a lot of important functions that take place in the soil and we have absolutely no understanding of how these functions change as a result of those fire disturbances, whether high or low severity," he says. "That is where I think a lot of the interesting questions are."

In addition to analyzing the pre- and postburn fungal community dynamics and nutrient levels, the study design of high- and low-intensity burning and unburned control plots would enable the researchers to measure how deeply the heat penetrated the soil and how rapidly fungi, specifically ectomycorrhizal fungi, recolonized the soil. Ectomycorrhizal fungi are crucial for seedling regeneration, particularly in areas such as eastern Oregon where the growing conditions are more challenging for seedlings to become established and survive.

Researchers with the U.S. Forest Service Pacific Southwest Research Station lent thermocouple probes to the project as well as data loggers to measure the soil temperatures. Hotshot fire crews from the Bend-Fort Rock Ranger District were recruited to conduct the prescribed burning. In the days preceding the scheduled burn, the researchers collected soil samples and buried temperature loggers in the soil beneath the mega-logs. Cowan recalls some misgivings that the equipment might not work, or worse, be damaged by the heat. They were also concerned that the prescribed fire might be delayed.

"We didn't know when the burn was going to happen because the conditions have to be just right for a prescribed fire," Cowan says. "We kept our fingers crossed that the fire would happen once the data loggers started recording."

On May 14, 2013, the broadcast burn happened without any complications. "The hotshot crew was fabulous to work with," Smith says. "They really took the research question seriously."

One week later, Smith and Cowan returned to the site to collect the temperature recorders and initial postburn soil samples. The following week they planted 2-year-old ponderosa pine seedlings across the plots. In September 2013, four months after they were planted, a subset of seedlings were harvested.

"Other [seedling] studies looked at longer growing periods, such as 1 or 4 years, but not too many looked at shorter timeframes," explains Cowan. "We grew the seedlings only for 4 months because this time spanned the growing season, which is when ectomycorrhizal fungi are most active."

Shaking, Computer Processing, and Examining

To re-create the fungal community recovery, Jumpponen and Cowan took different approaches: Jumpponen sought to identify the fungal species or their molecular proxies based on the DNA of the fungal community. Cowan was specifically interested in how quickly ectomycorrhizal fungi colonized the root tips of the ponderosa pine seedlings.

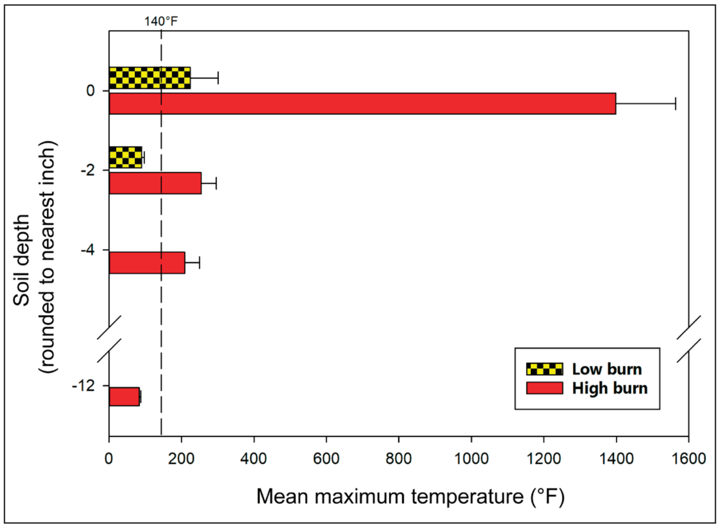
Of the process used to extract the fungi from the soil, "we shake the snot out of the soil and then chemically disrupt the fungal cells," Jumpponen says. "From this mixture, we capture all DNA but disregard that which we cannot assign to fungi." The DNA is diluted into a water solution and using a polymerase chain reaction, which involves using repeated heat applications to open up the double helix and expose a single DNA strand, it's possible to replicate certain regions of the DNA sequence. The replicated regions are then sequenced and run through a computer program that assigns the sequences into their respective operational taxonomic units.

"We're at the brink when we can actually identify the entire community in a sample," says Jumpponen, "which means we can ask questions about how many taxa there are and see what happens in response, to say, environmental manipulations, in this case high-severity fire."

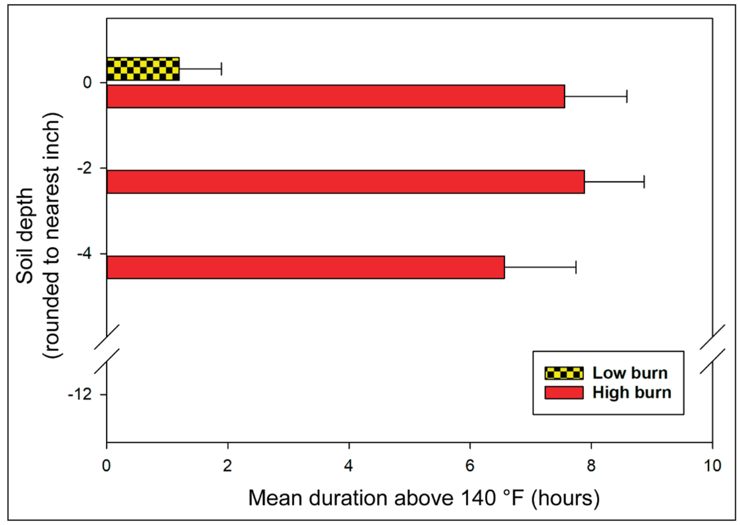
Jumpponen led the statistical analysis of the pre- and postburn samples to identify changes within the fungal communities: Did the number of species increase or decrease? Had the dominance of one species increased following the fire? The analysis revealed that on the high-intensity burn plots, the previously dominant basidiomycetes fungi (e.g., mushrooms, chanterelles, and puffballs) were replaced by ascomycetes fungi, and two fire-responsive species in particular dominated the sites—*Pyronema* and *Morchella* (better known as morels).

Regarding the abundance of *Pyronema,* "This is the first time I've seen such a dramatic change from nearly no detection level to super abundant," explains Jumpponen. "This could mean the spores that are in the soil get stimulated by these disturbances, leap into action, and the fungi accumulate very fast."

Meanwhile, at Oregon State University under the guidance of Smith, Cowan and her undergraduate assistants were examining the washed root tips of 108 ponderosa pine seedlings for ectomycorrhizal fungi. These fungi appear in a variety of forms—hairy to bulbous or fork-like—and in colors ranging from purple and pink to greenish and bluish hues.



Fungi and a tree's fine roots are destroyed when soil burn temperatures exceed 140 °F. On the high-intensity burn plots, lethal temperatures penetrated to at least 4 inches but were not recorded at 12 inches. In contrast, the low-intensity burn plots did not experience lethal heating below 2 inches except in two instances where the presence of buried woody material likely contributed to higher temperatures.



On the high-intensity burn plots, lethal temperatures persisted for 4 to 13 hours and penetrated down to at least 4 inches but were not recorded at 12 inches. In contrast, the adjacent low-intensity plots saw lethal temperatures at the surface for about an hour but were not recorded 2 inches below the surface.

With microscopy, taxa can be distinguished based on their features and colors. From a sampling of these root tips, they collected the fungi and ran a DNA analysis to identify the ectomycorrhizal taxa. In total, 66 taxa were identified, and there was no detected difference in the number of species between the high- and low-intensity burn and unburned plots.

A closeup of root tips from a ponderosa pine seedling that have been colonized by ectomycorrhizal fungi. These beneficial fungi help the plant process nutrients. Researchers analyzed the ectomycorrhizal fungi that had colonized the seedling roots 4 months after the controlled burn. They did not find a difference in the number of fungal species among the high- and low-intensity burn and unburned plots.

Cowan also conducted a statistical analysis on the temperature data and soil nutrient levels. As anticipated, there were differences in the heating patterns. On the high-intensity burn plots, the soil surface experienced temperatures ranging from 795 to 2,134 °F, and lethal temperatures penetrated to at least 4 inches below the soil but were not recorded at 12 inches. Because of the presence of the mega-logs, the surface temperatures remained lethal for far longer (4 to 13 hours). In contrast, the low-intensity burn plots saw surface temperatures ranging from 107 to 680 °F, which are the expected temperatures that occur during prescribed burns. The lethal temperatures did not penetrate below 2 inches except in two instances where the presence of buried woody material likely contributed to higher temperatures.

When it came to the nutrient levels, the high-intensity burn plots experienced a decrease in soil carbon and organic matter, compared to the low-intensity burn plots; however, this decrease was only noted down to 4 inches. Conversely, higher concentrations of calcium and magnesium, which require higher temperatures in order to be released, were found on the high-intensity burn plots. "There's still the beneficial release of certain nutrients that was higher in the high-intensity burned soils, so it's not all gloom and doom," Cowan explains. "These are ponderosa pine fire-adapted ecosystems that need fire; it's just what type of fire and the size of burn patches that matter."

What surprised her about the results was that at depths below 4 inches, there really was no difference between the soil burn intensities. "There's a lot of talk in fire science that when fire comes through an area, it's extremely destructive to the soil with long-lasting impacts, but really there's nuance to it. Depending upon the type of soil and direct contact with woody debris, the burning is not as deep as people originally thought."

The Dynamics of Soil Recovery

Collectively, what does this research tell us? "I think we're getting a handle on how different fire intensities affect the soil, and how quickly the fungal communities recover," explains Smith. "That's information managers can use for prescribed burning with less concern about what it might be doing to the soil."

Another takeaway that land managers may find valuable is knowing that different burn intensities can be used to create soil and fungal heterogeneity at the microsite level. "This project was such an eye opener in terms of differences of temporal dynamics on a very small scale," Jumpponen says. "If you have intrinsic value in biodiversity, managers can create little slash piles when doing prescribed burns."

Peter Sussmann, a soil scientist with the Deschutes National Forest, says that Smith's research has "certainly put my head a little bit more below ground than it was. Pun intended." Sussmann anticipates using these new findings in the course of his National Environmental Policy Act work. "It's very nice being able to reference scientific studies to support your effects' analysis [such as the effects of a prescribed burn upon the soil]," he

Tricia Wurtz

Morels are an example of fire-adapted fungi that will fruit after a wildfire. This edible genus is highly sought after by mushroom hunters.

explains. "Usually we're trying to correlate a study done in, say, Idaho or somewhere else in your region to your site, and it's nice to have research done on your own forest and immediate landscape to be able to reference. It's more powerful and strengthens your analysis."

Going forward, he would like to see continued monitoring of these plots because these data will be invaluable. "There's a lot going on in the soil and it's a very valuable part of the entire system out there that we're trying to protect," says Sussmann.

With Smith contemplating retirement, Jumpponen is taking the lead of the study and expects to continue the sampling in the short term; he is currently working to secure funding to sample the site every other year until 2023. "It's very rare to say that we have gone to the very same landscape unit and we understand the dynamics of returning to the preburned state," he says.

And just as Smith had outstanding questions regarding the heating of the soil, Jumpponen already knows his next quest: a better understanding of the ecosystem services that fungi provide, such as how the nutrients and carbon are being cycled through the system, and how high-intensity burns affect these services.

The ever-whirling wheel of change;
to which all mortal things doth sway.

—Edmund Spenser, poet

LAND MANAGEMENT IMPLICATIONS

- The intensity of soil burning during a fire determines the fungal response. Areas of high-intensity burning tend to be sporadic and limited in scale in ponderosa pine forests east of the Cascade Range. This means burned downed log have the potential to generate distinct patches that substantially contribute to fungal diversity.
- Incorporating mixed-fire effects in fuel management practices will help provide refugia to ectomycorrhizal fungi for ponderosa pine regeneration.
- Long-term monitoring of the effects of temperature-related changes to soils (e.g., microbes, nutrients, and seedling growth) will provide insight for achieving ecological objectives and appropriate management responses under increasing forest fire risk.

For Further Reading

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