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PNW Pacific Northwest Research Station

Science FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

The Secret Life of Microbes: Soil Bacteria and Fungi Undaunted by the Harvesting of Fire-Killed Trees

"We know more about the movement of celestial bodies than about the soil underfoot."

—Leonardo DaVinci

Becki Heath is no stranger to wildfires. As forest supervisor of the Okanogan-Wenatchee National Forest in north-central Washington, she witnessed one of the forest's busiest fire seasons of the last decade, as multiple fires consumed 117,000 acres within the first 3 months of the 2012 season.

Fires claimed twice as many acres while she was forest supervisor on Montana's Gallatin National Forest in 2006. In 1994, when she was on the Okanogan, a fire once burned more than 200,000 acres in a single county.

"I tend to work on (national) forests with a lot of fire activity," Heath says.

As disruptive as wildfires can be while they're burning, the time and effort invested in determining what to do with the newly burned land in the aftermath can be equally formidable, Heath explains.

"We're looking at where the burned areas are in respect to our land management plans, how severely the land was burned, and what are the risks of erosion, mudslides and flooding," she said. "We're trying to determine the best course of action to protect existing resources, while also aiding the recovery of what's been burned."

Doni McKay

Soil bacteria and fungi help to sustain forests by reestablishing nutrient processes and facilitating plant growth. These organisms appeared resilient to mechanical disturbance following a 2003 fire in central Oregon.

It's a decisionmaking process that's affecting more land managers in more complex ways as wildfires continue to grow in size and intensity.

In the last 12 years, wildfires have burned 6.8 million acres a year, on average, compared to the annual average of 3.5 million acres from 1960 to 1999, according to data from the National Interagency Fire Center in Boise, Idaho.

In some circumstances, such as in roadless or wilderness areas, land managers might do

IN SUMMARY

Soil health is fundamental to ecosystem health. Disturbances such as fire and timber harvesting can affect the abundance, activity, and composition of soil microbial communities and thus affect soil productivity. In response to forest managers, scientists with the Pacific Northwest Research Station compared health and productivity indicators between soils disturbed by logging machinery to adjacent soils that were burned but not mechanically disturbed after a wildfire in the Deschutes National Forest in central Oregon.

After a wildfire, one management option is to remove fire-killed trees. Postfire logging recoups some of the economic value of the timber and reduces the fuel available for future fires. Prior to this study, little was known about how harvesting activities might affect soils already exposed to disturbance by fire.

Scientists found that microorganisms essential to soil health appeared resilient to compaction from harvest machinery and to deep tilling (subsoiling). However, these mechanical disturbances appeared to reduce soil nutrients, such as nitrogen and phosphorus, in forms that are readily available for plant uptake. Over two years, the differences in nutrients between the disturbed and undisturbed sites lessened as microbial diversity increased and communities changed in composition.

nothing with the burned areas and allow nature to take its course. In other situations, where the area might have been designated for timber harvesting prior to the fire or there's concern that the amount of dead or dying trees could contribute to more extreme fires in the future, land managers might remove the trees through a practice commonly referred to as "salvage logging."

But little is known about the effects that logging has on soils disturbed by fires, leading scientists with the U.S. Forest Service's Pacific Northwest (PNW) Research Station to investigate that very question.

"In the early 2000s, there were a number of large, stand-replacing wildfires," recalls Jane Smith, a botanist with the PNW Research Station who led the study. "There was very little scientific information at the time on fire and soil effects, so that really provoked us."

KEY FINDINGS

- Soil microbes appeared resilient to disturbances caused by harvesting fire-killed trees. No significant differences were found in the number or composition of bacterial and fungal species in postfire soils compacted by logging equipment or postfire soils that were compacted and then tilled when compared to postfire soils that were not mechanically disturbed.
- Postfire soils disturbed by forest harvesting equipment had, on average, 27 percent less nitrogen in a form accessible for plant uptake than did postfire soils with no mechanical disturbance.
- Postfire soils compacted by forest harvesting equipment and then tilled had, on average, 26 percent less phosphorus in a form accessible for plant uptake than in postfire soils compacted but untilled, or with no mechanical disturbance.
- Soil nitrogen and phosphorus in forms accessible for plant uptake significantly increased two years following disturbance, correlating with changes in both bacterial and fungal community composition between the first and second year after the harvest of fire-killed trees.

A CHANCE OPPORTUNITY

Around that time, a geologist on the Deschutes National Forest contacted Smith to see if she'd be interested in conducting a study on postfire soil effects in central Oregon. In summer 2003, lightning ignited two fires on the forest—the Bear Butte and the Booth (which would eventually be known as the B&B Complex Fire)—that would consume 90,769 acres in a 5-week period.

"Part of the burn area had already been scheduled for a timber harvest," Smith said, "so we thought it was a perfect opportunity to come in and see what effects, if any, salvage logging would have on postfire soils."

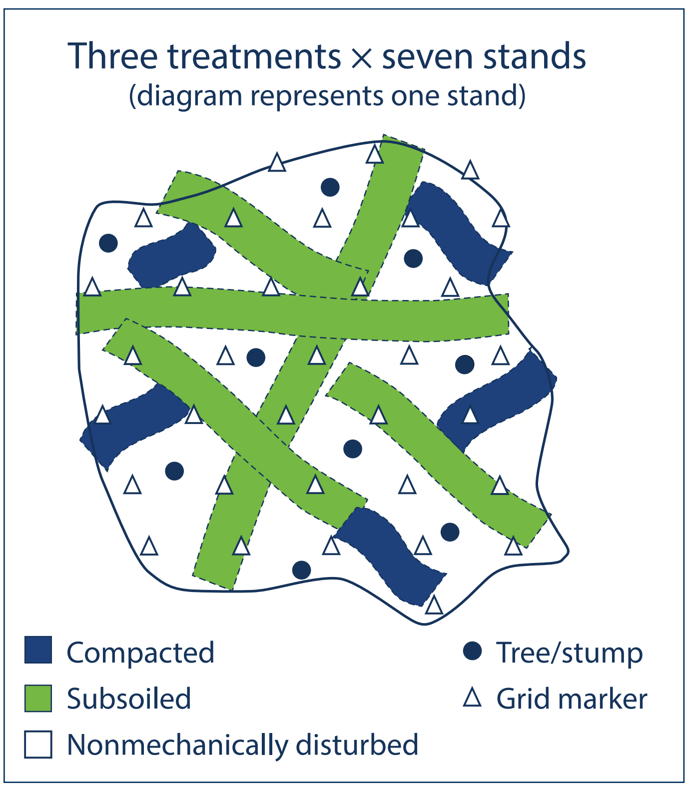
Smith and her colleagues established seven research sites shortly after the logging operations ended in summer 2004. The sites represented a mixture of burn severities and ranged in size from 12 to 29 acres. Within each test site, soil samples were taken from three disturbance categories: (1) compacted areas where logging machinery had traversed and compacted the soil, (2) subsoiled areas where a tillage tool was used to mechanically loosen compacted soil after harvest, and (3) undisturbed areas—burned but not affected by mechanical disturbance.

To evaluate soil health and productivity, Smith and her colleagues measured the diversity of microorganisms such as bacteria and fungi and their ability to transform nutrients into forms that plants can use, amounts of nutrients essential for plant growth, and soil strength and density.

"Microbes matter," says Tara Jennings, a PNW Research Station biologist who worked closely with Smith in the study. "They're the living component of the soil that breaks down organic material into nutritional forms taken up by plant roots and mycorrhizal fungi."

In essence, they're like chefs who take food in an unappetizing form and turn it into something delicious, Jennings explained.

Nitrogen and phosphorus levels also were measured. Nitrogen is critical to the synthesis of amino acids and proteins, as well as the



The experimental design: study sites ranged from 12 to 29 acres.

Purpose of PNW Science Findings

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formation of plant DNA. Phosphorus helps plant tissue, roots, and seeds to develop. It also helps form a necessary energy compound for the plant to take in nutrients and carry out photosynthesis. It's only after microbial enzymes break down these nutrients that they're accessible for plant absorption and use.

Soil strength and density can affect soil productivity in several ways. Soils with greater densities would have less pore space. This means there is less habitable space for microbes or for moisture to pass through the soil and transport or disperse organic matter and nutrients. Looser soils could negatively affect the diversity of microbes because larger pore spaces are more accessible to microbe predators.

A component of soil strength is soil aggregation, referring to how well soil sticks or clumps together. It can be a good indicator of microbe vitality because when microbes feed they exude extracellular enzymes that break down the organic matter into inorganic matter.


Doni McKay

A researcher collects a soil sample from an area with severe soil burning. The high temperatures killed most soil organisms and plant roots and altered the chemical and physical properties of the soil.

"These microbial exudates hold soil together," Jennings said. "The stickier the soil is, the better it combines to form bigger aggregates or clumps of soil. This helps roots and water pass through because the odd-shaped blocks provide lots of small openings and spaces."

DELICATE, YET RESILIENT

Scientists weren't sure what they would find when they began looking for microbes in the burned soil.

"Microbes actually have a fairly low heat tolerance," Jennings said. "Some can be killed at 120 °F, and most are killed at 400 °F. If the fire is hot enough, microbes will be killed and literally go up in smoke."

Although forest fires can burn at temperatures approaching 1,500 °F, heat lost through updrafts and the atmosphere can reduce the surrounding temperature to 140 to 212 °F. Soil heating, however, is a particular concern for microbial composition and function, because depending on the amount and size of fuel on the ground, temperatures may approach 750 °F at 4 inches beneath the surface.

When scientists analyzed the soil samples taken about 4 inches beneath the surface of the B&B Complex Fire, they found 275 bacterial and 160 fungal species across all three treatment areas.

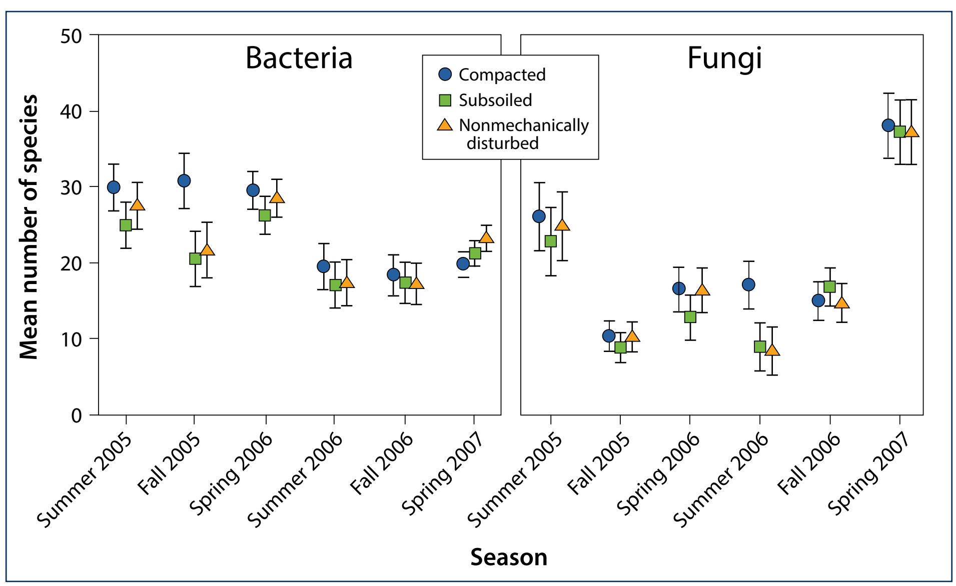
"We were surprised to see how resilient the microbes were to the disturbances that took place," Smith said.

Differences in chemistry, however, were detected among soils having different strengths. On average, there was 27 percent less nitrogen in a plant-available form in the compacted areas compared to the undisturbed areas. Meanwhile, the scientists found, on average, 26 percent less phosphorus in a plant-available form in the subsoiled areas compared to either the compacted or undisturbed areas.

Scientists collected samples from the sites six more times during the next 2 years and found less disparity between the treatment areas as time passed and microbial communities increased.

As hypothesized, scientists also found differences in soil strength among the three treatments, with compacted soils being the densest and the subsoiled areas offering the least resistance. Significant differences in soil strength stopped at about 7 inches of depth between the compacted and undisturbed groups. Subsoiled differences remained to about a foot in depth. Measurement a year later at 4 inches in depth showed soil density to be 15 percent less in the subsoiled areas compared to the other treatment areas; no significant differences were detected between the compacted and undisturbed areas. No significant differences in moisture content were observed among the three treatment areas.

Though not directly studied, researchers hypothesize the differences in soil density might offer an explanation for the variation found in the nitrogen and phosphate data

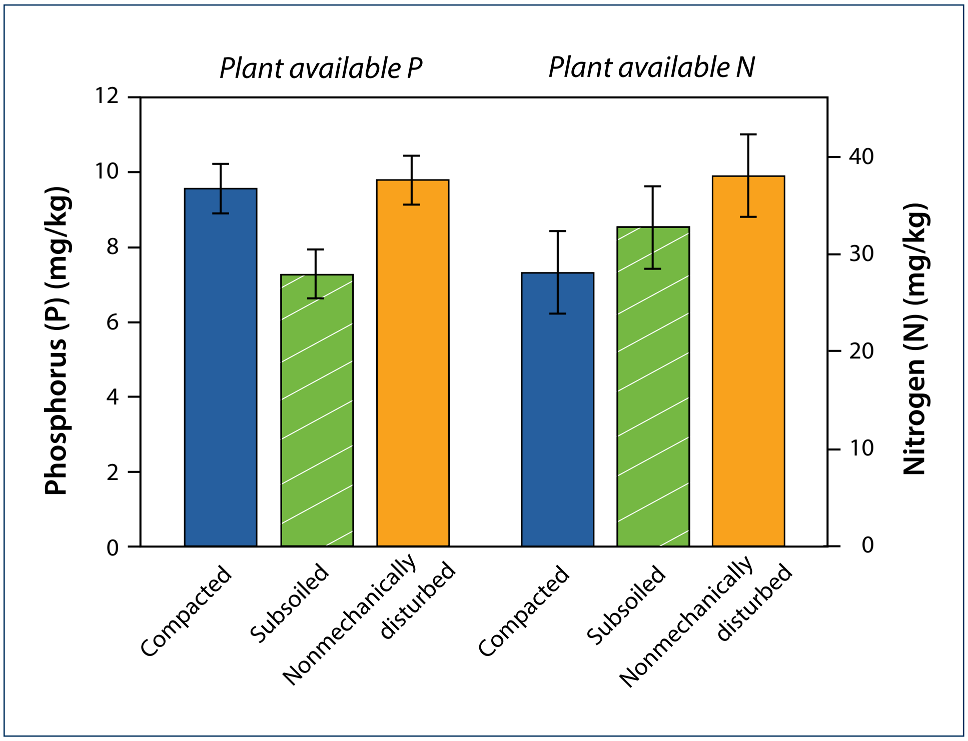


Bacterial species tended to be slightly higher in compacted soils, but there were no significant differences among treatments in the average number of bacterial or fungal species.

among the treatment types. Soil nitrogen, for example, often is derived from the tissues of microbes and other organisms. The small pore spaces in compacted soil might restrict microbes' movement throughout the compacted space, reducing the amount of organic matter that microbes could convert into plant-available nitrogen.

One way to quantify how much microbial activity is present in soils is to measure the concentration of known enzymes. The lower phosphate levels found in the subsoiled treatment areas corresponded with enzyme readings that indicated lower microbial biomass. All three treatment areas had a similar number and diversity of microbial species, but the scientists found the abundance of these organisms was less in the subsoiled areas. This reduced abundance translates into less microbial activity in converting organic phosphate into a form of the mineral available for plant uptake.

"It's always a challenge to measure what's going on beneath the ground because there isn't a single test that captures it all," Smith says. "So you have to pick and choose what you're going to look at and how you're going to look at it and realize that one study won't do it all."



Soils that had been subsoiled appeared to have, on average, 26 percent less phosphorus in a form accessible to plants, compared to the other treatments. Nitrogen in a plant-accessible form was found, on average, to be 27 percent less in compacted soils.

LAVA AND LIMITATIONS

Although Smith and Jenning's research provides new insights into the impacts of soil disturbance arising from post-fire salvage logging, Smith cautions land managers in how widely they can apply their findings.

"Soil type definitely played a part in our findings," she said, noting that the effects of compacting might be more severe in clay soils, compared to the coarser, granular soil that resulted from central Oregon's volcanic past. "You really have to look at the conditions in that study."

It's something Stephen Fitzgerald, an Oregon State University Extension forester based in Redmond, Oregon, already does, and it's exactly what has him excited about Smith and Jennings' study.

"It hits the center of the bull's-eye," he said. "There's a lot of good science out there, but maybe it's from the East, so it might not necessarily be the most applicable to the conditions I'm working in."

As an extension agent, Fitzgerald provides consultations to private landowners and public land managers throughout central Oregon and gives presentations on wildfire-related subjects across the state.

"I'm an interpreter of science," he says. "I share the literature we have, correctly interpreted, so we can make rational decisions."

Salvage logging research is coming at a critical time in land management history in the United States, says Richard Bigley, a forest ecologist with the Washington State Department of Natural Resources.

"Postfire salvage logging really has been one of the defining issues in the last decade of forest science," he said. "In terms of influence on policy and debate between forest science and traditional expectations of the forest, Jennings and Smith's study has really been a phenomenal case study. It's of broad interest and challenges some traditional thinking on the impacts of salvage logging."

Bigley is a member of a small science staff that helps implement a multi-species habitat

Doni McKay

Researchers shared their findings with land managers during a field workshop.

conservation plan, which includes fire-prone northern spotted owl habitat on the east side of the Cascade Mountains. He says he's appreciative of any research that examines management effects on the belowground portion of the forest.

"I've been in this business for about 30 years, and if you look at one of the most exciting developments in forest science, it's that we've discovered the belowground world," he said. "There's a lot happening in the forest below the trees. When I describe a forest to someone, the first thing I do is dig a soil pit."

Smith says she's also noticed an increased awareness of the importance of soil productivity in forest recovery.

"In the last 5 years, there's been a lot more interest in soil microbes than ever before," she said, noting that she has been asked to give a number of workshops on the subject across the country. "Maybe it's because we have the technology to better detect them. But whatever the reason, there seems to be a lot more interest in the life in the soil."

And understanding that life hopefully will assist land managers in their restoration decisions following major land disturbances such as wildfire, Smith says.

"People recognize the complexity of the ecosystem and understand how suppression of wildfires has thrown the system out of whack," she said. "So when looking at restoration techniques—and salvage logging can be a restoration technique—land managers need to consider the impacts of all actions and inaction."

Back on the Okanogan-Wenatchee National Forest, Heath and her staff haven't decided if any of their recently burned forest will be logged, but soil effects will be considered regardless of the decision, Heath says.

"Knowing how a logging operation might affect soil nutrients is important to us," she said. "We're not going to take actions that do not meet a restoration objective."

Doni McKay

A site's recovery potential and likelihood that a high density of fire-killed trees will increase the area of severely burned soil in a future fire are key considerations in the decision to harvest or not harvest fire-killed trees.

"… I cannot conceive of the time when knowledge of soils will be complete. Our expectation is that our successors will build on what has been done, as we are building on the work of our predecessors."

—R.S. Smith, director of the Illinois Soil Survey, 1928.

FOR FURTHER READING

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LAND MANAGEMENT IMPLICATIONS

- The availability of soil nitrogen and phosphorus provides a useful comparative basis for evaluating forest management activities. This study revealed changes over time in both bacterial and fungal community composition that corresponded with significant increases in plant-available nitrogen and phosphorus.
- Knowledge of fire and postfire logging effects on soil productivity can be used to develop silvicultural treatments to protect and restore habitat for these microorganisms.
- This information can be factored into management decisions to harvest or not harvest fire-killed trees. Two key considerations are the recovery potential of a site and the potential for a high density of fire-killed trees to increase the area of severely burned soil in the event of a future fire.

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