PNW
Pacific Northwest
Research Station

Science FINDINGS

INSIDE

issue sixty six / september 2004

"Science affects the way we think together."
Lewis Thomas

DEAD WOOD, LIVING LEGACIES: HABITAT FOR A HOST OF FUNGI

"The diversity of life forms, so numerous that we have yet to identify most of them, is the greatest wonder of this planet."
—E.O. Wilson

Why would anyone want to conduct surveys for a fungus that lives below ground, is smaller than a golf ball, and is often the same color as the soil? How would you even undertake such an enterprise?

For business entrepreneurs, the reason is simple: truffle hunting can carry a reward of hundreds of dollars per day, depending on the highs and lows of the mushroom market. For mycologists in the Pacific Northwest, however, the reason is both simple, and very tangled. Forest fungi, both edible and obscure varieties, are interwoven throughout forest food webs, and their conservation is today widely recognized as a crucial component of ecosystem management.

Increasingly, federal land managers are including lesser known species such as fungi in their assessments of ecosystem health. Indeed, the Northwest Forest Plan, which governs federal land management in the Pacific Northwest, requires consideration of all types of biodiversity. And throughout the region's conifer forests, there is a tremendous diversity of fungi hidden in the soil.

Scientists have only recently begun to understand their unique role in these ecosystems. But how do they find such cryptic organisms?

Digging. Lots and lots of digging.

"We'd love to recruit some squirrels or pigs to sniff out buried fungal fruits and show us just where to dig," says Jane Smith. Instead, they have the next best thing—legions of eager volunteers. Some are locals who are amateur mycologists and willing to learn more themselves in the process of helping the scientific enterprise. Others are professionals who come to Oregon from around the world with a fascination for forest fungi.

Even with the volunteers, there is just no easy way to do it. Surveyors carefully rake through the soil and look for small clusters of potato-like fungi known as truffles. These ectomycorrhizal fungi, like their aboveground mushroom relatives, colonize the fine root tips of trees in a mutually beneficial relationship with their hosts.

"It is meticulous work and you must keep sight of the rewards associated with learning something new," explains Smith, a research botanist at the PNW Research Station in Corvallis, Oregon. Days are long during the

Credit: Randy Molina

Researchers carefully rake the soil to unearth a truffle.

IN SUMMARY

The web of life that exists below ground and out of sight may be the final frontier for forest ecologists. Among the many unknowns in this realm are the thousands of species of so-called ectomycorrhizal fungi, those fungi that have mutual-need associations with both trees and mammals.

The richness and diversity of ectomycorrhizal fungi species contribute directly to biodiversity, and also have a significant impact on forest function through their interactions with other species. These fungi are extremely difficult to survey and identify; however, recent Station research has established better understanding of how fungi interact with forests of all ages.

The results suggest that fungi species change as forests age, and that unique species assemblages are found in each stage of forest development. In addition, the findings are providing data to address critical conservation biology questions such as how well legacy structures provide for aspects of biodiversity. Such knowledge is essential for making sound management decisions about the conservation of forest species, the organisms they support, and forest ecosystem sustainability.

field season. Researchers start early in the morning in order to train new volunteers and, when samples are abundant, work late into the night identifying all of the day's finds.

In case this assignment isn't already difficult enough, the surveyors are limited to only a few weeks in spring and autumn when the fungi are fruiting, producing mushrooms or truffles. That is the stage of their life cycle when they can be most easily identified. And if the conditions are too dry, the fungi might not fruit at all.

In Smith's first season with the research team, they found only a shoe box full of samples to show for their efforts. By contrast, the next autumn, when weather conditions induced abundant fruiting, they gathered thousands of fungi, which took up the better part of a room. This kind of annual variability means that when conditions (and fungi) are ripe, surveyors must work tirelessly to learn all they can before the fungi recede back into anonymity. It also means that the studies must continue over many years for scientists to understand the full range of possible habitat conditions and community dynamics.

KEY FINDINGS

- Rarely detected fungal species are more likely to occur in old-growth stands than in younger managed stands, although all age classes of forests are important for maintaining biodiversity of fungi and the organisms they support.
- Logs provide suitable habitat for the conservation of a variety of species in both old-growth and young managed stands; chemical properties of logs do not vary widely among forest age classes.
- Down coarse wood, including logs and stumps, is important to the persistence of some species of ectomycorrhizal fungi. For example, *Piloderma fallax* proved more likely to occur in plots with higher percentage of wood cover in advanced stages of decay.

PLAYING WELL WITH OTHERS

The union of ectomycorrhizal fungi and their host plants exemplifies mutually beneficial relationships called symbioses. According to common understanding, most conifer trees have a thin sheath of these fungi wrapped around their root tips. Because fungi cannot photosynthesize, they require tree roots to provide them with food in the form of sugars and other carbohydrates. Trees, in turn, benefit from fungi, which assist in gathering water and provide essential phosphorus and nitrogen that trees could not obtain otherwise.

"But fungal symbiosis doesn't stop there. Many fungi require small mammals, like squirrels, mice, and voles, to transport their reproductive spores through digestion and excretion," Smith explains. "This allows the fungi to spread their offspring across the landscape, a task they could not perform alone. The mammals seem happy to oblige since the fungal fruits are calorie-rich and can make up a large percentage of their diets. Not surprisingly, fungi are also an essential food source for other forest species, like mollusks and arthropods."

Through these relationships, ectomycorrhizal fungi are inexorably woven into the life history of forests. The fungi are tremendously diverse, and distinct fungal communities are found in each stage of forest development. Throughout its range and lifespan, Douglas-fir may associate with more than 2,000 species of fungi.

Compared to what we know of many forest dwellers, both animal and vegetable, knowledge about belowground fungal communities remains sparse. However, federal agencies have a growing interest in the effects of land management practices on the diversity of fungal species, particularly for those species associated with old-growth forests.

This is where Smith and her team of surveyors come in. For half a decade, they have raked the soil on more than 1,500 research plots at the H.J. Andrews Experimental Forest, east of Eugene in the western Cascades of Oregon. They are involved in a pioneering study of fungal communities that spans forests of many ages across the landscape.

This has been one of the largest studies of its kind, and Smith sensed early on that it could make a tremendous contribution to science. She was right. Just recently, her team discovered a whole new genus of fungus. "I would not have been surprised by, would even have expected a new species, given how little work had been done at the time. But not a whole new genus; that was very exciting," recalls Smith. A genus is a step above species in the biological categorization of nature. Often, there are scores of species within the same genus. Therefore, finding and naming a new genus of fungi isn't the sort of thing that happens every day.

In addition, they have compiled an extensive fungal database, which allows them to respond to the conservation issues outlined in the Northwest Forest Plan. For example, the research resulted in the development of a handbook that is used by Forest Service and Bureau of Land Management employees for recognizing rare and poorly understood fungal species. These species fall under the "Survey and Manage" section of the plan, which is a complex and ever-changing piece of forest policy.

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Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208
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USDA United States Department of Agriculture

Forest Service

DIVERSITY OF SPECIES AND HABITATS

Young forests were once considered the most biologically diverse, but in the past two or three decades, rapidly increasing understanding of old-growth forests and their ecosystems have garnered a reputation for their superior diversity of plant and animal species.

But as far as fungi are concerned, neither of these hypotheses is true.

Smith and her team undertook a large multispecies study of fungi based in the H.J. Andrews Experimental Forest. Over four autumn and three spring seasons, three forested stands from each of three age classes—young with closed canopy (30 to 35 years old); rotation age or ready for harvest (45 to 50 years); and old-growth (over 400 years)—were surveyed by dozens of volunteers.

Because the most rapid growth period in forest development is the first 50 years, Smith explains, the small difference in age between young and rotation-age stands can still show significant differences in stand development, stem density, and tree size. The selected stands encompassed a range of plant association groups but were dominated by Douglas-fir with western hemlock.

"By surveying within several stages of forest development, our research team has shown that species richness is roughly equal across age classes," Smith says. "But we did not find the same species in each type of stand. In fact, more than a third of the fungi species were unique to only one age class."

Results of their study suggest that as forests age, new species of fungi move in, and old species move out, paralleling the forest's succession. These findings are pioneering in the field of forest ecology. Smith expects that development of adaptive ecosystem management guidelines will benefit from an understanding of fungal succession.

"Our results suggest that all age classes of forests are important for maintaining the biological diversity of ectomycorrhizal fungi and the organisms they support."

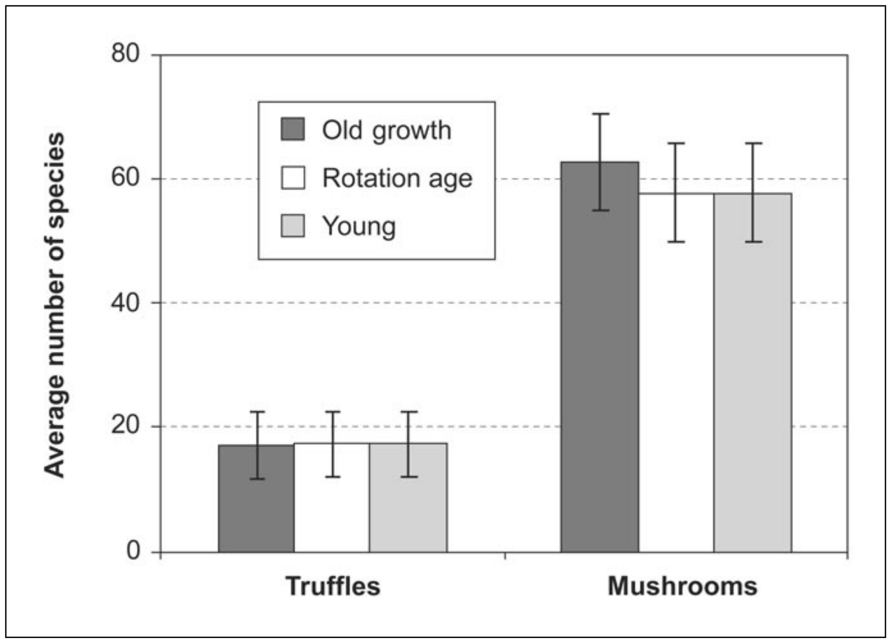
In the multispecies study, surveyors found rarely detected fungal species more frequently in old-growth stands than in younger managed stands. Many of these species were living in old, decayed logs ubiquitous in old-growth forests. This led Smith to wonder if it was the age of the forests, or just the decaying logs, that were supporting the fungi.

Big, old logs are vital to forest biodiversity conservation at many levels. Logs provide many important ecosystem functions, such as water and nutrient storage. Mammals, mollusks, and amphibians use logs for cover and travel corridors. A rich diversity of insects colonizes and consumes the wood. Seedlings perch on logs to obtain nutrients and reach for light. Decay fungi break down logs and release nutrients for overstory trees to absorb with their root-associated fungi.

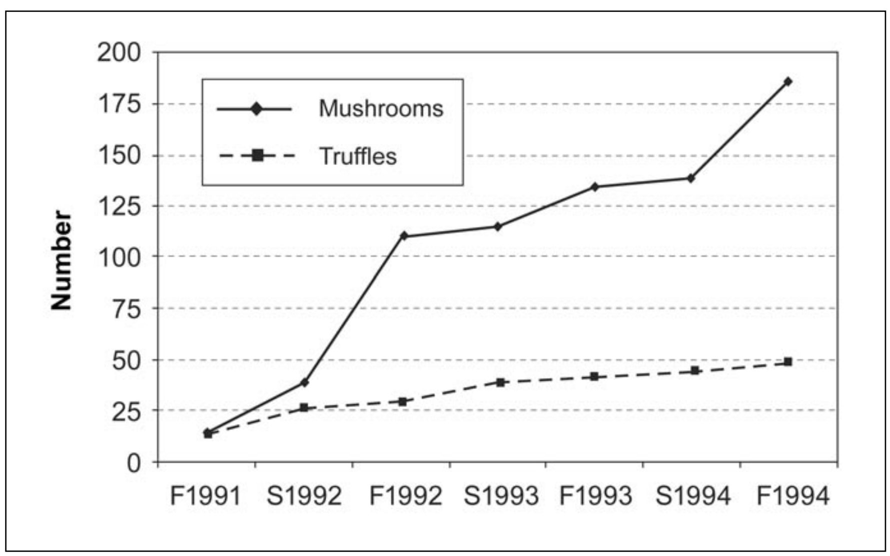
Within decaying logs, fungi form mutually beneficial associations with a host of wildlife and trees. When large logs are left in young managed forests they "lifeboat" a host of old-forest species for decades or even a century or more.

Through chemical lab work, she and her colleagues determined that the chemical environment in decayed logs was similar regardless of the age of the surrounding stand. And it is the chemistry of the logs that supports these fungi. Here the mycology team had made another important discovery for ecosystem managers.

"Forest management strategies that maintain old-growth components, like decaying logs, in young managed stands have the potential to conserve biodiversity through recruitment and retention of old-growth associated fungi," explains Smith.



Truffle and mushroom species richness is similar across age classes.



Cumulative number of mushroom and truffle species found in three forest age classes in the H.J. Andrews Experimental Forest (F = fall, S = spring).

LAND MANAGEMENT IMPLICATIONS

- Conservation of forest fungi has implications for wildlife planning and management at local and regional scales, involving habitat factors such as stand age and soil conditions.

- Coarse wood is thought to be critical to the recruitment and retention of old-growth associated species in young managed stands. Downed coarse wood in various stages of decay directly influences the occurrence and abundance of mycorrhizal species.

- Logs provide important ecosystem functions such as water and nutrient storage and critical habitat for the conservation of a variety of species, including mycorrhizal fungi, which form mutually beneficial associations with both wildlife and trees.

Credit: Jane Smith

This fungus, like many others, is found in legacy old-growth structures, such as soil formed from decaying logs.

Credit: Wes Colgan III

A northern flying squirrel feasts on a truffle.

A GOLDEN YELLOW STREAK OF LUCK

Although most fungi are difficult to find, one species has distinctive golden yellow mycelia, which is the vegetative mat of the fungus. *Piloderma fallax*, like most fungal species, has no common name even though it is distributed worldwide and is rather abundant. Its unique coloration makes it easy to find, and its association with old-growth forest makes it an interesting subject for study.

"Although a few other fungi have yellow mycelia, this one is quite distinct, and we became very skilled at spotting this particular shade of yellow," recalls Smith. At least in this case, the pigs and squirrels weren't necessary.

This fungus is closely associated with logs in advanced stages of decay. Typically, more logs on a site means more *P. fallax*. As one might expect, old logs are most common in old-growth forests. For this reason, *P. fallax* has long been considered an old-growth species. Old growth provides the unique chemistry of the soil and logs this fungus requires. This makes *P. fallax* a valuable indicator of old-growth soil components.

The inherent complexity of natural systems can be daunting. Therefore, finding individual species that can be used to indicate the state of the ecosystem they occupy (called indicator species) is invaluable for ecologists and land managers. One famous indicator of old-growth forest conditions, for example, is the spotted owl. The owl's presence is thought to indicate large patches of old-growth forest conditions.

Finding the yellow mycelia of *P. fallax* woven through logs, stumps, and soil is a sign of complex old-growth soil conditions. It is indicative of soils that can support other ground-dwelling old-growth species that are not so easy to find.

Through the Northwest Forest Plan, the Forest Service and Bureau of Land Management have embraced a multispecies approach to conservation and have focused on maintaining and creating old-forest habitat. The use of *P. fallax* as an indicator species may be key to assessing the plan's success on the ground.

Credit: Jane Smith

Soil cores are used to extract fungi with their host tree roots.

Credit: Randy Molina

Eager volunteers were vital to completing hundreds of fungus surveys.

REFINING THE SEARCH TOOLS

As more information on fungal communities is unearthed, habitat models can be developed to predict the presence of differing fungal communities across broad landscapes. This will inform land managers when predicting the impacts of disturbance and management on food webs and assist in planning for the retention of legacy structures, such as old-growth stands and decayed logs.

"Such knowledge is essential for making sound management decisions influencing the conservation of forest species, the organisms they support, and forest ecosystem sustainability," explains Smith.

Many of the limits to surveying for ectomycorrhizal fungi relate to the short fruiting season in which they can be identified. Even with a room full of samples at the end of a hectic month of work, there's only so much troops of volunteers can achieve.

Until recently, mycologists have needed either the truffles or mushrooms to positively identify the species. Technological advances are beginning to overcome this problem. Researchers at the PNW Research Station in collaboration with colleagues at Oregon State University have begun applying molecular techniques and DNA analysis to fungi.

Through these methods, fungi can be identified by using only the mycelia associated with tree root tips, which can be surveyed through soil cores year-round. The mycology team has been able to identify hundreds of species from dry forest habitats where fungi fruit infrequently. "We have really just scratched the surface with regard to understanding the ecology of ectomycorrhizal fungi, and there is still much about their distribution and life-history dynamics that remains unknown," says Smith.

The new survey techniques provide a different look at the ectomycorrhizal fungal community than we see from mushroom and truffle surveys, and result in fewer 12-hour days spent raking through the soil. This is good for the soil, good for the backs of the surveyors, and it probably means the pigs and squirrels will have to look elsewhere for work.

"Over the long haul of life on this planet, it is the ecologists, and not the bookkeepers of business, who are the ultimate accountants."

—Steward Udall

FOR FURTHER READING

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Science

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