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INSIDE

"Science affects the way we think together."

Lewis Thomas

TIES THAT BIND: PACIFIC NORTHWEST TRUFFLES, TREES, AND ANIMALS IN SYMBIOSIS

"Presently, we were aware of an odour gradually coming towards us, something musky, fiery, savoury, mysterious—a hot drowsy smell, that lulls the senses, and yet enflames them—the truffles were coming."
—William Makepeace Thackeray

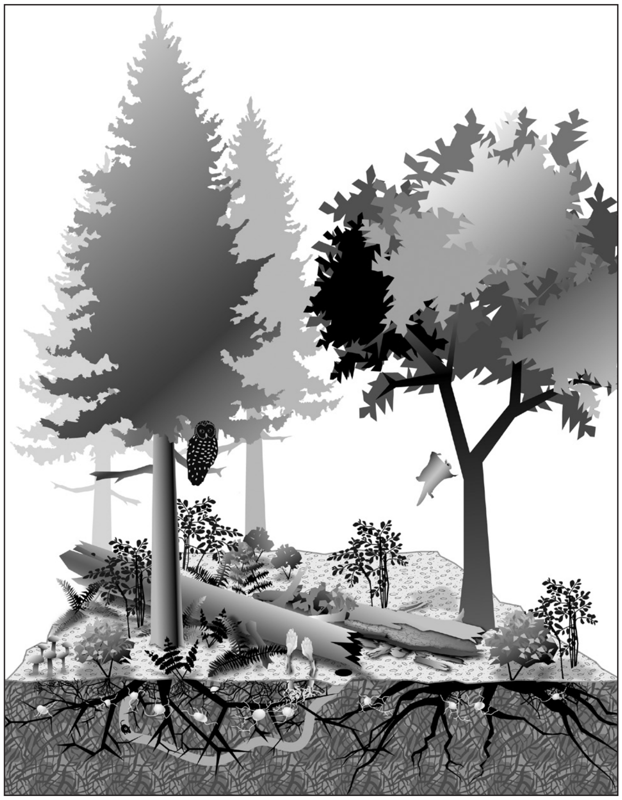


Illustration by Gretchen Bracher

Truffles are an integral part of the forest food web. The fungi form beneficial root associations with host plants to exchange nutrients, and are a major food source for small mammals such as the northern flying squirrel—the primary prey of the northern spotted owl.

IN SUMMARY

Soil organisms play essential roles in forest health, and truffle fungi are one of the more fascinating groups of these important organisms. After 40 years of specimen collection and study, scientists with Pacific Northwest Research Station have published a report documenting how truffle fungi affect tree survival and growth, perform valuable functions in nutrient cycling and retention, and serve as a major food source for many forest animals.

Fungi do not photosynthesize. Instead, many form symbiotic relationships with the root systems of shrubs and trees to access essential carbon and sugars. In return, the fungi enable the trees and plants to glean valuable phosphorus, nitrogen, and water from the soil. Forest-dwelling mammals also rely on truffle fungi to supply vital nutrients, and these animals must consume the truffle fruit-body and distribute the spores through their feces to complete the fungi's reproductive cycle.

Like trees and animals, truffle fungi are affected by natural and human-caused landscape disturbances. Studies show that silvicultural practices such as clearcutting can drastically reduce truffle fungi populations, but variable-density thinning does not seem to adversely affect recovery. High-intensity fire that consumes the litter layer—microhabitat for the fungi—can also be quite harmful to their populations.

Hidden from human view in the forest floor, a vast and unique kingdom flourishes—an amazingly rich and diverse community of fungi that perform essential functions to sustain the visible plants and animals above the ground. As part of this intricate web of existence, truffle fungi are an indispensable link in a long chain of ecosystem processes that ensure the health of our forests and the animals that live there.

The critical roles soil organisms such as truffle fungi play in ecosystem dynamics are often overlooked in ecosystem management, says Randy Molina, a research botanist who recently retired from the Pacific Northwest (PNW) Research Station. "The organisms are difficult to monitor, and managers lack tools to integrate protection of soil biota into management plans," he says.

Molina and eight other scientists associated with the PNW Research Station recently published a 194-page report called *Diversity, Ecology, and Conservation of Truffle Fungi in Forests of the Pacific Northwest* that promises to be a critical hands-on tool for supporting key forest management decisions.

The report documents 350 truffle species in 50 genera—a listing made possible by more than 40 years of research by PNW Research Station scientists who have amassed one of the largest truffle specimen collections in the world. Although truffles can be found around the globe, nowhere is home to more truffle species than the Pacific Northwest, except, perhaps, Australia. "The Pacific Northwest has been a hotbed of evolution for the development of truffle fungi," says Molina.

The report provides the first complete listing of currently known truffle species in the Pacific Northwest, detailed descriptions of each truffle genus with accompanying photographs, and a key for identifying truffle genera. It is written to appeal to a wide audience ranging from mycologists and forest managers to conservationists, truffle hobbyists, entrepreneurs, and chefs. The report covers truffle evolution and the history of truffle science in the Pacific Northwest.

In addition, the report includes a complete categorized listing of Pacific Northwest animal species known to consume truffles and provides general scientific principles to conserve and protect truffle populations. People who are interested in the edible varieties will appreciate the chapter covering the history, cultivation, harvesting, and management of culinary truffles.

"The strength of this report is that there were so many different authors with different areas of expertise," says Jane Smith, a research botanist with the PNW Research Station. "We've brought all our knowledge together in this publication." Smith's contributions focused on how disturbances such as prescribed fire and wildfire affect the soil and microbial communities in which truffles live.

KEY FINDINGS

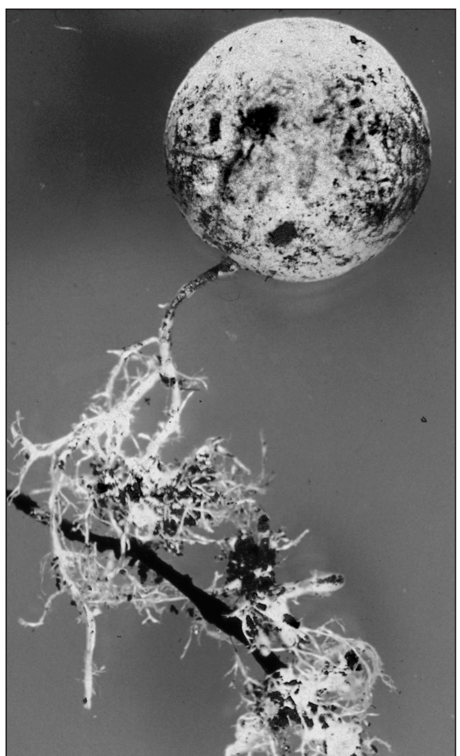
- The Pacific Northwest region, encompassing Oregon, Washington, northern California, and parts of Idaho and British Columbia, is home to 350 truffle species in 50 genera.
- More than 100 Pacific Northwest plant species in all forest types associate in mycorrhizal symbiosis with truffle fungi.
- Truffle fungi serve as critical biological links and energy pathways that connect trees, small mammals, and birds of prey. Most forest mammals consume truffles, and many depend on them as a major food source.
- Truffle fungi are affected by natural and human-caused disturbances.

TANGIBLE EVIDENCE OF INTERDEPENDENCE

Along with their mushroom and puffball cousins, truffles are at the top of the fungal evolutionary ladder. They developed along with conifers, hardwoods, and various other trees and plants. Truffles are the sporocarp—commonly called the fruit-body—and means of reproduction for microscopic fungal filaments collectively called mycelia. These mycelia permeate the soil and other organic materials in the forest floor, forming a relationship with the roots of trees and plants in a process called mycorrhizal symbiosis (mycorrhiza is Greek for "fungus roots").

More than 100 trees and plants in the Pacific Northwest form mycorrhizal symbioses with truffle fungi. In these relationships, trees and plants access nutrients such as phosphorus, nitrogen, and water from the fungi. In turn, the fungi obtain carbon and sugars (glucose and sucrose) from the trees and plants. Certain plants such as snowplants and pinedrops do not photosynthesize, so they are completely dependent on mycorrhizal symbiosis for their survival. "The only way they can get their source of carbon is by having a mycorrhiza in common with a tree," says Smith.

If the mycorrhizal symbiosis were the whole story, it would be interesting enough. But these fungi are even more closely tied to forest health. In this expanded symbiosis, small mammals depend on truffles for nutrition, and truffles depend on small mammals to help them complete their reproductive cycle.



B. Zak

Truffles developed along with conifers, hardwoods, and various other trees and plants. Shown here are the mycorrhiza (fungus roots) and truffle formed by Hysterangium *on a Douglas-fir root.*

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Truffles evolved from their mushroom ancestors. The mushroom fruit-body grows up out of the ground on a stem and develops a cap that contains spores. It reproduces by releasing spores into the wind once the cap dries out. Truffles live in the soil, so the mushroom spore dispersal mechanism is no longer viable for these fruit-bodies. "They've lost the ability to pop out of the ground," says Molina. The cap has evolved into a solid mass that resembles a small potato, and it contains the spores of the fungi.

Purpose of PNW Science Findings

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

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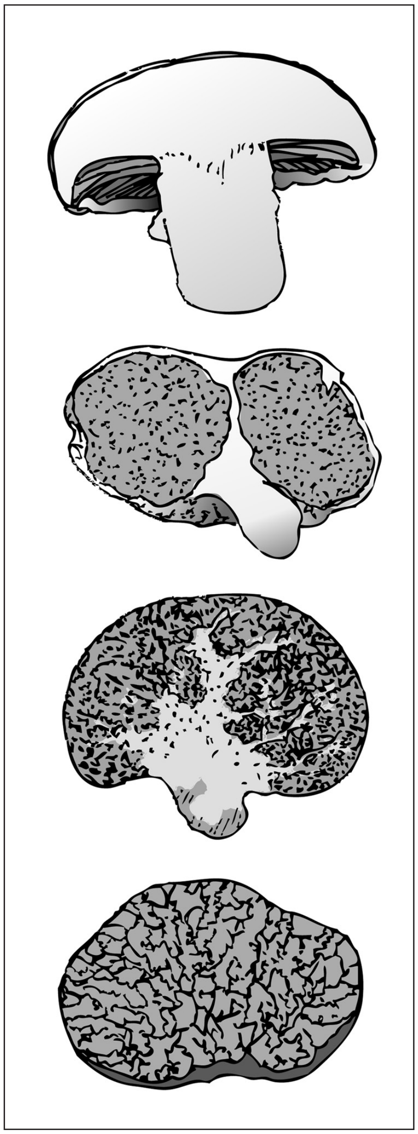

Illustration by Gretchen Bracher

So how do truffles reproduce? That's where the mammals come in. As the fruit-body matures, it begins to give off an odor. Some species have a distinctive smell that may be fruity, garlicky, lemony, fishy, or earthy, although other species have odors that are less identifiable. The odor attracts forest-dwelling mammals who then dig up and eat the truffles. Once eaten, the spores remain intact through an animal's digestive system and are dispersed when the animal defecates.

"For many of our small mammals, this is a major part of their diet," says Molina. "They have evolved to use these fungi as a major food source." Some of the 45 identified animals that depend on truffles include voles, gophers, squirrels, chipmunks, shrews, rabbits, marmots, mice, and opossums, as well as larger mammals such as mountain goats, elk, deer, and bear.

"Like humans, these mammals seem to enjoy a variety of tastes," says Smith. "They actually like a whole smorgasbord of different tastes, so they'll eat just a little bit and then they'll go on to another one. There are a lot of vitamins and minerals in truffles that aren't available anywhere else."

Most truffles evolved from mushrooms. During this process, the reproductive tissue found in the mushroom cap became completely enclosed, leaving the truffle dependent on animals and birds to dig it up and disperse the reproductive spores.

Quail, turkeys, jays, and other birds eat truffles too. Birds of prey such as the northern spotted owl are also linked to the chain of dependence because they feed on northern flying squirrels, which depend on truffles for a major part of their diet. Additionally, these birds play a key role in widening the distribution area for fungal spores.

Jim Grace

As the truffle matures, it emits an odor that attracts many small animals such as this northern flying squirrel in Alaska.

MOLECULAR SCIENCE UNLOCKS THE INVISIBLE WORLD

Although scientists have been hunting, documenting, and studying the ecological function of truffle fungi for nearly 200 years, mycologists are relatively rare, and vast forested areas remain to be studied. It is only recently that soil science has progressed to the point where the deep connections among fungi, plant, and animal life can begin to be fully understood.

"It's probably been within the last 10 to 12 years that the molecular DNA tools have made it possible for us to actually identify organisms that are in the soils," says Smith. "It was always referred to as the 'black box'—everybody knew that a lot happened there and that it was critically important, but it was difficult to say how it all happened. It's really the molecular methods that have totally revolutionized the science."

In the past, the only way to find truffles was by carefully raking the ground and digging them up. Scientists can now use DNA traces in soil samples to identify which fungi live in the soil of a particular area. The raking process is still necessary for other reasons, however. "It takes a number of different approaches to really look at the whole community," says Smith. "It's pretty tedious, but you also need a DNA sequence from the fruiting bodies to positively identify the DNA in soil."

New truffle fungi continue to be identified each year in the Pacific Northwest, and it is impossible to say how many species have yet to be discovered. Some species are found only in a specific ecosystem, and many form their mycelia and fruit-bodies in association with one particular host, such as Douglas-fir or hemlock or spruce.

"We find certain species everywhere," says Smith, "and then we find certain species only in the old growth and certain species only in the young growth. It shows the importance of keeping trees in all age classes, so we keep the diversity of the truffle population." Out of the 350 documented Pacific Northwest truffle species, about 70 species are currently considered to be rare or sensitive. A large number of these require old-growth habitat and are protected under the Northwest Forest Plan.

A CALL FOR INTEGRATED RESEARCH

Molina, Smith, and their co-authors point out that much work remains to be done to fully understand the impacts of disturbance and management on truffle fungi. They issue a strong call for integrated research that will help identify the wise management practices that will ensure total ecosystem health. "There are many hundreds of organisms that play very important roles in the way these ecosystems work. It's important to manage for this diverse biota," says Molina.

Studies have shown that when forests are clearcut and not replanted quickly, the rate at which fungal populations regenerate can be seriously affected. Results from several silvicultural experiments show that variable-density thinning, which leaves a mosaic of stand structure on the landscape, helps to maintain fungi population levels. Additionally, retaining selected live trees—especially larger trees—provides habitat for birds, mammals, and soil organisms and therefore helps the forest to more quickly develop old-growth characteristics.

In addition to managing for variable-aged stands and retaining targeted trees, it is important to maintain a diversity of tree species and understory shrubs, explains Molina. "When we replant areas that have either been harvested or undergone some disturbance, it's important to try to restock with a diversity of the plants that were naturally there," he says. "A diversity of plants will provide the hosts for these many different mycorrhizal fungi, including the truffle species. By maintaining the fungi, you're helping to maintain the forests, the trees, and the other plant species, because these things are intricately connected."

Smith says that less intense wildfires or prescribed fires do not seem to affect truffle fungi, but if the fire is too hot, the litter layer—and thus the microhabitat that feeds the fungi—can be lost. "It emphasizes that we need to manage forests thoughtfully and for multiple values," says Smith. Her research suggests that using prescribed fire to reduce fuel loads in the spring may help reduce the intensity of fires that traditionally occur in the fall.

Small pioneering shrubs that come back quickly after a fire can sometimes maintain the diversity of mycorrhizal fungi in the soil. Later, the young trees can take advantage of the fungi that have been nourished by the shrubs. "Those shrubs are an important part of the disturbance cycle, and you may want to manage to take advantage of them because eventually they will benefit the way the whole system recovers," says Molina.

He says that maintaining a diversity of habitats and hosts will probably also protect the rare species, but more research is needed to determine exactly what these sensitive species require. "To conserve rare truffle species, you must be able to locate, identify, and monitor their presence, and then consider their specific ecology and habitat needs in management plans," he says.

The authors also recommend keeping significant amounts of large, coarse woody debris such as standing snags and fallen trees when harvesting. "Those are very important in maintaining organic matter for the long term," says Molina. "Many of these fungi use the wood substrate that is decomposing in the soil as an important part of their microhabitat. It is also habitat for the small mammals that disperse the truffle's reproductive spores."

TRUFFLEMANIA

People all over the globe are interested in truffles—and not just the chocolate candies that were named after them. Several truffle species are sought after by cooks and gastronomic aficionados who use them to add flavor to gourmet dishes. Some species of culinary truffles are highly valued, and a culinary truffle industry is beginning to develop in the Pacific Northwest. "In price per pound, truffles are one of the most valued organisms in the world," says Molina.

It's not only the scientists and chefs who care about truffles, however. Many people simply enjoy hunting for them and appreciating their diversity and unique contributions, and some are interested in truffles from the standpoint of conservation. Two organizations based in Oregon—the North American Truffling Society and the Oregon Mycological Society—study these fascinating fungi, and collect them in their group forays. "A large segment of the population is interested in these fungi and want to see them protected just like animals and plants," says Molina.

"Whenever we try to pick out anything by itself, we find it hitched to everything else in the universe."

—John Muir

David Pilz

Dogs also can smell out truffles. Here, a dog hunts for truffles in a truffle plantation near Corvallis, Oregon.

LAND MANAGEMENT IMPLICATIONS

- About 70 truffle species are considered to be sensitive species and are listed for protection within federal programs. *Diversity, Ecology, and Conservation of Truffle Fungi in Forests of the Pacific Northwest* (PNW-GTR-772) can be used to locate, identify, and monitor these species.

- Results from several silvicultural experiments show that clearcutting drastically reduces truffle species populations, but variable-density thinning and green tree retention can maintain population levels.

- Small mammals ensure the reproduction of truffle fungi and are primary prey for birds such as the threatened northern spotted owl. Report PNW-GTR-772 suggests silvicultural approaches to integrate truffle and wildlife biology into ecosystem management planning.

David Pilz

Charles Lefevre

*The brown (*Leucangium brunneum*) and black truffle (*L. carthusianum*) are commercially harvested in the Pacific Northwest.*

David Pilz

The annual Oregon Truffle Festival attracts people interested in both the cultivation and conservation of Pacific Northwest truffles.

FOR FURTHER READING

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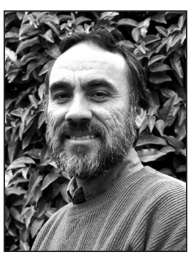

RANDY MOLINA was a research botanist with the PNW Research Station in Corvallis, Oregon, for 32 years. As team leader of the forest mycology team, he conducted key research on the symbiotic relationships among truffle fungi and forest trees and shrubs. He was lead PNW Research Station scientist in the conservation of forest fungi under the Northwest Forest Plan and was lead organizer/editor for the recently released general technical report on truffle fungi. He is now an adjunct professor at Oregon State University, Department of Forest Ecosystems and Society, and managing editor for the international journal *Mycorrhiza*.

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JANE E. SMITH has been a research botanist with the PNW Research Station since 1987. She earned a B.A. in botany from Humboldt State University and an M.S. in forest ecology and Ph.D. in botany and plant pathology from Oregon State University. She is currently investigating belowground ecosystem dynamics and soil recovery after fire and salvage logging in forests east of the Cascade Range in Oregon. Her research also examines microbial interactions with nonnative invasive plants. She was lead scientist on major field studies on the community ecology of truffle fungi.

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