OREGON'S
AGRICULTURAL PROGRESS

Summer 2005

OSU's microbial observatory allows scientists to glimpse the microscopic menagerie that connects forests and soil.

by Gail Wells

When most people think of an observatory, they think of a telescope — an instrument that extends our vision into hidden corners of the universe.

A microbial observatory is like that, only the instruments point in the other direction. Scientists at Oregon State University have developed a microbial observatory at the H.J. Andrews Experimental Forest, using tools such as biochemical tests and DNA analysis to gaze down into the universe of microscopic bacteria, fungi and other creatures living, metabolizing, reproducing and dying beneath our feet.

The universe of microbes is vast, and much of it is yet unknown to science. The microbial observatory at the Andrews Forest, in the foothills of the Cascade Mountains east of Eugene, is one of a network of sites established in 1999 by the National Science Foundation to increase our knowledge of microbes inhabiting many different environments.

"Our observatory is figurative, not literal," says Kermit Cromack, Jr. "But like the Hubble telescope, our instruments and techniques are extending our vision by orders of magnitude."

Cromack is a forest ecologist and professor emeritus in the department of forest science at OSU. He has spent his career studying fungi, a kingdom of microorganisms that occur in soil and almost everywhere else. Cromack is interested in how soil fungi help deliver nitrogen, phosphorus and other elements to plants in a form they can use to grow and reproduce. This conversion of nutrients from one form to another is one example of nutrient cycling, by which all living things on earth get the basic nutrients they need to build and maintain their bodies.

"Plants don't have mouths or stomachs," Dunham says, "so they rely on soil fungi and bacteria to digest these nutrients for them. In return, they feed the soil organisms with the sugars they make via photosynthesis."

The term "microbes," shorthand for microorganisms, covers fungi, bacteria, algae, viruses and protozoa. Microbes live everywhere on earth: on and in everything, including our own bodies. At this moment you and I are playing host to perhaps a billion microbes, skating around on our skins, swimming in our mouths and navigating our intestinal tracts.

Microbes are the oldest life forms on earth — some have been here for billions of years. “Microorganisms had the world to themselves for seven or eight times as long as there’ve been multicelled animals,” says Peter Bottomley, a microbiologist in Oregon’s Agricultural Experiment Station and a co-investigator in the microbial observatory project. “But they didn’t stop when the rest of us came along, of course. They kept evolving and are still with us.”

When scientists peer down into the earth, they see a universe largely unexplored. The study of microbes is still a young science. Obviously the small size of these creatures is a constraint, and there are so darned many of them. A teaspoonful of soil has about a billion bacteria in it and about 5,000 distinct kinds of microbes. As more microbial forms are discovered, scientists are struggling to organize them into top-down categories like those used to classify life above the soil surface — kingdom, phylum, class, order, family, genus and species. Most multicelled animal life is divided into two phyla, vertebrates and invertebrates. Bacteria alone have been divided into about 52 phyla, and scientists are still counting.

It was back in 1683 when Anton van Leeuwenhoek, a Dutch cloth merchant and lens-grinder, used a microscope of his own invention to examine a glob of plaque he had scraped from his teeth. He reported that he saw “many very little living animalcules, very prettily a-moving.” It was one of the first observations of living bacteria ever recorded.

From Leeuwenhoek’s time until a few years ago, the only way to study microbes was to grow them in a laboratory and observe them under a microscope. Then in the early 1990s came new tools for determining the genetic blueprint of previously unknown life forms. Surprise! DNA sequencing techniques revealed many more types of microbes than ever had emerged from a Petri dish. How had they been overlooked?

The newly discovered organisms won’t grow in a Petri dish, but they’d been there all along. One research team, in the spirit of Leeuwenhoek, sampled plaque from the gums of a human subject, ran it through a DNA sequencing process and found 59 distinct types of microorganisms. DNA technology has yielded a flush of discovery. New microbial life forms reported in the past 15 years have more than doubled the microbial family tree.

But mapping out a family tree does not reveal what an organism does — whether it fixes nitrogen from the atmosphere, or releases nitrogen from the compost heap or something else entirely. To understand the bacterium’s function, scientists sequence genes that are directly involved in its metabolism. From there, they can better understand the role of that organism in the processes that keep life running on earth.

Cromack, Bottomley, Dunham, and their colleagues Joey Spatafora, Bruce Caldwell and Dave Myrold are looking at aspects of nutrient cycling in forests and meadows in the Cascade foothills. They recently finished a two-year study in which they dug up cores of soil from forests and swapped them with cores dug from meadows. They wanted to look at the process of nitrification, in which certain soil bacteria digest organic nitrogen and turn it into mineral form available to plants. Knowing the fine details of nutrient cycling in forests could help improve understanding of forest productivity, an important concern in the forested Northwest.

Nitrification in forests seems to be a fairly specialized function carried out by a narrow range of bacterial species, according to Myrold, a microbiologist with Oregon’s Agricultural Experiment Station. Nitrification rates in meadows are typically higher than they are in forests. Is this because different bacteria are doing the job there? Or is it because the same bacteria are operating differently?

The team found that both nitrification rates and the numbers of nitrifying bacteria increased in the forest soil cores planted in the meadows. They also found evidence that the community composition of the bacteria had changed in the forest soil cores. In some of the meadow soil cores planted in the forest, they found a decrease in nitrification rates and evidence of change in the microbial community there as well. Both these findings suggest that the same nitrifying bacteria are doing the job, but environmental conditions in forest soils limit how fast they can work.

The team is also looking at the structure and functions of mycorrhizae, the beneficial association between certain forest fungi and the roots of trees. Mycorrhizae are neither fungus nor tree, but rather a sort of barter arrangement between them: the tree delivers sugars to the fungus, and the fungus delivers usable nitrogen and phosphorus to the tree.

Cromack, Dunham and Joey Spatafora, a mycologist and curator of fungi at OSU's Department of Botany and Plant Pathology, are trying, among other things, to measure the amount of biomass of mycorrhizal hyphae in a given quantity of soil. Hyphae are long, slender structures that act as the fungus' factory for processing nutrients, breaking down organic matter and converting nitrogen into a tree-friendly form. In some species of mycorrhizal fungi, these hyphae form dense, visible mats in the soil that dramatically alter soil structure.

"Plants seem to put a lot of resources into keeping those mats happy all year round," Dunham says. "We've just figured out who's making the mats. But the major mat-forming species isn't well understood because it makes very tiny, hard-to-find fruit bodies [mushrooms]." Consequently, the researchers are focusing their attention on the hyphae and the mycorrhizal root tips, where plant and fungus connect to exchange the goods.

The team would like to know how other soil microbes respond to and are affected by the mat-forming fungi. The conversion process these fungi undertake is leaky — sugars leak out into the soil, and microbes grab them up. "What are these microbes, and what are they doing?" Dunham asks. "Are they a useful extension of the mycorrhizal relationship? Or are they parasitizing the nutrient transfer between plants and fungi?"

And what are the fungi doing amid all these bacteria? Do they play some sort of organizing role in the bacterial community? "Generally you think of fungi as decomposers," says Peter Bottomley. "That's true, but some bacteria also decompose dead plant material." Are the fungi doing the decomposition themselves, or are they recruiting other organisms to do it?

"Fungi are filamentous; they have these hyphae that are like bridge systems — they can physically connect one piece of soil carrying out function A with another piece carrying out function B." Could it be, Bottomley asks, that fungi act as a giant, delicate communications network in the soil that keeps the processes synchronized?

There are many unanswered questions. "This is true discovery-based science," Myrold says. "Soil is still much like a black box to us. Nitrogen goes in and nitrogen comes out, but we don't know much about what happens inside. We hope eventually to figure out these processes more fully, but right now we're still asking the basic question, 'Who's down there, and what are they doing?'"

There are NSF-sponsored microbial observatories at many terrestrial and aquatic sites around the world. To learn about them, see http://www.tigr.org/tdb/MBMO/otherMOs.shtml.

OREGON STATE UNIVERSITY
AGRICULTURAL EXPERIMENT STATION