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Science FINDINGS

INSIDE

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

Canaries in a Coal Mine: Using Lichens to Measure Nitrogen Pollution

The biggest problem in the world could have been solved when it was small.
—Lao-tzu

Lichens grow all over the world in natural and human-made environments. They cling to rocks, hang from tree limbs, creep along branches and leaves, and spread across otherwise barren earth, rusty metal, or concrete. Not to be confused with mosses—which are plants—lichens are formed through a symbiotic relationship between fungi and algae or cyanobacteria (blue-green algae).

Certain beneficial lichen species play dominant roles in nutrient cycling. In Pacific Northwest forests, they provide winter forage for animals, habitat for invertebrate species, and nesting materials and camouflage for birds and arboreal rodents. Cyanolichens, which are formed by symbiosis between fungi and cyanobacteria, fix atmospheric nitrogen, converting it to a form useable by other plants.


Stephen Sharnoff

Lichens serve as indicators of air quality. The species most sensitive to air pollution are often the ones used by wildlife, either as food or nesting material. Above, a hummingbird used lichen to camouflage its nest.

Around the world, lichens are often a pioneering species in inhospitable environments and can thrive in the most extreme weather conditions on Earth. But as prevalent and tenacious as these life forms can be within balanced ecosystems, beneficial lichen species are declining in some areas because of excess nitrogen in the air.

"Lichens are very sensitive to pollution," says Sarah Jovan, a lichenologist with the U.S. Forest Service (USFS) Pacific Northwest (PNW) Research Station. "It doesn't take much at all to wipe them out." Jovan joined Linda Geiser and Doug Glavich, ecologists

IN SUMMARY

In Pacific Northwest forests, lichens provide essential winter forage for deer and elk and also nesting materials and habitat for rodents, birds, and invertebrates. Although lichens are often the first organisms to populate a landscape and many species can survive in the most barren environments, lichens with the greatest ecological value tend to be the most sensitive to excess atmospheric nitrogen. In areas with high levels of human-generated nitrogen, ecologically beneficial lichen species are disappearing and "weedy" species are thriving. Because lichen are innately sensitive to nitrogen, scientists use lichen community composition as an early indicator of encroaching nitrogen pollution.

A recent Forest Service lichen study in the Pacific Northwest establishes numeric benchmarks called "critical loads" that quantify the amount of nitrogen pollution-sensitive lichen species can tolerate before sustaining harm. Critical loads provide valuable information that policymakers can use to establish air pollution controls and also help land managers assess ecosystem health and prioritize recovery projects. After the model for the lichen study was completed, for example, the Forest Service began applying it to evaluate watershed health across the Nation. The model will predict where nitrogen critical loads in each watershed are becoming dangerously high, and will be combined with other ecosystem health indicators to score watershed condition on all National Forest System lands.

with the USFS Pacific Northwest Region Air Program, and Matt Porter from the Washington State University Laboratory for Atmospheric Research to produce the first regional analysis of lichen-based critical loads for nitrogen in North America.

The Clean Air Act—enforced by the U.S. Environmental Protection Agency (EPA)—establishes primary air quality standards based on threats to human health and secondary standards for damage to vegetation, crops, animals, and buildings. The primary threats to human health from nitrogen come in the form of particulate matter that can get into our lungs and from nitrate ingested via drinking water. Lichens, however, passively absorb nitrogen and other air pollutants over the entire surface of their bodies. Although plants and lichens require nitrogen to survive, too much of a good thing can over-fertilize and kill off some species.

Their exceptional sensitivity to nitrogen makes lichens valuable as indicator species for monitoring encroaching harm from human-generated pollutants such as nitrogen. Similar to the way canaries were used historically to indicate the presence of harmful gasses in coal mines, lichens are being used to evaluate forest health.

"We want to catch pollution early," says Geiser. "If you monitor the most sensitive organisms, you can find the places where pollution effects are just beginning as well as the places that are more obviously impacted. If the lichens are healthy, then the less sensitive species are probably fine, too."

KEY FINDINGS

- A 10-year analysis of lichen communities throughout the western Pacific Northwest region revealed that nitrogen deposition measuring between 3 and 9 kilograms (kg) per hectare (ha) (2.47 acres) per year triggers at least a 20- to 40-percent decline of ecologically important lichen species and a three- to fourfold increase in "weedy" species.
- Precipitation has a moderating effect on lichen response to air pollution, presumably by diluting exposure levels. In the driest forests of the study area, critical load for nitrogen is 3 kg/ha versus 9 kg/ha in the wettest forests.
- Atmospheric nitrogen exceeded safe levels primarily in urban areas and areas with intense agricultural activity, although wind patterns also caused high pollution levels in the Columbia River Gorge.
- Most of the study area was within 1 to 2 kg of the naturally occurring nitrogen load.

NITROGEN CRITICAL LOADS

Nitrogen pollution is formed when compounds like ammonia and nitrogen oxides are emitted into the atmosphere. Fossil fuel combustion by vehicles, industry, and other sources produces nitrogen oxides, and agricultural activity (animal husbandry and crop production) and catalytic converters produce ammonia. "It's not realistic that we're going to stop polluting the air completely—there are all kinds of comforts we get from the pollution we generate," says Jovan, "so it's imperative for us to know how much pollution can be tolerated by nature."

The term "critical load" expresses a quantitative measurement of a pollutant below which scientists have determined that no environmental degradation should be expected. These values provide benchmarks of ecological harm that can be used to guide pollution permitting and regulation. "Nitrogen critical loads define for policymakers how much nitrogen is okay—what level is harmful as dictated by the lichens," says Jovan. "If we figure out what level harms the lichens and we keep our emissions below that, it should be protective of the larger ecosystem."

Critical loads have been used to guide emissions control in Europe since the early 1980s, but studies to determine a numeric expression for pollutant thresholds are not as widely available in North America. "We've gotten on the bandwagon a little late," says Jovan. In the United States, land managers have been using critical loads to manage air quality in the Sierra Nevada Mountains and Rocky Mountain National Park, but the study

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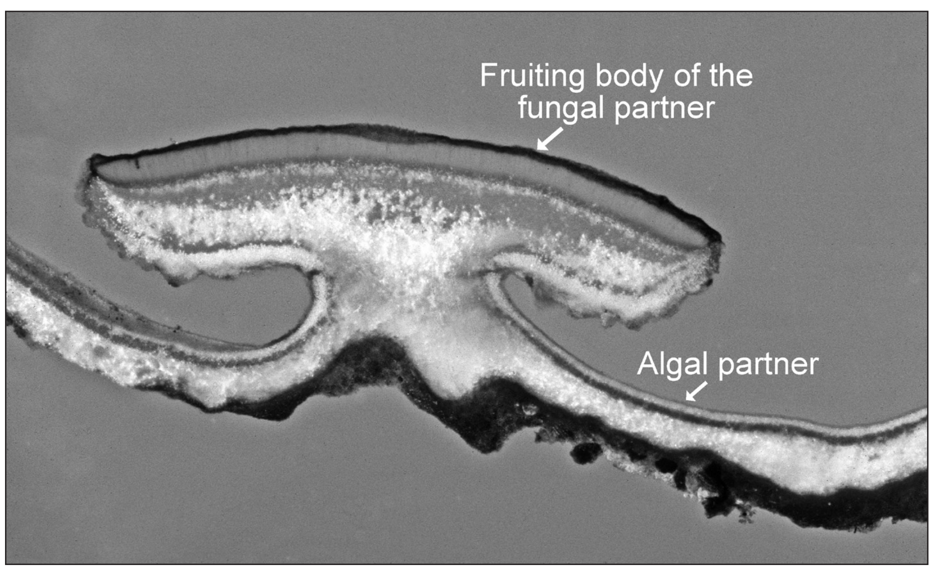


Stephen Sharnoff

Lichens are composite organisms, formed by the symbiotic relationship between fungi and algae. This species, Lobaria oregana*, is found in old-growth forests where it fixes atmospheric nitrogen, thus playing an important role in the forest's nutrient cycle.*

conducted by Geiser and Jovan is the first that establishes critical loads of pollutants in the Pacific Northwest and the first in North America that establishes them across a broad region.

Jovan says the critical load concept is an excellent management tool for guiding policy and the pollution permitting process because critical loads provide ecologically relevant benchmarks. "Using critical loads to guide air pollution policy is gaining a lot of momentum among managers and within the EPA, but it's not widely adopted as a guiding policy yet," says Jovan. The EPA has used critical loads of acidity as an assessment tool in the eastern United States, notably the Adirondacks and southern Appalachian Mountains.

The critical load values established as an outcome of the Forest Service study correlate well with the IMPROVE (Interagency Monitoring of Protected Visual Environments) network, which was established in 1985 to track visibility impairment in national parks and wilderness areas. "The point of IMPROVE is to measure pollution inputs into remote areas," says Jovan, "so it was exciting to see the correlation. It helps us to identify risks to these areas."

Linda Geiser

These weedy nitrogen-loving lichen were found growing in an agricultural setting.

LICHENS AS AN ASSESSMENT TOOL

The Clean Air Act requires federal land managers to assist in identifying whether a proposed source of pollution will detrimentally affect major wilderness areas and other federal lands. Air quality is monitored in the Pacific Northwest by state governments, and most current monitoring sites are located in urban areas. These monitoring stations are not only expensive to maintain, they require electricity to operate, making them unfeasible for use on remote lands.

To address this challenge, Geiser's team began in 1990 to study how lichens could be used to monitor air quality in national forests and wilderness areas. They surveyed lichen communities in Oregon and Washington national forests and analyzed samples to determine the levels of nitrogen and 26 other elements (such as lead and mercury) present. The first round of air quality monitoring was completed in 2000.

In 2001, PNW Research Station scientists with the Forest Inventory and Analysis (FIA) Program finished a related project that involved collecting data on lichen communities on all public and private forested lands in Oregon and Washington. The survey pinpointed the locations and densities of specific lichen species throughout the region.

Stephen Sharnoff

These beard lichen on a tree growing along the Cascade crest provide critical winter forage for deer, elk, and small mammals and nesting material for squirrels and birds.

Stephen Sharnoff

The northern flying squirrel uses beard lichen in its nest.

The Geiser team and the FIA team used both data sets to build an interpretive model that related lichen community composition to nitrogen input and established critical load values to score air quality throughout the region. The study determined that for each hectare (2.47 acres) of land, nitrogen levels exceeding 3 to 9 kilograms (kg) per year causes a harmful decline in ecologically important lichens and the subsequent encroachment of "weedy" lichen species that perform no discernable ecological function. "This analysis pulled out a pattern that showed decreasing sensitive species and increasing weedy species as a function of nitrogen," says Jovan.

Weedy lichen species are similar to plant weeds: they are relatively small, grow rapidly, and have short life cycles. Many weedy lichen species are bright orange or yellow. "In environments that exceed these critical loads of nitrogen deposition, we see a substantial decline in the ecologically important species—meaning the beard-like lichens used for forage by animals and the cyanolichens that aid nutrient cycling—and a three- to fourfold increase in the weedy species," says Jovan. "The weedy species can tolerate really high levels of nitrogen—in fact, they require a high amount of it—but the forage and cyanolichen species are just not equipped to deal with excess nitrogen."

Jovan says scientists have not yet determined exactly why the ecologically beneficial lichens are so sensitive to nitrogen, but it seems to be an imbalance in the symbiotic relationship between the fungus and algae/cyanobacteria that form lichen. "The nitrogen fertilizes the algae and the algae grows out of control, causing an imbalance between the two partners," she says. "The algae can benefit from the nitrogen, but somehow the fungus can't. The lichen ends up dying."

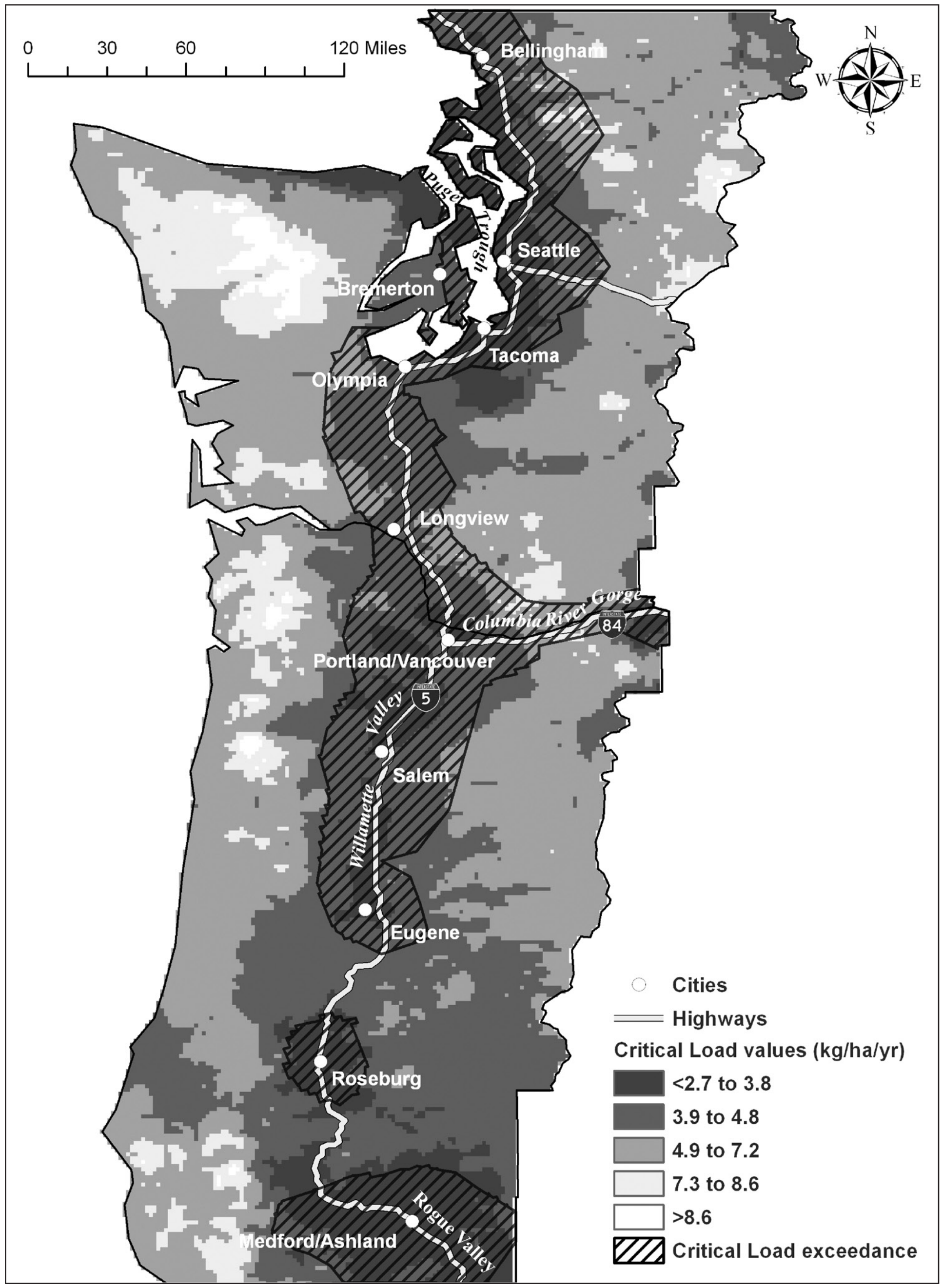
EFFECTS OF WEATHER AND CLIMATE

Precipitation levels affect how lichens respond to nitrogen pollution. Geiser and her colleagues first observed this connection in 2007 while using the data sets to build a model to score air quality and climate. “While comparing lichen community composition and pollutants in precipitation, we noticed that the lichen results were correlating much better to concentrations of pollutants in precipitation rather than to the total amount of pollutants that were deposited over a year,” she says. “We were able to make an important distinction between the loading and the concentration—lichen community composition shifts more dramatically in response to a concentrated solution than to a dilute solution.”

The recent study allowed Geiser and Jovan to put the 2007 theory to the test by comparing areas that receive differing amounts of precipitation. By using an EPA open source model to develop estimates of nitrogen deposition, the team mapped critical loads of nitrogen in Oregon and Washington west of the Cascade Mountains. “Since this is the first critical loads study for North America that covers a really wide region, we could compare differences in precipitation across sites,” says Jovan. “It allowed us to cull out this interesting relationship that we haven’t seen in other studies. Usually you look at a small area, so you don’t see that moisture effect.”

The scientists concluded that it takes less pollution to affect lichen communities in drier landscapes. “For example, Seattle and Medford look similar in lichen response, even though there is a lot more pollution in Seattle,” says Geiser. The critical load associated with the loss of sensitive species in the wettest forests is approximately 9 kg, compared to only 3 kg in the driest forests.

Regardless of climate, however, the areas that exceeded established critical loads tended to be in densely populated, agriculturally intense areas. Not surprisingly, the Willamette Valley, the Rogue Valley, and the Puget Sound region are some of the most heavily polluted areas; however, the Columbia River Gorge is also compromised due to geologically influenced weather patterns. “The Columbia River Gorge is a special case because the steep-sided gorge traps emissions from Portland in the winter. The other half of the year, it gets it from the east, which is pretty agriculturally rich,” says Jovan. Gasses and particulates that drift into the area get trapped and cannot fully disperse into the atmosphere, causing pollutants to build up in the air and soil.



Areas along the I-5 and I-84 corridors had the highest levels of nitrogen deposition. Interestingly, researchers found that lichen growing in wetter areas such as Seattle were able to handle higher levels of nitrogen pollution compared to lichen growing in drier areas such as Medford.

The good news is that, excluding the problem areas mentioned above, nitrogen pollution is below the scientists’ recommended critical load values throughout most of the Pacific Northwest region. Even problem areas have readings that are lower than they were before the Clean Air Act was passed forty years ago. “Air quality is generally improving in the Pacific Northwest,” says Geiser.

Although the work to establish nitrogen critical loads based on lichen health was initiated in the Pacific Northwest, the lichen-based model developed for the study can be used to predict critical loads well beyond the study area. “Ultimately, we hope to have a refined set of critical loads for the entire Nation,” says Jovan, “so the more we can understand how environmental variables like precipitation and temperature interact with lichen sensitivities to the nitrogen, the more comprehensive we can be.”

BEYOND THE PACIFIC NORTHWEST

A potential user of the critical load concept is the EPA as they develop new air quality standards. Jovan says that forest health is noticeably affected by a much lower level of nitrogen pollution than is human health. "That means the primary standards are not necessarily protective of any organisms or environmental systems that are more sensitive than humans," she says. "Secondary standards have not yet been established for most nitrogen pollutants, and the existing standard for nitrogen oxides is well above the amount known to cause lichen community shifts."

Individual state regulatory agencies and federal land managers can use critical load values to assess ecosystem health and prioritize recovery projects. For instance, the Forest Service is in the process of measuring air quality in national forest watersheds throughout the country. "We're giving them a very simple reading—good, fair, poor—for nitrogen deposition," says Geiser. "This is a great example of how critical loads can be used to assess the condition of the resource. You can map out where the problem spots are and those can be targeted for cleanup."

Although critical loads have been used as benchmarks in Europe for many years, Jovan notes that the critical load values for nitrogen that have come out of the current study are much lower than the target loads now in force on the European continent. "We think their critical loads are too high," she says. "A lot of damage to their lichen communities had already occurred before they tried to empirically determine what load was harmful."

In other words, higher benchmarks were set in Europe because the region has had more exposure to pollutants over a much longer timeframe. "We have a unique situation in the Pacific Northwest. We have a lot of fairly pristine environments, so we're able to look at unharmed lichen communities and really see the onset of these community shifts," says Jovan. The Pacific Northwest study is helping American scientists support the efforts of their European counterparts to establish critical load values that will help guide efforts to achieve deeper ecosystem recovery.

To halt the decline of an ecosystem, it is necessary to think like an ecosystem.

—Douglas P. Wheeler

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Stephen Sharnoff

Usnea longissima *is one of the Pacific Northwest lichens most sensitive to air pollution. The luxurious growth on this tree in northwestern Washington indicates excellent air quality.*

LAND MANAGEMENT IMPLICATIONS

- Critical load values quantitatively link pollutant levels to specific ecological harm and therefore provide a pragmatic land management tool.
- Because lichen community response in remote forests is closely correlated with concentrations of the nitrogen-based aerosols measured by the IMPROVE (Interagency Monitoring of Protected Visual Environments) network, managers can now use IMPROVE data to screen wilderness and other remote federal lands that are most at risk for environmental degradation.

FOR FURTHER READING

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