US FOREST SERVICE NORTHERN RESEARCH STATION

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Measuring Critical Loads of Nitrogen Deposition in the U.S.

Air pollution is a serious environmental and public health problem resulting from emissions by power and industrial plants, motor vehicles, and agriculture. Sulfur (S) and nitrogen (N) emissions are two components of air pollution and cause wide-ranging, long-term threats to the health of forest, range, and wetland ecosystems. Sulfur and nitrogen gas emissions can combine with moisture in the air to become acidic molecules that fall to earth as acid deposition (commonly called acid rain, fog, or snow). Most pollution control efforts have focused on sulfur dioxide (SO_2) emissions and these efforts have shown some positive results, with a measurable reduction in acidity of some lakes and wetlands.

MORE NITROGEN ISN'T ALWAYS A GOOD THING

Negative impacts of nitrogen in deposition were overlooked because nitrogen is usually thought of as a fertilizer or a "good thing." This is not always the case: Elevated N availability can also result in nutrient imbalances that increase plant susceptibility to stressors such as cold, drought, or pests. For example, winter injury in high-elevation red spruce can be attributed to elevated N. The most serious effect of excess N, however, is the alteration of ecosystem diversity. In most terrestrial ecosystems in the United States, plant growth is limited by nitrogen availability. Thus, when additional nitrogen is added to an ecosystem, native plants (those that are original to a site) may lose their competitive edge. The excess nitrogen allows other plants (which often are nonnative invasive species that do not thrive in low nitrogen) to out-compete native plants and thus alter the species composition of an ecosystem. For example, in Joshua Tree National Park in southern California, N deposition favors the production of sufficient invasive grass biomass to sustain fires that threaten the survival of the namesake species.

NORTHERN RESEARCH STATION SCIENTIST LEADS TEAM EVALUATING NITROGEN EFFECTS ON U.S. ECOSYSTEMS

Linda Pardo of the U.S. Forest Service's Northern Research Station (NRS) is an environmental engineer who has specialized in studying terrestrial nitrogen cycling. She led a large group of scientists who recently estimated critical N loads for ecoregions in the United States. (The **critical load** is defined as *the threshold level of a pollutant that results in a detrimental ecological effect over the long term.*) This team includes experts on ecosystems and organisms that occur across the U.S. Team members are from governmental

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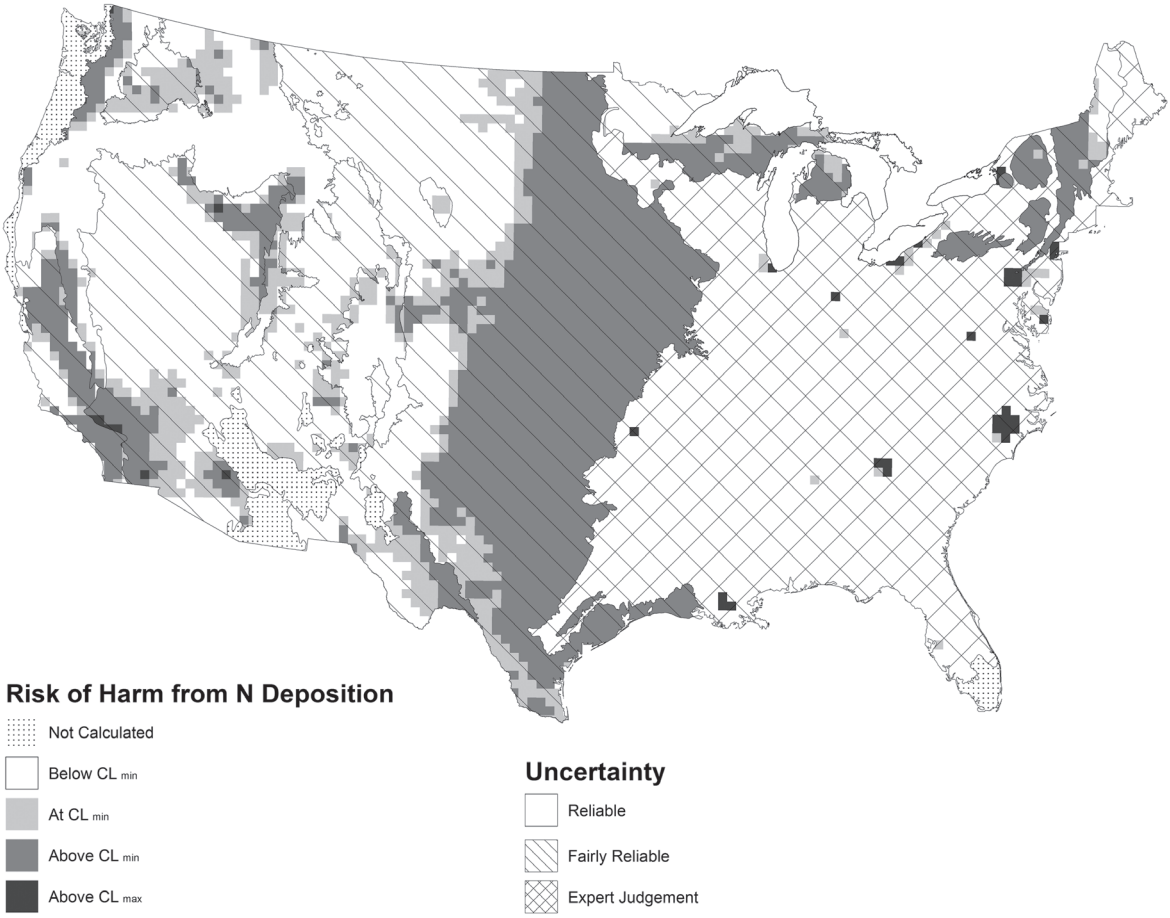
Photo used with permission by Aaron Ellison, Harvard Forest



Exceedance of critical load for N deposition for herbaceous species. The exceedance (that is, the actual deposition—critical load) indicates when regions are at risk for detrimental effects from N deposition. Reliability of estimates is shown with hatching.

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organizations and universities. Their report (General Technical Report NRS-80), the first comprehensive assessment of N deposition effects in the United States, was recently published by the Northern Research Station (see page 5, fourth reference for availability).

Members of the team analyzed the scientific literature to determine the effects of the N deposition load on different organisms in land and water environments. They evaluated the following organisms (from small to large): aquatic diatoms (single-cell plants), mycorrhizal fungi and other soil microbes, lichens (a complex symbiosis of fungi and algae), herbaceous plants (forbs, grasses, and grass-like plants), shrubs, and trees. The team reported values at the ecoregion level at this time. The main responses reported fell into two categories: (1) biogeochemical and soil microbial responses and (2) individual, population, and community plant and lichen responses. The findings are organized by the ecoregions defined by the Commission for Environmental Cooperation.

CRITICAL LOADS VALUES AND ECOSYSTEM EFFECTS

The range of critical loads for nutrient N reported for U.S. ecoregions, inland surface waters, and wetlands is 1 to 39 kg of N per hectare per year. This broad range spans the range of N deposition observed over most of the country. The empirical critical loads for N tend to increase in the following sequence for different life forms: diatoms; lichens and mosses; mycorrhizal fungi; herbaceous plants and shrubs; and finally, trees.

Large parts of the East and the Great Plains, as well as localized areas in the West, are experiencing N deposition that exceeds the critical load for sensitive ecosystem components including certain lichens, fungi, herbaceous plants, and tree species. The resources most threatened include freshwater diatoms, lichens, mosses, and herbaceous plants. The most significant changes currently observed are changes in species

composition: losses of sensitive species, shifts in dominance, and loss of native species in favor of nonnative invasive species. Alterations in herbaceous species are broadly observed (see map) but are not always clearly documentable because of long-term pollution inputs and other disturbances that caused changes prior to most current studies. In coastal areas, increased N export has led to toxic algal blooms

Forests are generally not showing immediate effects because of their size, lifespan, and access to a large pool of nutrients. Gradient studies in northeastern forests have demonstrated that N deposition has variable effects, enhancing growth of some tree species, slowing growth of others, and not showing any effects on other species. Similarly, N deposition enhances survivorship in a few species and decreases it in others. Over the long term, the differential effects of N deposition on tree growth and survivorship are likely to shift species composition.

Changes in ecosystem structure (for example, species composition) are linked to changes in ecosystem function. For example, extirpation of lichens in the tundra can alter food webs by reducing the availability of nesting material for birds, habitat for invertebrates, and critical winter forage for mammals (caribou and reindeer), as well as affecting nutrient cycling. In California, where elevated N deposition and arid low-biomass ecosystems coincide (coastal scrub, desert), N-enhanced growth of invasive grass species results in major alterations of plant communities, conversions of vegetation type, and increased fire risk.

CRITICAL LOADS ASSESSMENTS ARE VITAL FOR GOOD POLICYMAKING AND RESOURCE MANAGEMENT

Critical loads analyses have already been used in Europe as a tool for negotiating decreases in air pollution and have great potential to simplify complex scientific information and effectively communicate with policy makers and the public in the United States. The team's synthesis represents the first comprehensive assessment of critical loads of N for ecoregions across the United States. It will give land managers the ability to compare nitrogen loads with pollution sources and levels, thus pointing out those areas with the greatest susceptibility and those with the greatest need for action. What is needed next are critical loads at the ecosystem level rather than by the larger ecoregions. However, this synthesis represents a major step in providing a framework for collaboration between the scientific community and decisionmakers to guide emissions control programs.

Photo by Aaron Ellison, Harvard Forest

Lost Pond Bog in Vermont.

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Photo by Manfred Mielke, U.S. Forest Service, Bugwood.org

Mountainside red spruce in New England can be killed by excess nitrogen deposition effects and winter cold.

Nitrogen Deposition Is One Factor in Nonnative Grass Invasions in Southwestern Deserts and California Shrublands

Two of the American West's most problematic nonnative invasive plants, red brome (*Bromus rubens*) and Mediterranean splitgrass (*Schismus barbatus*), have invaded millions of square miles of desert and coastal scrub, almost completely replacing native vegetation and changing fire regimes in many areas of southwestern deserts and California shrublands. These are annuals that proliferate during winter, displacing native plant species and producing so much dry vegetation that fires become hot enough to kill creosote bush, sage scrub, and other native shrubs and the federally protected desert tortoise. Both grass species have been found to thrive and often dominate under conditions of increased nitrogen availability.

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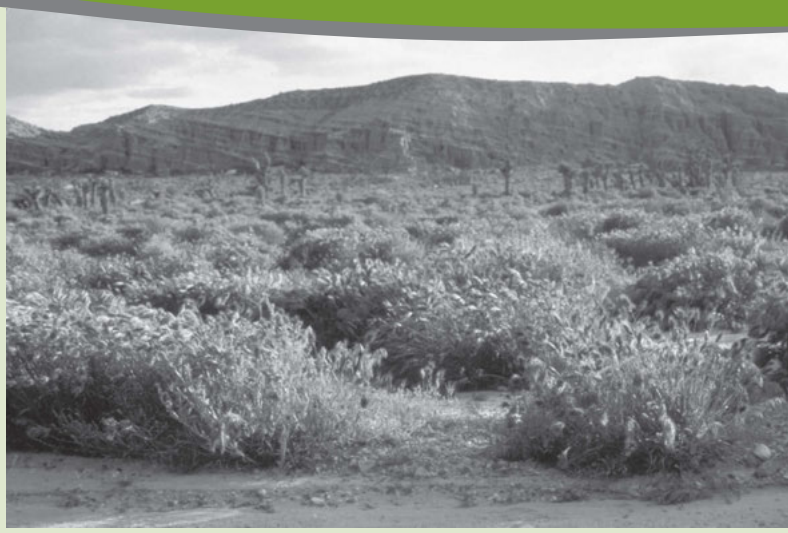

Photo by John M. Randall, The Nature Conservancy, Bugwood.org

Bay Checkerspot's Larval Food Plants Threatened by Nitrogen Deposition

In California's San Mateo and Santa Clara counties, the Bay checkerspot butterfly (*Euphydryas editha bayensis*) is threatened by excess nitrogen deposition, which is increasing the production of invasive grasses (red brome and Mediterranean splitgrass) in its habitat and causing die-out of the butterfly's preferred larval host plant, the native plantain (*Plantago erecta*), and the nectar plants that usually grow on the serpentine soils of the butterfly's range.

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Photo by John Clecker, U.S. Fish & Wildlife Service

Northern Pitchers Plants Don't Grow Pitchers in High-Nitrogen Deposition Environments

Northern pitcher plants (*Sarracenia purpurea*) are iconic, carnivorous plants of rain-fed bogs, which are extremely nutrient poor and acidic. Although they take up some nutrients with their roots, pitcher plants obtain more than 80 percent of their nutrients from insect prey. The insects that are captured by the pitchers are then broken down by a food web of bacteria and arthropods that live in their pitchers; the excreted nitrogen, phosphorus, and potassium provides the essential nutrients that feed the plant.

Photo by Aaron Ellison, Harvard Forest

In the northeastern U.S., where excess nitrogen deposition is now relatively common, pitcher plants can bypass the food web and get some of their nutrients directly from the sky. Research by Aaron Ellison (Harvard University/Harvard Forest) and Nicholas Gotelli (University of Vermont) showed that pitcher plants receiving precipitation with excess nitrogen stop producing carnivorous pitchers and start producing flattened, leaf-like pitchers that are better at capturing sunlight. Although in the short-term, this shape-shifting is a good indicator of the N deposition rate, in the longer term, atmospheric nitrogen increases the risk that pitcher plant populations will shrink in size, perhaps to extinction.

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