Critical issues for critical loads

Gary M. Lovett
Cary Institute of Ecosystem Studies, Millbrook, NY 12545

I

n the United States and most other countries, primary air quality standards are designed to protect human health and are based on concentrations of pollutants in the air. However, from the perspective of ecosystem health, a more appropriate metric for the impacts of nitrogen (N) and sulfur (S) pollutants is the total atmospheric deposition (or “load,” in kg ha\(^{-1}\) \(\cdot\) yr\(^{-1}\)) of N and S, because ecosystem effects are more strongly determined by cumulative annual loading than by short-term atmospheric concentrations. The European Commission has adopted the concept of a “critical load,” defined as the load of a pollutant “below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (1). In PNAS, Payne et al. (2) provide new information on the impact of N deposition on European grassland ecosystems and illustrate some of the important complexities involved in quantifying and implementing critical loads.

Nitrogen deposition affects ecosystems in two ways. It can be an acidifying agent if the N is nitrified in the soil or nitrate is leached from the ecosystem. Nitrogen can also cause eutrophication, meaning that the oversupply of this nutrient can stimulate productivity of certain species (3). This may sound like a good thing, but in many herbaceous plant communities, the excess N deposition can stimulate growth of N-responsive (nitrophilic) graminoids that crowd out less responsive plants, particularly forbs and bryophytes (Fig. 1). The soil acidification and increased competition can lead to the decline of sensitive species in high-deposition areas. This general pattern of species change in favor of nitrophilic or acid-tolerant species has been established by previous work in grasslands, coastal dunes, heathlands, and alpine tundras, among other ecosystem types, although the pace and outcome of the change can be altered by such factors as soil pH, grazing, and disturbance to the dominant vegetation (4–8). Payne et al.’s analysis takes this one step further by focusing on responses of individual plant species in a large dataset of plant abundance in acid grasslands occurring across a gradient of N deposition in northwestern Europe. The critical load for this ecosystem type has been set at 10–15 kg N ha\(^{-1}\) \(\cdot\) yr\(^{-1}\) (9). Using a statistical procedure capable of identifying points along the N deposition gradient where particular species show significant decline, Payne et al. are able to identify change points for 155 species. Each species has its own change point, and about a third of the change points fall below 10 kg N ha\(^{-1}\) \(\cdot\) yr\(^{-1}\), and another third fall between 10 and 15 kg N ha\(^{-1}\) \(\cdot\) yr\(^{-1}\). A community-level analysis showed the most significant point of plant community change at about 14 kg N ha\(^{-1}\) \(\cdot\) yr\(^{-1}\). Thus, from the whole-community perspective, a critical load between 10 and 15 kg N ha\(^{-1}\) \(\cdot\) yr\(^{-1}\) is too high to protect the system from gross community change, and more importantly, from an individual-species perspective, roughly 60% of the species were affected at levels at or below the critical load. Furthermore, the most sensitive species responded at very low N loads, making it nearly impossible to determine a level of N deposition that does no harm in this plant community.

The critical load as defined above involves elements of both science and policy. Determining the amount of N deposition and determining the dose–response relationship between deposition loads and ecosystem responses are clearly scientific issues. Deciding which elements of an ecosystem are to be considered and what constitutes significant harm are policy issues. This paper speaks to both aspects of the problem. It describes the application of a sensitive statistical technique to determine dose–response relationships from gradient studies, which represents a scientific advance for this field. However, it also causes us to confront key policy questions: What kinds of information should be used to set critical loads? What constitutes “significant harm”? What if the critical load is zero or too low to be quantified? Should policies be set to protect the most sensitive species, or should some of those species be compromised for the sake of achievable emission targets?

This latter issue may force a reevaluation and redefinition of the critical loads concept. If there is no level of N pollution that does not cause harm, then the current definition is not useful and must be replaced by a more nuanced policy that defines a tolerable level of harm. This is closely analogous to the setting of air quality standards to protect human health, where the uncomfortable reality is that standards are set to protect the bulk of the population, with the knowledge that the most sensitive individuals will still suffer pollution-caused illness.

A related issue involves how to focus emission reduction efforts. If relatively pristine areas lose sensitive species quickly as N deposition increases, then keeping N deposition low in those areas, even if they are below the critical load, may be more important than trying to reduce deposition in more polluted areas where the plant communities have already shifted to N-tolerant species. This would require a rethinking of emissions control policies that seek to reduce the exceedance of the critical load if those policies allow N deposition to rise in more pristine areas.

Payne et al. emphasize that their findings do not diminish the usefulness of the critical load as a tool for assessment of air pollution effects on ecosystems. The critical load provides a framework for organizing, simplifying, and applying the large volume of information on impacts of air pollution. Critical loads are being used to evaluate the effects of S and N pollution in Europe and in Canada, but have so far been seen only very limited use in the United States (10, 11), and there is as yet no US federal policy to establish critical loads for sensitive regions. The US Clean Air Act requires the setting of “primary standards” to protect human health and “secondary standards” to protect public welfare, including the environment. Like the primary standards, the secondary standards are based on atmospheric concentrations and thus are not easily compatible with the deposition metric that provides the basis of the critical loads approach. Even without a regulatory basis in the Clean Air Act, the critical load could and should be used in the United States as an assessment tool to evaluate the effectiveness of air pollution control policies.

Author contributions: G.M.L. wrote the paper. The author declares no conflict of interest.

See companion article on page 984.

1E-mail: lovettg@caryinstitute.org.
pollution control measures and the risk to sensitive resources from N and S pollution (12–14). An integrated national framework for setting and using critical loads in the United States, such as is currently in place in Europe, would help the United States assess the threat of air pollution to its ecosystems and could help guide emissions control policy.

Globally, there are many plant species potentially at risk from N deposition, especially when one considers the recent increases in N pollution in the tropics (15). To make this problem manageable, ecologists will need to identify potentially susceptible community types through broad-scale surveys and then zero in on the most susceptible species using experimental and gradient studies. Of course, the decline of a plant species results in its principal host plant is being displaced by proliferation of graminoids fueled by elevated levels of N deposition (7).

Moreover, plant species do not merely respond to N availability in the soil; they can also partially control it through their uptake of N from the soil and through the quality of their litter, which regulates decomposition rates (16). A full accounting of the long-term consequences of N deposition and species change will require ecosystem models that incorporate the characteristics of individual species and simulate the dynamic, reciprocal interactions between changing plant species and changing soil conditions. This modeling approach will be especially necessary for forests, where because of the long life span of the trees, N-induced changes in species composition play out on a much slower timescale that does not lend itself to field experiments. Such models will be necessary for evaluating ecosystem impacts and setting critical loads for the long term and for predicting the interactions among N deposition, species shifts, and other perturbations such as invasive species and climate change.

Critical loads remain an important tool for assessing the impacts of atmospheric deposition on ecosystems, but the best use of this tool requires effective interplay between science and policy, including periodic reexaminations of the policy to incorporate the most recent scientific advances. In some cases, such as the Payne et al. paper (2), those advances may cause us to reconsider the fundamental concepts that underlie the policy.

**Payne et al. provide new information on the impact of N deposition on European grassland ecosystems.**