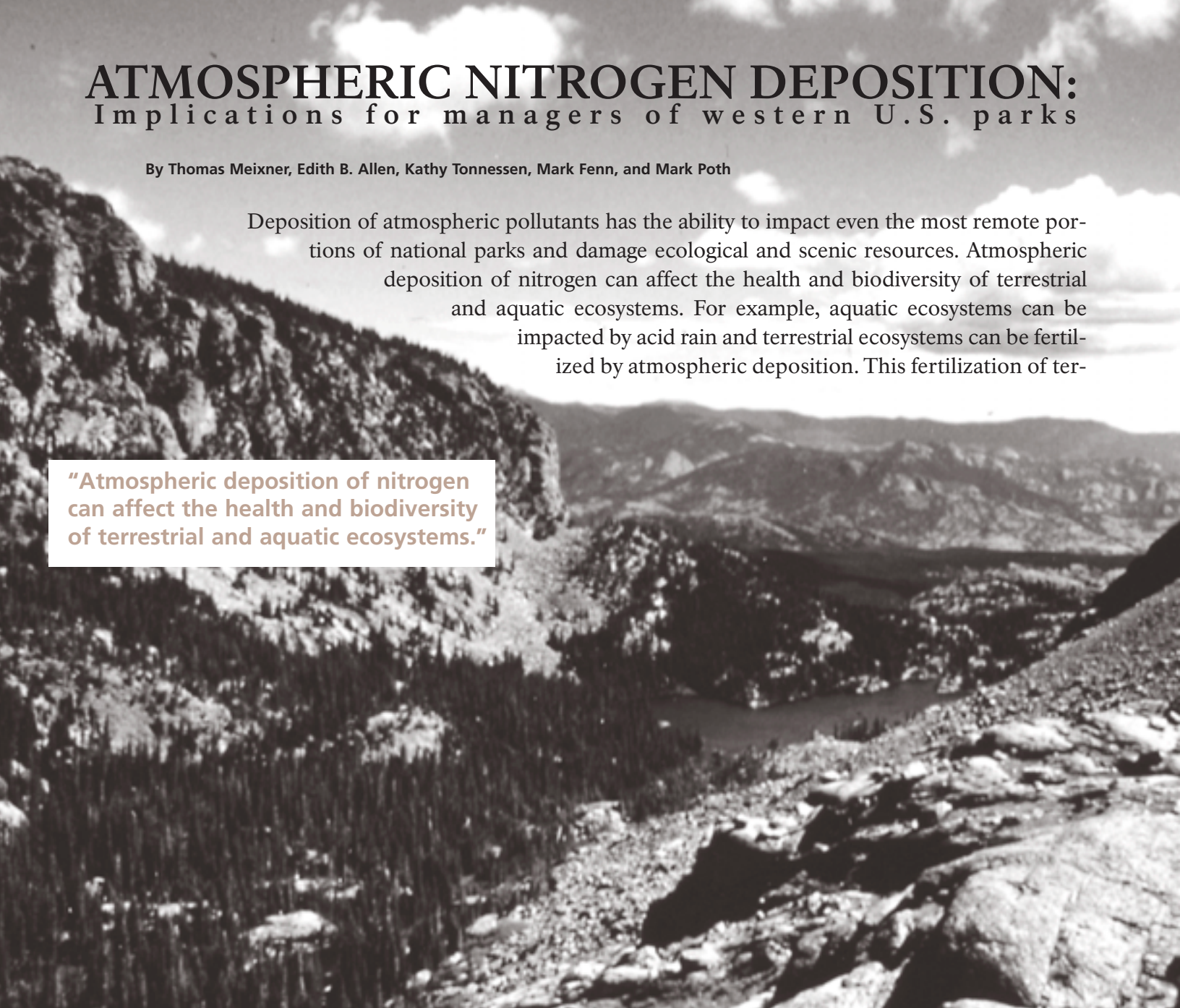




ATMOSPHERIC NITROGEN DEPOSITION: Implications for managers of western U.S. parks

By Thomas Meixner, Edith B. Allen, Kathy Tonnessen, Mark Fenn, and Mark Poth

Deposition of atmospheric pollutants has the ability to impact even the most remote portions of national parks and damage ecological and scenic resources. Atmospheric deposition of nitrogen can affect the health and biodiversity of terrestrial and aquatic ecosystems. For example, aquatic ecosystems can be impacted by acid rain and terrestrial ecosystems can be fertilized by atmospheric deposition. This fertilization of ter-

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restrial ecosystems may in turn lead to decreases in biodiversity. Also, leaching of large quantities of nitrate from terrestrial ecosystems into streams might impact aquatic ecosystems through eutrophication (i.e., nutrient enrichment in places like Lake Tahoe, for example) or possibly by direct toxicity to fish and amphibians.

The impact of nitrogen deposition on terrestrial and aquatic ecosystems depends on a number of variables, including meteorological variability, vegetation type, historical land use, fire history, hydrology, and proximity to the pollution source. In the eastern United States research on atmospheric deposition has generally focused on the problems of acid rain and its impacts on terrestrial and aquatic ecosystems. The problems in the East tend to be more widespread than in the western

United States and while many of the issues are similar in the two regions there are differences that prevent simple extrapolation from one ecosystem to the other. This report will focus on western systems since they have historically not been studied as much as the more humid systems typical of the eastern United States. Ongoing research in three different western U.S. ecosystems—alpine lakes and tundra in the Front Range of the Rocky Mountains and the Sierra Nevada, conifer forests in southern California, and the coastal sage scrub of southern California—is examining nitrogen deposition and its varied impact on these systems. While these ecosystems are by no means ubiquitous, they do have analogs throughout the National Park System and the United States.



Figure 1. The Loch Vale watershed in Rocky Mountain National Park, Colorado, has played a prominent role in understanding the impact of nitrogen deposition on ecosystem dynamics. The Front Range of the Rocky Mountains appears to be more affected by nitrogen deposition than the Sierra Nevada on account of thunderstorms that feed on air from the Denver area.

Figure 2. The high amount of biomass and winter-dominated hydrology of conifer forests in California appear to reduce the forest's short-term susceptibility to nitrogen deposition.



Impacts on western U.S. ecosystems

A comparison of alpine ecosystems in the Rocky Mountains and in the Sierra Nevada and their different exposures and responses to atmospheric deposition can provide insight into how factors such as ecosystem biomass, proximity to urban areas, and meteorology affect ecosystem sensitivity to nitrogen deposition. Alpine ecosystems are sensitive to nitrogen deposition because

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very little soil and only sparse vegetation exists to cushion the impacts of atmospheric deposition. The alpine zone of the eastern slope of the Front Range of the Rocky Mountains appears to have been impacted by changes in atmospheric dep-

osition, with stream nitrate concentrations much higher than on the western slope of the Rockies. In contrast, the alpine zone of the Sierra Nevada has exhibited no significant change in ecosystem dynamics or in stream water quality despite the proximity of large cities in California to the mountains. The lack of summer rain originating from polluted air masses in the Sierra Nevada and the stable inversion over the Central Valley of California limit nitrogen deposition in the alpine zone during the summer months. Much of the precipitation in the Sierra Nevada is winter snow that comes from clean, Pacific air masses that have limited interaction with industrial or urban areas. The Front Range of the Rockies appear to have higher rates of nitrogen deposition than the Sierra Nevada alpine zone. In part, this is because of its proximity to the Denver metropolitan area in combination with more summer rain. These factors encourage the deposition of pollutants from the urban air mass (fig. 1). Also, dry deposition of nitrogen is likely limited in the Sierra Nevada compared to the Front Range because this form of atmospheric deposition decreases rapidly as distance from the source increases. Nevertheless, although the alpine zone of the Sierra Nevada is not currently being impacted by nitrogen deposition, impacts may be occurring in the lower conifer and chaparral zones of the range. These areas are experiencing much higher dry deposition rates than the alpine zone.



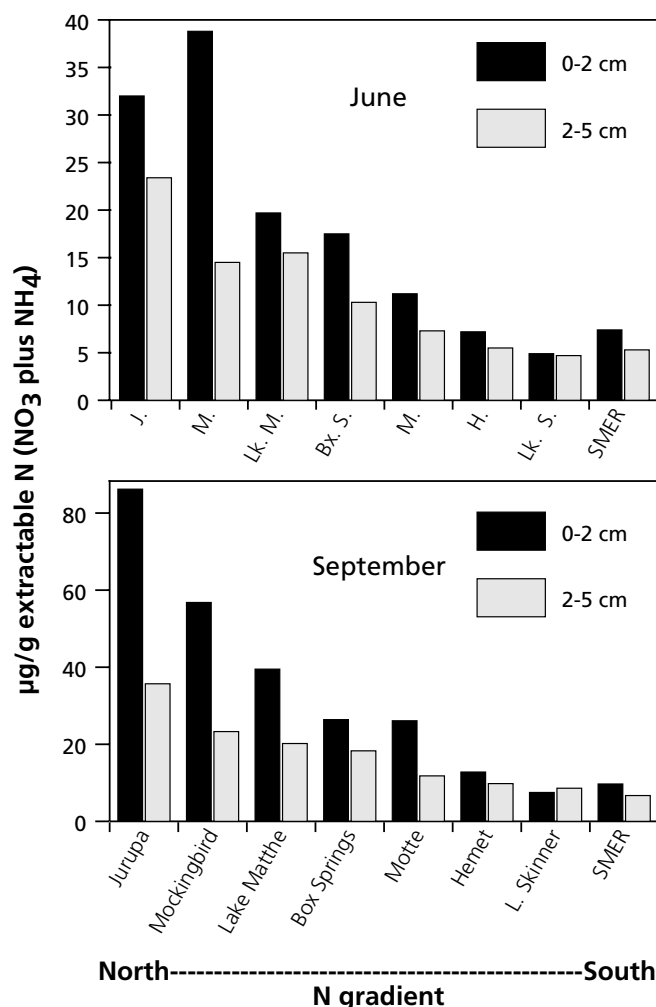


Figure 3. Soil nitrogen gradient in sites lying north to south in the coastal sage scrub ecosystem of the Riverside-Perris Plain, California. Biodiversity at these sites is inversely proportional to nitrogen concentrations in the soil with the highest biodiversity at the southern (low concentration) end of the gradient and the lowest biodiversity at the northern (high concentration) end of the gradient.

Conifer forests demonstrate the importance of hydrological and meteorological processes and ecosystem biomass on ecosystem sensitivity to nitrogen deposition (fig. 2, page 31). In contrast to the sensitivity of alpine ecosystems, the ponderosa and Jeffrey pine forests of southern California appear to be fairly resistant to increases in atmospheric nitrogen deposition at least in the short term. This resistance is despite the 30–40 kg nitrogen per hectare (163–217 lb/acre) per year that the most exposed forests receive (compared to about 2 kg/ha [11 lb/acre] in the alpine Sierra Nevada and 4–8 kg/ha [22–43 lb/acre] in the alpine Front Range). The interaction between hydrology and plant physiology appears to control the susceptibility of this ecosystem to nitrogen deposition. Summertime dry deposition of particulates and nitrogen-based gases dominate deposition in this ecosystem. Winter rains, which arrive when the vegetation is generally dormant, flush the atmospheric deposition rapidly off the vegetation and out of

the soil, sending a large pulse of nitrate into the streams of the San Bernardino and San Gabriel Mountains. When trees become active again in spring much of the nitrogen available to the plants has been leached out. The high rates of atmospheric deposition have increased plant nitrogen uptake, and physiological functioning has been altered by increased nitrogen deposition in these systems. Despite these changes fertilization experiments show that the vegetation will still respond to additional nitrogen. Conifer forests might also be more resistant in the short term because of the relative long life of conifer trees. These conditions indicate that nitrogen deposition is having a slower, less visible impact on the terrestrial component of the conifer ecosystem than it is on nearby aquatic systems.

Coastal sage scrub ecosystems may be among the most sensitive terrestrial environments because of their relatively *closed* hydrology and low biomass. Nitrogen deposition has been implicated in the replacement of native grasses and shrubs by invasive grasses, which have led to a decrease in biodiversity in areas of southern California previously dominated by coastal sage scrub vegetation (figs. 3 and 4). Coastal sage scrub is especially susceptible to nitrogen deposition on account of dry summers when nitrogen deposition is highest and nitrogen accumulates, followed by moist, relatively warm winters when the accumulated nitrogen becomes available for the growth of native and exotic species. Unlike the conifer forests, sage scrub is biologically active during winter, and plants rapidly respond to the onset of winter rains with the growth of shrubs, annual forbs, and grasses. Low rainfall in the coastal sage scrub accounts for very little nitrogen leaching out of the root zone of most vegetation. Thus, atmospherically deposited nitrogen in soil is available throughout the winter growing season. The exotic grasses are biologically designed to take advantage of the excess nitrogen, while



Figure 4. This coastal sage scrub site near Riverside, California, has been degraded by atmospheric nitrogen deposition. Note smog in the background.

the sage scrub has lower rates of nitrogen uptake. Exotic grasses are prolific seed producers and have an increased fire cycle. These factors along with increased productivity from nitrogen deposition are allowing exotic grasses to replace the native sage scrub.

Susceptibility of ecosystems

These three case studies allow us to derive a number of rules of thumb about the susceptibility of natural ecosystems to nitrogen deposition in the near future. (In the long run, if nitrogen deposition continues, all of these ecosystems will likely change.) The closer an ecosystem is to a large city the greater the likelihood for ecosystem damage from nitrogen deposition (e.g., Front Range of the Rockies and coastal sage scrub). Ecosystems dominated by storms originating at sea that do not move through major urban or industrial areas are less susceptible to nitrogen deposition (e.g., the Sierra Nevada, fig. 5). Terrestrial ecosystems that are dormant during the peak time of nitrogen availability are less susceptible to the impacts of nitrogen deposition, whereas aquatic ecosystems might be more susceptible (e.g., the conifer forests of southern California). Ecosystems with high biomass (e.g., conifer forest) are less susceptible to nitrogen deposition than those with low overall biomass (e.g., alpine tundra and coastal sage scrub). Ecosystems with low rainfall (e.g., coastal sage scrub) are more susceptible to the effects of nitrogen deposition than systems with relatively high rainfall rates (e.g., southern California coniferous forests) because the nitrogen is not substantially flushed out of the root zone of most plants.

Implications

Work remains on the occurrence and susceptibility of ecosystems to atmospheric nitrogen deposition. Still, enough evidence has been compiled for managers to be



Figure 5. Researchers conduct a survey of the quantity and quality of snow in the Emerald Lake watershed in Sequoia National Park. Sierra Nevada alpine watersheds appear to be unaffected by atmospheric deposition due to the clean, marine-air origin of much of the precipitation in the range.

concerned about the possible impacts of nitrogen deposition on the natural resources of our western national parks. Western U.S. problems with nitrogen deposition are more localized in areas impacted by urban air masses. Thus these problems differ from the more widespread, and in some cases more severe, problems present in eastern national parks such as Shenandoah and Great Smoky Mountains National Parks. In particular, managers of western national parks near urban areas (e.g., Rocky Mountain, Sequoia-Kings Canyon, Joshua Tree, Yosemite, and Saguaro National Parks and Santa Monica National Recreation Area) should be aware of issues involving atmospheric deposition, and resource managers should be encouraged to spend their time and funds on studying this issue. The types of studies that might be done to understand the susceptibility of ecosystems to nitrogen deposition include water quality monitoring in the parks over a number of years, measurements of soil or litter carbon:nitrogen ratios, and monitoring of vegetation to investigate nutrient ratios of standing vegetation. **P**

"Resource managers should be encouraged to spend their time and funds on studying [nitrogen deposition]."

Additional reading on the effects of nitrogen deposition on ecosystems

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