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Long-Term Trends in Ecological Systems:

A Basis for Understanding Responses to Global Change

Contents

Chapter 6

Cross-Site Comparisons of Precipitation and Surface Water Chemistry

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The biogeochemistry of ecosystems involves the transport or cycling of elements (such as sulfur, carbon, nitrogen, calcium) and compounds (such as water) through the biotic (plants, animals, microbes) and abiotic (soils, atmosphere) components. All elements and compounds cycle through the Earth's system, although at different rates and by different pathways that depend on their chemical characteristics and the extent to which they are utilized by organisms.

Cycling involves both inputs to and losses from different pools or standing stocks and the transformations of major and trace elements (figure 6-1). Inputs include weathering from rocks and minerals and deposition from the atmosphere (wet in precipitation and dry as gases or particles). Losses can occur either through gaseous emissions to the atmosphere or drainage below the soil surface or from land to ocean. Pools include the accumulation of elements in the soil, sediments, and vegetation of an ecosystem. Important internal transformations of elements include litter inputs, mineralization of organic matter, uptake of nutrients by vegetation, and the retention or release of material in soil or sediments.

Ecologists measure these pools and fluxes to learn critical information about the functioning of ecosystems. Because the time for a molecule to be completely transported through an ecosystem may be decades to millennia, long-term data provide one of the few means to estimate how ecosystems use and respond to changes in inputs of nutrients and toxic substances. Long-term data can characterize the average size and variability in ecosystem pools and the rates of flow among pools. Monitoring biogeochemical indicators provides useful insights on the response of ecosystems to chronic change, such as in climate or land use, the introduction of invasive species, or changes in air pollution, and short-term disturbances such as fire or climatic events including hurricanes, ice storms, and droughts. Many important ecosystem services, such as the supply of clean air and water, ecosystem productivity, and carbon sequestration, are closely coupled to the biogeochemistry of ecosystems.

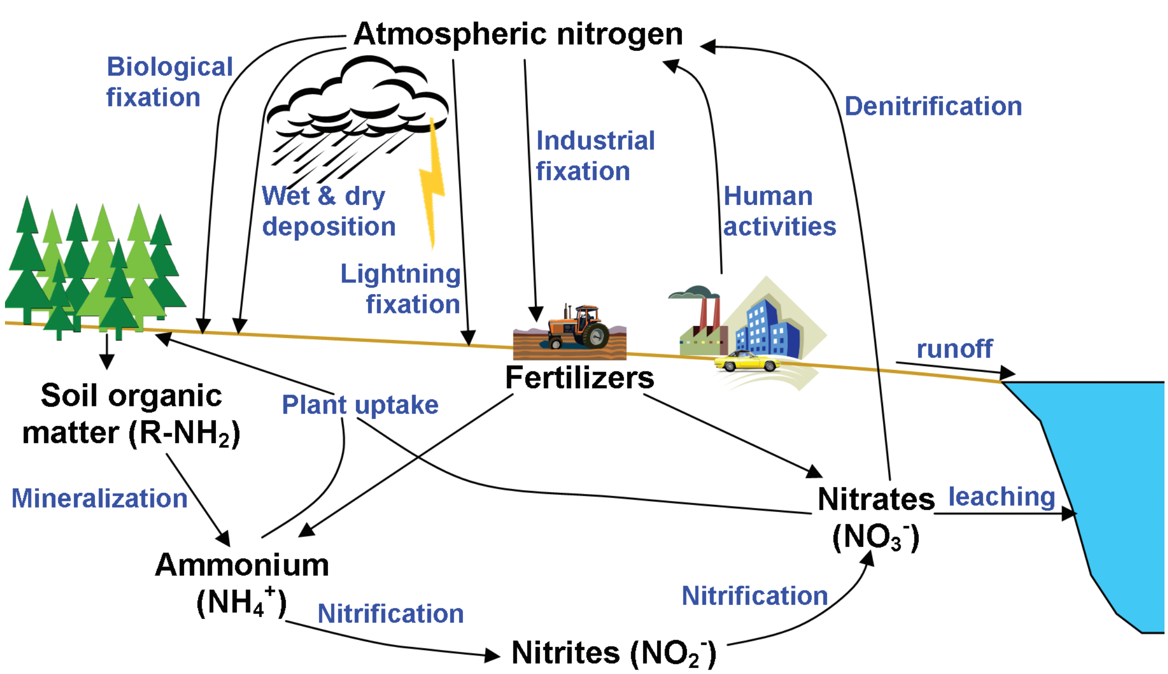


Figure 6-1. Nitrogen cycling through the Earth system involves inputs for wet deposition (in rainfall) and dry deposition (in dust particles and gases), as well as direct human activities such as application of fertilizer. Inputs to the atmosphere come from fossil fuel emissions and gaseous emissions from the soil. Nitrogen also can be exported from land to water bodies through leaching, deep drainage, and runoff. Nitrogen is a major nutrient for plants, animals, and microbes.

Over the past 150 years, marked changes have occurred in atmospheric emissions from human sources and deposition in precipitation across the United States (chapter 12). These changes have been driven by industrialization, human population increases, land-use change, and since the early 1970s, Federal Government controls on industrial and vehicle emissions. Air pollution through atmospheric deposition can influence ecosystem structure and in turn alter ecosystem functioning and services. Atmospheric deposition influences terrestrial ecosystems—including soil chemistry, vegetation nutrient cycling, and species health and distribution—and aquatic ecosystems—including surface water chemistry (chapter 12) and aquatic productivity, density, and composition (chapter 14).

A number of interesting and society-relevant hypotheses can be tested using long-term biogeochemistry data collected from a number of sites located in different ecosystem types and climatic regimes. In this chapter, we use data from chapter 12 to test two hypotheses related to patterns in biogeochemistry across EcoTrends sites and elements:

- Patterns in atmospheric deposition over the past 20 years are different for the eastern and western parts of the United States.
- Changes in atmospheric deposition are related to changes in human population density for some sites.

We test these hypotheses using chemical measurements in wet deposition (nitrate, ammonia, sulfate). To help interpret the patterns and trends in precipitation chemistry, we used sulfur dioxide, nitrogen oxide, and ammonia emission data compiled by the U.S. Environmental Protection Agency (EPA) (www.epa.gov/air/data/geosel.html).

Hypothesis 1. Patterns in Atmospheric Deposition Over the Past 20 Years Are Different for the Eastern and Western United States

In support of our hypothesis, total sulfur dioxide and nitrogen oxide emissions were higher through time for the region of the United States east of the Mississippi River than in the western region (figure 6-2). These patterns are consistent with higher population density on average in the eastern than the western parts of the country (figure 8-1, chapter 13). Emissions of sulfur dioxide are largely associated with coal-fired electric utilities located in the East (Dennis et al. 2007) that contribute sulfate to precipitation. Emissions of nitrogen oxides are largely due to a combination of electric utilities and transportation sources, resulting in nitrate in precipitation. Ammonia emissions are higher in the West than in the East, and are largely associated with agricultural activities (Driscoll et al. 2003).

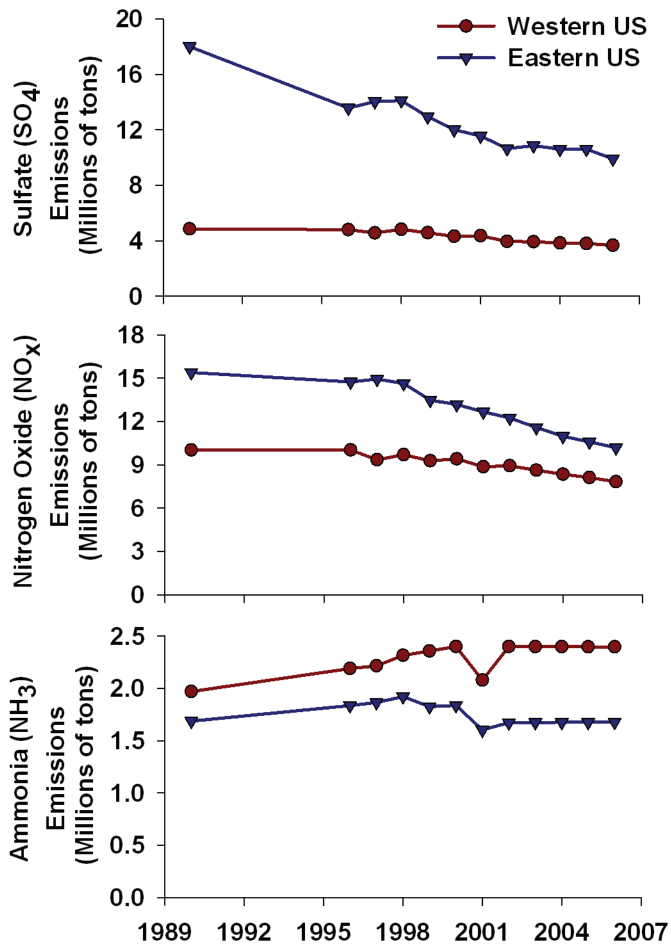
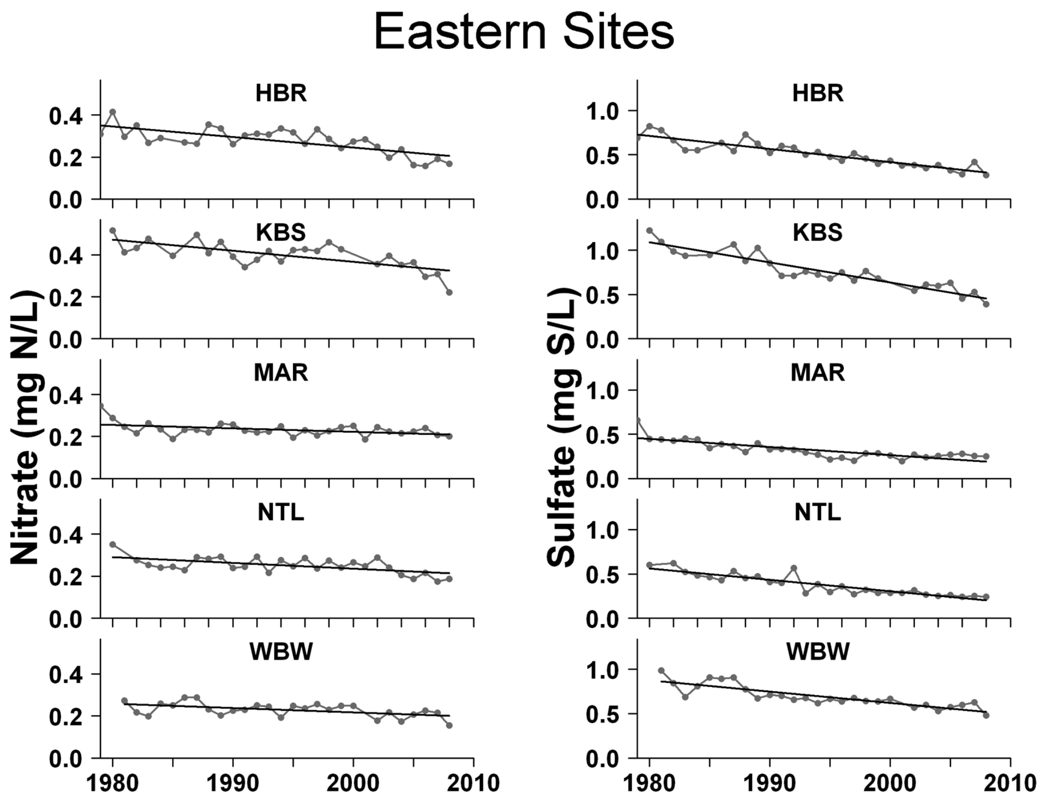


Figure 6-2. Annual atmospheric emissions of sulfur dioxide, nitrogen oxides, and ammonia for the eastern (east of the Mississippi River) and western States from 1990 to 2006 (www.epa.gov/air/data/geosel.html).



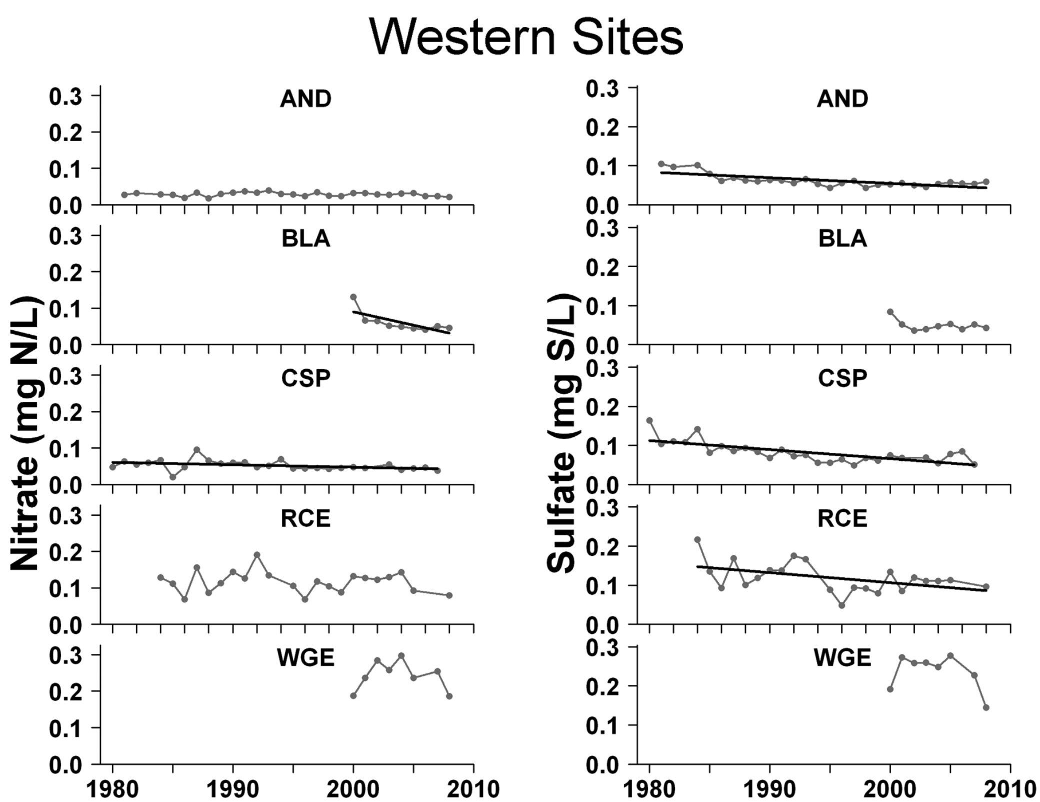


Figure 6-3. Change in annual volume-weighted concentration of nitrate and sulfate in precipitation at five eastern (upper panel: HBR, KBS, MAR, NTL, WBW) and five western sites (lower panel: AND, BLA, CSP, RCE, WGE). (Original data from Internet home pages—see table 1-1—and http://nadp.sws.uiuc.edu/. Synthesized data from http://www.ecotrends.info.)

The temporal trends in sulfate and nitrate concentrations in precipitation also reflect emission trends regionally. In the East, considerable effort has been made to control sulfur dioxide and nitrogen oxide emissions from electric utilities through the 1990 Amendments of the Clean Air Act and the Nitrogen Oxide Budget Trading Program (Dennis et. al. 2007). These control efforts have resulted in significant decreases in sulfate and nitrate concentrations in precipitation in eastern EcoTrends sites in both forests (HBR, MAR, NTL, WBW) and grasslands (KBS) (figure 6-3, top). In contrast, emissions of nitrogen oxides and sulfur dioxide in the West are either decreasing at a lower rate or not changing (figure 6-2). This limited change in trends through time is reflected by patterns in nitrate concentrations in precipitation for several forest (AND, BLA, CSP) and aridland (RCE, WGE) sites in the West (figure 6-3, bottom). These patterns are likely associated with increasing human development and associated transportation emissions, as well as less aggressive emission controls in the West than in the East.

In general, ammonia emissions have not changed appreciably for either region (figure 6-2) as a result of limited changes in agricultural activities. These trends in nitrogen emissions suggest a pattern of increasing importance of ammonium in the future as a percentage of total atmospheric nitrogen deposition if nitrogen oxide emissions continue to decrease.

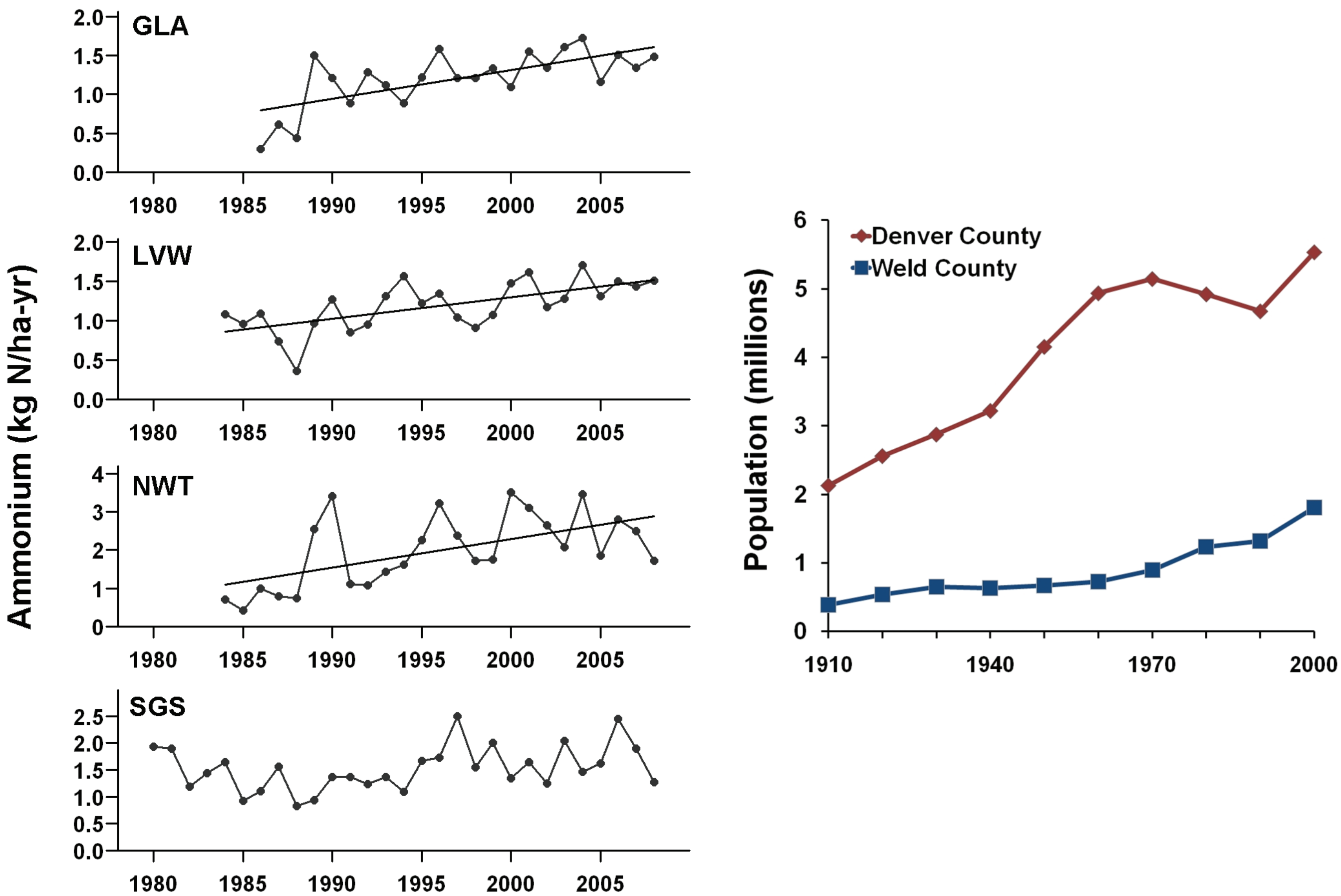


Figure 6-4. Left panel: An increase in ammonium deposition (kg/ha-yr) at three upslope Rocky Mountain locations (GLA, LVW, NWT) and no trend at a grassland site (SGS). Right panel: Patterns in nitrogen deposition for mountain sites reflect high rates of population increase in metropolitan Denver (represented by Denver County), the main source of nitrogen in rainfall in spring and summer. The county of the grassland site (Weld) also increased in population, but the source of nitrogen deposition is rainfall from surrounding agricultural land and rangeland. (Original data from Internet home pages—see table 1-1, http://nadp.sws.uiuc.edu/, and http://www.census.gov. Synthesized data from http://www.ecotrends.info.)

Hypothesis 2. Changes in Atmospheric Deposition Are Related to Changes in Population Density for Some Sites

Sites in the Rocky Mountains show a different trend in nitrogen deposition than other sites in the West, and these patterns are related to location rather than to ecosystem type (figure 6-4 left panel). For three high-elevation sites in the central Rockies, ammonium (and nitrate, not shown) deposition has increased through time (GLA, LVW, NWT). These sites are located upslope to the west of the Denver metropolitan area along the Front Range of the Rocky Mountains where human population density has been rapidly increasing (figure 6-4, right). Spring and summer moisture at these mountain sites is influenced mainly by westerly upslope storms from the Front Range; these storms provide an important source of atmospheric nitrogen deposition (Burns 2003). Thus, a rapid increase in density of humans may explain, at least in part, the higher nitrogen deposition rates in the mountains. In contrast, the lack of a trend in ammonium (or nitrate) for grasslands at lower elevations east of the mountains (SGS) likely reflects the long distance and easterly location of this site away from the influence of the major cities along the Front Range.

Conclusions

Human activities have greatly altered patterns in atmospheric deposition over the past 20 years. Effects of these activities vary regionally and across the continent as a result of variation in factors such as human population density, energy and agricultural production and use, atmospheric circulation and sources of rainfall, and government regulation. Cross-site comparisons of long-term data provide new insights into these spatial patterns.

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