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Ecosystem Responses and Behaviors Under Changing Pressures of Air Pollutants

Ecosystem responses and behaviors under changing pressure of air pollutants: Special article collection from the 10th International Conference on Acid Deposition “ACID RAIN 2020”

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Email: nobu@i.kyoto-u.ac.jp**Abstract**

This special issue is a partial compilation of research papers from the 10th International Conference on Acid Deposition “ACID RAIN 2020” conference held in Niigata, Japan in April 2023, focusing on ecosystem responses to air pollution. The Acid Rain Conference series began in 1975, initially addressing the harmful effects of acid deposition on ecosystems. Over time, the research focus evolved from simple acid rain issues to effects of excess nitrogen deposition and saturation in the 1980s, and then to ecosystem recovery studies in the 1990s. Current research examines interactions with climate change and air pollution in developing countries. The special issue contains 11 papers: eight on long-term ecosystem responses, two on plants' role in reducing air pollution, and one technical note on soil sampling in biogeochemical monitoring. The long-term studies, from Japan and Norway, show different regional responses to acid deposition. Japanese forests demonstrate higher acid buffering capacity than Northern European ones, partly due to the composition of volcanic soil. Nordic papers focus on modeling tools, MAGIC (Model of Acidification of Groundwater In Catchments), which has been improved over time to simulate the combined effect of acid deposition and climate change impacts. It is significant that exactly half a century after the first conference, this collection of contemporary papers will be published in *Ecological Research*. This is because findings from research on biogeochemical cycles in ecosystems related to acid rain should be widely shared among the ecological community, and through this, a variety of audiences should be informed.

KEYWORDS

acid deposition, Acid Rain Conference, biogeochemical cycles, ecosystem response, nitrogen saturation

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This special issue is a partial compilation of research papers presented at the 10th International Conference on Acid Deposition “ACID RAIN 2020—Future Environment and the Role of Multiple Air Pollutants” held in Niigata, Japan in April 2023, collected around the theme of “Ecosystem responses and behaviors under changing pressure of air pollutants.” This international conference, called the “Acid Rain Conference,” has a long history, with the first one held in Columbus, Ohio, USA in 1975. As the name of the conference suggests, acid rain was a significant environmental issue that was being addressed as a social problem in developed countries, mainly in the United States and Europe, at the time.

The main problem was that precipitation, mainly containing sulfuric acid, acidified the soil, causing damage to plants and acidifying land waters, resulting in fatal effects on aquatic organisms. It became an urgent task to clarify what type of biogeochemical reactions were taking place in terrestrial and aquatic ecosystems. Research on the causes of air pollution and the mechanisms of chemical reactions behind these biogeochemical processes also began to develop around this time (e.g., Likens et al., 1979). These studies were carried out mainly in developed countries such as North America, Europe, and Japan, including urban areas where air pollution was severe, and have been a strong driver of progress in biogeochemical research on terrestrial ecosystems.

Following the rapid introduction of technologies to suppress gas emissions that cause sulfuric acid deposition in the atmosphere, attention began to be paid to the impact of excess nitrogen deposition on terrestrial and aquatic ecosystems in the late 1980s. The phenomenon known as nitrogen saturation was reported in many areas damaged by acid rain, prompting intensive research into the issue. Since the nitrogen cycle is a fundamental process for the activity and maintenance of ecosystems, the impact of excess nitrogen deposition on this cycle became a topic of interest, not only in terms of environmental pollution but also as an important research area in ecosystem ecology (e.g., Aber, 1992).

During this time, as a result of technological and political efforts to reduce sulfur oxide and nitrogen oxide emissions, the amount of acid deposition from both sources decreased in various parts of Europe and the northeastern United States. In the course of this environmental change, research on the recovery of ecosystem processes from the effects of acid rain increased from the late 1990s (e.g., Driscoll et al., 2001; Likens et al., 1996). These studies did not simply report cases in which the acid neutralization capacity of soils and land waters had recovered but also included studies attempting to elucidate the changes in ecosystem structures that occurred during the process, and there was a movement to expand

the coverage of research from biogeochemistry to community ecology (Blum et al., 2002).

In addition, in recent years, interest has been growing in the overlap of effects with climate change such as global warming, and research on this topic is also being conducted. Air pollution is a contemporary issue in emerging countries with rapid economic development, and research to solve this problem requires not only the accumulation of knowledge in natural sciences, but also social scientific research that can be reflected in policy discussions, and research groups are beginning to produce results in this area (e.g., Molina & Molina, 2004).

In this way, the activities of the Acid Rain research community have developed into comprehensive studies on the effects and mechanisms of pollution caused by anthropogenic atmospheric deposition on both terrestrial and aquatic ecosystems.

The 11 papers included here cover a wide range of fields, with a wide variety of research subjects and methods. The contents are as follows: eight papers (described later) dealing with long-term ecosystem biogeochemical changes over decades that are directly related to the theme of this special issue, two papers on the function of plants to reduce air pollution (Roy et al., 2025; Tangahu et al., 2025), and one technical note on tools for soil biogeochemical surveys and monitoring in forests (Watanabe et al., 2025).

As mentioned above, a decrease in acid deposition has been reported in developed countries since the 1980s, and the eight papers on long-term observations also document the observed changes and the status of “recovery.” Six of the eight papers were from Japan and two were from Nordic countries. It has been shown that the acid buffering capacity of forest ecosystems, which are the water sources of Japanese streams and rivers, is higher than in areas such as Northern Europe, where acidification of freshwater due to acid rain was once a problem (e.g., Ohte & Tokuchi, 1999). Inagaki et al. (2025) and Urakawa et al. (2025) also pointed out this difference, and Koshikawa et al. (2025) discussed the influence of soil originating from volcanic ash as a characteristic of the soil conditions related to this high buffering capacity. Makino et al. (2025) showed that the decreasing trend in nitrogen deposition was occurring nationwide in Japan. The methodology is unique in that it uses citizen activities to collect the nationwide data. Baba et al. (2025) and Takahashi and Kawakami (2025) clarified how the reduction in nitrogen deposition has been affecting nitrogen-saturated forests through monitoring conducted over the past 10 to 20 years. In both cases, it was shown that the reduction in nitrogen load leads to a reduction in aluminum runoff, and as a result, the acid buffering mechanism, including aluminum mobilization, was functioning.

On the other hand, both Nordic research cases were papers about models originally developed in the 1980s to examine the impact of acid deposition on soil and water. An update on the application of the representative model, the Model of Acidification of Groundwater In Catchment (MAGIC), to long-term observational data and improvements to consider the impact of climate change was presented (Norling et al., 2025). It was shown that it is possible to logically interpret long-term fluctuations from the impact of anthropogenic disturbances to the effects of natural acidification due to climate change using MAGIC (de Wit et al., 2025). This demonstrates a remarkable possibility of using it as a tool to predict biogeochemical changes in terrestrial ecosystems in the context of climate change.

The year 2025, when this special feature is published, will mark half a century since the first conference was held in Columbus, Ohio, and a quarter of a century since the first Acid Rain Conference in Japan was held. I believe it is very significant that a contemporary collection of papers in commemoration of ACID RAIN 2020, which was held again in Japan, is published at this time in *Ecological Research*, a journal of the Ecological Society of Japan. This is because, as mentioned above, findings from research on biogeochemical cycles in ecosystems affected by acid deposition should be widely shared within the ecological community, which approaches ecosystems using a variety of methods. Through this, knowledge should be spread in society, and a variety of audiences should be informed. I hope that this special issue will spark lively and contemporary discussions on acid rain and ecosystems among readers and authors from diverse backgrounds.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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