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Patterns of Nutrient Dynamics in Adirondack Lakes Recovering from Acid Deposition

Summary Report

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Patterns of Nutrient Dynamics in Adirondack Lakes Recovering from Acid Deposition

Report Summary

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1 Background

In this study, changes in nutrient dynamics were examined in Adirondack lakes of New York State in response to recovery from acidification. Atmospheric deposition of nitrate and sulfate are decreasing as a result of decreases in emissions of nitrogen oxide and sulfur dioxide. This decrease in acid deposition is resulting in increases in pH as well as decreases in concentrations of nitrogen and possibly increases in phosphorus. Biological communities are dependent upon both nitrogen and phosphorus as critical nutrients. Adirondack drainage lakes are currently phosphorus limited, while seepage lakes are co-limited by nitrogen and phosphorus (Baron et al., 2011). In a future with anticipated further decreases in lake nitrogen concentrations resulting from decreases in deposition and increases in phosphorus concentrations. This is a result of soil and sediment release with increased pH, making it possible that seepage lakes may become nitrogen limited and phosphorus may begin to increase in drainage lakes. This shift could result in changes in biological communities in Adirondack lakes.

2 What is a limiting nutrient?

Organisms require six major elements (carbon, nitrogen, phosphorus, sulfur, hydrogen, and oxygen) and 19 minor elements to perform metabolic functions, growth, and reproduction. In aquatic ecosystems, these elements are required in a narrow ratio as long as they are provided in individual organisms and communities of organisms that can grow and reproduce. In natural ecosystems, there is at least one element present at a value below the ratio required by the organisms. This element(s), known as the limiting nutrient, acts as an upper limit to the growth the ecosystem can achieve. In general, lake ecosystems in the northeastern United States are limited by phosphorus, though some lake ecosystems are co-limited by both phosphorus and nitrogen (Baron et al., 2011).

The limiting nutrient(s) in an ecosystem is not constant over space or time. Rather, it is dependent upon inputs to the system and the needs of the organisms present. Thus, even though most northeastern United States lakes are phosphorus-limited since the nitrogen concentration is much greater than the phosphorus concentration, it is possible that the limiting nutrient could change (i.e., if nitrogen inputs decrease to a level that reduce the nitrogen to phosphorus ratio and tip the nutrient limitation to nitrogen). Additionally, if the types of organisms present in the lake ecosystem shift, their nutrient needs could also change, thereby altering the required ratio of elements for metabolism, growth, and reproduction; thus, the element failing to meet the required ratio could shift. Finally, all lake systems have different inputs related to weathering of rocks and minerals, material derived from nearby forest within the watershed, and atmospheric deposition of different elements. These inputs will all impact the ratio of elements in the lake.

3 How has acid deposition affected the northeastern United States?

During the 20th century, global emissions of nitrogen oxides and sulfur dioxide were high due to the burning of fossil fuels. Once emitted into the atmosphere, sulfur and nitrogen is deposited to the Earth's surface either as dry deposition (as gases or associated with particles) or as wet deposition (dissolved in precipitation – rain, snow, ice). Due to the presence of sulfuric and nitric acids, this deposition was acidic with a characteristic low pH. As a result of high emissions in the 20th century, the deposition of nitrogen and sulfur to the Earth's surface increased more than five-fold above pre-industrial conditions in industrialized areas (Galloway 1984). This deposition resulted in elevated concentrations of nitrate and sulfate in lakes and streams, while simultaneously lowering the pH and increasing the acidity. These changes in lake chemistry negatively affect biodiversity, community structure, and nutrient patterns within the aquatic communities (Lovett et al., 2009). Acid deposition and its impact on lake ecosystems has been particularly apparent in the northeastern United States.

Though nitrogen oxides and sulfur dioxide emissions and deposition were elevated during most of the 20th century, the past few decades have seen dramatic decreases in acid deposition in the northeastern United States. This change is primarily the result of increased regulation of atmospheric emissions. Consequently, lake chemistry has responded with increased pH (decreased acidity) and decreased nitrogen and sulfur concentrations. Higher pH is also likely increasing the release of phosphorus from watershed soils and lake sediments, thereby increasing lake phosphorus concentrations, though there are few long-term records of surface water concentrations of total phosphorus in remote areas impacted by acid deposition. Along with these decreases in lake acidity, aquatic biological communities are likely recovering with increased biodiversity and population numbers.

4 How are Adirondack lakes classified?

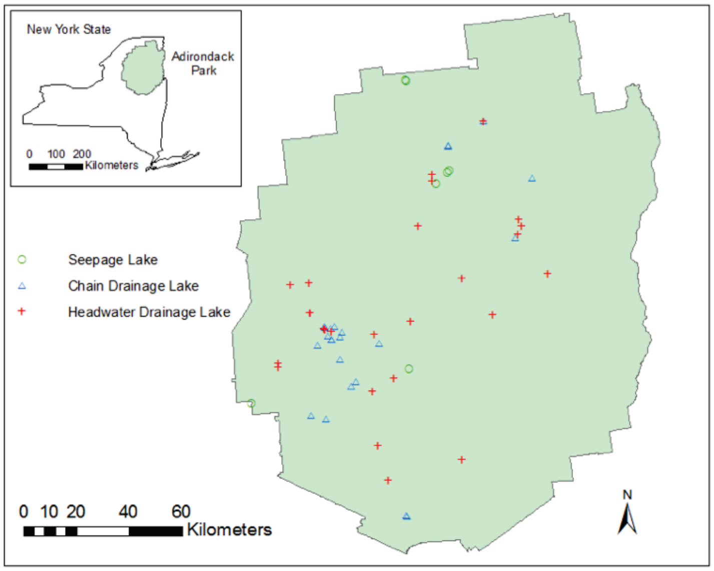
Adirondack lakes can be divided into two lake types: perched seepage lakes and drainage lakes. The difference between these lake types is important since they vary dramatically in the input of water and nutrients. As a result, the recovery from acid deposition, chemical composition (i.e., nutrients), and biological communities differs greatly between lake types. An earlier survey suggests that 86 percent of the lakes in the Adirondack Park are drainage lakes (Baker et al., 1990). Drainage lakes are somewhat larger (mean surface area 18 ha) and distributed throughout the Adirondack Park, while seepage lakes are smaller (mean surface area five ha) and are primary located near the western boundary and northcentral Adirondacks. Fifty-two lakes in the Adirondacks were examined that are part of the Adirondack Long-term Monitoring (ALTM) Program; of these, seven are seepage and 45 are drainage lakes (Figure 1).

Perched seepage lakes do not contain a surface outlet. They are disconnected from streams and receive the majority of water directly via precipitation and shallow groundwater inflows adjacent to the lake. Nutrients that enter the lake originate from direct atmospheric deposition and recycling of materials within the lake (from organisms and lake sediments). Due to the lack of connection with the terrestrial environment, perched seepage lakes respond rapidly to changes in atmospheric nitrogen and sulfur deposition patterns.

Conversely, drainage lakes are connected via streams to the forest terrestrial ecosystem and watershed inputs. Direct precipitation and deep groundwater flow account for only a small fraction of inputs. Though nutrients enter the lake via direct atmospheric deposition to the lake surface, most of the nutrient inflow is derived from the interaction with soils in the watershed. As the water flows over or through soil and geologic materials, nutrients are transported into the lake ecosystem. This connection to the terrestrial system causes drainage lakes to respond slower to changes in atmospheric nitrogen and sulfur deposition patterns. Drainage lakes can also be further subdivided into headwater drainage and chain drainage lakes. Headwater drainage lakes are the first lake in a series of drainage lakes with inflowing water occurring primarily from streams, whereas chain drainage lakes are further in a series of drainage lakes with inflowing water occurring after passing through another lake.

Figure 1. Location of Adirondack Long-Term Monitoring (ALTM) sites within the Adirondack Park in New York, USA.

Shown are the location of seepage, headwater drainage, and chain drainage lakes.



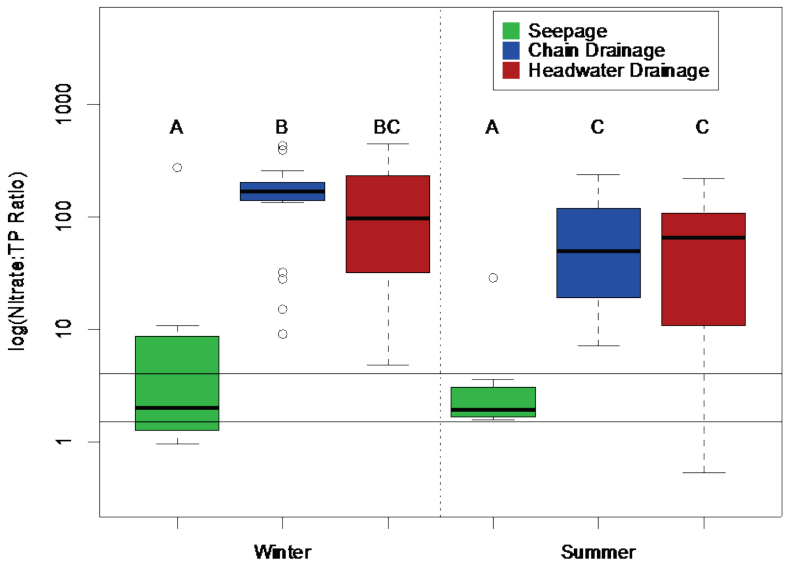
5 How are changes in acid deposition to the northeastern United States impacting lake nutrient dynamics?

Concentrations of nutrients are typically low in Adirondack lakes, particularly total phosphorus, which occurs at very low concentrations. We found that seepage lakes have the highest values of total phosphorus (median of 12.0 µg P/L), followed by headwater drainage (4.3 µg P/L) and chain drainage lakes (4.0 µg P/L). Seepage lakes have much lower nitrogen to phosphorus ratios compared to drainage lakes. In fact, seepage lakes appear to currently be co-limited by both nitrogen and phosphorus, whereas drainage lakes appear to be highly phosphorus limited (Figure 2).

In the 52 ALTM lakes, acid deposition is impacting nutrient dynamics differently in seepage compared to drainage lakes; the impact was similar for both headwater drainage and chain drainage lakes. With decreases in acid deposition, lakes will receive lower inputs of nitrogen; as a result, nitrogen concentrations in lakes are expected to decrease. As nitrogen concentrations decrease, the lake nitrogen to phosphorus ratios will also decrease. There is also a possibility for increases in phosphorus concentrations in lakes associated with decreases in acid deposition (Kaňa and Kopáček. 2006; Kopáček et al., 2015). With decreases in acid deposition, the pH of lakes will increase, which could cause phosphorus to release from soil in the watershed and lake sediments. Increased phosphorus concentrations in lakes will cause a decrease in the lake nitrogen to phosphorus ratios. With an already low nutrient ratio, seepage lakes could be pushed into nitrogen limitation. The higher nutrient ratio in drainage lakes will likely also decrease, but not enough to become nitrogen limited, and these lakes will remain phosphorus limited.

Figure 2. The nitrate:total phosphorus (TP) mass ratio in Adirondack lakes.

A ratio less than 1.5 (lower line) indicates nitrogen limitation, between 1.5 and 4 (upper line) indicates nitrogen and phosphorus co-limitation or influence of another variable, and a ratio above 4 indicates phosphorus limitation, as defined by Bergström (2010). Letters signify a statistically significant difference in concentration.



6 How might these changes impact biological communities?

It is difficult to project how changes in lake chemistry and limiting nutrient dynamics might impact biological communities. However, it is likely that chemical alterations will lead to biological changes. Currently, these lakes do not support a large biologic community; however, increased phosphorus inputs associated with the increased pH of lakes along with the decreased nitrogen inputs could stimulate biological growth. This could be particularly evident for phytoplankton communities limited by phosphorus inputs and zooplankton populations that graze on these phytoplankton populations.

With decreased acidification and subsequent recovery, the question arises of whether lakes can return to their pre-acidification biological conditions. It seems likely that a combination of species loss, interspecies competition, and the impact of climate change on water dynamics will modify the trajectory of biologic recovery from acidification. Projected changes in nutrient dynamics with recovery is also dependent upon geology, land use, atmospheric deposition patterns, and global change patterns that drive lake recovery processes. Nevertheless, though it is not possible to determine the future biologic communities in these Adirondack lakes, it is likely there will be profound shifts in food web dynamics.

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