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Abrupt Increase in Stream Water Nitrate Can Be Caused by Multiple Climate-Related Factors Over Time

For decades, researchers at the Hubbard Brook Experimental Forest have monitored nitrate levels in streams to better understand nitrogen cycling in forests. Researchers have reported that peaks in stream water nitrate levels often occur within months of single disturbance events, such as clearcutting or ice storms.

In the summer of 2013, researchers discovered a sharp increase, or pulse, of nitrate in stream water that was not connected to a known disturbance event. This puzzling observation prompted an investigation into why stream nitrate levels had increased so drastically. Scientists Linda Pardo, John Campbell, and cooperating scientist Mark Green, all with the U.S. Department of Agriculture, Forest Service, Northern Research Station, and several colleagues used long-term datasets and machine-learning techniques to determine that multiple environmental factors, rather than a single disturbance event, contributed to the pulse of nitrate observed in 2013.

Puzzling Pulse in Stream Water Nitrate Level

Nitrogen is an important nutrient in forests and is required by trees for growth. When the amount of nitrogen available in soil exceeds the demand by plants and trees, the excess nitrogen can enter streams and degrade water quality. Monitoring nitrate levels in streams allows researchers and land managers to learn more about the status of nitrogen cycling in a particular forest and whether changes in the environment are affecting nutrient cycling and water quality.

KEY MANAGEMENT CONSIDERATIONS

- Stream water nitrate levels can reflect how forests respond to changes in climate, carbon dioxide concentrations, and air pollution.
- Many factors can contribute to changes in stream nitrate levels, such as reduced uptake of nitrogen by plants, increased nitrogen cycling rates, and changes in weather and hydrology.
- Models using long-term datasets and machine learning techniques can help improve understanding of complex environmental interactions.

For example, clearcutting often leads to an increase in stream nitrate levels because the removed trees would otherwise have taken up nitrogen from the soil. Other conditions that can reduce nitrogen uptake by plants include ice storms, soil frost, and drought.

In the summer of 2013, stream nitrate levels in one of the watersheds at Hubbard Brook were about ten times higher than they had been at any other time since 2003, but the researchers were unaware of a disturbance event that could explain the increase. They came up with several possible causes—higher inputs of nitrogen from air pollution, faster rates of nitrogen cycling due to wetter or warmer conditions, reduced uptake of nitrate by plants due to soil frost or wind damage, or enhanced nitrate transport from soil to streams caused by more precipitation or intense rain events—all of which are harder to pinpoint than a single disturbance event.

Northern Research Station forester Ian Halm collecting a water sample for chemical analysis at Hubbard Brook. USDA Forest Service photo.

Long-Term Records and Machine Learning

Interpreting nitrogen measurements can be difficult because nitrogen cycling is complex and can be influenced by a number of factors. The consequences of disturbance events or changes in the environment can also take up to several years to show up in water chemistry data. To tackle this challenge, researchers built a model based on machine learning and long-term datasets from Hubbard Brook to predict stream water chemistry. They used data from 2003 through 2018—a period that encompassed the pulse of nitrate in the summer of 2013 and did not include any substantial disturbance events.

This complex modeling approach allowed the researchers to predict stream water chemistry from prior weather and environmental conditions. They were also able to determine the optimum time window of past conditions that could explain current stream nitrate levels.

Multiple Factors Revealed by Modeling

The researchers' model indicated that several environmental factors likely contributed to the 2013 change in the nitrogen cycle. One possible explanation was that warmer and wetter conditions caused an increase in nitrogen cycling rates. Another was that increased soil frost, reduced solar radiation, or both that occurred for several years before 2013 reduced plant growth and therefore reduced uptake of nitrate. Still another explanation was that changes in hydrology influenced stream nitrate levels, which suggests that precipitation and baseflow could have influenced this pulse of nitrate. Together, these factors could have been responsible for the increase.

Northern Research Station research ecologist John Cambell describing research in the sample archive at the Hubbard Brook Experimental Forest. USDA Forest Service photo by Suzanne Flory.

Conclusions

Nutrient cycling is complicated and affected by changes in the environment. Advanced machine learning techniques can help to isolate these changes and improve understanding of how forests function. These techniques work best with large datasets, making long-term datasets at sites like Hubbard Brook and elsewhere important for use in models designed to help predict nutrient cycling and environmental changes that can affect ecosystem services, such as water quality.

This study demonstrates that forest nutrient retention and uptake can be disrupted by multiple climate-related conditions that do not present as a visible disturbance. Analyzing data from other sites during similar periods and with similar environmental conditions could provide new insight. The study is important for land managers because it improves the understanding of ecosystem nitrogen budgets and their response to environmental changes, which can enable managers to better predict and manage forest health and productivity. By identifying the multiple and interacting causes of large losses of nitrogen from forests, land managers can make informed decisions to support sustainable forest management.

PROJECT LEADS

Linda Pardo is a research environmental engineer with the Northern Research Station in Burlington, Vermont.

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FURTHER READING

Green, Mark B.; Pardo, Linda H.; Campbell, John L.; Rosi, Emma; Bernhardt, Emily S.; Driscoll, Charles T. [et al.]. 2023. **Combination of factors rather than single disturbance drives perturbation of the nitrogen cycle in a temperate forest**. Biogeochemistry. 166: 139–157. https://doi.org/10.1007/s10533-023-01105-z.