Legacy of acid rain: A tale of two species

Background

Changes in emissions, deposition and streamwater

Soil calcium depletion and effects on red spruce and sugar maple

Watershed calcium addition experiment

Legacies of acid rain

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NSF LTER Mini-symposium, March 21, 2017
Temporal trends in total U.S. emissions

Power Plant Contribution

- $\text{SO}_2$: 69±4%
- $\text{NO}_x$: 21±4%
- $\text{NH}_3$: < 1%

USEPA 2015
Hubbard Brook Experimental Forest
White Mountain National Forest, NH
PnET-BGC - Forest biogeochemical model

- Climatic Data
  - Solar radiation
  - Precipitation
  - Temperature

- Atmospheric Chemistry
  - Carbon dioxide
  - Ozone

- PnET
  - Water balance
  - Photosynthesis
  - Living biomass
  - Litterfall

- Net Mineralization

- BGC
  - Aqueous reactions
  - Surface reactions
    - Cation exchange
    - Adsorption
    - Humic binding
    - Aluminum dissolution/precipitation

- Weathering

- Shallow water flow

- Deep water flow

- BGC - Surface water
  - Aqueous reactions
Past and future deposition

The diagram shows the historical and projected deposition of sulfate, nitrate, and ammonium over different time periods. The graph indicates the current condition, a reference carbon standard, and a pre-anthropogenic condition. The data suggests a significant increase in deposition up to the mid-20th century, followed by a decline as of the early 21st century.
With decreases in emissions there have been decreases in wet deposition and stream concentrations.
Time-series of calcium mass balance

[Bar chart showing the time-series of calcium mass balance from 1965-1977 to 2007-2012. The chart includes the following categories:
- **Sources**:
  - Stream
  - Biomass
  - Deposition
  - Weathering
  - Net Soil Ca Depletion

- **Sinks**:
  - Stream
  - Biomass
  - Deposition
  - Weathering
  - Net Soil Ca Depletion

The x-axis represents time (years 65-77, 77-82, etc.), and the y-axis represents Ca$^{2+}$ (mmol/m$^2$-yr). The chart illustrates the balance between sources and sinks over the specified time periods.]
ACID DEPOSITION EFFECTS ON TREES

Red Spruce
- Calcium leached from needle membranes
- Decreased cold tolerance
- Increased freezing injury

Sugar Maple
- Calcium & magnesium leached from soil
- Aluminum mobilized & taken up by tree
- Root function & nutrition impaired
Biomass of sugar maple has declined substantially
Winter injury of red spruce
Wollastonite Addition: Hubbard Brook W1 1999

- CaSiO₃ mining
- 9.6 µm
- 1.5-4 mm
- 45 1 ton hoppers
- 1028 kg Ca / ha
- Water soluble binder
Aboveground Live Tree Biomass (Mg ha\(^{-1}\))

- 121.6
- 135.0
- 145.0
- 155.0
- 165.0
- 175.0
- 185.0
- 195.0
- 197.7

W1

- 1993
- 1995
- 1997
- 1998
- 1999
- 2001
- 2003
- 2005
- 2007
- 2009
- 2011

Leaf Area Index (m m\(^{-2}\))

- 3.79
- 4.00
- 5.00
- 6.00
- 7.00
- 8.00
- 8.96

W6

Battles et al. 2014
Relative growth rate of major tree species in W6 (2007-2012)

Red spruce is doing well because winter injury is diminished due to warmer winters and decreases in acid deposition.

Growth of sugar maple remains poor because soil calcium is slow to recover, due to inherently slow mineral weathering.
Past and future deposition
Simulated stream and soil chemistry for watershed 6
Forest Ecosystem Response to Increases and Decreases in Acid Deposition

- Reversible (is any disturbance reversible?)
  - Leaching of sulfate and nitrate
  - Changes in pH, acid neutralizing capacity, and increases in dissolved inorganic aluminum
  - Aquatic effects: decreases in diversity, loss of sensitive species and recovery (?)
  - Terrestrial effects: red spruce due to deposition effects on foliage

- Irreversible (legacies)
  - Depletion of available nutrient cations
  - Loss of sugar maple
  - Leaching of dissolved organic matter (browning)

- The HBR-LTER is supported by the NSF. Any opinions, findings, conclusions, or recommendations expressed in the material are those of the author(s) and do not necessarily reflect the views of the NSF.