Major changes in forest carbon and nitrogen cycling caused by declining sulphur deposition

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Three things that I am going to talk about:

- Global extent of acid deposition (namely S)
- Effects of acid deposition on DOC
- Effects of acid deposition on forest soil carbon and nitrogen dynamic
Global extent of sulphur and nitrogen deposition

Total S deposition (mg m\(^{-2}\) yr\(^{-1}\))

Simulation of future (2030) S deposition using CLE (Current Legislation scenario)

Global Anthropogenic SO\(_2\) Emissions

Total N deposition (mg m\(^{-2}\) yr\(^{-1}\))

Ratio of total N deposition for scenario CLE (2030) compared to base simulation (2000)

Smith S.J. et al., 2011, ATMOSPHERIC CHEMISTRY AND PHYSICS, 11, 1101–1116

Dentener F. et al., 2006, GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 20, GB4003
Effects of acid deposition on DOC

Why is dissolved organic carbon (DOC) important?

- Most important form of organic carbon transport from terrestrial to aquatic ecosystems
  - Global estimates of both annual riverine organic C transport and soil C sequestration rates are comparable, suggesting that riverine losses of organic C may regulate future changes in soil C storage
- Stream DOC flux may represent around 10% of the net ecosystem exchange (NEE) for boreal forests (Schelker et al., 2012) and 25% of the NEE for boreal bogs (Nilsson et al., 2008)
  - Stream DOC may reflect changes in catchment C cycling


- Net CO₂ Exchange -278 (+25)
- Precipitation DOC -31
- CH₄-C Emission +41
- Stream Surface CO₂ Evasion Loss +46
- TOC: +283 (+57)
- DIC: +12 (+3)
- CO₂-C: +9 (+2)
- CH₄-C: <0.1

Annual C increment in tree biomass ~ 1745 kg C ha⁻¹ yr⁻¹
Annual DOC flux ~ 97 kg C ha⁻¹ yr⁻¹ (6%)
Effects of acid deposition on DOC
Why is dissolved organic carbon (DOC) important?

**DOC has increased:**

- In much of Europe and North America
- In lakes and streams
- In forests and moorlands
- In waterlogged and aerated soils
- At high and low flows
Effects of acid deposition on DOC

Strong evidence of a relationship between acid deposition and organic matter solubility

Solubility of DOC is dependent on:

- Acidity
- Ionic strength
- Aluminium concentration

Decomposition of organic matter (which produces DOC) also affected by pH, ...and N

Temporal coherence between SO₄ declines and DOC increases in Central European catchments

Results from acidity manipulation experiment in UK \textit{(wait for Tim Jones talk)}

Acid treatment – H₂SO₄
Alkaline treatment - NaOH + MgCl₂

Consistent, positive relationship between DOC and acidity change

Oulehle F. and Hruska J., 2009, ENVIRONMENTAL POLLUTION 157: 3433-3439

Evans C.D. et al, 2012, GLOBAL CHANGE BIOLOGY (accepted)
Conclusions

• Declining S deposition appears able to explain a large part of observed DOC trends.

• Therefore, rising DOC in well studied areas (Europe, USA) should not be misconstrued as evidence of rising DOC in unmonitored waters globally.
  - threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO₂ concentration may have been overstated in those areas.

• Past acid conditions may have reduced decomposition rates, allowing a pool of relatively labile organic matter to accumulate, from which DOC is generated as acidity decreases.
Effects of acid deposition on soil C accumulation

Experimental evidence:

- Suppression of litter decomposition under simulated acid (S) deposition (e.g. Pennanen et al., 1998; Persson et al., 1989)
- Adverse effect of aluminium on C availability for microorganisms (e.g. Scheel et al., 2007)
- pH effect on microbial enzyme activity (e.g. Sinsabaugh, 2010)

Al addition (as AlCl$_3$):
- effects on soil water chemistry

Al addition:
- effects on soil respiration

Mulder J. et al., 2001, WATER, AIR AND SOIL POLLUTION 130: 989-994
Effects of acid deposition on soil C accumulation

Long-term evidence:
- Across Czech forest catchments (n=14), S bulk deposition explained 32% variability in soil C/N ratio and 50% variability in forest floor depth (Oulehle et al., 2008)

Nacetin spruce forest research plot:

Wet deposition of sulphur (top) and nitrogen (bottom) in Europe based on the EMEP model

Source www.emep.int

Oulehle F. et al., 2011, GLOBAL CHANGE BIOLOGY 17, 3115-3129
Effects of acid deposition on soil C accumulation

**Nacetin spruce forest research plot:**
- Forest floor C pool reduced by 47% since 1994
- Total S deposition reduced by 77% since 1994

$$\frac{dC}{dS} = 509$$

Oulehle F. et al., 2011, GLOBAL CHANGE BIOLOGY 17, 3115-3129
Effects of acid deposition on soil C accumulation

Solling (Germany) spruce forest research plot:

Wet deposition of sulphur (top) and nitrogen (bottom) in Europe based on the EMEP model

S and N deposition (kg ha$^{-1}$ yr$^{-1}$)

Forest floor OM pool (kg m$^{-2}$)

Source www.emep.int

Unpublished data kindly provided by Henning Meesenburg
Effects of acid deposition on soil C accumulation

Solling (Germany) spruce forest research plot:
- Forest floor C pool reduced by 39% since 1990
- Total S deposition reduced by 75% since 1990

\[ \frac{dC}{dS} = 560 \]
Effects of acid deposition on soil C accumulation

GB’s countryside survey (http://www.countrysidesurvey.org.uk/)

Change in GB topsoil carbon concentration
(Countryside Survey results; Emmett et al. 2010)

Best predictor of spatial and temporal changes in topsoil C concentrations was change in soil pH (soil C loss where soil pH has increased)
Effects of acid deposition on N dynamic

Loss of N from forest floor

Decline of N concentration in needles

Cessation of N leaching

Increase of litterfall C/N ratio
Effects of acid deposition on C and N dynamic
Conclusions

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  - Threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO₂ concentration may have been overstated in those areas.

• Past acid conditions may have reduced decomposition rates, allowing a pool of relatively labile organic matter to accumulate, from which DOC is generated as acidity decreases.

• It appears that past acidification caused the suppression of decomposition leading to the accumulation of a large pool of organic matter on the forest floor. The alleviation of this acidification pressure over the last two decades appears to have triggered the remobilisation of the soil C pool.

• The loss of OM from the Oa horizon coincided with a substantial nitrogen leaching in the 1990s to almost no leaching since 2006. Forest floor net N mineralization also decreased. This had consequences for spruce needle N concentration, an increase in litterfall C/N ratio, and a significant increase in the Oi + Oe horizon C/N ratio between 1994 and 2009/2010.

• Acidity changes in forest ecosystems might have a strong confounding influence on ecosystem sensitivity to eutrophication, with acidification accelerating N saturation (nitrate leaching), and recovery potentially resulting in reversion to N limitation (nitrate retention).
Conclusions

- Declining S deposition appears able to explain a large part of observed DOC trends.
- Therefore, rising DOC in well studied areas (Europe, USA) should not be misconstrued as evidence of rising DOC in unmonitored waters globally.
- Threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO$_2$ concentration may have been overstated in those areas.
- Past acid labile organic matter accumulations on the forest floor leading to the accumulation of relatively labile organic matter on the forest floor.
- Acidification has caused the suppression of decomposition leading to the accumulation of a large pool of organic matter on the forest floor. The alleviation of this acidification pressure over the last two decades appears to have triggered the remobilisation of the soil C pool.
- The loss of OM from the Oa horizon coincided with a substantial nitrogen leaching in the 1990s to almost no leaching since 2006. Forest floor net N mineralization also decreased. This had consequences for spruce needle N concentration, an increase in litterfall C/N ratio, and a significant increase in the Oi + Oe horizon C/N ratio between 1994 and 2009/2010.
- Acidity changes in forest ecosystems might have a strong confounding influence on ecosystem sensitivity to eutrophication, with acidification accelerating N saturation (nitrate leaching), and recovery potentially resulting in reversion to N limitation (nitrate retention).

THANK YOU FOR YOUR ATTENTION