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Summary

Nitrogen deposition and the combination of nitrogen (N) and sulfur (S) deposition have long been studied for their direct acidifying or eutrophication effects. While the biogeochemical pathways for acidification, N saturation, and eutrophication are known, recent studies suggest calcium (Ca^{2+}) depletion from soils and nitrogen enrichment of surface waters, which are consequences of atmospheric N and S deposition, are changing the nutrient balance, or stoichiometry, of keystone or charismatic species in many ecosystems. This will have long-lasting ecosystem scale consequences.

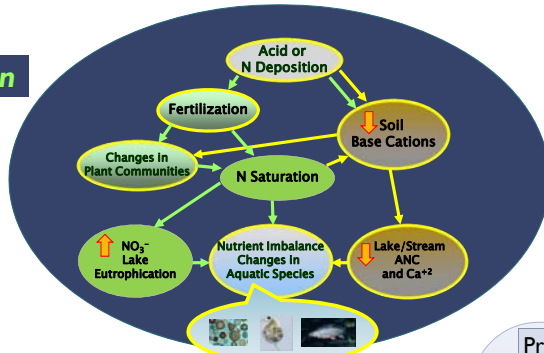
Our Ca^{2+} depletion examples of eastern deciduous forest, forest floor macro-invertebrates, passerine birds, and freshwater zooplankton come from scientists whose visionary work we gratefully acknowledge. Our N enrichment and disruption of lake N:P ratios comes from a series of studies by the authors and their colleagues.

Together, these examples illustrate additional pathways by which N and S deposition are altering ecosystems. They suggest profound and possibly permanent changes in northern hemisphere ecosystems via alterations of major biogeochemical cycles.

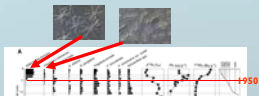
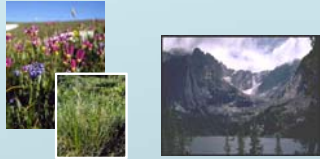
Pathways and Effects of Nitrogen Deposition

← Eutrophication

← Acidification



Changes in terrestrial and aquatic plant dominance in Colorado Rockies

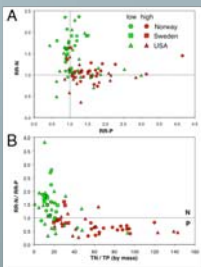


Baron, JS, HM Rueth, AP Wolfe, KR Nydick, EJ Allstott, JT Minear, B Moraska 2000 Ecosystem Responses to Nitrogen Deposition in the Colorado Front Range. *Ecosystems* 3:352-368

Bowman, WD, JR Gartner, K Holland, M Wiedermann 2006 Nitrogen Critical Loads For Alpine Vegetation And Terrestrial Ecosystem Response: Are We There Yet? *Ecol. Appl.* 16:1183-1193

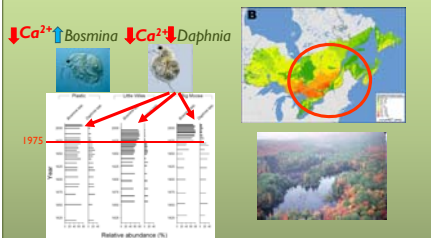
Lafrancois, BM, KR Nydick, BM Johnson, JS Baron 2004 Cumulative effects of nutrients and pH on the plankton of two mountain lakes. *Can. J. Fish. Aquat. Sci.* 61:1153-1165

Changes in N:P resource response in Colorado and Scandinavia



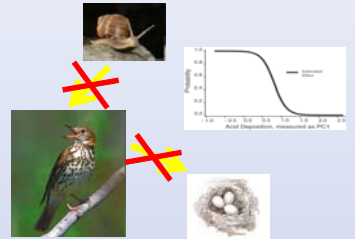
Elser JJ, T Andersen, JS Baron, A-K Bergström, M Jansson, M Kyle, KR Nydick, L Steger, DO Hessen 2009 Shifts in Lake N:P Stoichiometry and Nutrient Limitation Driven by Atmospheric Nitrogen Deposition. *Science* 326:835-837

Calcium decline alters zooplankton assemblages



Jeziorski A, ND Yan, AM Paterson, AM DeSellas, MA Turner, DS Jeffries, B Keller, RC Weeber, DK McNicol, ME Palmer, K McIver, K Arsenau, BK Ginn, BF Cumming, JP Smol. 2008. The Widespread Threat of Calcium Decline in Fresh Waters. *Science* 322:1374-1377

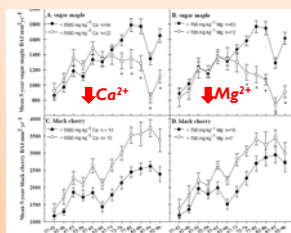
Probability of breeding success is reduced for wood thrush and other passerine birds



Graveland J, R van der Wal, JH van Balen, AJ van Noordwijk 1994 Poor reproduction in forest passerines from decline of snail abundance on acidified soils. *Nature* 368:446-448.

Hames, RS, KV Rosenberg, JD Lowe, SE Barker, AA Dhondt 2002 Adverse effects of acid rain on the distribution of the Wood Thrush *Hylocichla mustelina* in North America. *PNAS* 99:11235-11240

Sugar maple decline from Ca^{2+} and Mg^{2+} deficiency



Long RP, SB Horsley, RA Hallett, SW Bailey 2009 Sugar maple growth in relation to nutrition and stress in the northeastern United States. *Ecol. Appl.* 19:1454-1466