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COMMENTARY

Can Nitrogen Sequestration Explain the Unexpected Nitrate Decline in New Hampshire Streams?

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Goodale and others (2003) pose an intriguing question: How can we explain the unexpected decline in nitrate concentration in New Hampshire's streams? Theory of forest nitrogen (N) biogeochemistry suggests that retention of atmospherically deposited N can occur through vegetation uptake, accumulation in soil organic matter, abiotic immobilizaton, and accumulation in coarse woody debris including roots and stumps. The latter mechanism occurs through microbial processes that narrow the C:N ratios of this pool and may be underappreciated, but is well documented (Harmon and others 1986; Fahey and others 1988; Fahey and Arthur 1994). The relative strength of these sinks depends upon site conditions and, in particular, on historical land use (Dise and others 1998; Gundersen and others 1998a; Goodale and others 2000). In general, the greater the previous disturbance and resulting soil N depletion, the greater the soil N sequestration potential. Forest N sinks are limited, thus, N sequestration will not continue indefinitely (Stoddard 1994; Aber and others 2003), but the capacity of this N sink and its dynamics over time are uncertain. As an example of the uncertainty in the temporal dynamics of this N sink, consider the lag between N additions and measurable effects on process. There can be a significant delay between the initiation of inorganic N additions and the induction of detectable increases in net nitrification (Magill and others 2000).

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The unexpected decline in nitrate concentrations in New Hampshire streams cannot be explained by trends in forest maturation or atmospheric deposition of N (Goodale and others 2003). Likewise, mechanisms for the decline, based on a re-equilibration following recovery from insect defoliation and severe drought in the 1960s (Aber and others 2002), and soil frost dynamics, were provisionally ruled out based on their failure to explain the regional nature of the stream water nitrate decline (Goodale and others 2003). Potential explanation based on enhanced N uptake through growth increases caused by CO_2 fertilization (Idso 1999) was rejected as having too small an effect on forest growth and the lack of a growth response at the Hubbard Brook Experimental Forest (HBEF). Forest growth data from HBEF (Goodale and others 2003) and Forest Inventory Analysis (FIA) survey data for New Hampshire (FIA data files online) do not support substantial growth increases in recent decades. Goodale and others (2003) concluded that interannual climate variation remained a plausible mechanism; however, they noted that the specific climate factors were uncertain. This region has experienced warmer (Keim and others 2003), wetter (Groisman and others 2001), and longer growing seasons (Cooter and LeDuc 1995; Hodgkins and others 2003) in recent decades, all of which would argue for increased, rather than decreased, N uptake.

There may be another more likely explanation that the authors have not considered. Immobilization of inorganic N (accumulation in organically bound soil pools) in combination with a regionwide recovery from past disturbances may explain the decrease in stream water nitrate in recent decades. Net immobilization can occur through several mechanisms: (1) decomposition and microbial transformations of organically bound N in plant residues, (2) microbial uptake of inorganic N and assimilation into microbial biomass that is subsequently transformed into soil organic matter, (3) abiotic N immobilization, (4) microbial transformation of extant soil organic matter that leads to a decrease in C:N ratio, and (5) a suppression of N mineralization. A recent synthesis provides some insight into whether the latter two mechanisms are likely contributing factors. Aber and others (2003) report that soil data from a broad spectrum of northeastern U.S. forests "show an increase in nitrification with decreasing soil C:N ratio." They found weaker relations between N deposition and soil C:N ratio or nitrification. Studies along N-deposition gradients indicate that soil C:N ratios decrease under conditions of chronically elevated N deposition (McNulty and others 1991; Gundersen and others 1998b). These studies are consistent with a model of elevated N deposition resulting in increases in nitrification and decreases in C:N ratio, but they do not support the suppression of N mineralization as a likely mechanism for increasing N sequestration.

Forests across most of New Hampshire, like the HBEF, represent ecosystems that are recovering from major historical disturbances such as logging, grazing, and sometimes cultivation (Cogbill and other 2002; Sundquist and Stevens 1999). Aggrading forests usually have a large capacity to accumulate organic matter as they gradually approach predisturbance equilibrium (Johnson 1992; Huntington 1995). These soil pools include the mineral soil, organic-rich forest floor, and coarse woody debris. Disturbance associated with timber harvesting redistributes high C:N ratio forest floor and coarse woody debris under mineral soil (Ryan and others 1992) that can prime the soil for N sequestration during forest regrowth through microbial transformations. The amount of annual soil N accretion necessary to offset the observed average 71% decrease in stream-water nitrate loss (Goodale and others 2003) (nominally, from $\sim$1.2 to 0.3 g N m^{-2} y^{-1} based on nitrate losses at HBEF during the late 1990s) is only about 0.1% of the estimated soil N content at Hubbard Brook (760 g N m^{-2}) (Huntington and others 1990). It seems plausible that forest soils could sustain the accumulation of N at these relatively low levels, which would be very hard to detect upon remeasurement.

The regional soil N sink strength could be greater in recent decades because environmental conditions are now more favorable for soil N sequestration, if not forest growth. Elevated atmospheric CO_2 concentrations intensify carbon cycling that supplies more labile carbon to soil microbes (Hungate and others 1997), increasing capacity for immobilization of inorganic N. Chronically elevated N deposition can intensify N cycling (Galloway and others 2003) that, in turn, can increase net N sequestration rate, provided the supply of labile carbon is not limited. Stimulation of forest growth by CO_2 fertilization, N deposition, and more favorable climate may have exerted more influence on the production of organic carbon belowground (fine root turnover and root exudate) and leaf litter than on stem biomass. Such a differential effect of elevated CO_2 has been demonstrated in Free Air Carbon dioxide Enrichment (FACE) studies (Norby and others 2002). These rapidly cycling pools can contribute to the accumulation of soil organic N (Hungate and others 1997). This proportionately greater stimulation of belowground carbon production could account for an increase in soil organic-N storage without concomitant increase in forest growth. However, it remains uncertain why forest stemwood biomass would not have responded to more favorable climate, CO_2 enrichment, and elevated N deposition in recent decades. Other factors such as growth inhibition due to ozone (Gregg and others 2003) and other stressors or nutrient depletion (Federer and others 1989) may have suppressed stem growth. Abiotic N immobilization is another mechanism of N retention in forest soils (Davidson and others 2003) but its quantitative importance is not yet established. The rate of abiotic N immobilization could be increasing because it has been shown that the ratio of abiotic to total N immobilization is positively related to N concentration and ecosystem N saturation (Johnson and others 2000).

REFERENCES

Aber JD, Ollinger SV, Driscoll CT, Likens GE, Holmes RT, Freuder RJ, Goodale CL. 2002. Inorganic nitrogen losses from a forested ecosystem in response to physical, chemical, biotic and climatic perturbations. Ecosystems 5:648–58.

Aber JD, Goodale CL, Ollinger SV, Smith M-L, Magill AH, Martin ME, Hallett RA, Stoddard JL. 2003. Is nitrogen deposition altering the nitrogen status of Northeastern forests? BioScience 53:375–89.

Cogbill CV, Burk J, Motzkin G. 2002. The forests of presettlement New England, USA: spatial and compositional patterns based on town proprietor surveys. J Biogeogr 29:1279–304.

Cooter EJ, LeDuc S. 1995. Recent frost date trends in the Northeastern U.S. Int J Climatol 15:65–75.

Davidson EA, Chorover J, Dail DB. 2003. A mechanism of abiotic immobilization of nitrate in forest ecosystems: the ferrous wheel hypothesis. Global Change Biol 9:228–36.

Dise NB, Matzner E, Gundersen P. 1998. Synthesis of nitrogen pools and fluxes from European forest ecosystems. Water Air Soil Pollut 105:143–154.

Fahey TJ, Hughes JW, Pu M, Arthur MA. 1988. Root decomposition and nutrient flux following whole-tree harvest of northern hardwood forest. For Sci 34:744–68.

Fahey TJ, Arthur MA. 1994. Further studies of root decomposition following harvest of a northern hardwoods forest. For Sci 40:618–29.

Federer CA, Hornbeck JW, Tritton LM, Martin WC, Pierce RS, Smith CT. 1989. Long-term depletion of calcium and other nutrients in eastern US forests. Environ Manage 13:593–601.

Galloway JN, Aber JD, Erisman JW, Seitzinger SR, Howarth RW, Cowling EB, Cosby J. 2003. The nitrogen cascade. BioScience 543:341–56.

Goodale C, Aber JD, McDowell WH. 2000. Long-term effects of disturbance on organic and inorganic nitrogen export in the White Mountains, New Hampshire. Ecosystems 3:433–50.

Goodale CL, Aber JD, Vitousek PM. 2003. An unexpected nitrate decline in New Hampshire streams. Ecosystems 6:75–86.

Gregg JW, Jones CG, Dawson TE. 2003. Urbanization effects on tree growth in the vicinity of New York City. Nature 424:183–7.

Groisman PY, Knight PW, Karl TR. 2001. Heavy precipitation and high streamflow in the United States: Trends in the 20th Century. Bull Am Meteorol Soc. 82:219–46.

Gundersen P, Emmett BA, Ko J, Koopmans CJ, Tietema A. 1998a. Impact of nitrogen deposition on nitrogen cycling in forests: A synthesis of NITREX data. For Ecol Manage 101:37–56.

Gundersen P, Callesen I, de Vries W. 1998b. Nitrate leaching in forest ecosystems is related to forest floor C/N ratios. Environ Pollut 102:403–7.

Harmon ME, Franklin JF, Swanson FJ, Sollins P, Gregory SV, Lattin JD, Anderson NH, Cline SP, Aumen NG, Sedell JR, Lienkaemper GW, Cromack JR, Cummins KW. 1986. Ecology of coarse woody debris in temperate ecosystems. Avd Ecol Res 15:133–302.

Hodgkins GA, Dudley RW, Huntington TG. 2003. Changes in the timing of high river flows in New England over the 20th century. J Hydrol 278:244–52.

Hungate BA, Lund CP, Pearson HL, Chapin FSI. 1997. Elevated CO_2 and nutrient addition alter soil N cycling and N trace gas fluxes with early season wet-up in a California annual grassland. Biogeochemistry 37:89–109.

Huntington TG. 1995. Carbon sequestration in an aggrading forest ecosystem in the southeastern USA. Soil Sci Soc Am J 59:1459–67.

Huntington TG, Ryan DF. 1990. Whole-tree-harvesting effects on soil nitrogen and carbon. For Ecol Manage 31:193–204.

Idso SB. 1999. The long term response of trees to atmospheric CO_2 enrichment. Global Change Biol 5:493–5.

Johnson DW. 1992. Effects of forest management on soil carbon storage. Water Air Soil Pollut 64:83–120.

Johnson DW, Cheng W, Burke LC. 2000. Biotic and abiotic nitrogen retention in a variety of forest soils. Soil Sci Soc Am J 646:1503–14.

Keim BD, Wilson A, Wake C, Huntington TG. 2003. Are there spurious temperature trends in the United States Climate Division Database? Geophys Res Lett 30:(7)1404(doi:10.1029/2002GL016295).

Magill AH, Aber JD, Berntson GM, McDowell WH, Nadelhoffer KJ, Melillo JM, Steudler P. 2000. Long-term nitrogen additions and nitrogen saturation in two temperate forests. Ecosystems 3:238–53.

McNulty SG, Aber JD, Boone RD. 1991. Spatial changes in forest floor and foliar chemistry of spruce-fir forests across New England. Biogeochemistry 14:13–29.

Norby RJ, Hanson PJ, O'Neill EG, Tschaplinski TJ, Wullschleger SD, Gunderson CA, Edwards NT, Weltzin JF, Hansen R, Cheng W, Johnson DW. 2002. Net primary productivity of a CO_2–enriched deciduous forest and the implications for carbon storage. Ecol Appl 12:1261–6.

Ryan DF, Huntington TG, Martin WC. 1992. Redistribution of soil nitrogen, carbon and organic matter by mechanical disturbance during whole-tree-harvesting in northern hardwoods. For Ecol Manage 49:87–99.

Stoddard JL. 1994. Long-term changes in watershed retention of nitrogen: its causes and aquatic consequences. In: Baker LA, editor. Environmental Chemistry of Lakes and Reservoirs. Washington, DC: American Chemical Society. p 223–84.

Sundquist D, Stevens M. 1999. New Hampshire's Changing Landscape; Population Growth, Land Use Conversion, and Resource Fragmentation in the Granite State Society for the Protection of New Hampshire Forests and the Nature Conservancy, Concord, NH, 110 p + Appendix.