Nitrogen Cycling in High Elevation Forests of the Northeastern US in Relation to Nitrogen Deposition

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Synopsis

Nitrogen Cycling in High Elevation Forests of the Northeastern US in Relation to Nitrogen Deposition

Nitrogen saturation of forest ecosystems (the availability of ammonium and nitrate in excess of biological demand) (1, 2) is increasingly seen as a threat to the forest and freshwater resources of highly industrialized northern temperate regions. Excess N availability can be viewed as a unique stress on plants; one to which they are not pre-adapted, and one which can lead to direct toxic effects, critical nutrient imbalances, and under extreme conditions, to forest decline (1, 3–10). Through the induction of nitrification and nitrate leaching, N saturation has been linked to acidification of soils and streams (11–16, 30) and to increased aluminum mobility (16, 28). Increased rates of nitrogen cycling and nitrification may also lead to decreased methane consumption (31) and increased emissions of N_2O (1, 14, 16), contributing to increases in atmospheric pools of these greenhouse gases, and to global warming.

US regulatory agencies have shown less concern over nitrogen saturation effects than their European counterparts. However, N deposition has been shown to be very high in certain regions of the US, especially at high elevations where slow-growing spruce-fir forests create low biotic demands for N (18, 19). In this paper, we present the results of a regional survey of net N mineralization and nitrification potentials for spruce-fir forests of the northeastern US, and their relationship with regional trends in N deposition.

In most forest soils, low pH (or base saturation) and high nitrogen demand for ammonium by microbes and mycorrhizal plants normally inhibit the nitrification process (16, 20). However, net nitrification may be induced even at low pH under conditions of increased nitrogen availability, decreased plant nitrogen demand, or both (15, 20–22, 29). We have hypothesized a series of changes in both vegetation and soil processes in response to chronically elevated N deposition (1). Increasing nitrification with increasing N deposition is one such change.

Between mid-June and mid-August in 1987 and 1988, 161, 15 · 15 meter spruce-fir sites were sampled from 11 areas within this region (Fig. 1) in a randomized order. Soil pH, stand mortality and rates of potential net N mineralization and nitrification were determined on randomly selected sites within each area. The majority (143) of the inland sites ranged in elevation from 844 to 1259 meters while three sites were located above the tree line, between 1440 and 1590 meters. Additionally, 15 coastal Maine sites (average elevation range 20 to 100 meters) were also sampled. Mortality was measured as dead standing trees/total number of trees, within the site.

For N mineralization and nitrification measurements 20 replicate 50 g samples of the Oa plus Oe horizons were taken from the forest floor at each site. After all twigs, roots, stones and mineral particles > 1 mm were removed by hand, the 20 samples were randomly grouped into 5 composites from each site. Composite samples were incubated in the laboratory (22°C, 28 days). Net mineralization was calculated as ammonium-N plus nitrate-N in incubated samples minus initial values. Nitrification was calculated as incubated nitrate-N minus initial nitrate-N. Nitrate and ammonium contents were determined before and after incubation by extraction of subsamples in 1N KCl for 48 hours. Initial soil pH was measured in a 1:2 (weight:volume) soil to $CaCl_2$ solution (0.01M).

Low elevation N deposition generally decreases west-to-east across the northeastern US (24), ranging from 5.6 $kg \cdot ha^{-1}$ in eastern New York to 2.9 $kg \cdot ha^{-1}$ in eastern Maine (25). Regional trends in N deposition were estimated from the mean annual wet deposition for 17 low elevation National Atmospheric Deposition Program (NADP) sites within the region (25). Kriging techniques (26) were used to extrapolate these data to equivalent low-elevation deposition rates for our study areas (Fig. 2). These were strongly correlated with longitude (adjusted $R^2 = 0.66$, $P < 0.001$), and represent regional trends only. They do not account for orographic effects of elevation or for dry deposition inputs.

Potential net N mineralization rates varied widely between areas. Howland, ME, had the lowest potential mineralization value (mean = 51 $mg\ N \cdot kg^{-1}$

soil, SE = 9.5, N = 5) and Mt. Mansfield, VT had the highest value (mean = 281 mg N · kg^{-1} soil, SE = 54, N = 4). Although there was an apparent trend towards higher potential mineralization with higher N deposition, no statistically significant relationships were found. There were also no correlations between mineralization rates and longitude, elevation, percent mortality, soil pH, or any linear combinations of these variables. Potential nitrification rates ranged from 0 for all Maine sites, to 42 mg NO_3-N · kg^{-1} soil (SE = 20, N = 4) on Mt. Mansfield, VT. On an area basis, nitrification potential was correlated with longitude (R^2=0.49, P <0.01, N = 11), and with approximated deposition (R^2=0.77, P <0.0001, N = 11).

An even clearer regional trend was evident for nitrification normalized for net mineralization, (nitrification divided by mineralization; Fig. 3). The lowest fraction occurred in ME (0%), the highest on Whiteface Mtn, NY (22%), and there was a significant relationship with both longitude (adjusted R^2 = 0.92, P <0.001, N = 11), and estimated deposition (R^2 = 0.68, P <0.01, N = 11). Again, regressions against elevation, slope, soil pH and stand mortality were not significant.

The general co-occurrence of high mineralization potentials and high nitrification potentials in the New York and Vermont sites, relative to study areas farther east, suggests that excess N availability (nitrogen saturation) is occurring as a function of induced an-

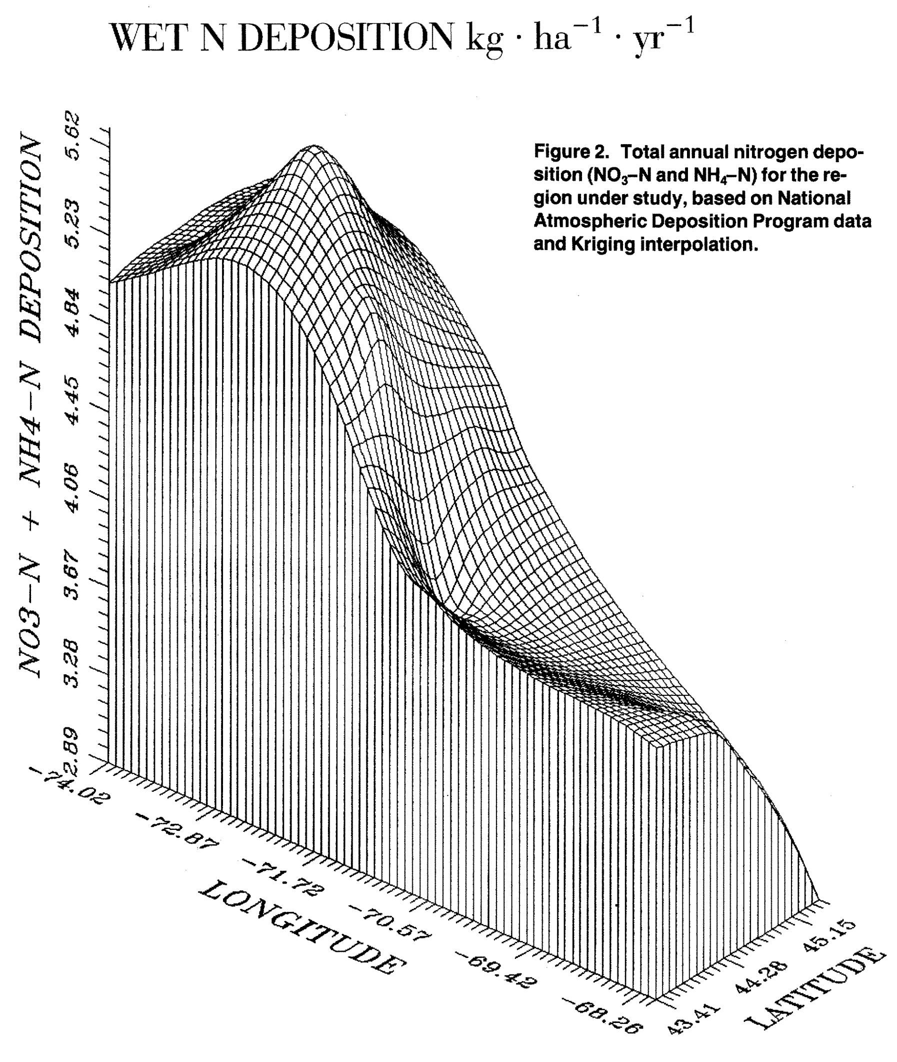
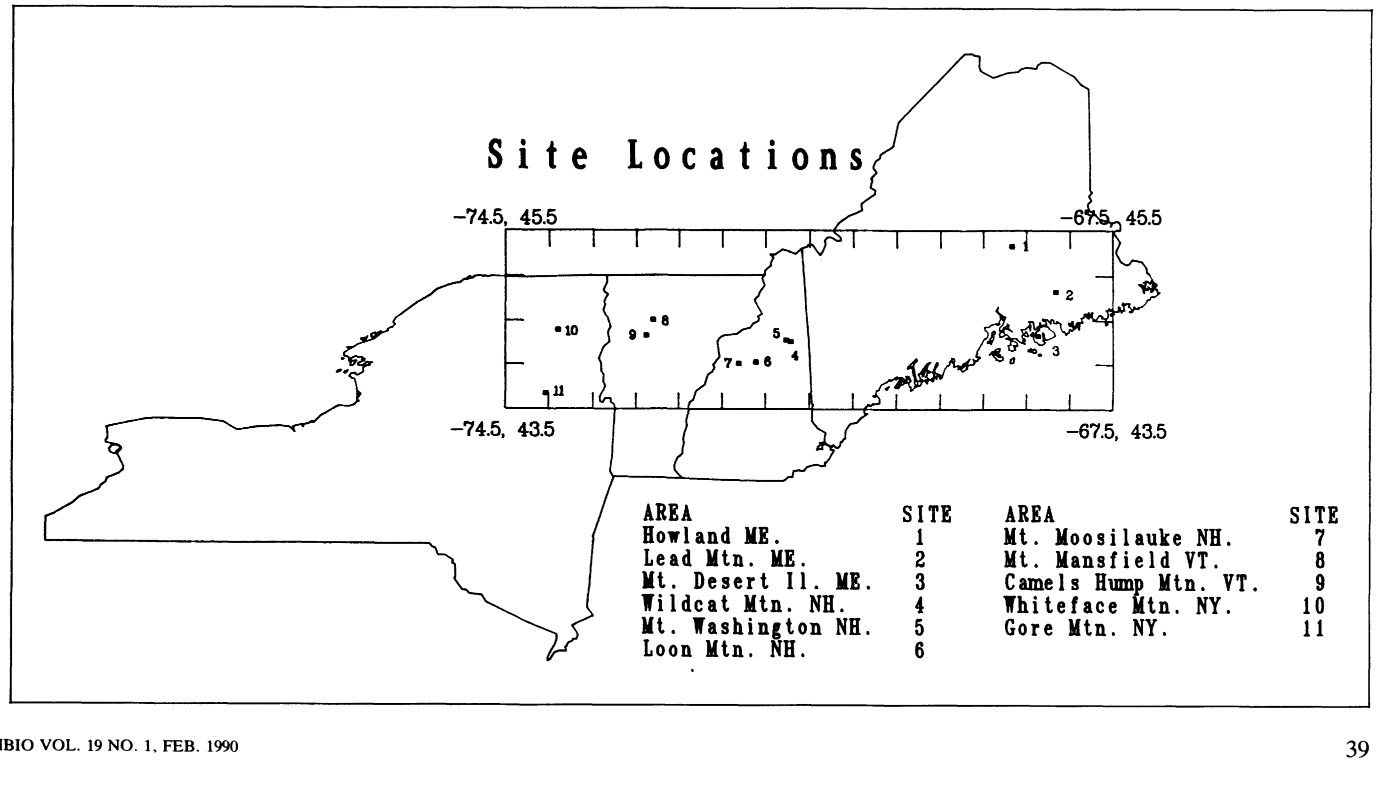


Figure 2. Total annual nitrogen deposition (NO_3–N and NH_4–N) for the region under study, based on National Atmospheric Deposition Program data and Kriging interpolation.

Figure 1. Location of the 11 study areas within the northeastern United States used in this investigation.



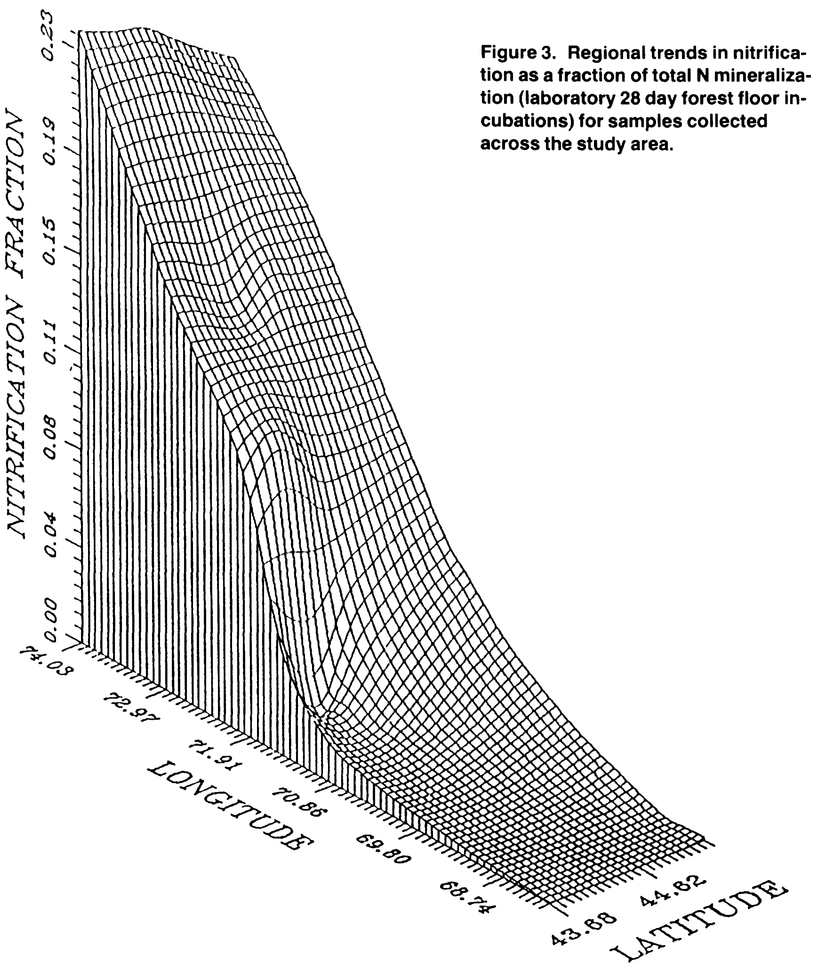


Figure 3. Regional trends in nitrification as a fraction of total N mineralization (laboratory 28 day forest floor incubations) for samples collected across the study area.

thropogenic sources of nitrogen Experimental studies are currently underway to test specifically the potential for chronic N additions to induce nitrification and also to examine other consequences of excess N availability (1). However, we feel that these regional observations, along with other studies of increased nitrate mobility in US forests and streams (17, 27), should be sufficient to generate concern within the US regulatory community over the potential consequences of N saturation, and to support initiatives for further research and regulatory activity on this topic.

References and Notes

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