Susceptibility of Forests in the Northeastern U.S. to Nitrogen and Sulfur Deposition: Implications for Forest Health

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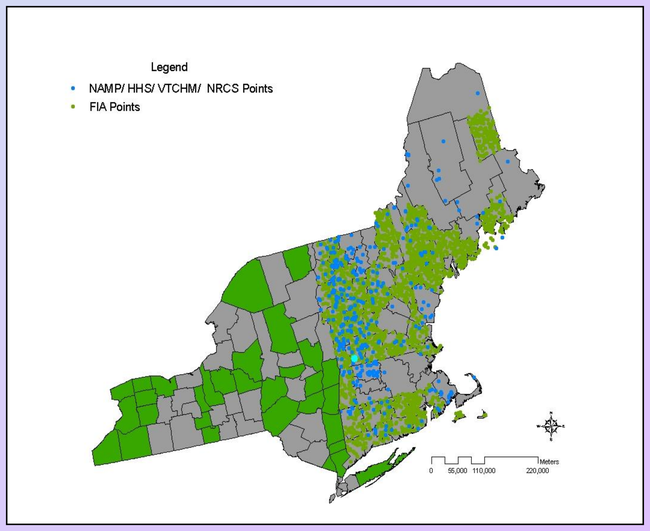
OBJECTIVE

To relate measures of forest susceptibility to acid deposition with indicators of forest health in order to assess the impact of acid deposition in the northeastern US.

BACKGROUND

Acid deposition is caused by emissions of sulfur (S) and nitrogen (N) from power plants and vehicles. Although S emissions have decreased, as a result of SO_2 control programs, projected emissions of acidifying S and N compounds are expected to have continuing negative impacts on forest health and productivity. In addition, N deposition can be harmful to forests beyond these impacts of acidification, because excess N can lead to N saturation and plant nutrient imbalances. Nutrient depletion leads to increases in the susceptibility of forests to climate, pest and pathogen stress which results in reduced forest health, reduced growth, increased mortality, and eventual changes in forest species composition.



According to FIA protocol, the publicly available coordinates for all New York FIA plots are the geographic center of the county within which the plot is located (county centroid). Therefore it was not possible to show spatial patterns within the county. Instead, we plotted the mean of the county for the entire county, in order to give a general idea of the larger-scale, regional spatial patterns.

SITE LOCATIONS

Site Group	CT	MA	ME	NH	NY	RI	VT
FIA (P2 plots)	231	116	631	552	1012	99	509
FHM (P3 plots)	12	3	31	22	402	4	17
VMC-FH							19
NAMP	10	10	18				35
VT HHS							62
NRCS	27	56	33	37		2	61
VT Additional Research Sites							75
Total number of sites by state	**280**	**185**	**713**	**591**	**1414**	**103**	**778**
Total number of sites							**4064**

Other forest surveys included in this assessment: VMC-FH=Vermont Monitoring Cooperative Forest Health Plots; NAMP=North American Maple Program; VT HHS=Vermont Hardwood Health Survey; NRCS=National Resources Conservation Service soil pits

APPROACH

The approach we used to determine acceptable levels of deposition is a steady-state, ecosystem mass balance for nutrient cations (calcium, magnesium, and potassium). We calculated the ***critical load*** (CL) of S + N (the level of deposition below which no harmful ecological effects occur for a forest ecosystem), and the ***exceedance*** (the difference between the current deposition and the CL), which can be used to identify susceptible forest ecosystems.

DATA USED

Precipitation and climate ClimCalc Model www.pnet.sr.unh.edu/climcalc

Nutrient removal plot biomass measures were used to calculate harvestable biomass, Tree Chemistry Database values were used for nutrient concentrations (http://www.hubbardbrook.org/treechem/index.htm)

Mineral weathering The substrate type/clay content method was used to estimate soil mineral weathering rates. The primary soil series were determined from digitized county soil survey maps (Soil Survey Geographic (SSURGO) Database). The Official Soil Series Descriptions were used to determine minimum, maximum and midpoint values for the required soil parameters (depth, clay percent, texture, moisture, substrate type). The midpoint value is the midpoint of the range (max-min). For comparison NSSC soil pit data (Soil Survey Staff, 2003) were averaged across New England to generate mean values for the required soil parameters by soil series, however, because pit data were not available for many areas, these values are not necessarily representative.

CL for Acidity

$$CL\ S{+}N = BC_{dep} + BC_w - BC_u - BC_{le} \quad (1)$$

where: BC_{dep} = sum of Ca + Mg + Na+ K deposition rate (eq ha^{-1} yr^{-1})
BC_w = soil weathering rate of Ca + Mg + K + Na (eq ha^{-1} yr^{-1})
BC_u = net Ca + Mg + K uptake rate (eq ha^{-1} yr^{-1}) removed by harvest or disturbance
BC_{le} = acceptable acid neutralizing capacity (ANC) leaching rate (eq ha^{-1} yr^{-1}).

The acceptable ANC leaching rate, BCle, is calculated based on the critical chemical criteria of *no change in base saturation* according the NEG/ECP Forest Mapping Group Protocol (NEG/ECP, 2001). In order to achieve the condition of no change in base saturation, a BC/Al ratio of 10 (mol/mol) was used.

CL for Nutrient N

$CL_{nut}(N)$ can be expressed as

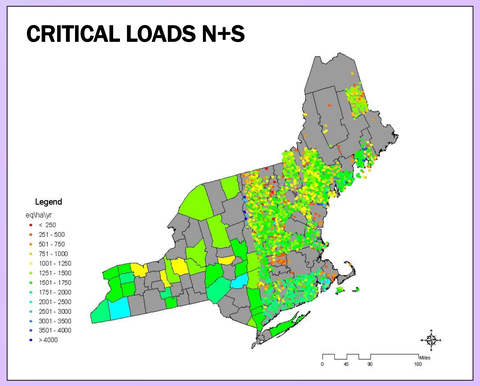
$$CL_{nut}(N) = N_a + N_u + N_{de} + N_{le}$$

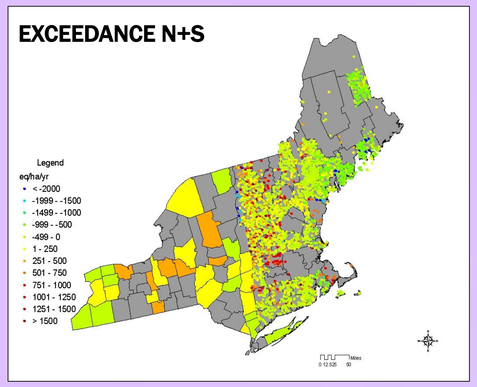
N_a-N accumulated in soil
N_u- net N removal via biomass
N_{de}-N loss via denitrification assumed →0
N_{le}-accceptable N leaching
The acceptable N leaching rate, N_{le}, is the maximum acceptable leaching rate for an ecosystem that is not at N saturation. This leaching rate is given by

$$N_{le(acc)} = Q*[N]_{crit} \quad (2)$$

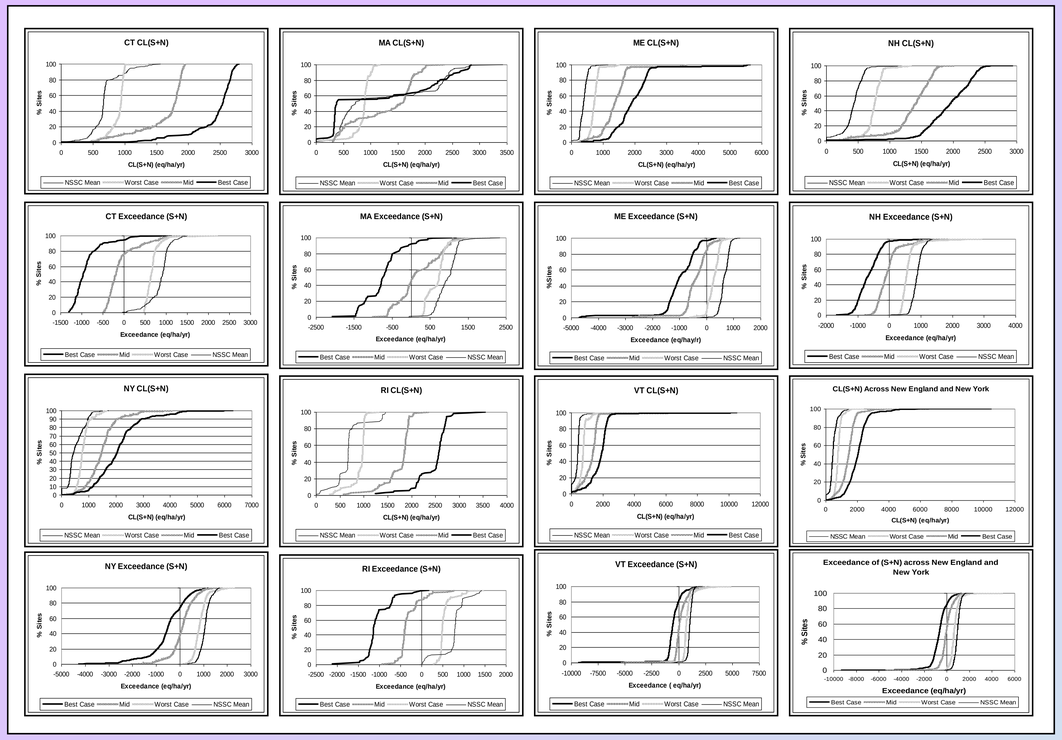
where:
$N_{le(acc)}$ =acceptable leaching of N
$[N]_{crit}$ =the N concentration in the soil solution above which it would be considered detrimental to ecosystem or soil

$[N]_{crit}$ was set at 0.2 g N/m3, per the ICP Mapping and Modelling Manual (http://www.oekodata.com/icpmapping/index.html).

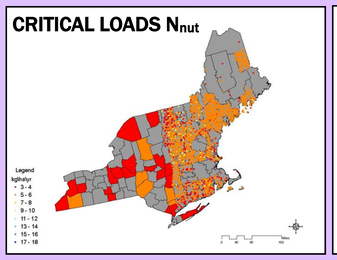




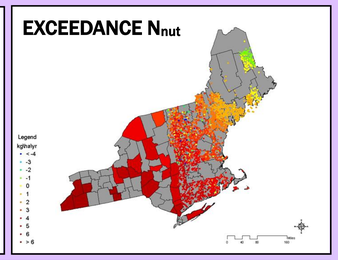
The most susceptible forest ecosystems are in mountainous regions where glacial till and soils are thinnest, and where atmospheric deposition rates are highest. The cumulative frequency charts (below) show the best case, worst case and mid scenarios that demonstrate the range in CL and exceedance caused by different estimates of mineral weathering. The percentage of plots where the CL was exceeded in the mid scenario ranged from 13% in RI to 62% in NY. Since the weathering rates are based on depth and clay content ranges for the soil series rather than those measurements on the site, our ability to identify the most sensitive sites is limited. The map (mid scenario; above) does a better job of identifying general patterns under average conditions than in identifying individual sensitive sites.



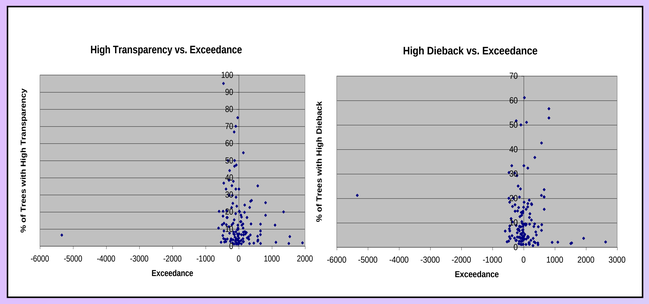
CRITICAL LOADS N_{nut}



EXCEEDANCE N_{nut}



CL N_{nut} are typically lower than CL S+N, so the CL N_{nut} was exceeded for nearly all plots in the Northeast.



FOREST HEALTH INDICATORS

We expected indicators of damage to be higher at sites where deposition exceeded the CL (exceedance>0), however, we observed no such pattern for canopy transparency or dieback, mortality, low density, or moderate-severe decline. This lack of correlation may reflect that factors other than acid deposition may be the dominant forces influencing damage at this time. The main difficulty with the current assessment is that, because the CL estimates are not based on site soil measurements, they may not reflect the most sensitive sites' susceptibility to acid deposition. CL estimates could be improved with more detailed plot soils information.

RECOMMENDATIONS FOR FHM SAMPLING/ANALYSIS

- Soil sampling by horizon rather than depth including depth and bulk density measurements
- Measurement of soil depth to bedrock
- Soil sampling to bedrock or to bottom of rooting zone
- Exchangeable base cation measurement
- Soil mineralogy measurements

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For more information on Critical Loads, go to http://www.nrs.fs.fed.us/clean_air_water/clean_water/critical_loads/