New England Governors/Eastern Canadian Premiers

Acid Rain Action Plan
Action Item 4 : Forest Mapping Project

Mapping Forest Sensitivity to Atmospheric Acid Deposition

2006-2007 Annual Report

Prepared by

The Forest Mapping Group

For

The Committee on the Environment of
The Conference of New England Governors and Eastern Canadian Premiers

Summary

The Forest Mapping Work Group has undertaken to map the sensitivity of the entire New England Governor and Eastern Canadian premier (NEG/ECP) jurisdictions' forests to atmospheric sulfur and nitrogen deposition loadings. Unprecedented for level of detail and size of area studied, this comprehensive project is the first scientific large-scale study of forest sensitivity to sulfur and nitrogen deposition in northeastern North America.

Critical Load

The term 'critical load' implies a tipping point, or threshold. Most generally, critical load may be defined as the maximum load that a system can tolerate before failing. As applied to environmental issues, however, critical load usually refers to exposure to pollutants; a critical load is an estimate of the level of exposure to one or more pollutants below which no harmful effects are known to occur to specified elements within an environment.

The common definition of critical loads agreed upon by the Forest Mapping Group is the definition originally developed by the United Nations Economic Commission for Europe in 1988:

> *A critical load is a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge* (Nilsson and Grennfelt, 1988).

The use of critical loads within the context of air quality management is premised on the notion that the effectiveness air quality policy is reflected in ecosystem impacts. The critical load concept is uniquely well suited toward informing air quality policy because its receptor-based approach takes into account both the spatial and topographical variables of atmospheric deposition.

As it applies to the atmospheric deposition of acid forming compounds then, a critical load is that level of exposure to sulfur and nitrogen compounds below which no harmful effects are known to occur within a specified environment (or ecosystem).

A unified critical load map for NEG/ECP region is now being completed; for this map, critical loads have been calculated for Northeastern North American forest ecosystem.

The approach used to identify critical loads for sulfur and nitrogen in the region's forest ecosystem is an ecological assessment based on an overall (steady-state) ecosystem budget for nutrient cations of calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}). This budget exists within a dynamic system of nutrient inputs, exports, and recycling.

In its simplest terms, the inputs to the nutrient budget for the Maine forest ecosystem include the addition of the nutrients Ca, Mg, and K through atmospheric deposition; acid forming compounds of sulfur (S) and nitrogen (N) are also introduced through deposition. Additional inputs of Ca, Mg, and K are occur through the chemical weathering of the bedrock and soils.

Nutrient losses or exports from the system occur as a result of chemical reactions within the root zone which may render a portion of nutrients unavailable for plant nutrition, and through soil leaching in response to the presence of acids. Additional losses or exports occur as a result of forest fires and through the harvesting of trees from the forest.

Nutrient recycling occurs throughout the lifecycle of the trees in the forest through the shedding of leaves and/or needles and through the decay of vegetative and woody debris on the forest floor.

The overall ecosystem budget is based upon the relative values of the inputs to and exports from the system. A condition where nutrient input values exceed exports suggests that an equilibrium state of biologic capacity exists for that ecosystem. Conversely, a condition where nutrient exports exceed imports suggests a net nutrient deficit and increasing soil acidification; conditions ultimately unsustainable for that ecosystem over the long term.

The critical load map developed for the NEG/ECP region is derived on the basis of steady-state or static models. Consequently the map reflects conditions of nutrient balance rather than absolute measures of soil acidity/fertility. Nevertheless one might observe that where a negative nutrient imbalance is small, forest health problems and growth decline may not yet be evident; in those locations where the imbalance is significant, the impacts on forest health are likely to be observable today.

Critical load approaches offer air quality and natural resource managers a powerful tool with which to identify ecosystems at risk and to tailor management strategies to address specific resource issues.

Results

The Critical Load mapping performed for the Region indicates that up to 61% of forested land within certain of the region’s jurisdictions have been characterized as ‘sensitive’, and thus may be experiencing a net nutrient deficit and increasing soil acidification. Soil mineral nutrient depletion has been linked to a wide variety of forest health problems, including reduced growth rates and increased mortality.

Figure 1. Forest areas sensitive to acid deposition in the New England states and Eastern Canadian provinces.
(Please note discussion of data variability on page 7)

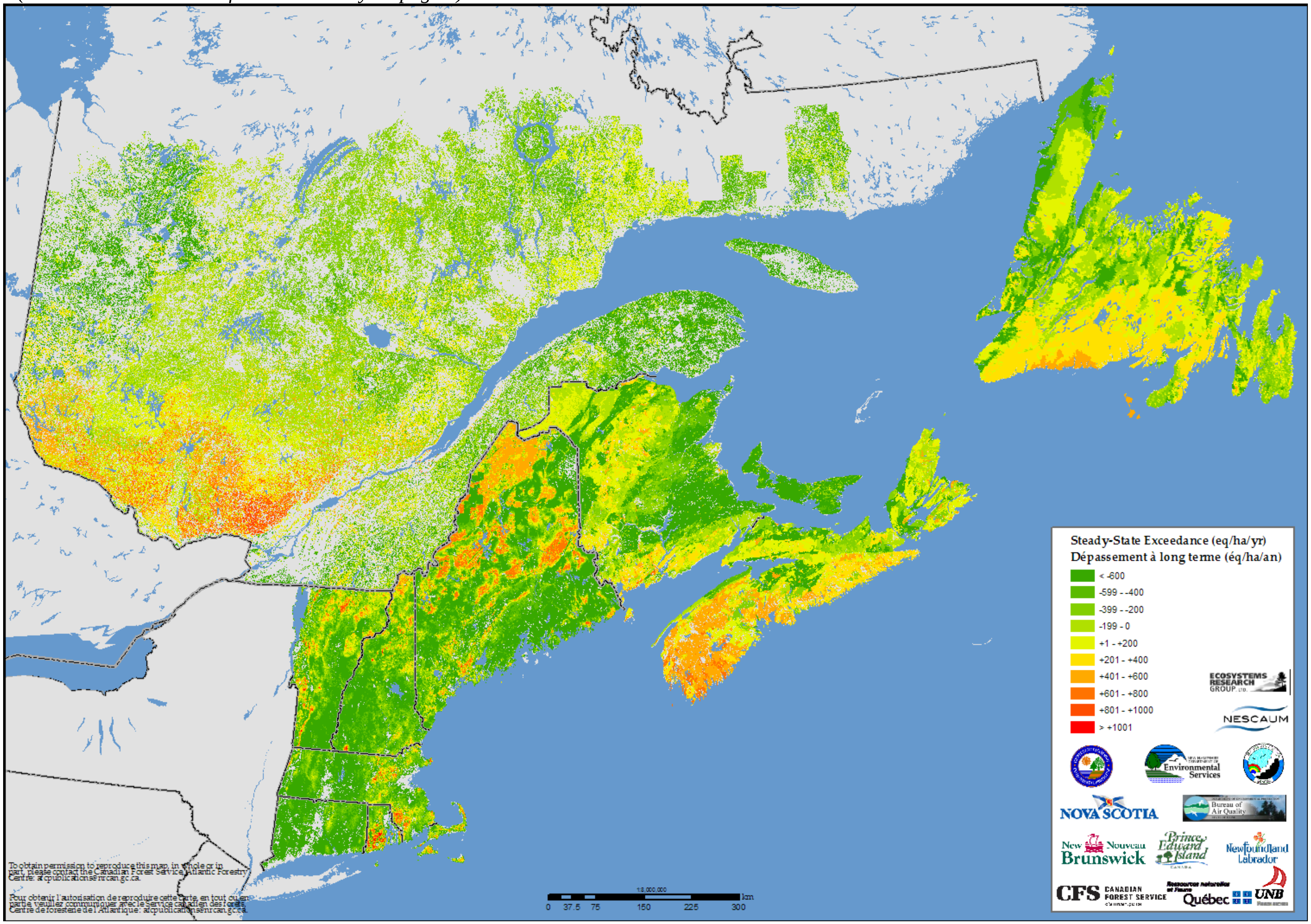

Table 1. Forest soil critical loads by NEG/ECP jurisdictions and their exceedances. Values are area-weighted. The terrestrial mapped area covers 162,674 km^2 in the U.S. and 547,424 km^2 in Canada.

Jurisdiction	Critical Load: Median	Critical Load: 5^{th} percentile	Exceedance: Median	Exceedance: 95^{th} percentile exceedance	Exceedance: Area mapped as exceeded
	($eq\ ha^{-1}\ y^{-1}$)				(%)
Maine	1280	340	-420	660	35.8
New Hampshire	1350	440	-520	600	17.6
Vermont	1600	390	-390	930	29.9
Rhode Island	1130	230	70	1260	51.6
Massachusetts	1770	540	-420	1250	29.1
Connecticut	2290	1330	-790	-10	4.4
Total New England states	1590	360	-470	730	29.3
Newfoundland	519	227	16	343	52.3
Nova Scotia	692	353	81	538	61.2
Prince-Edward-Island	2212	876	-1549	-190	3.3
New Brunswick	960	488	-215	298	28.2
Quebec	934	420	-175	532	31.6
Total Eastern Canadian provinces	946	423	-220	444	37.6

Table 2. Comparison of statewide average metrics for elements of the forest sensitivity assessment in the New England states to show the relative importance of forest management activities compared with acid deposition.

Jurisdiction	S+N Deposition eq ha^{-1} y^{-1}	S+N Range[1]	Base Cation Leaching eq ha^{-1} y^{-1}	Base Cation Harvesting eq ha^{-1} y^{-1}	Base Cation Weathering eq ha^{-1} y^{-1}	WX SD[2]	Critical Load eq ha^{-1} y^{-1}
Maine	680	1320	530	410	2440	1870	1280
New Hampshire	900	2050	810	260	1800	0430	1350
Vermont	1010	2100	890	230	2500	2090	1600
Rhode Island	1290	870	1360	330	2200	330	1130
Massachusetts	1310	1510	1400	210	2270	1240	1770
Connecticut	1350	1180	1450	170	2680	1150	2290
Newfoundland	528	416	601	47	383	394	616
Nova Scotia	739	381	638	69	445	507	633
Prince-Edward-Island	637	97	1386	71	1221	767	1922
New Brunswick	681	902	984	132	885	625	1051
Quebec	770	980	190	60	740	1690	930

Highlights

- Forest areas sensitive to acid deposition reach 253,685 km^2 (35.7%) of the mapped area for the NEG/ECP jurisdictions (Figure 1, Table 1).
- In the Eastern Canadian provinces, the most sensitive forest areas occur in Southern Quebec, especially in the Lower-Laurentides located at the north of the St. Lawrence River, in Southeastern Nova Scotia, and in Southern Newfoundland.
- In New England, the most sensitive forest areas occur in the mountain ranges and coastal areas where soils are poor and weathering rates low, and where there is greater demand for nutrients due to more intensive harvesting (Table 2).
- The greatest forest sensitivity areas correspond to locations where acid deposition rates are high (south and west areas), and where critical loads are low (varies with geology and harvesting rate – Table 2).
- Direct comparisons between jurisdictions should be made with caution since they were mapped at different resolutions and accuracy depending on data availability. Variations in data availability and scales result in impaired alignment at border limits.

[1] The range between the spatial minimum and maximum estimated atmospheric deposition of sulfur and nitrogen for different locations in the state expressed in eq ha^{-1} y^{-1}.
[2] One standard deviation of the weathering rate estimated for different locations in the state expressed as eq ha^{-1} y^{-1} of base cations released.

- Research has shown that sensitive forest areas show losses in forest health and productivity, and are more susceptible to climatic stress events, pests and diseases. For instance, preliminary results from the 30 sites of the Quebec Forest Monitoring Network (RESEF) show that forest sites in sensitive areas are growing 30% more slowly than sites located in tolerant areas. These findings point out the need to a more precise assessment of the risks associated with critical load exceedances.

Data variability within the NEG/ECP Region

The Forest Mapping Group recognized early on that the type and availability of the data necessary to perform critical load mapping for the region was not consistently uniform among the jurisdictions; consequently a certain amount of variability becomes evident upon close examination of the mapping results, particularly along the U.S./Canadian border. The Forest Mapping Workgroup agrees that each jurisdiction has been mapped in accordance with the Forest Mapping Protocol. The variability of the mapping results in no way detracts from or diminishes the impact or value of the data presented here as a tool with which to inform policymakers within the region. Some of the variability noted at the US/Canadian border is also due to differences in land use and landcover differences which can be pronounced in some border regions.

For example, the atmospheric deposition rates for sulphur and nitrogen which were used to identify exceedences of the calculated critical load values for forest ecosystems in the New England states are based on 1999-2003 total atmospheric deposition using a high-resolution deposition model (Miller, 2000; Miller et al., 2005); while they are based on the 1999-2002 total atmospheric deposition for forest ecosystems in Quebec and the Atlantic Canadian provinces (Shaw et al., 2006).

The critical load map for the Atlantic Provinces doesn't differentiate between agricultural and forested lands; whereas the maps for Quebec and the New England States include only forested land.

The variability in data attributes resulted in the New England states, the Atlantic provinces, and Quebec being mapped at different resolutions, varying from 0.09 ha grid cells for the New England states up to an average polygon size of 150 ha in Atlantic Canada (average polygon size in Quebec: 14.6 ha).

The soil mineral weathering rate estimation methods applied were also different among jurisdictions as permitted in the protocol (NEG/ECP Environment Task Group 2001). For the New England states, it was possible to use the data-intensive PROFILE model to estimate soil chemical weathering rates, while in Atlantic Canada the simpler soil substrate – texture model was used and its values seemed to correctly reflect forest soil conditions in Atlantic Canada (Whitfield et al., 2006). For Quebec, the latter model was applied with the use of a correction factor derived from the PROFILE model outputs from Maine used as calibration. The Forest mapping Group suggests that the evaluation of soil mineral weathering rates could be improved – and uncertainty reduced – through additional field studies.

Conclusions

More than one third of the mapped area of the NEG/ECP has been designated as sensitive to the extent that these areas are subjected to acid deposition in excess of their terrestrial critical loads. The possibility that high critical load exceedances leading directly or indirectly to poor forest growth and health in the exceeded regions appears strong. The critical load maps produced thus far demonstrate that further reductions in national and international S and N emission rates should be undertaken in order to protect forests from excessive soil acidification.

Additional work is necessary to improve upon the accuracy which could enhance and the utility of the regional critical load maps. Data variability between jurisdictions compromises our ability to draw seamless maps and a workshop bringing together forest mapping specialists and related disciplines in the region would build upon the success demonstrated to date.

Recommendations

1. In general, that a sustained incremental effort be made to improve the consistency of the data and the spatial resolution of the regional critical load map.

2. A regional forest sensititivity mapping workshop be organized within the next year.

3. An effort be made to improve the resolution of the soil weathering maps for the New England states, Quebec, and the Atlantic provinces.

4. Areas designated sensitive undergo further investigation to more precisely determine the scope and magnitude of the nutrient depletion occurring under current conditions of use and deposition.

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