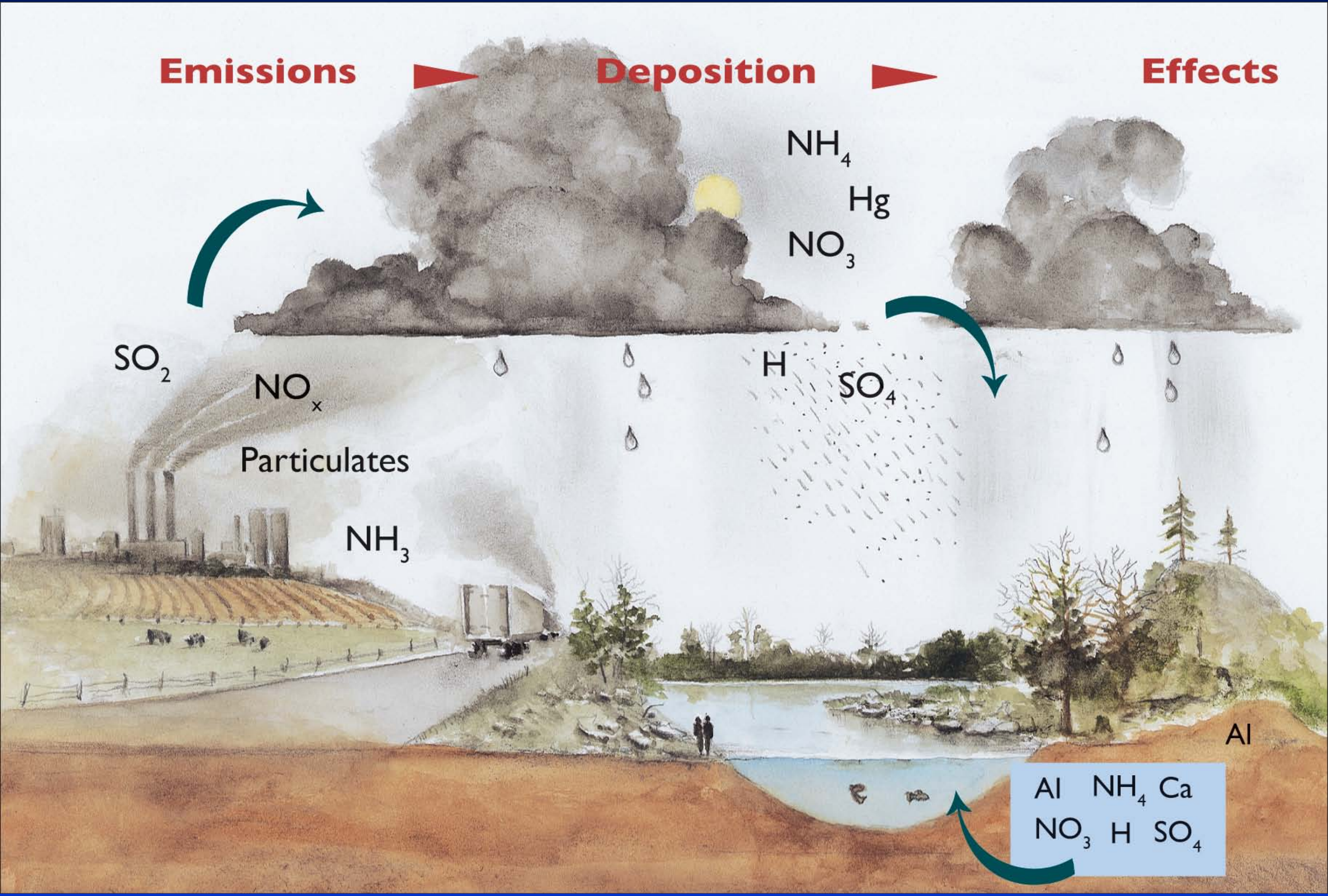
Continuing Acidification of Organic Soils Across the Northeastern U.S. between 1984 and 2001: Fact or Fiction

Richard A. F. Warby (Ph.D.)

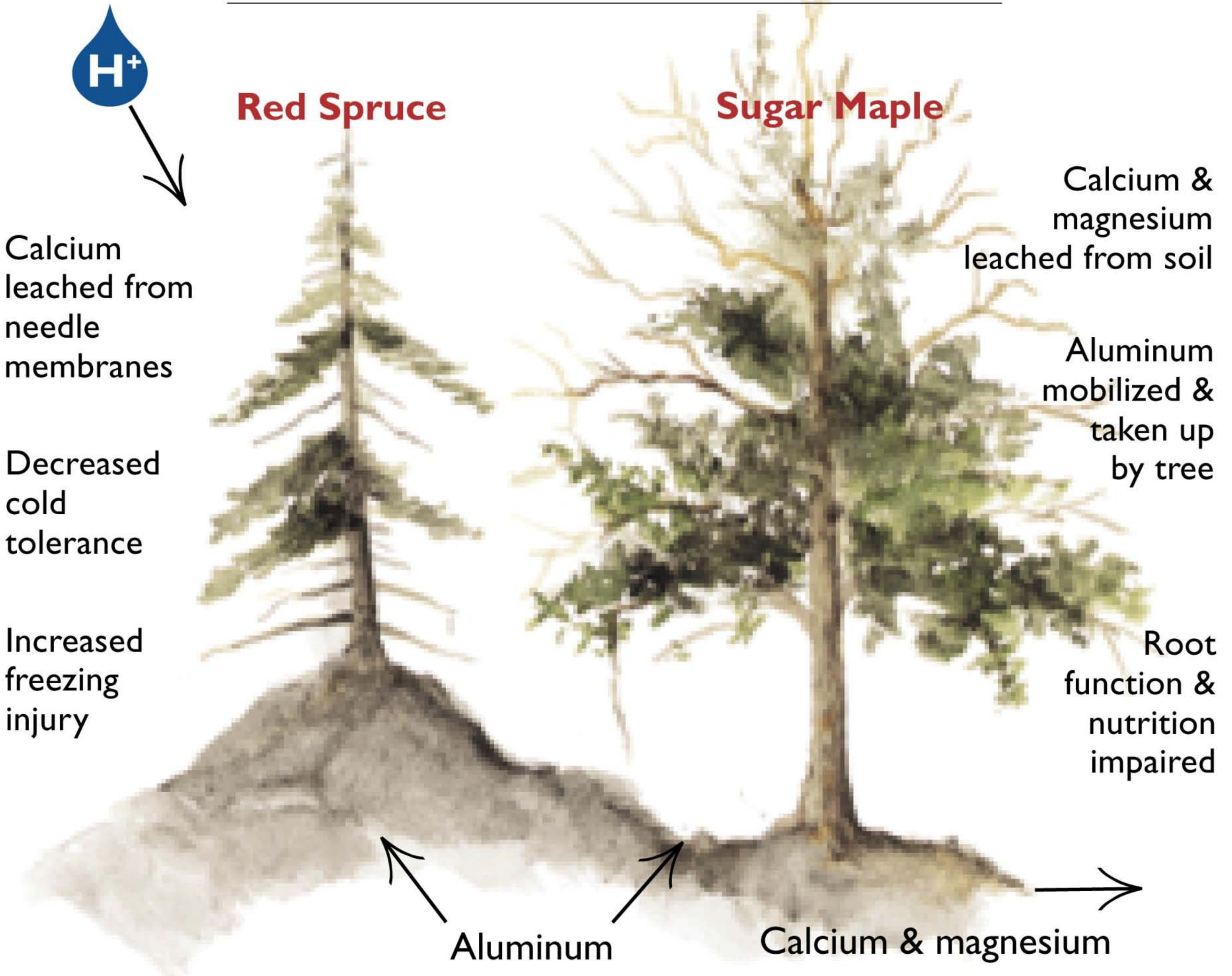


Emissions
Deposition
Effects
SO2
NOx
Particulates
NH3
NH4
Hg
NO3
H
SO4
Al
Al NH4 Ca
NO3 H SO4

Acid Deposition Effects on:

- Soils:
- Soil sulfur and nitrogen enrichment
- Nutrient cation (calcium, magnesium) depletion
- Aluminum mobilization and leaching
- Surface waters:
- Increases in sulfate, nitrate, and aluminum concentrations
- Decreases in pH and Acid Neutralizing Capacity
- A shift in Al to more toxic monomeric inorganic species

Acid Deposition Effects on Trees



pH CHANGE	GENERAL BIOLOGICAL EFFECTS
6.5 to 6.0  Fathead minnow. © NY State Dept. Of Environmental Conservation	Little community change; possible effects on highly sensitive fish species (e.g. fathead minnow, striped bass).
6.0 to 5.5  May fly. © Howard Cheek/BigStockPhoto.com	Loss of sensitive species of minnows and dace (fathead minnow, blacknose dace). Perhaps decreased reproduction of walleye and lake trout; increased accumulation of filamentous green algae. Changes in species composition and decrease in species richness in phytoplankton, zooplankton and benthic invertebrate communities. Loss of some zooplankton species and many species of clams, snails, mayflies, amphipods and some crayfish.
5.5 to 5.0  Rainbow trout. © Genadj Kurlin/ BigStockPhoto.com	Loss of lake trout, walleye, rainbow trout, smallmouth bass, creek chub. Further increase in filamentous green algae. Loss of many zooplankton species as well as all snails, most clams and many species of mayflies, stoneflies and other benthic invertebrates.
5.0 to 4.5  Leopard frog	Loss of most fish species. Further decline in the biomass and species richness of zooplankton and benthic invertebrate communities. Loss of all clams and many insects and crustaceans. Reproductive failure of some acid-sensitive amphibians, including spotted salamanders, Jefferson salamanders and the northern leopard frog.

From Baker et al. 1990

Approach

- Resample surface waters and soils in 2001 originally sampled as part of the DDRP in 1984.

- Using the same chemical analyses where possible, compare the 1984 and 2001 chemical data.

- Determine the chemical response of surface waters and organic soils over the study period following reduced inputs of acidic deposition.

The DDRP

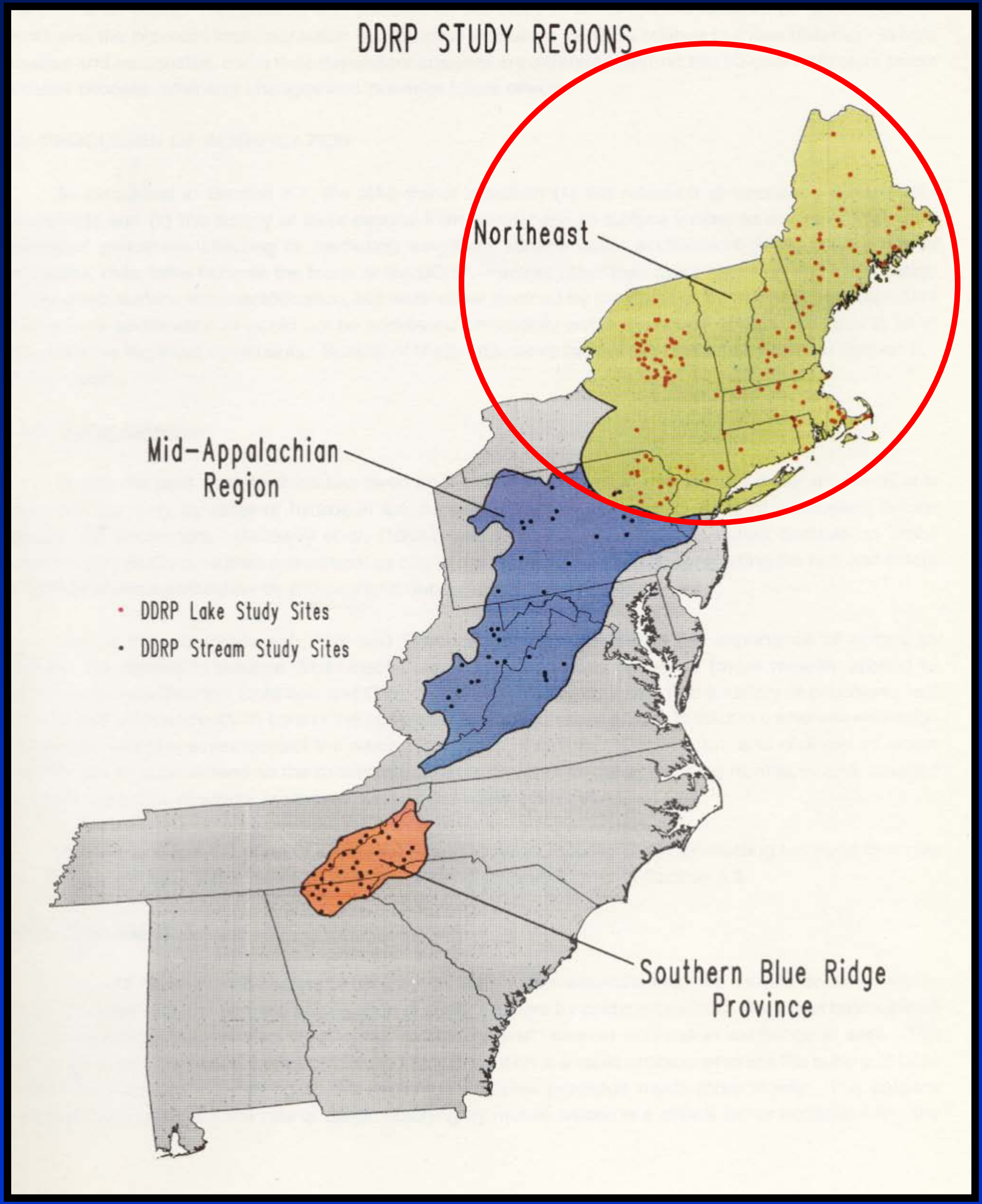
- The DDRP was started in 1984 under the National Acid Precipitation Assessment Program at the request of the Administrator of the U.S. Environmental Protection Agency (EPA)

- The central question that the DDRP hoped to address was:

  "How many surface waters would become acidic due to current or altered levels of acidic sulfur deposition, and on what time scales?"

- However, the central questions in this project focus on the chemical responses of these ecosystems

The three DDRP Study Regions



DDRP Watershed Selection Criteria

- The DDRP watersheds were a subset of 768 watersheds studied during the Eastern Lakes Survey Phase I;
- Lakes with ANC less than 400 μeqL^{-1};
- Lakes deeper than 1.5 m;
- Lakes with surface area greater than 4 ha;
- Culturally disturbed lakes were not sampled; and
- Lakes with a watershed area > 3000 ha were not sampled.

DDRP Watershed Selection Criteria

The DDRP used a random stratified approach to select lakes.

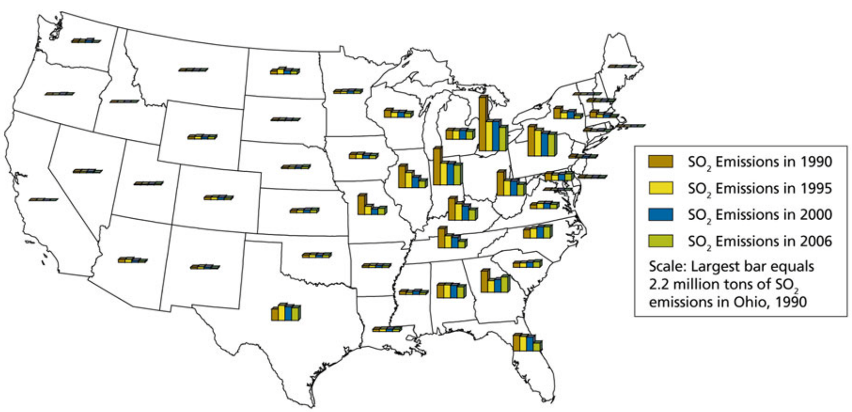
Using preliminary results from the ELS Phase I, lakes were divided into three strata based on ANC class.

A random sample of 50 lakes was selected from each ANC class.

Refusal of access and other factors ultimately reduced the total to 145 lake watersheds.

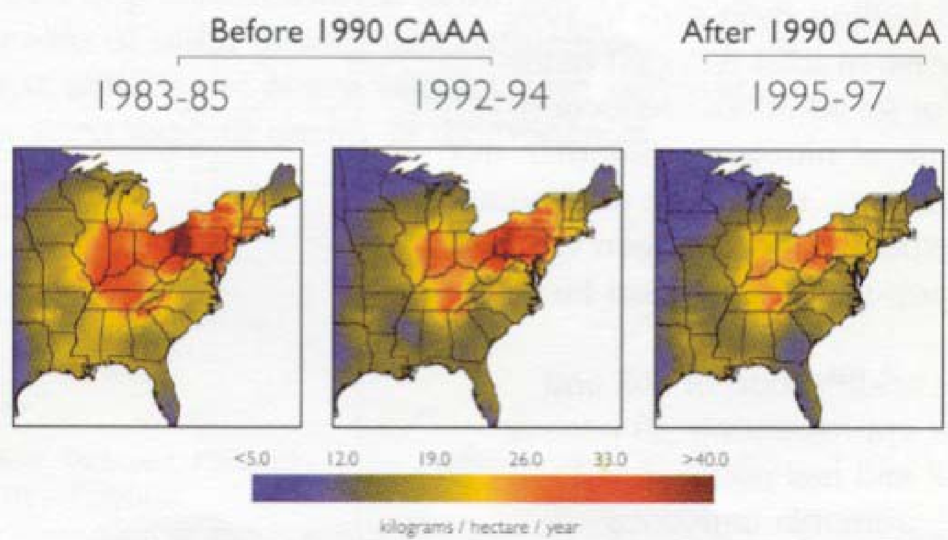
The random stratified sampling approach allowed the lakes to be extrapolated to a population of 3666 lakes across the northeastern U.S.

State-by-State SO_2 Emission Levels, 1990-2006

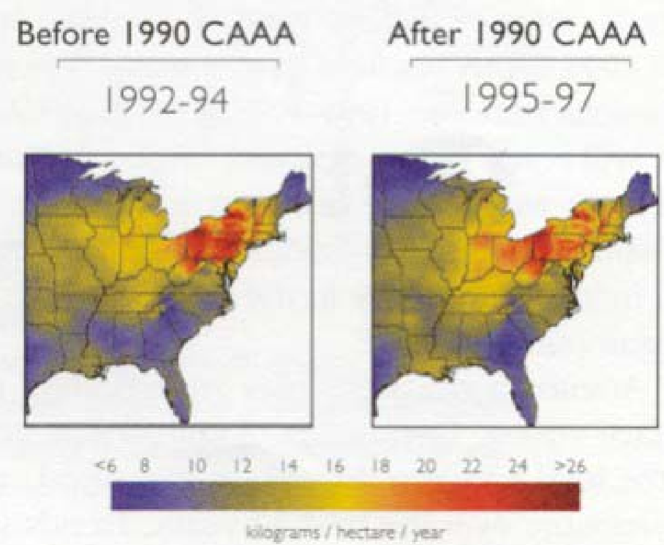


Source: EPA, 2007

Sulfate Wet Deposition



Nitrate Wet Deposition



Unknown Pond in the Adirondacks





Coleman

Part II: Chemical Changes in Oa-Horizon Soils

Specific Hypotheses

1. CEC in Organic soils will have increased between 1984 and 2001.

2. Exchangeable base cations, Ca in particular, will have shown a greater increase than exchangeable acidity, resulting in increased base saturation.

3. The pH of soils across the northeastern U.S. will have increased during the study period.

Approach

- As outlined in Part I, a total of 139 watersheds were sampled during the summer of 2001 and 2002.
- In each watershed we dug a soil pit, chose a face which was cleaned, and each horizon was sampled.
- The samples were bagged and sent back to Syracuse University for analysis.

Soil Profile at Unknown Pond in the Adirondacks

Data Screening

- Oa Horizons
  - DDRP sampled horizons greater than 3-cm in thickness
  - Watersheds in the SNE subregion typically did not have Oa horizons
  - Omitted samples with total carbon < 16%

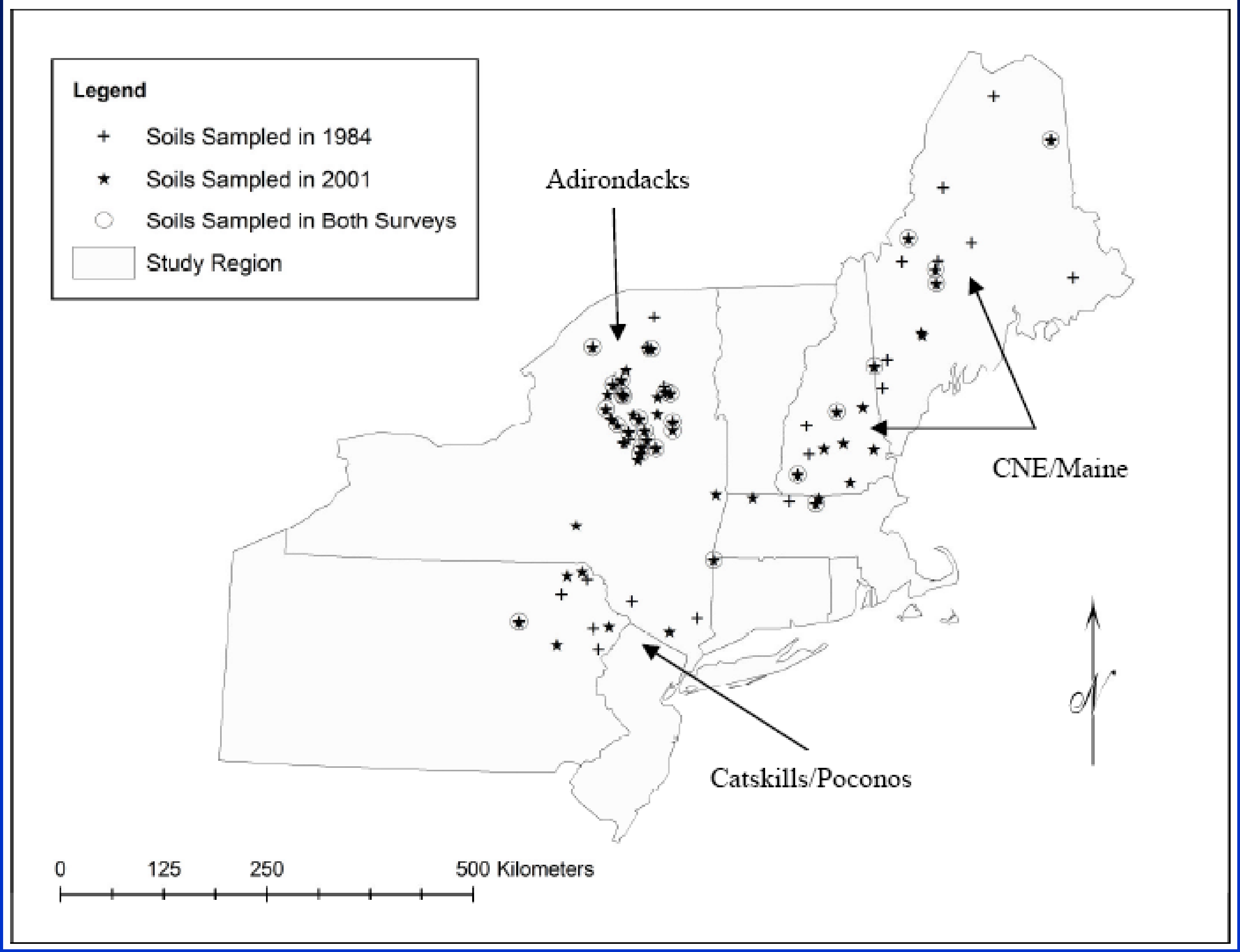
→ Final data set:

1984 (DDRP): 75 Oa horizons

2001: 55 Oa horizons

3 Sub-regions: Adirondacks, Cat/Poc, CNE/Maine

Soil sampling sites



Soil Chemical Measurements

- Same as DDRP to the extent possible
- Soil pH (DI water and 0.01 M $CaCl_2$)
- Total C and N (combustion/gas chromatography)
- Exchange Acidity (1 M KCl)
- Exchangeable Ca, Mg, K, Na, Al (1 M NH_4Cl)
- BC = Ca + Mg + Na + K ($cmol_c$ kg^{-1})
- CEC_e = BC + EA
- Base Saturation

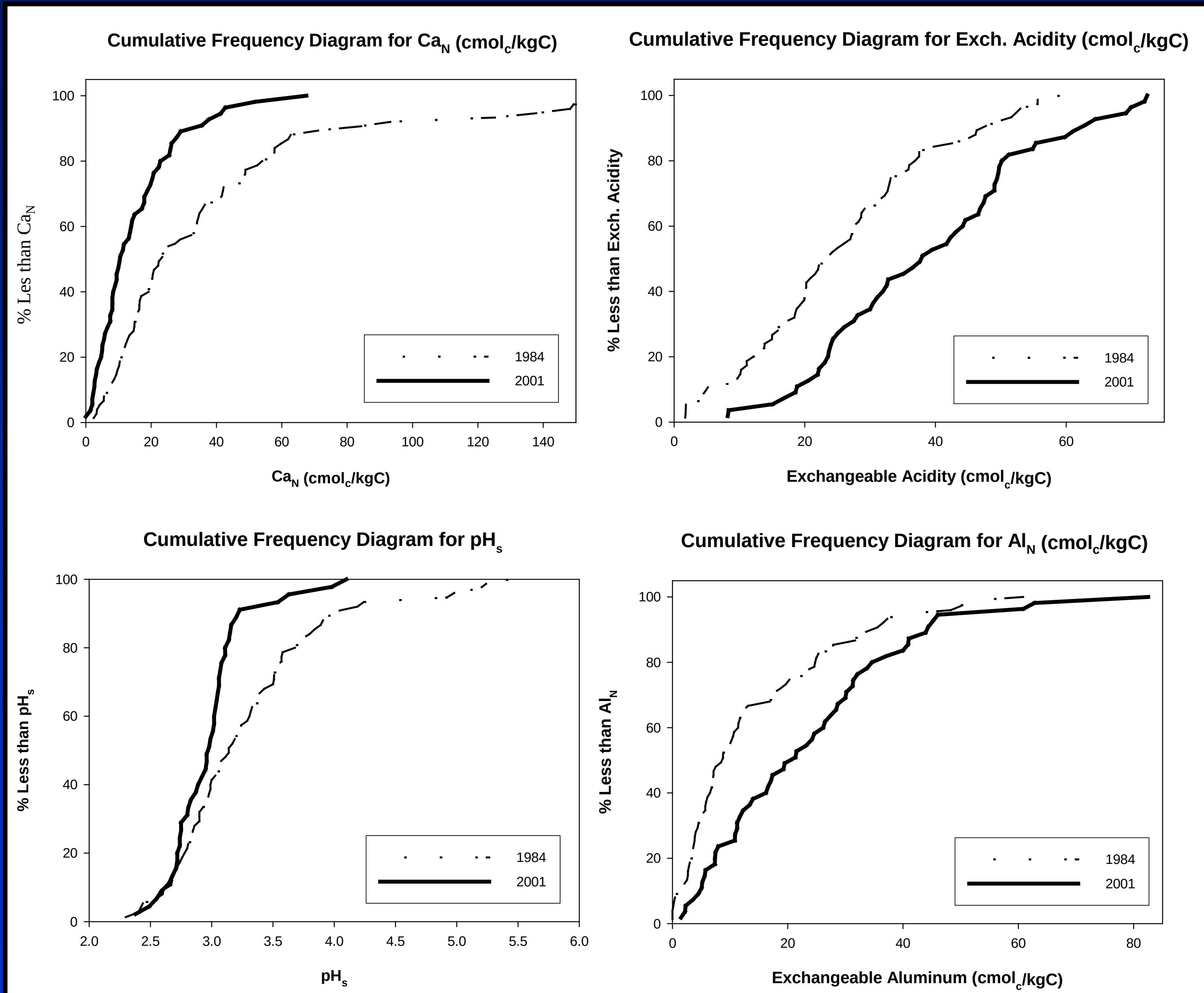
Data Analysis

- Non-Parametric Statistics
  - Medians for central tendency
  - Mann-Whitney U test
- Exchangeable Concentrations Normalized to Carbon
  - Units: $cmol_c \, (kg\ C)^{-1}$

Region-Wide Results

	1984 Median	2001 Median	Significance
Calcium, $cmol_c\ (kg\ C)^{-1}$	23.5	10.6	$P < 0.01$
Aluminum, $cmol_c\ (kg\ C)^{-1}$	8.8	21.3	$P < 0.01$
Acidity, $cmol_c\ (kg\ C)^{-1}$	23.6	38.0	$P < 0.01$
CEC_e, $cmol_c\ (kg\ C)^{-1}$	62.7	60.6	None
pH	3.14	2.98	$P < 0.05$
Base Saturation, %	56.2	33.0	$P < 0.01$

Region-Wide Results

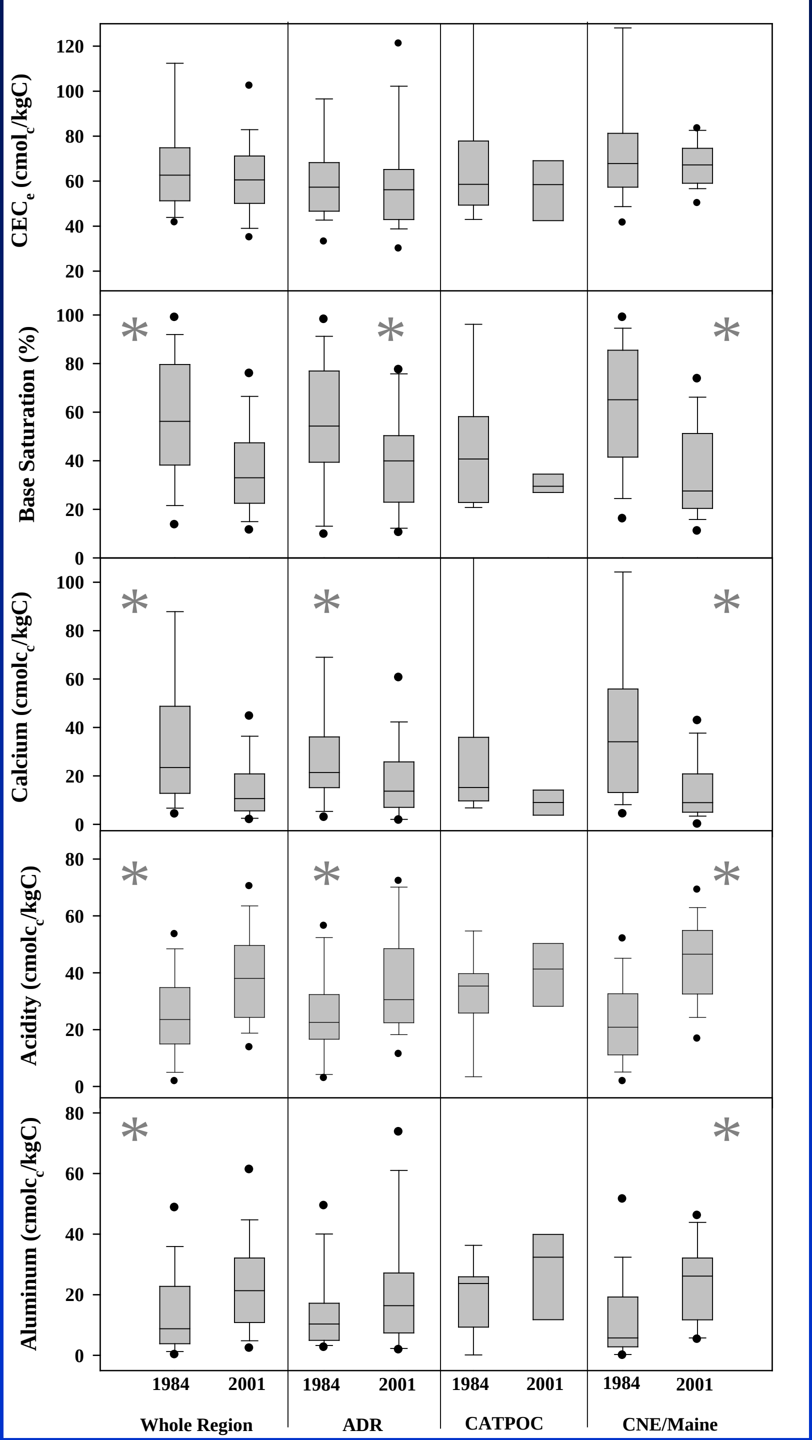


Sub-Regional Results

* Indicates P < 0.05

Sample Size (N):

Region	1984	2001
All	75	55
ADR	28	28
CATPOC	10	8
CNE/Maine	37	19



Acidification Most Profound in Watersheds with Moderate ANC Lakes

	ANC < 0		0 < ANC < 25		ANC > 25	
	1984	**2001**	**1984**	**2001**	**1984**	**2001**
Number of Samples	10	13	14	17	51	25
Base Saturation	33.44	25.28	41.40	38.20	65.62**	36.24**
CEC_{eN}	52.39	60.47	57.31	52.90	69.24	64.39
$Acidity_N$	35.18	44.60	29.98	32.78	19.92**	38.02**
Ca_N	13.47	8.17	16.82	8.40	34.80**	17.14**
Al_N	18.86	27.40	13.72	17.38	6.50**	16.20**
pH_s	2.94	3.03	2.88	2.96	3.24**	2.96**

** Indicates P < 0.01

Part II Overview

- Oa horizons in the northeastern USA experienced substantial decreases in exchangeable Ca, and increases in exchangeable Al between 1984 and 2001-02.

- These changes are consistent with other long-term monitoring results in the region.

- Acidification of Oa horizon soils was most profound in the CNE/Maine sub-region, and in watersheds that supported moderate-ANC lakes.

- The continuing acidification of Oa soils may help explain the sluggish recovery of ANC in regional surface waters.

Final Thoughts

Despite the general pattern of chemical recovery, many ponds remain chronically acidic or are susceptible to episodic acidification.

There is no doubt that organic soils are continuing to acidify, at alarming rates, despite decreases in acidic deposition.

This is likely one of the main reasons for the sluggish recovery of surface water ANC.

Final Thoughts

Understanding the extent, if any, of the acidification of mineral soils across the northeastern U.S. will provide valuable insight into the possible future recovery of both aquatic and terrestrial ecosystems.

All modeling efforts to date have indicated that for the continuing recovery of surface waters, and a reduction in the rates of soil acidification to occur, stricter emissions controls on S, and particularly N, will have to take effect.

While Stoddard *et al*. (2000) believes that true recovery of soils may take centuries, I believe that some soils may never recover to pre-industrial revolution conditions.

Future Research Question

- Why do we continue to chemical recovery of surface waters while soils continue to acidify?
- Does this phenomenon indicate that soil are more sensitive to acidic deposition than surface waters?
- Will the continuing acidification of soils result in the future decline in surface water quality?
- What land management and land use has the greatest impact on how these ecosystems respond to decreases in acidic deposition?


Questions ?