Assessment of Extent to Which Intensively-Studied Lakes are Representative of the Adirondack Mountain Region, New York

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Preliminary Results

ABSTRACT:

This initiative represents a multi-disciplinary and multi-institutional effort to extrapolate research, monitoring, and modeling results, including physical, chemical, and biological findings, from intensively-studied lakes to the regional population of acid-sensitive Adirondack lakes. Extrapolation is based on the statistical framework of the Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP). Intensively-studied sites were drawn from Rensselaer Polytechnic Institute Adirondack Effects Assessment Program (AEAP) and New York Department of Environmental Conservation Adirondack Long-term Monitoring Project (ALTM). A total of 70 watersheds are included in this effort, which has involved field sampling during summer, 2003 to develop a statistically-representative soils database and subsequent model projections using the MAGIC and PnET-BGC models to classify lakes according to their sensitivity to change in sulfur and/or nitrogen deposition. The results of this research will allow fuller utilization of data from on-going chemical and biological monitoring and process-level studies by providing a mechanism to extrapolate findings regionally and to develop/refine relationships among watershed characteristics, chemical change, and biological responses to changing levels of acid deposition. This project is important for the management of New York ecosystems that are most sensitive to changes in acid deposition because it will define the acidified lakes that are likely to recover and the extent of the expected recovery in response to varying future deposition scenarios. It will also identify types of watersheds in which recovery is unlikely, and will provide critical information for determining which areas require the most intensive research or remediation efforts.

BACKGROUND:

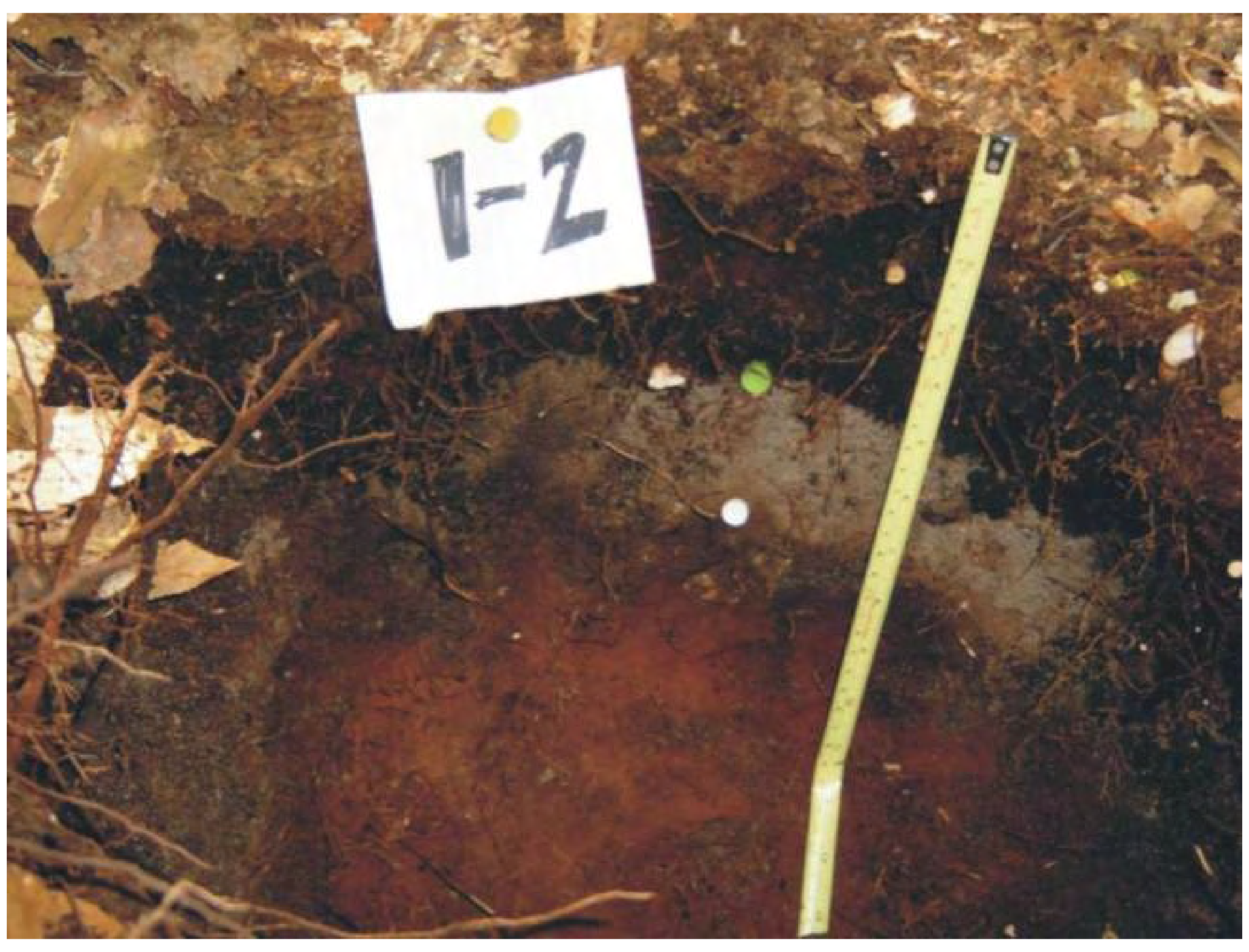
Ecosystem damage from air pollution in the Adirondack Mountains, New York has been substantial. In particular, many surface waters have experienced decreases in pH and acid neutralizing capacity (ANC) and concentrations of inorganic Al have increased, with consequent adverse impacts on fish, zooplankton, and other aquatic biota. In recent years, S deposition has declined, and is projected to continue to decline, in response to enactment of the Clean Air Act Amendments of 1990. Long-term monitoring programs have been collecting data for the past one to two decades, and continue to collect chemical and biological data, some of which show evidence of resource recovery. However, there previously was not a mechanism available to extrapolate results of these monitoring studies to the regional population of Adirondack lakes, and this has seriously curtailed the ultimate utility of these important data. Resource managers and policymakers need to know the extent to which current and projected future emissions reductions will lead to ecosystem recovery, both chemical and biological. Such recovery is being quantified at these monitoring site locations, but previously could not be directly extrapolated to the region.

Prior to this study, there was not a regional soils database for the Adirondack Mountains that was well-suited for providing the basis for model projections of resource recovery. This previous information gap was important because the degree to which regional Adirondack soils conditions exert controls on lakewater chemistry is not well understood, but may be substantial. Regional knowledge will provide a stronger basis for setting emissions reduction goals, for evaluating incremental improvements, and for conducting cost/benefit analyses.

MAJOR OBJECTIVES:

- Develop approaches for extrapolating spatially-limited knowledge regarding chemical and biological recovery of acid-sensitive lakes and their watersheds to the regional population of Adirondack lakes and watersheds
- Develop a statistically-representative soils database for the Adirondack region
- Classify watersheds according to their responsiveness to ongoing and future changes in S and/or N deposition

APPROACH:



- Acquire chemical and biological long-term monitoring data for 32 acid-sensitive lakes
- Statistically select a subsample of Adirondack lake watersheds from EPA's Environmental Monitoring and Assessment Program (EMAP) for regional characterization
- Compile watershed data on atmospheric deposition, vegetation, soils types, land use, and disturbance
- Conduct a survey of soils chemistry within 70 long-term monitoring and EMAP watersheds, stratified by lakewater ANC, soils type, and forest cover type
- Implement Quality Assurance/Quality Control (QA/QC) procedures
- Apply the Model of Acidification of Groundwater in Catchments (MAGIC) and the PnET-BGC model to the 70 study watersheds, and simulate past and future responses of lakewater chemistry to changing levels of S and N deposition
- Classify watersheds according to responsiveness to future decreases in S and N deposition and develop approaches to extrapolate results from the intensively-studied sites to the regional population
- Compare and contrast model output from MAGIC and PnET-BGC

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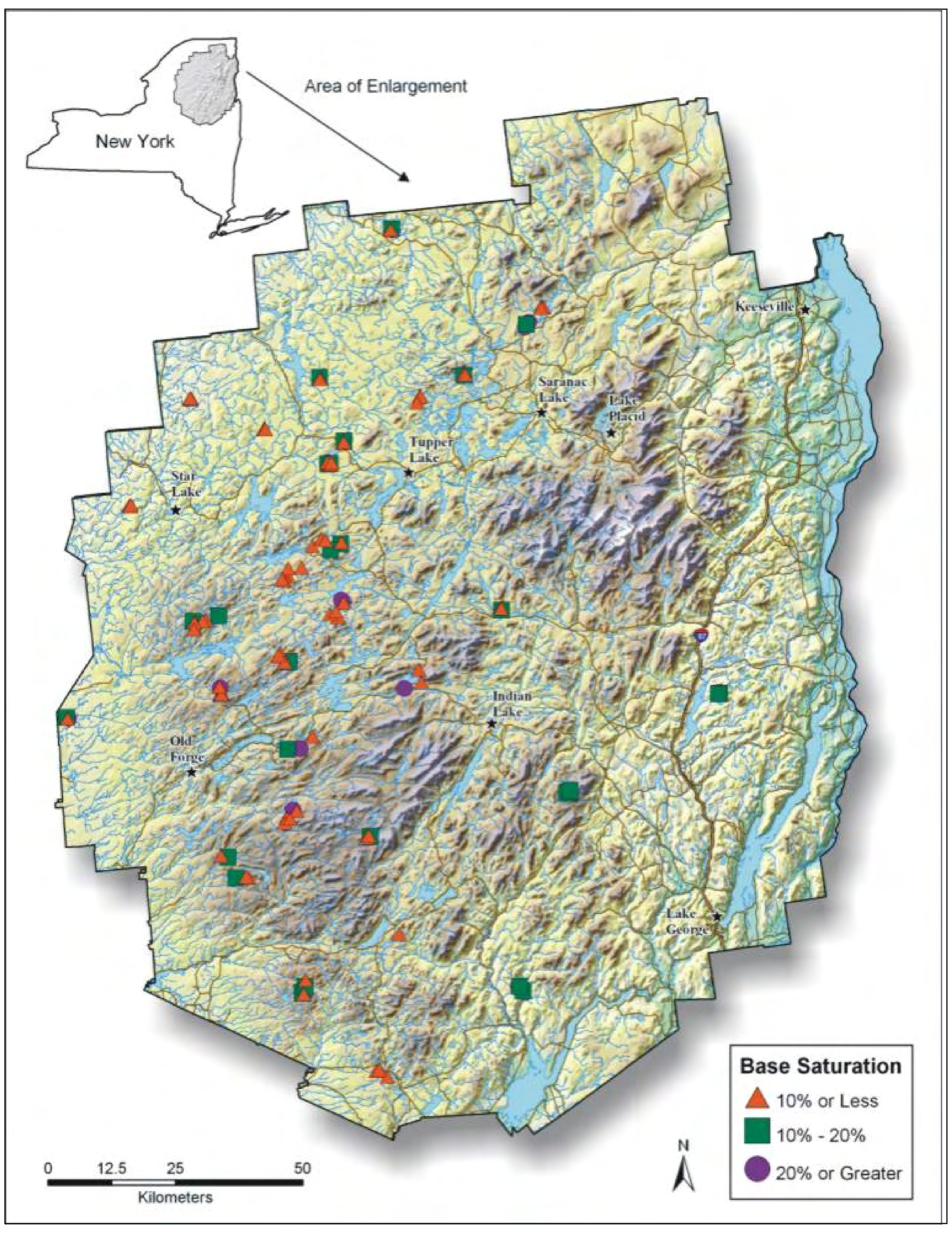


Figure 1. Map of the Adirondack Park indicating the location of soil sampling sites coded by measured soil base saturation.

WORK ACCOMPLISHED TO DATE:

- Site selection
- Soils type and forest type data compilation
- Soils survey
- Laboratory analyses
- Data compilation
- Database development
- QA/QC
- Model calibrations
- Model projections of future lakewater chemistry in response to 3 scenarios of emissions control
- Development of extrapolation procedures
- Watershed classification
- Integration and assessment

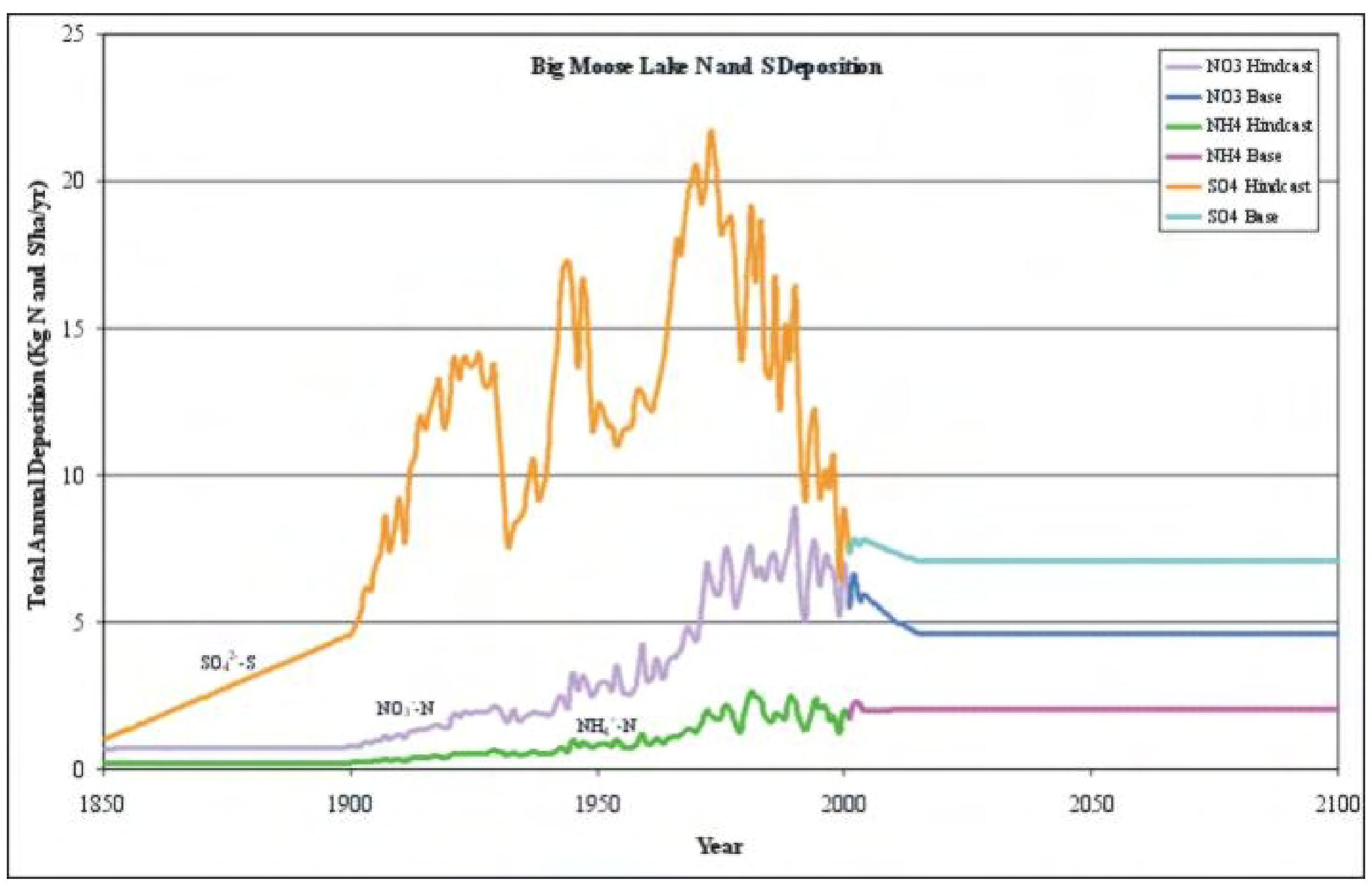


Figure 2. Estimated total annual atmospheric deposition of S and N from pre-industrial times to 2100 at the location of a representative watershed in the southwestern Adirondacks (Big Moose Lake). Future emissions were estimated by U.S. EPA, assuming existing and expected emissions control legislation.

RESULTS TO DATE:

Soil Conditions

Soil characteristics were determined at 199 locations within 70 watersheds. Results of soil analyses were extrapolated to the population of 1,320 watersheds containing lakes larger than 1 ha that had ANC less than 200 eq/L. More than 75% of the lake population received drainage from watersheds having average B horizon exchangeable Ca concentrations less than 0.52 cmolc/kg, base saturation less than 10.3%, and pH (H_2O) less than 4.5. Soils having base saturation less than 10% were widely distributed throughout the western half of the Adirondack region (Figure 1). These data provide a baseline against which to compare future changes in regional soil chemistry, and also provided input data for the aquatic effects models.

MODEL PROJECTIONS:

Model simulations were conducted using the MAGIC and PnET-BGC models. Results for the 44 statistically-selected lakes and their watersheds were extrapolated to the population of 1,817 Adirondack lakes less than 1 ha in area depicted on 1:100,000-scale topographic maps, and also to the subpopulation of 1,320 of those lakes that had ANC less than 200 eq/L at the time of EMAP sampling. MAGIC outputs have been more thoroughly analyzed to date and are presented here. Model simulations were extended into the future assuming S and N emissions controls expected to be enacted under existing air pollution control regulations. Under the Base Case emissions control scenario (Figure 2), SO2 emissions were projected to decrease over a 15-year period by 10.9% from 2001 values. NOx emissions were projected to decrease by 30.6% and NH3 emissions to increase by 4.8% over the same period. Both models showed close agreement between simulated and measured water chemistry. Model simulations suggested large decreases in lakewater ANC and pH from pre-industrial times to the period of maximum acidification (approximately 1980 to 1990). Limited chemical recovery is currently occurring (Table 1). The median Adirondack lake, from among the population of 1,320 lakes having current ANC 200 eq/L, was simulated to have decreased in ANC by 38 eq/L between 1850 and 1990. Twenty-five percent of those lakes were simulated to have acidified since pre-industrial times by more than 56 eq/L. Under the scenario of existing and expected emissions control legislation, more than 75% of these 1,320 lakes will increase in ANC between 1990 and 2050, with a median future increase of 6 eq/L. However, not all lakes were simulated to recover some of the lost ANC in the future. Model simulations suggested future reacidification of some lakes under S and N emissions control regulations that are currently in place or expected. In particular, the simulations suggested future increases in the number and percentage of lakes that are acidic (ANC 0) or very low in ANC (20 eq/L, Table 2). Model simulations for those lakes that are lowest in ANC suggested that the on-going chemical recovery will come to an end around 2020 and will be followed by a lengthy period of gradual reacidification (Figure 3A). Such reacidification was not simulated for the study lakes currently highest in ANC (Figure 3B). In fact, the MAGIC model suggested that the number of acidic lakes would hold constant from 2000 to 2050, and then more than double by 2100. The model also projected that the numbers of lakes having ANC less than 20 eq/L and less than 50 eq/L will both increase between 2000 and 2050 under existing and expected emissions control legislation. These simulation results may be attributable to decreasing soil base saturation in many of the modeled watersheds.

Table 1. Simulated water chemistry percentile values for the population* of potentially acid-sensitive Adirondack lakes, based on the MAGIC model, for the period from 1850 to 2100, assuming existing S and N emissions control regulations.

Variable	Year	Percentile				
		10	25	50	75	90
ANC	1850	28	72	95	174	253
	1900	29	69	97	180	259
	1980	4	25	64	133	189
	1990	4	31	63	118	180
	2000	6	35	67	117	183
	2050	0	35	67	129	200
	2100	-7	32	61	132	200
pH	1850	5.9	6.5	6.8	7.1	7.3
	1900	5.8	6.5	6.8	7.1	7.3
	1980	4.8	5.5	6.5	6.9	7.2
	1990	4.8	5.5	6.5	6.9	7.2
	2000	4.9	5.8	6.5	7.0	7.2
	2050	5.0	5.8	6.5	7.0	7.2
	2100	5.0	5.7	6.5	7.0	7.2
SO_4	1850	5	7	9	15	23
	1900	17	20	23	32	38
	1980	86	95	107	123	138
	1990	71	81	93	108	129
	2000	49	55	71	81	94
	2050	36	40	50	57	62
	2100	36	40	49	57	59
SBC	1850	45	88	111	199	293
	1900	65	109	134	232	320
	1980	101	145	172	260	342
	1990	85	131	151	239	320
	2000	68	114	133	215	295
	2050	46	95	117	195	286
	2100	41	89	115	191	286

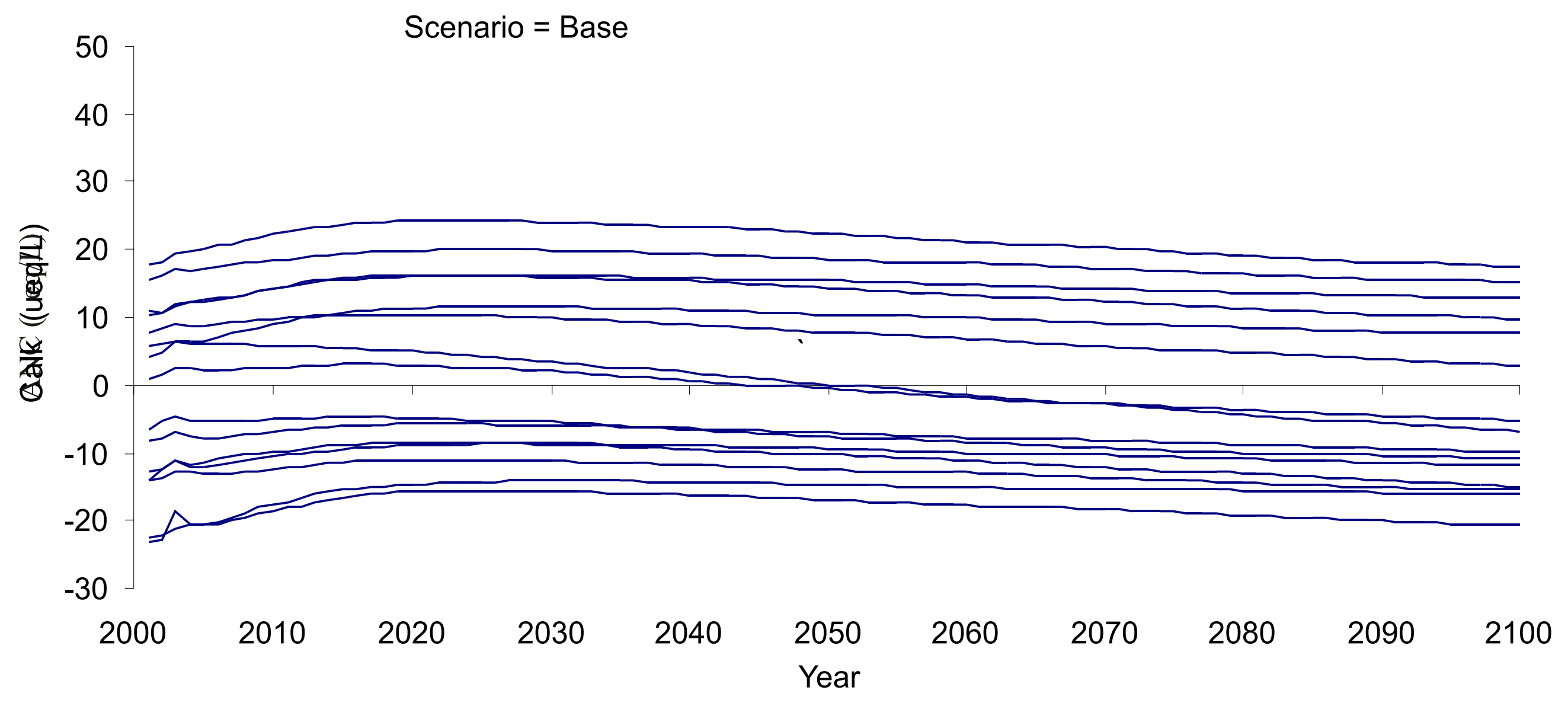
* Percentages are based on the population of 1,320 Adirondack lakes having ANC less than 200 eq/L. This population constitutes a subset (based on having ANC 200 eq/L) of the larger population of 1,817 Adirondack lakes greater than 1 ha depicted on 1:100,000-scale topographic maps

Table 2. Estimated number of Adirondack lakes below ANC and pH criteria values for the population of 1,320 Adirondack lakes larger than 1 ha that have ANC less than 200 eq/L, based on MAGIC model simulations for 44 statistically-selected lakes.

Year	ANC (eq/L)			pH		
	0	20	50	5.0	5.5	6.0
1850	0	0	174	93	93	186
1900	0	104	216	93	93	186
1980	96	266	505	175	330	443
1990	82	279	505	175	326	426
2000	82	217	399	159	268	381
2050*	82	229	437	142	268	379
2100*	175	229	437	159	284	422

* Simulations for future years (2050 and 2100) are based on a scenario of emissions controls that have been or are expected to be enacted under existing regulations.

A) 15 lakes having lowest ANC



B) 15 Lakes having highest ANC

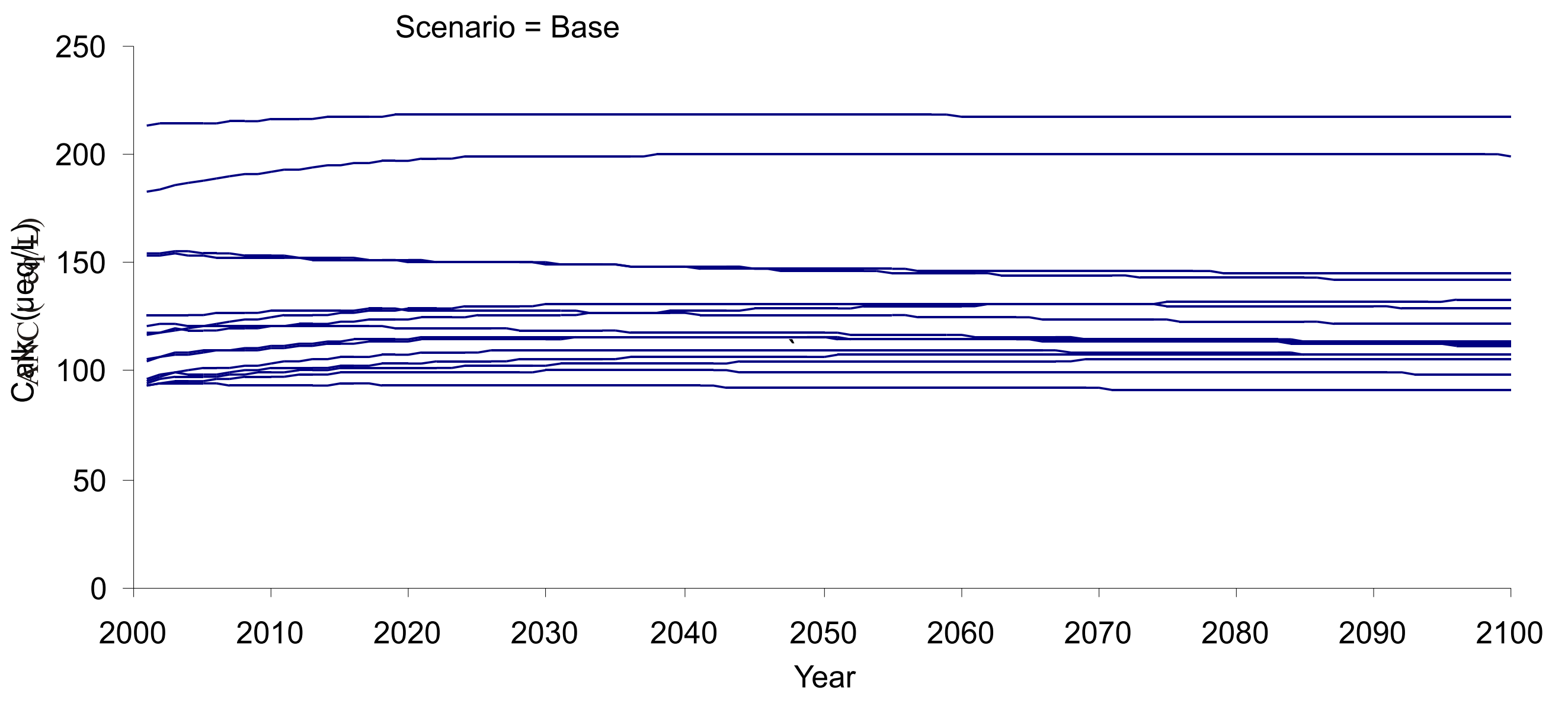


Figure 3. Simulated future ANC of the 15 study lakes having A) lowest ANC, and B) highest ANC in response to the Base Case emissions control scenario illustrated in Figure 2.

REPRESENTATIVENESS OF ALTM LAKES:

ALTM lakes included in this study are not representative of the population of Adirondack lakes larger than 1 ha with respect to current water chemistry or the degree to which they have changed, or in the future will change, in response to acidic deposition (Figure 4). Rather, the ALTM study lakes are reasonably well distributed across the population cumulative frequency distribution (cfd) for current ANC only for the portion of the population distribution below ANC ~125 eq/L (the approximately 55% of the lakes in the EMAP statistical frame having lowest current ANC). Similarly, of the 32 ALTM study lakes, only one falls within the lower half of the population distribution of acid-sensitivity based on simulated historical acidification, and only three lakes fall within the lower half of the population distribution for ANC recovery from 1990 to 2050 (Table 3). The ALTM study lakes having the lowest current ANC (Willys, Squash, Carry, Round, and Jockeybush; all acidic in 2000) were generally variable in terms of amount of historical acidification (1850 to 1990) or chemical recovery (1990 to 2050). For example, only 5% of the population of 1,320 low-ANC Adirondack lakes were estimated to have current ANC lower than Squash Pond (-21 eq/L). Nevertheless, nearly one-half of the population was simulated to have acidified more than Squash Pond since 1850 and one-fourth of the population was simulated to increase more in ANC from 1990 to 2050 in response to reduced emissions and acidic deposition (Table 3). Of the lakes that were simulated to be most responsive to acidic deposition (largest historical acidification and largest future chemical recovery; Willys Lake, Cascade Lake, Sagamore Lake, Raquette Lake Reservoir, Moss Lake, Arbutus Pond) most had intermediate current ANC (50 to 100 eq/L). The watersheds of ALTM study lakes are more evenly distributed across the population cfd's for soil acid-base chemistry (Table 4) than for lakewater chemistry (Table 3). ALTM watersheds exhibited a variety of B-horizon soil base saturation and exchangeable Ca2+ conditions.

Table 3. Modeled relationship between each of the studied ALTM/AEAP lakes and the population of Adirondack lakes with respect to acid-base chemistry status, acidification, and recovery responses based on MAGIC model simulations.

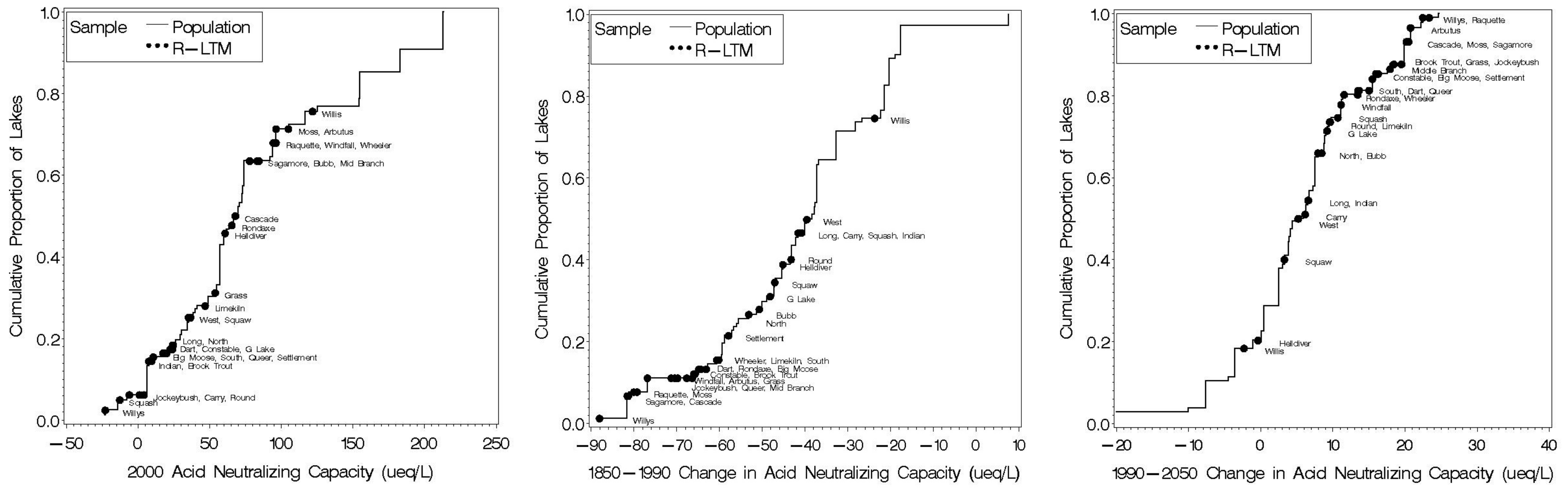
ALTM Lake		Estimated Percentage of Lakes in the Population Having:			
Name	ID	Lower 2000 ANC	Greater Historical Acidification (1850 to 1990)	Greater ANC Recovery Under Base Case Scenario (1990 to 2050)	Lower 2050 ANC Under Base Case Scenario
Willys Lake*	040210	2.4	1.3	1.0	2.4
Squash Pond	040754	5.0	46.6	25.4	3.7
Carry Pond	050669	6.2	46.6	49.0	5.0
Round Pond	040731A	6.2	40.1	26.4	6.2
Jockeybush Lake	050259	6.2	11.1	12.3	14.5
Indian Lake*	040852	14.5	46.6	45.5	14.5
Brook Trout Lake	040874	14.5	12.1	12.3	15.5
South Lake*	041004	15.5	15.5	18.8	15.5
Big Moose Lake	040752	16.4	13.3	14.7	17.4
Queer Lake	060329	16.4	11.1	18.8	17.4
Middle Settlement Lake	040704	16.4	21.5	14.7	18.4
G Lake	070859	17.4	31.0	28.6	17.4
Dart Lake	040750	17.4	13.3	18.8	18.4
Constable Pond	040777	17.4	12.1	15.9	19.6
Long Pond	050649	18.4	46.6	45.5	17.4
North Lake*	041007	18.4	26.7	34.0	18.4
Squaw Lake*	040850	25.2	34.5	60.0	20.8
West Pond	040753	25.2	49.9	50.0	26.3
Limekiln Lake	040826	28.0	15.5	26.4	33.1
Grass Pond	040706	31.2	11.1	12.3	45.2
Helldiver Pond	040877	45.8	38.8	79.7	42.0
Lake Rondaxe	040739	47.8	13.3	19.8	61.2
Cascade Lake	040747	50.0	6.7	6.9	63.5
Bubb Lake	040748	63.5	27.9	34.0	63.5
Middle Branch Lake	040707	63.5	11.1	13.5	66.9
Sagamore Lake	060313	63.5	6.7	6.9	67.9
Windfall Pond	040750A	67.9	11.1	22.2	67.9
Wheeler	040731	67.9	15.5	19.8	67.9
Arbutus Pond*	050684	71.3	11.1	3.5	71.3
Raquette Lake Reservoir	060315A	67.9	7.7	1.0	71.3
Moss Lake	040746	71.3	7.7	6.9	72.5
Willis Lake	050215	75.6	74.6	81.7	72.5

* Lake is also part of the EMAP probability sample.

Table 4. Relationship between each of the long-term monitoring study watersheds and the EMAP population of Adirondack lake watersheds* with respect to modeled soil base status in the year 2000 based on MAGIC model simulations.

		Estimated Percentage of Lake Watersheds in the Population Having:	
ALTM Lake	ID	Lower B-Horizon BS	Lower B-Horizon Exch. Ca^{2+}
Middle Settlement Lake	040704	2.8	0.0
Middle Branch Lake	040707	4.1	28.8
Round Pond	040731A	8.7	10.4
Grass Pond	040706	11.6	56.5
Carry Pond	050669	11.6	7.2
Willys Lake	040210	14.7	7.2
West Pond	040753	16.7	30.1
Helldiver Pond	040877	16.7	30.1
Wheeler	040731	26.0	36.2
Brook Trout Lake	040874	26.0	36.2
Arbutus Pond	050684	33.1	79.2
Dart Lake	040750	46.6	61.8
Constable Pond	040777	46.6	73.6
Sagamore Lake	060313	46.6	80.4
Indian Lake	040852	46.6	60.8
Jockeybush Lake	050259	47.9	56.5
Big Moose Lake	040752	50.2	75.8
Long Pond	050649	50.2	30.1
Lake Rondaxe	040739	51.2	75.8
Cascade Lake	040747	51.2	75.8
Moss Lake	040746	52.2	79.2
North Lake	041007	52.2	61.8
G Lake	070859	61.5	73.6
Squash Pond	040754	62.6	82.7
South Lake	041004	62.6	82.7
Limekiln Lake	040826	63.8	79.2
Windfall Pond	040750A	70.2	73.6
Raquette Lake Reservoir	060315A	70.2	86.0
Queer Lake	060329	70.2	92.5
Bubb Lake	040748	78.5	86.0
Squaw Lake	040850	80.7	73.6
Willis Lake	050215	98.1	95.9

* Based on the EMAP population of 1,320 acid sensitive Adirondack lake watersheds containing lakes larger than 1 ha.


(A) Predicted 2000 Lakewater ANC

(B) Predicted Historic Acidification (1850 to 1990 change in ANC)

(C) Predicted Future ANC Recovery (1990 to 2050) - Base Scenario

Figure 4. Cumulative frequency distributions (cfd) of the population of 1,320 Adirondack lakes larger than 1 ha depicted on 1:100,000-scale topographic maps that had lakewater ANC less than 200 eq/L at the time of EMAP sampling. Superimposed on each cfd is the location within the population distribution of each ALTM study lake. Projections are given for MAGIC model simulations of A) lakewater ANC in the year 2000, B) historic acidification from 1850 to 1990, and C) chemical recovery from 1990 to 2050 under existing and expected emissions control regulations.

LINKAGES TO BIOLOGICAL RESPONSES:

Among the most responsive species to changes in lakewater acid-base chemistry are the zooplankton, especially large cladocerans and other crustaceans, and to a lesser extent, rotifers. Data from 97 Adirondack lakes, collected in conjunction with three U.S. EPA research programs (EMAP, Eastern Lakes Survey Phase 2, and STAR) were used to establish relationships between lakewater ANC and metrics of zooplankton richness (Figure 5). These empirical relationships will be used to estimate past and future changes in zooplankton communities in response to changes in lakewater ANC. They suggest that by 1990 the median Adirondack lake had acidified sufficiently to lose about four zooplankton species in response to acidification, and that the emissions reductions that are expected based on existing regulations on average might yield lakewater chemistry that would allow recovery of approximately one species by 2050.

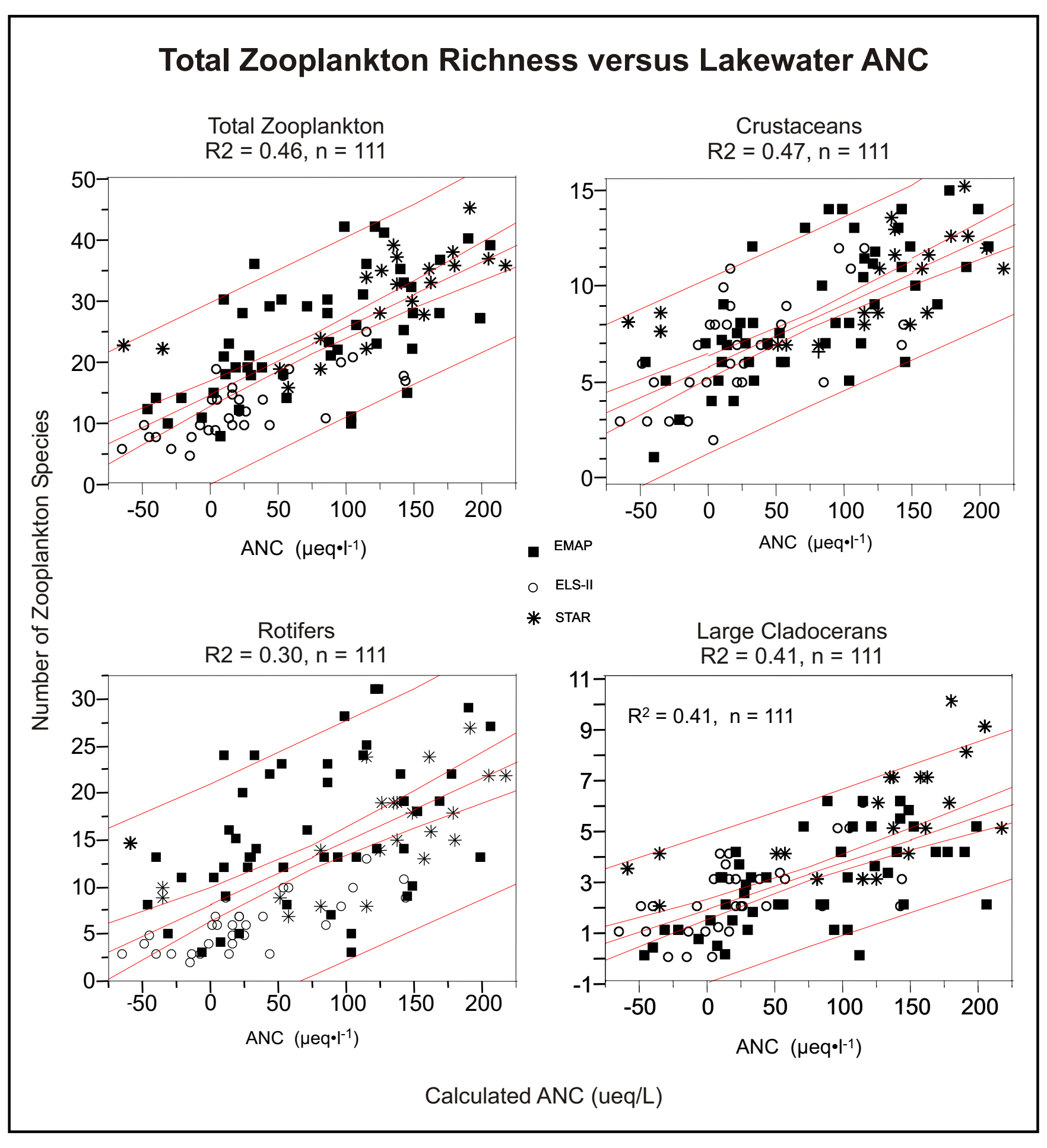


Figure 5. Relationships between lakewater ANC and zooplankton species richness.

CONCLUSIONS:

ALTM lake watersheds are not representative of the Adirondack population. They generally represent only:

- Lakes having current ANC less than about 125 eq/L (~ 1,000 lakes)
- Lakes that have acidified the most in response to 20th century acidic deposition (~ 660 lakes)
- Lakes expected to recover the most ANC in response to existing and expected emissions control legislation (~ 660 lakes)

In response to existing and expected S and N emissions control regulations:

- Some lakes have been increasing in ANC and many of those having higher ANC are expected to continue increasing in ANC. Some of those having lower ANC are expected to stop recovering chemically and reacidify in the future.
- MAGIC simulations suggested that the number of acidic lakes is expected to remain constant between now and 2050, but then double by 2100.
- The number of lakes having ANC less than 20 peaked in about 1990 (279 lakes) and declined during the 1990s (to 217 lakes). Model projections suggest a reversal of that decline, with 229 lakes having ANC 20 eq/L by 2050.

Research Partners:
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