Critical Loads: A Boundary Spanning Approach to Air Quality Management to Protect Ecosystems

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Outline

- Background: Critical loads and TMDLs
- Adirondack TMDL case study
- Great Smoky Mountain National Park case study
- Final thoughts
- Future research recommendations

What is a Critical Load ?

"Estimate of exposure to pollutants below which harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson & Grennfelt, 1988)

How was the concept developed ?

Developed in Europe for nitrogen and sulfur deposition; used in negotiations to guide emission control strategies.

Why are Critical Loads used ?

Based on the idea that control strategies to protect ecosystems against acidification and eutrophication should be effects-driven.

What is a Dynamic Critical Load/Target Load ?

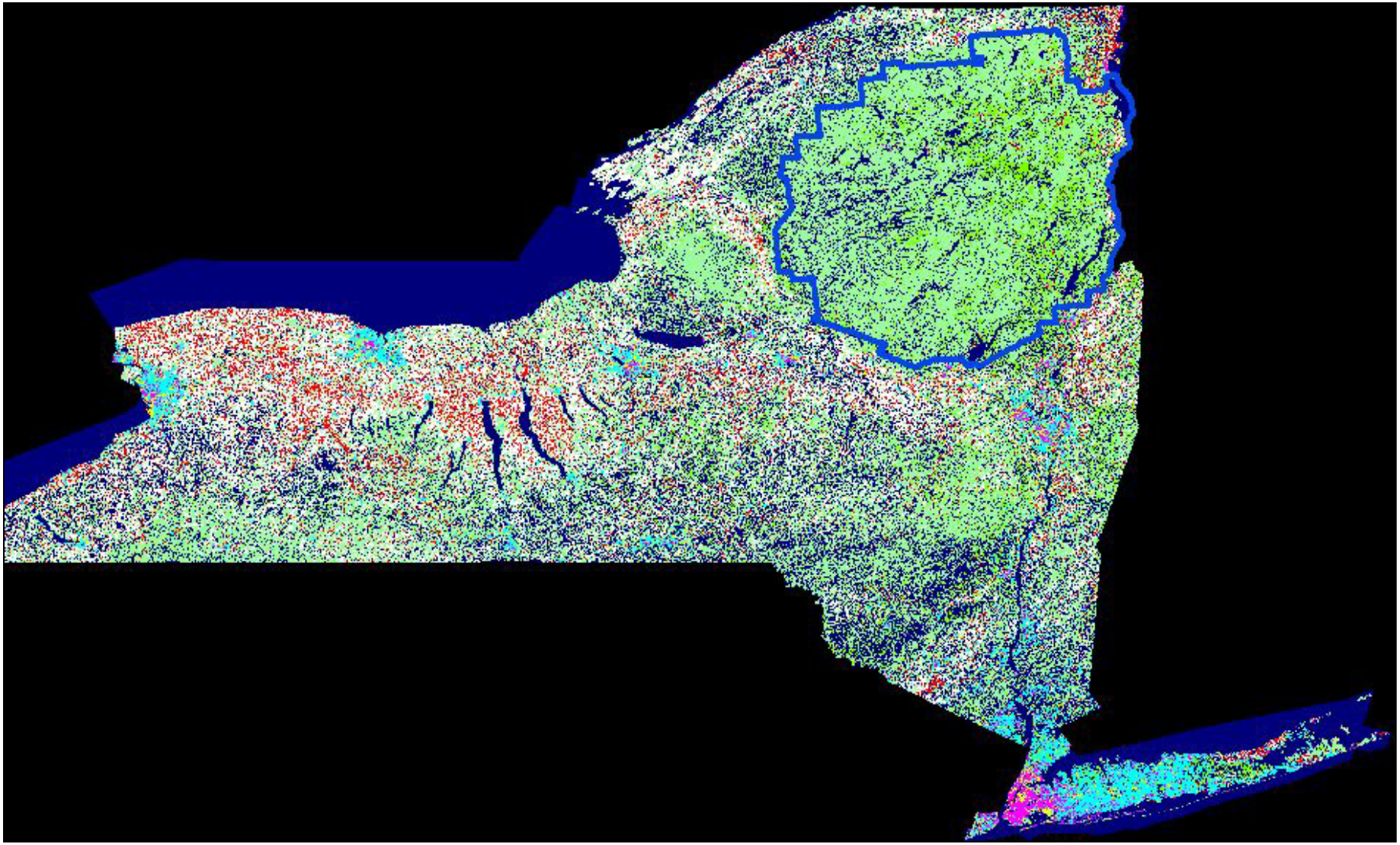
Consideration of a time-scale for ecosystem recovery.

Systematic Clean Water Act framework

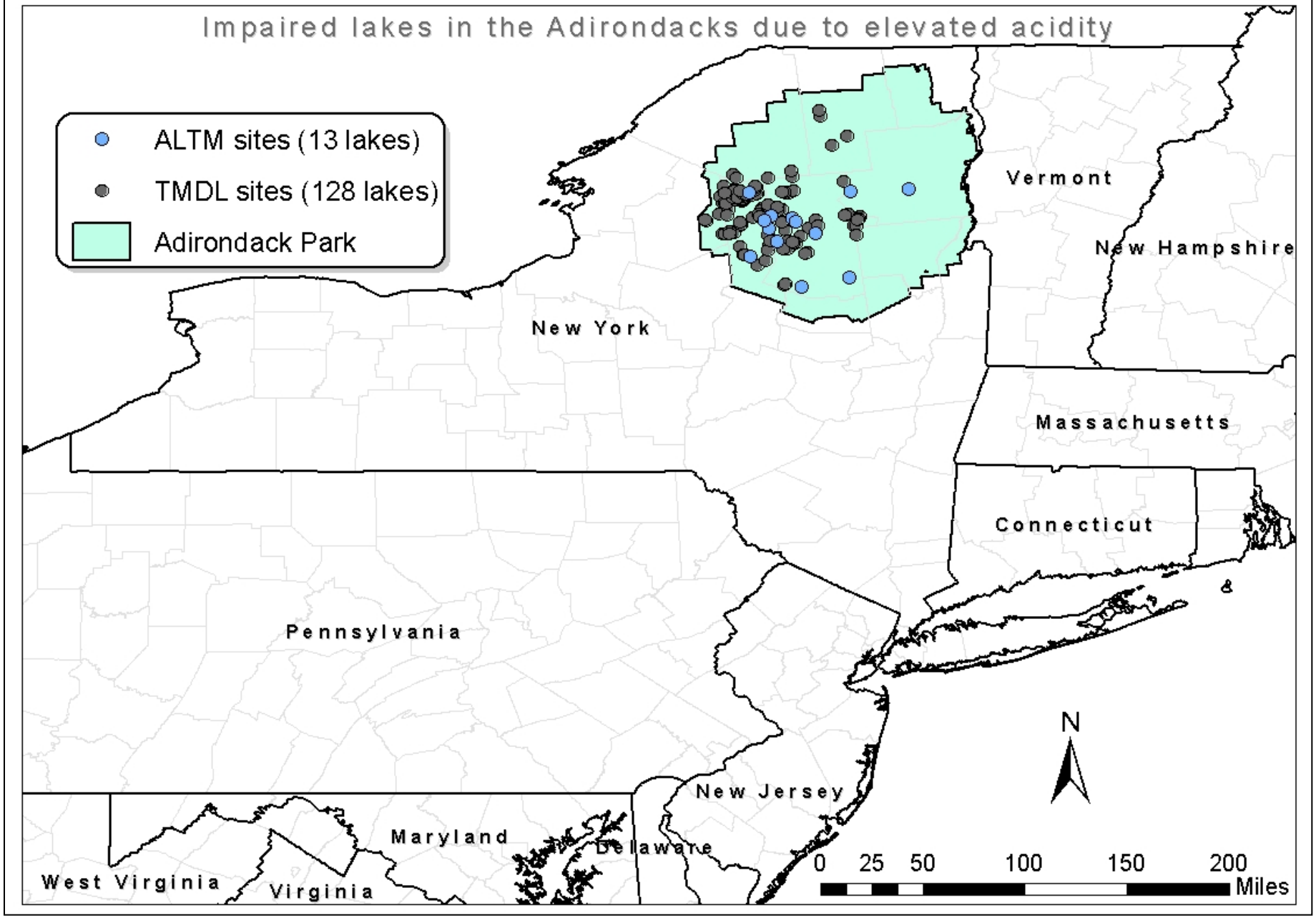
- Establish Water Quality Standards
- Assess Waters of the State
- Identify Impaired Waters on 303d List
- Conduct TMDL Analysis
- Implement TMDL
- Evaluate (Post-Audit)

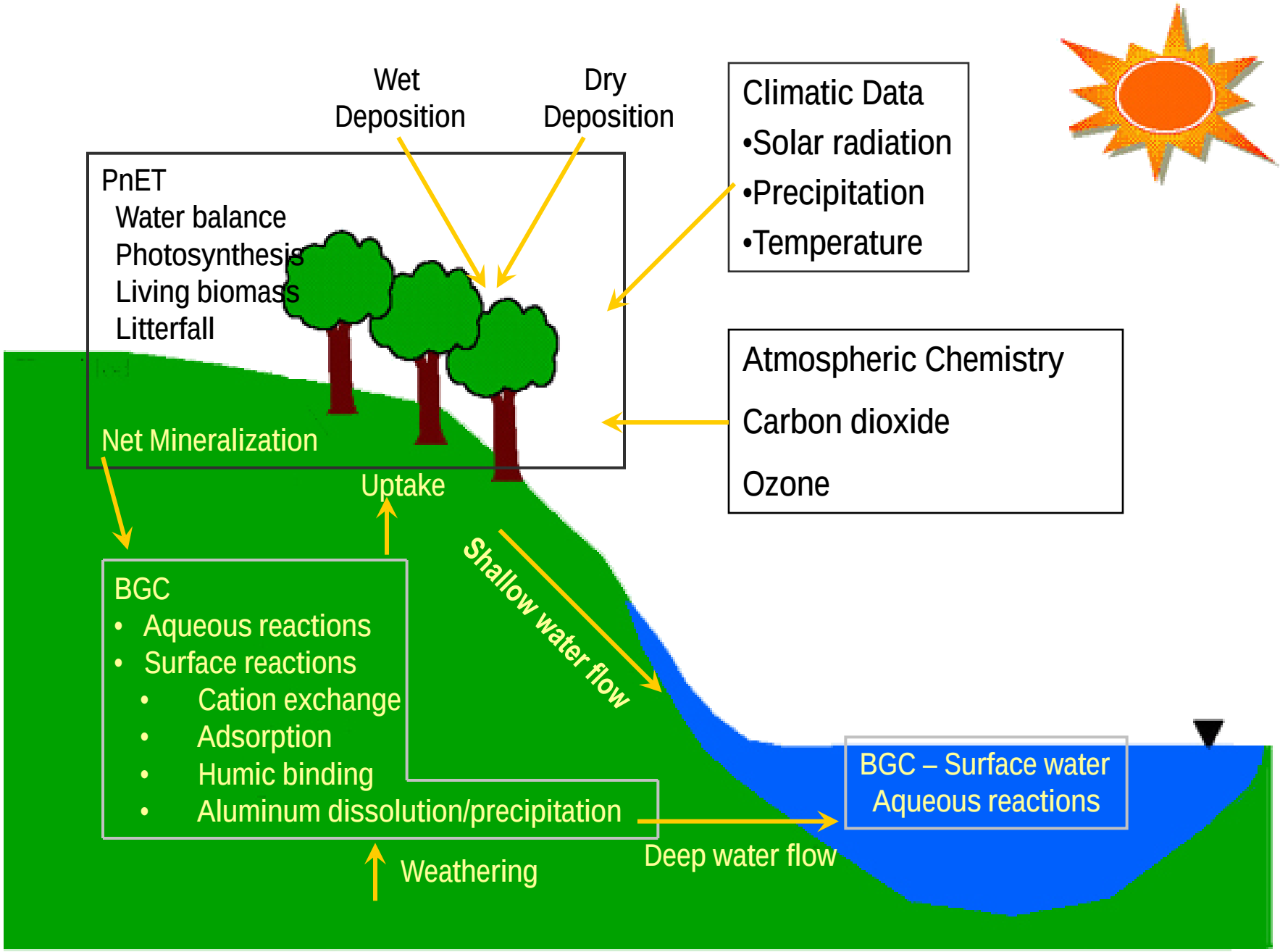
Acidification indicators

Media	Indicators	Criteria	Reference
Soil	**BS_e (%)**	**< 15%: mineral soil**	Cronan and Grigal, 1995; Cronan and Schofield, 1990; Palmer et al., 2004
Soil water	**Ca/Al**	**< 1.0: 50% risk** **< 0.5: 75% risk** **< 0.2: 100% risk**	Cronan and Grigal, 1995
	Bc/Al (20% growth decrease)	**< 1.2: 50% risk** **<0.6 :75% risk**	Sverdrup and Warfvinger 1993
Stream Water	**pH**	**< 6.0**	Baker et al. 1990
	ANC	**< 0, 20, 50, 100 µeq/L**	Driscoll et al., 2001; Van Sickle et al., 1996
	Al_i	**> 2 µmol/L**	Driscoll et al., 2001

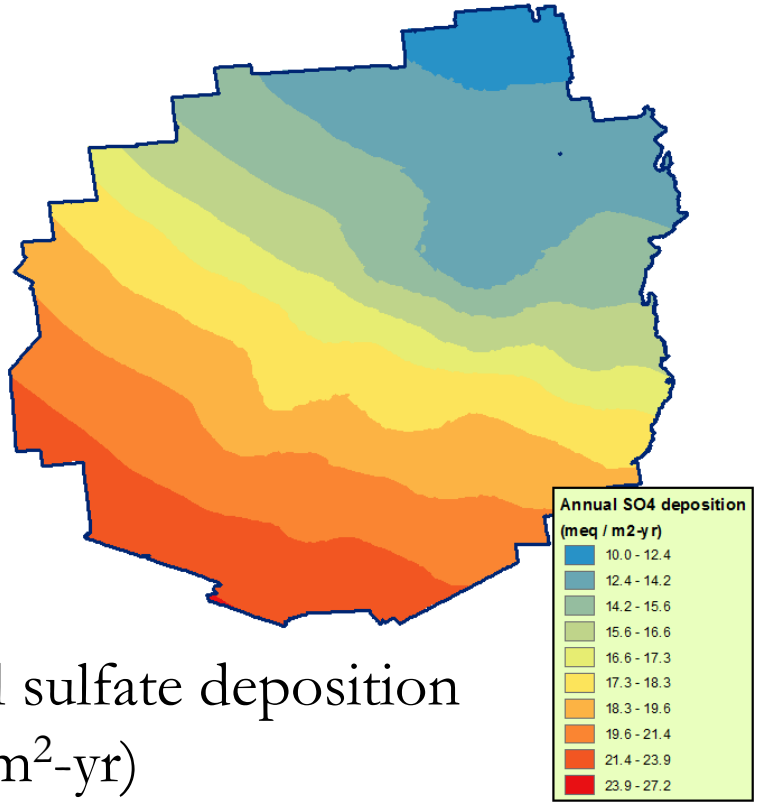


Arbutus Lake – 48.2 ha

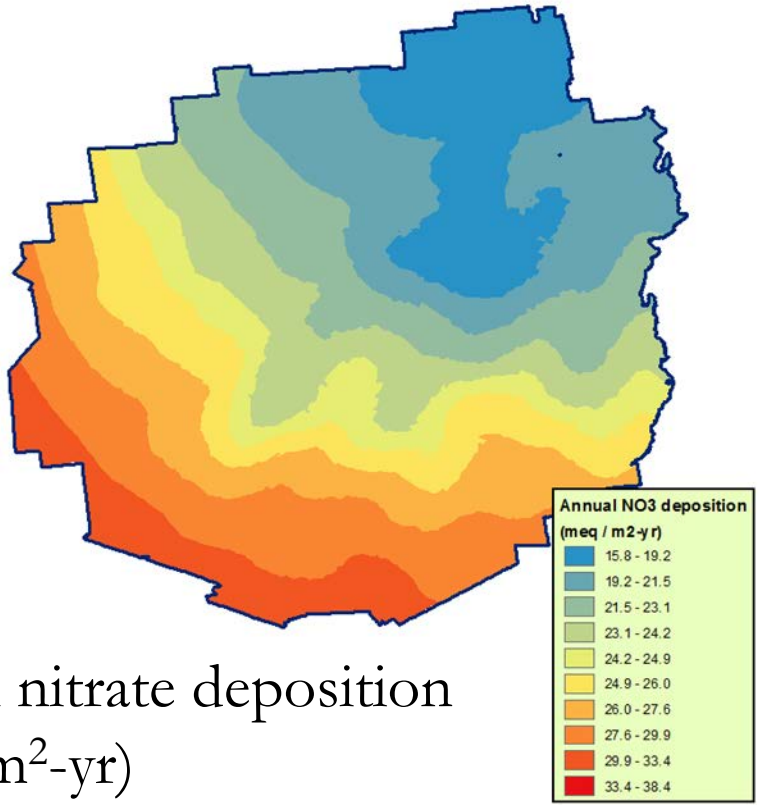

Impaired lakes in the Adirondacks due to elevated acidity
ALTM sites (13 lakes)
TMDL sites (128 lakes)
Adirondack Park
Vermont
New Hampshire
New York
Massachusetts
Connecticut
Pennsylvania
New Jersey
Maryland
Delaware
West Virginia
Virginia
N
0 25 50 100 150 200
Miles


Wet Deposition
Dry Deposition
Climatic Data
•Solar radiation
•Precipitation
•Temperature
PnET
Water balance
Photosynthesis
Living biomass
Litterfall
Net Mineralization
Uptake
Atmospheric Chemistry
Carbon dioxide
Ozone
Shallow water flow
BGC
• Aqueous reactions
• Surface reactions
• Cation exchange
• Adsorption
• Humic binding
• Aluminum dissolution/precipitation
BGC – Surface water
Aqueous reactions
Deep water flow
Weathering

Spatial models for deposition

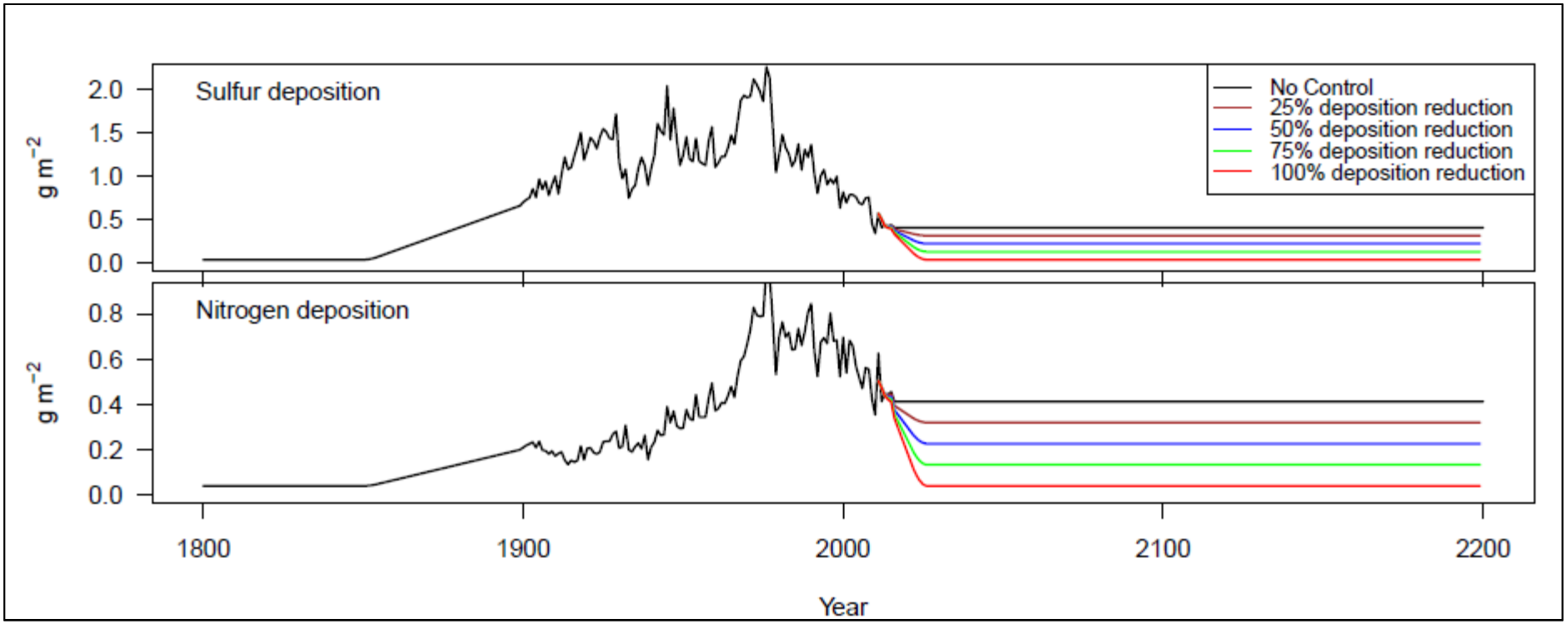


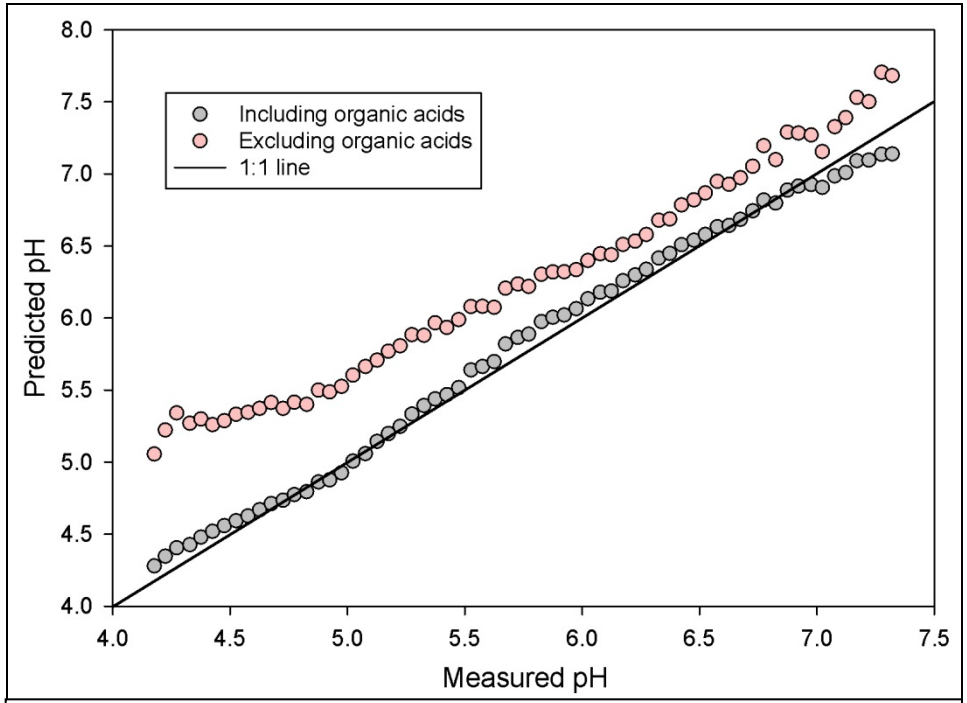
Annual sulfate deposition (meq/m^2-yr)

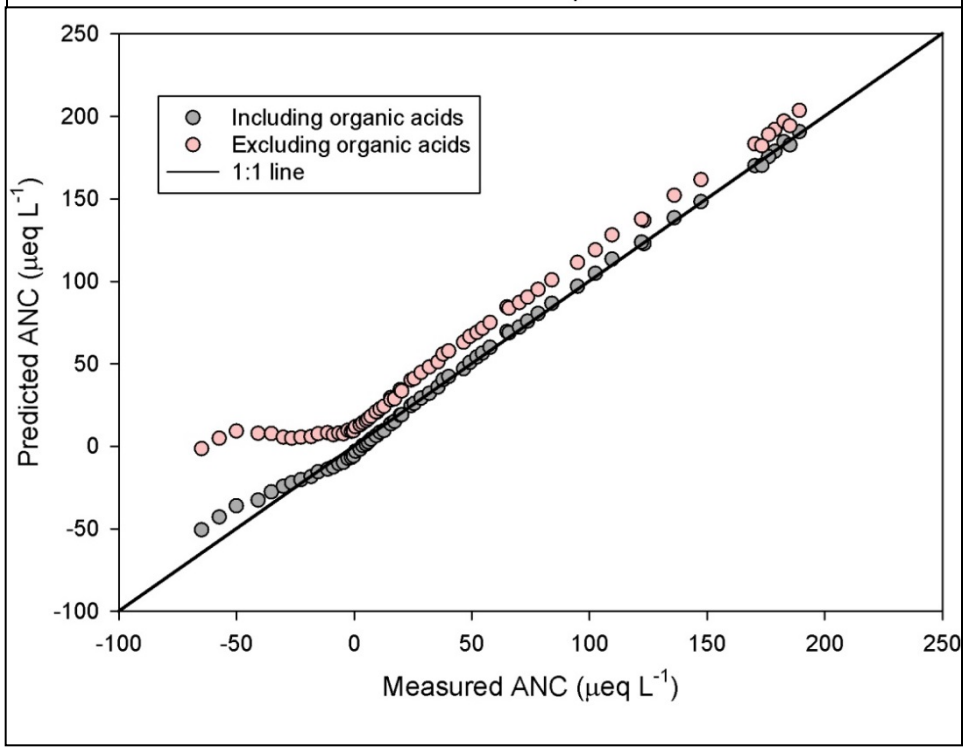


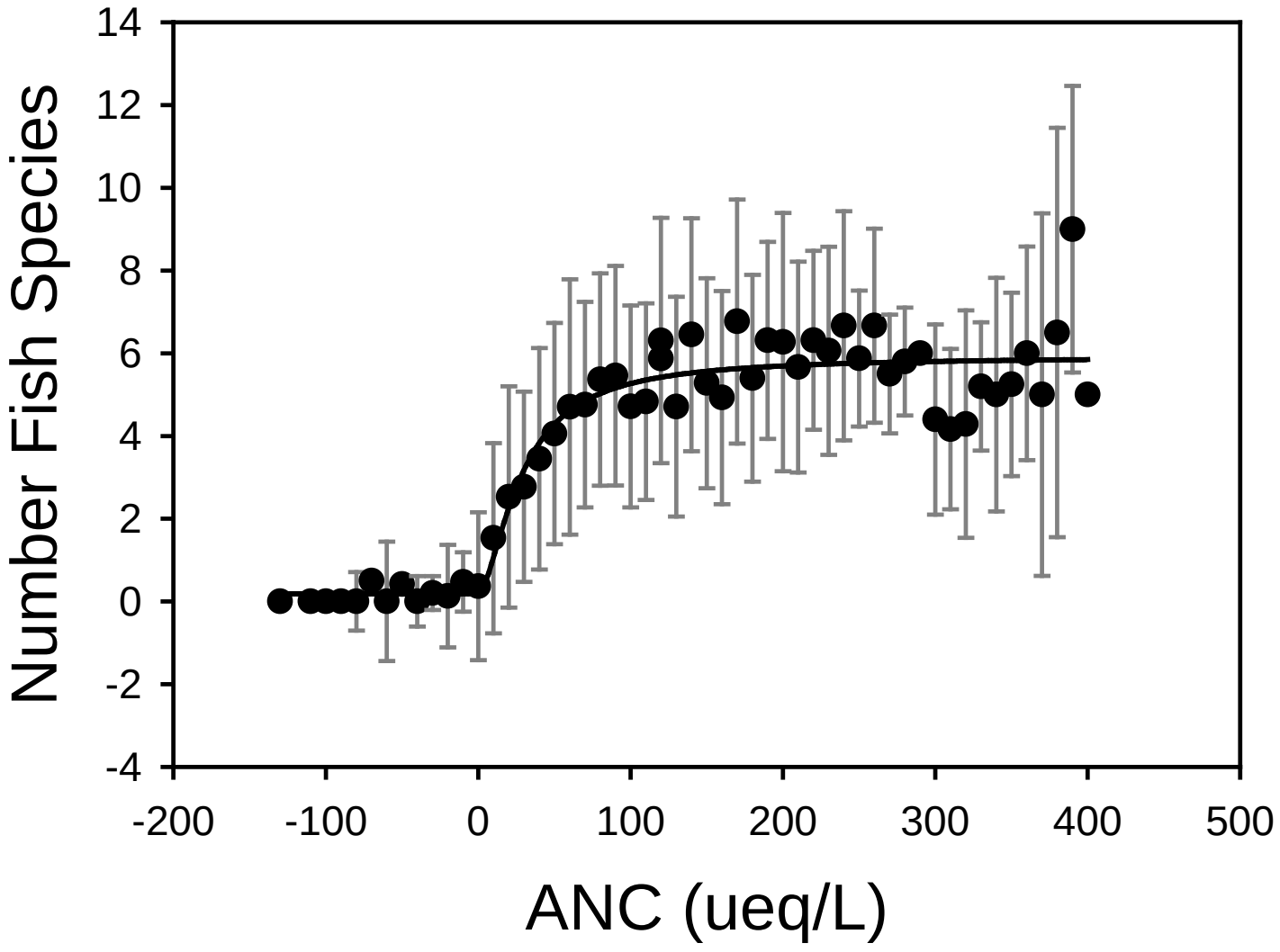
Annual nitrate deposition (meq/m^2-yr)

Hindcast and Forecast Scenarios




Including organic acids
Excluding organic acids
1:1 line
Predicted pH
Measured pH
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5

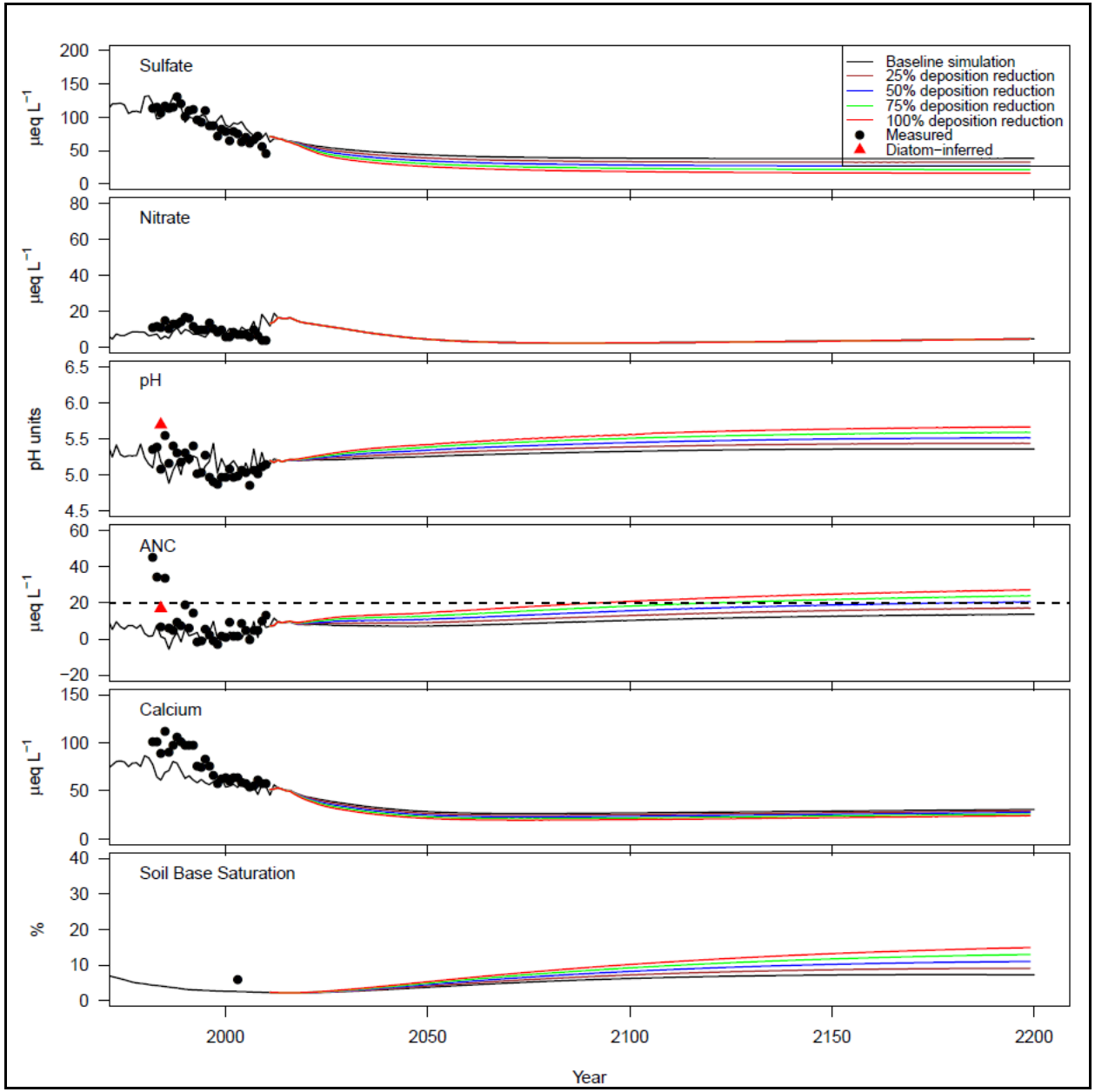

Including organic acids
Excluding organic acids
1:1 line
Predicted ANC (μeq L-1)
Measured ANC (μeq L-1)
250
200
150
100
50
0
-50
-100
-100
-50
0
50
100
150
200
250


Number Fish Species
14
12
10
8
6
4
2
0
-2
-4
-200
-100
0
100
200
300
400
500
ANC (ueq/L)

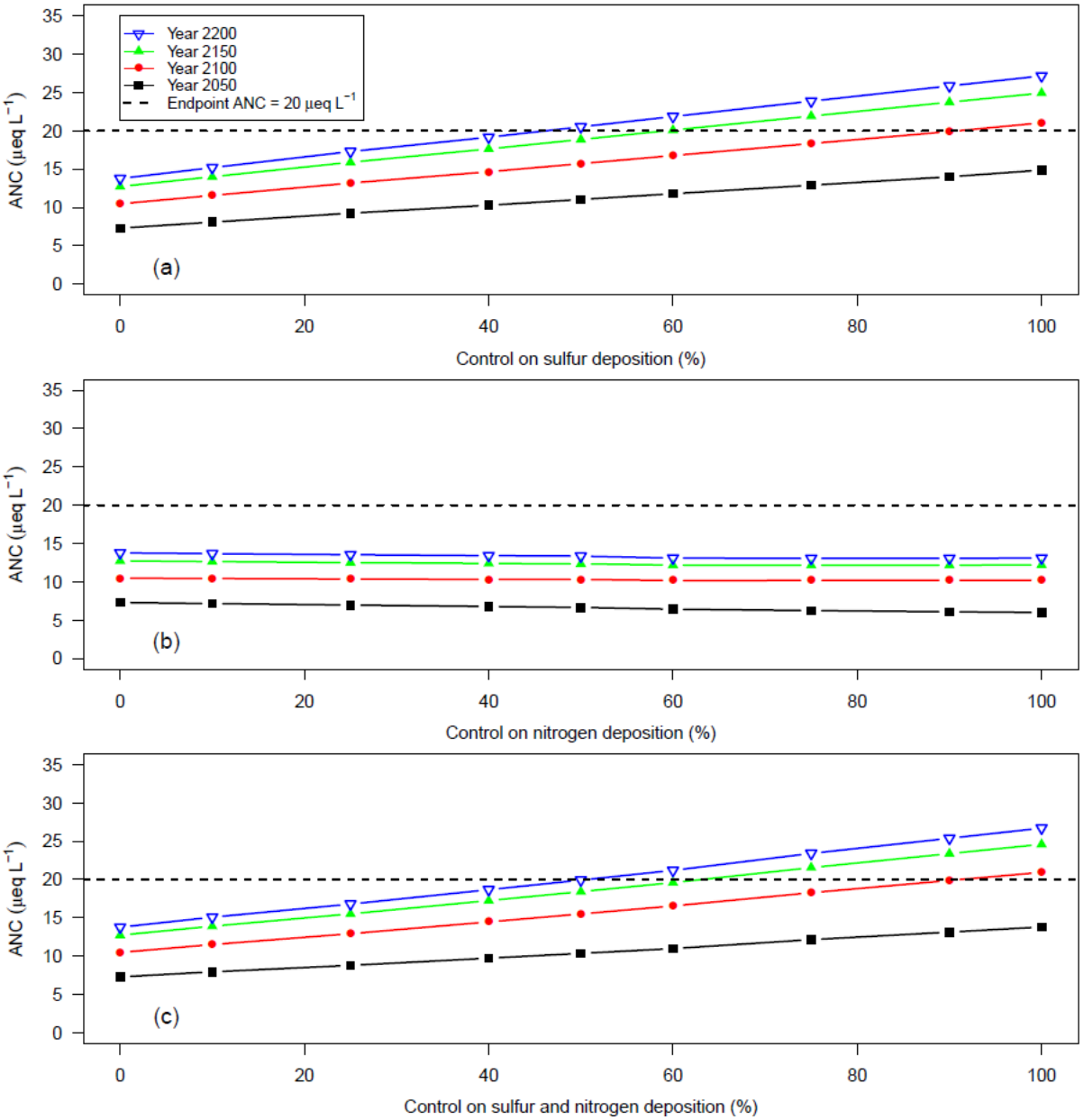
Future Projections

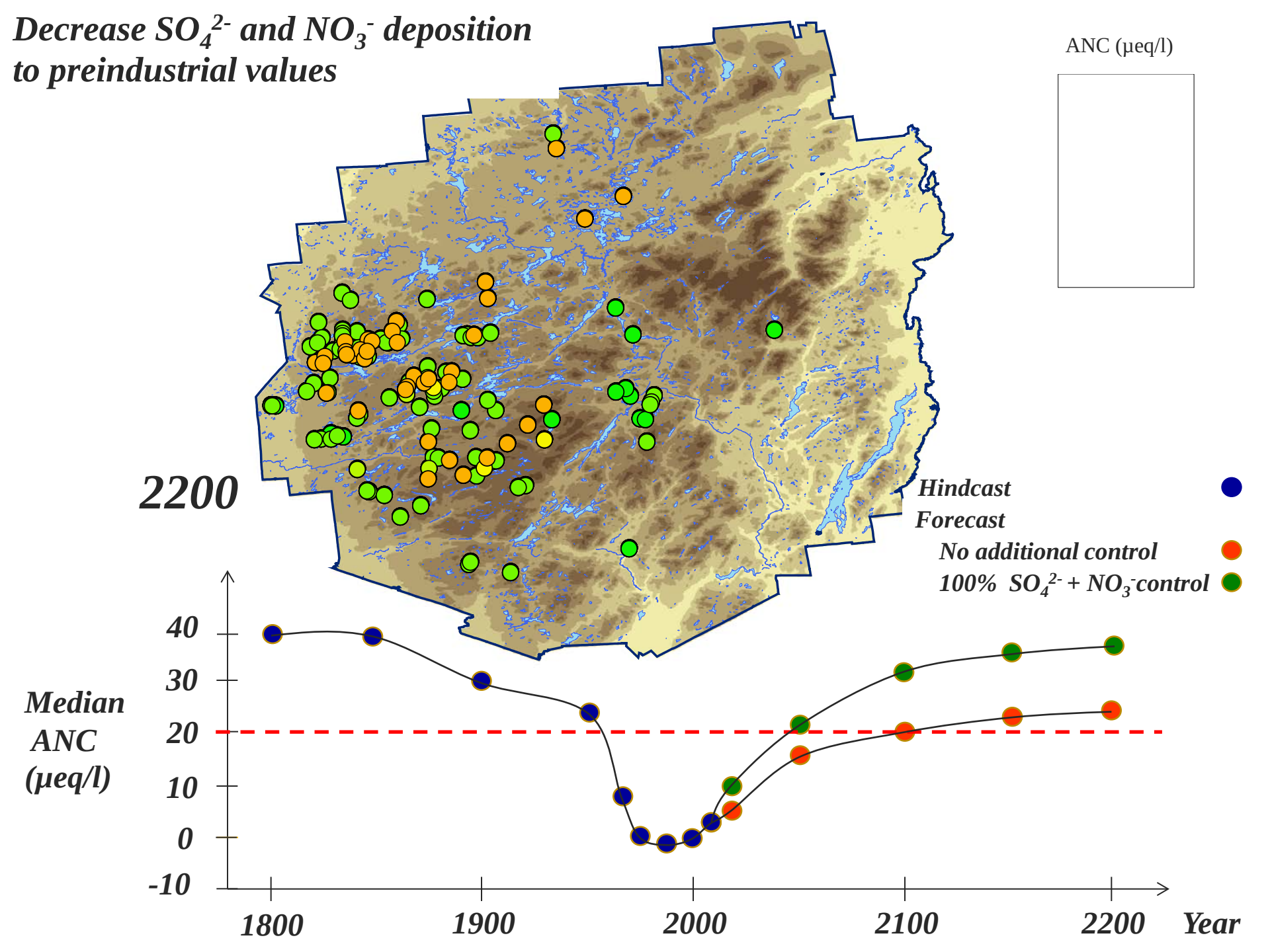
West Pond

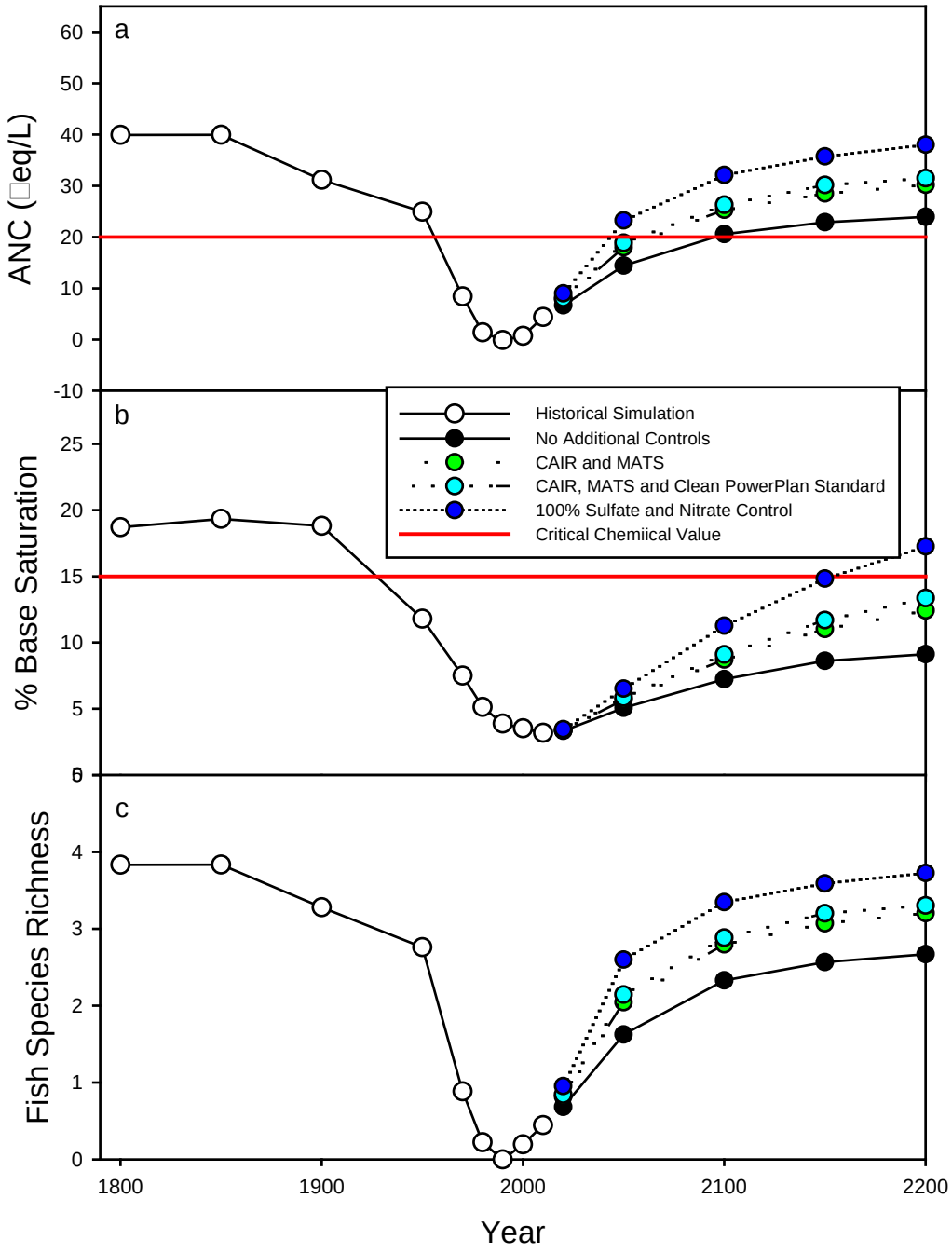
Forecast



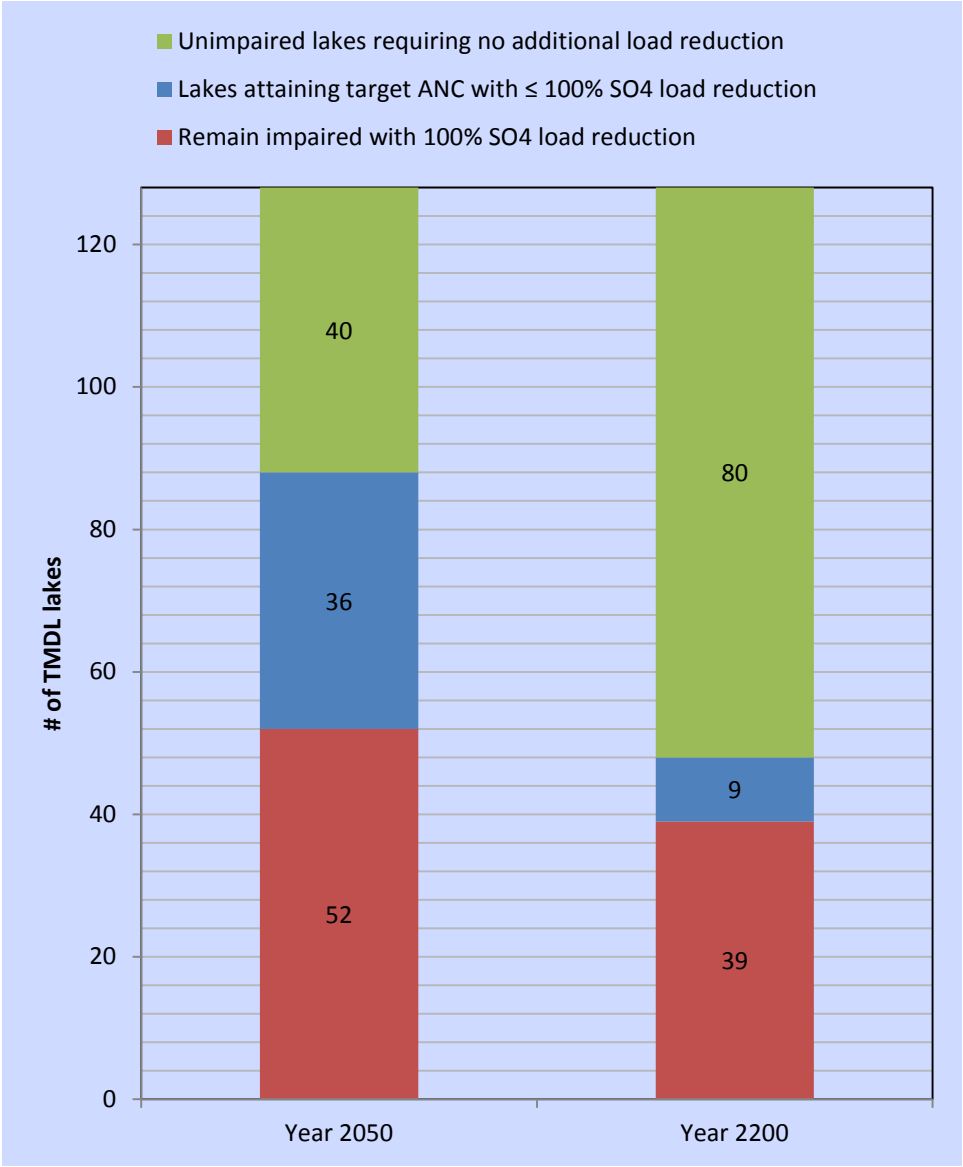
West Pond ANC in response to
(a) Sulfur control
(b) Nitrogen control
(c) Sulfur and nitrogen control




Decrease SO_4^{2-} and NO_3^- deposition to preindustrial values
ANC (µeq/l)
2200
Hindcast
Forecast
No additional control
100% SO_4^{2-} + NO_3^-control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year


a
b
c
ANC (□eq/L)
% Base Saturation
Fish Species Richness
Year
60
50
40
30
20
10
0
-10
25
15
5
4
3
2
1
1800
1900
2000
2100
2200
Historical Simulation
No Additional Controls
CAIR and MATS
CAIR, MATS and Clean PowerPlan Standard
100% Sulfate and Nitrate Control
Critical Chemiical Value

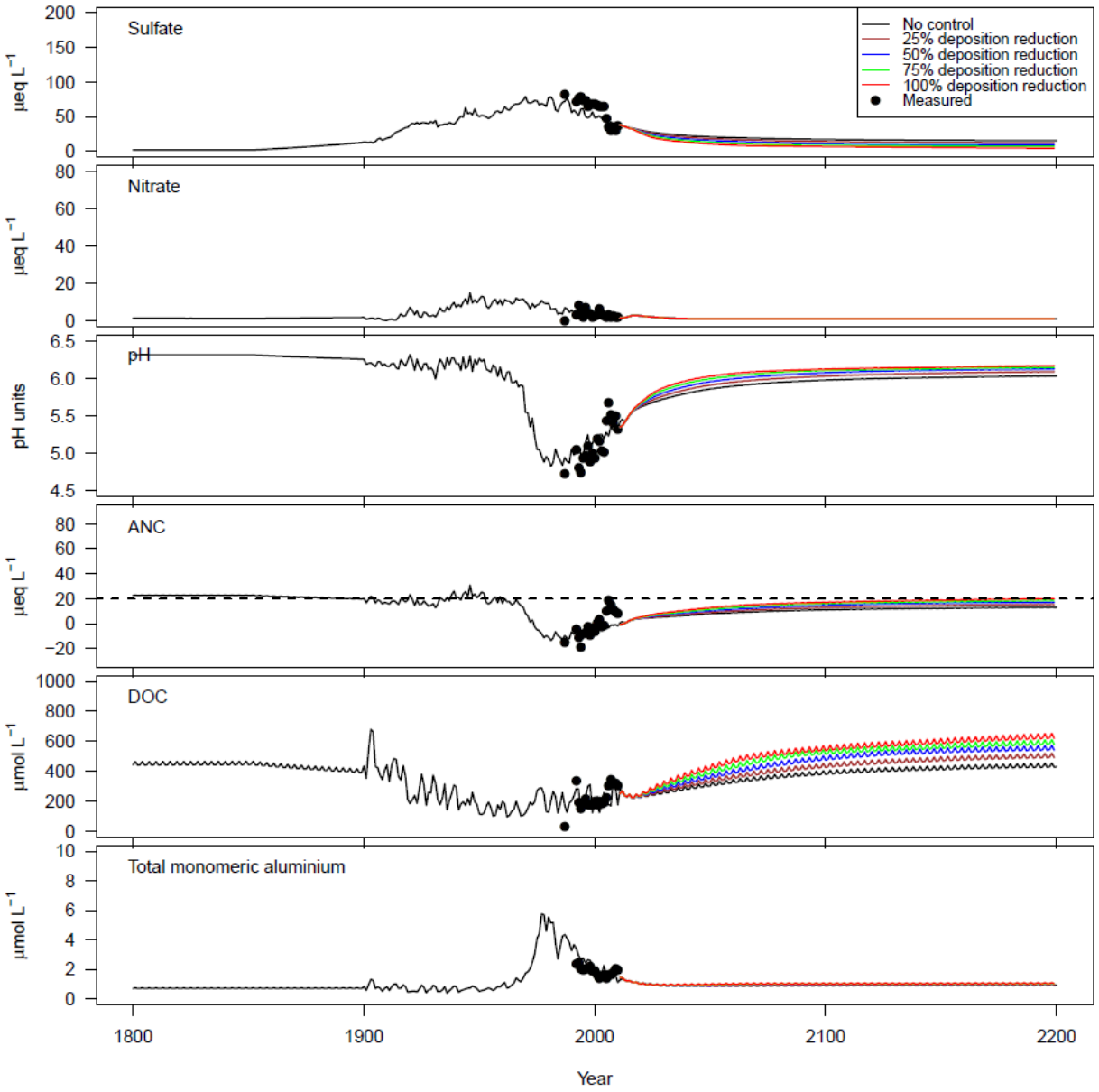
Number of lakes in three categories: not recoverable, recoverable and unimpaired lakes



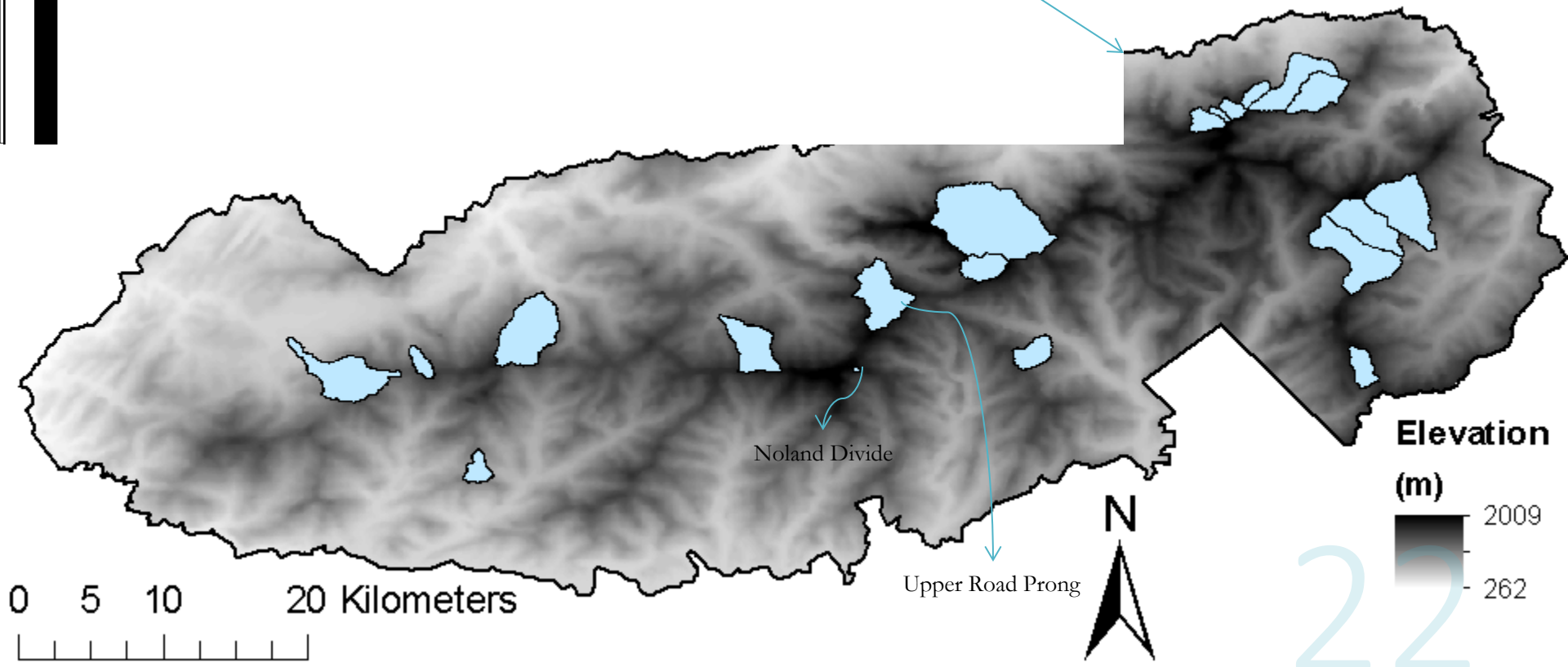
Endpoint 20 (µeq/l)

Carry Pond

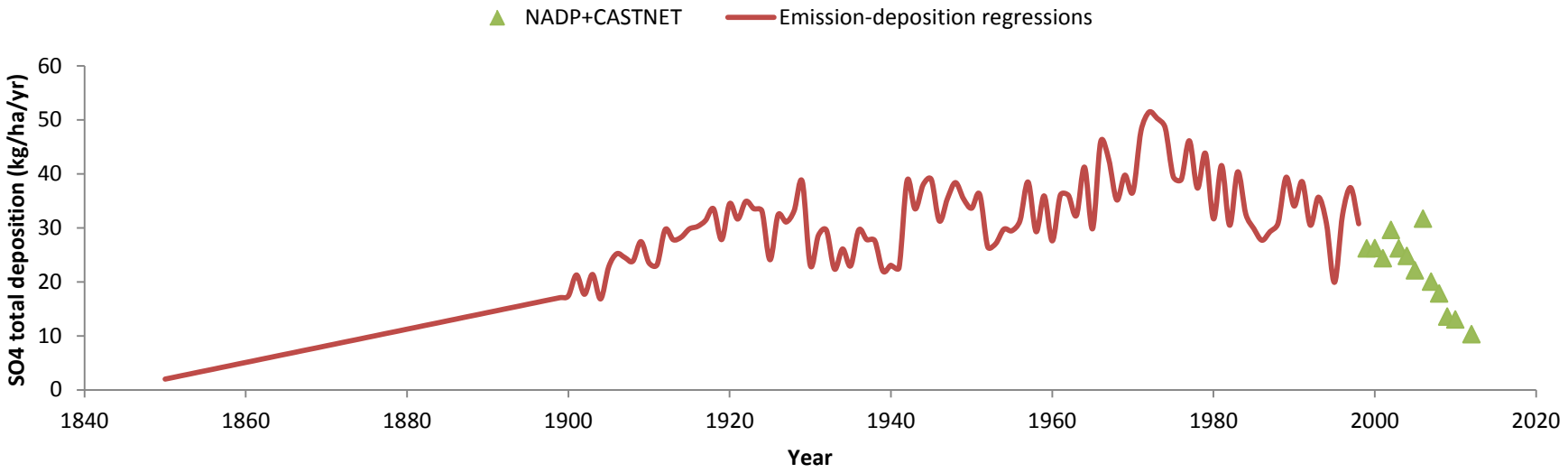
Simulation of Carry Pond with DOC algorithm

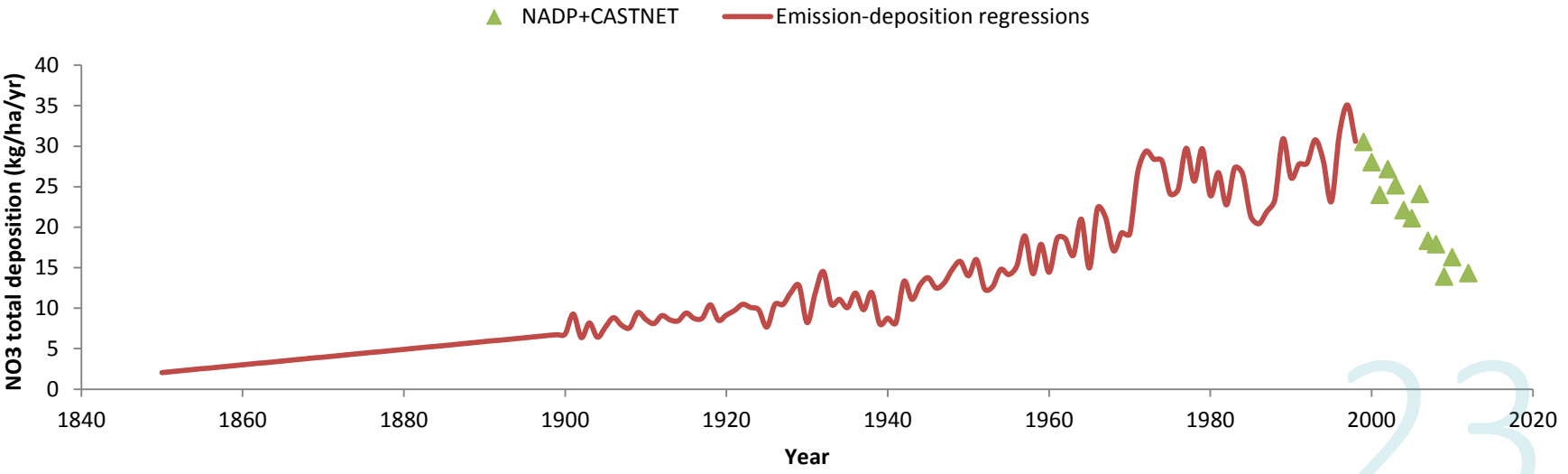


Location of Smoky Mountains and 24 study watersheds

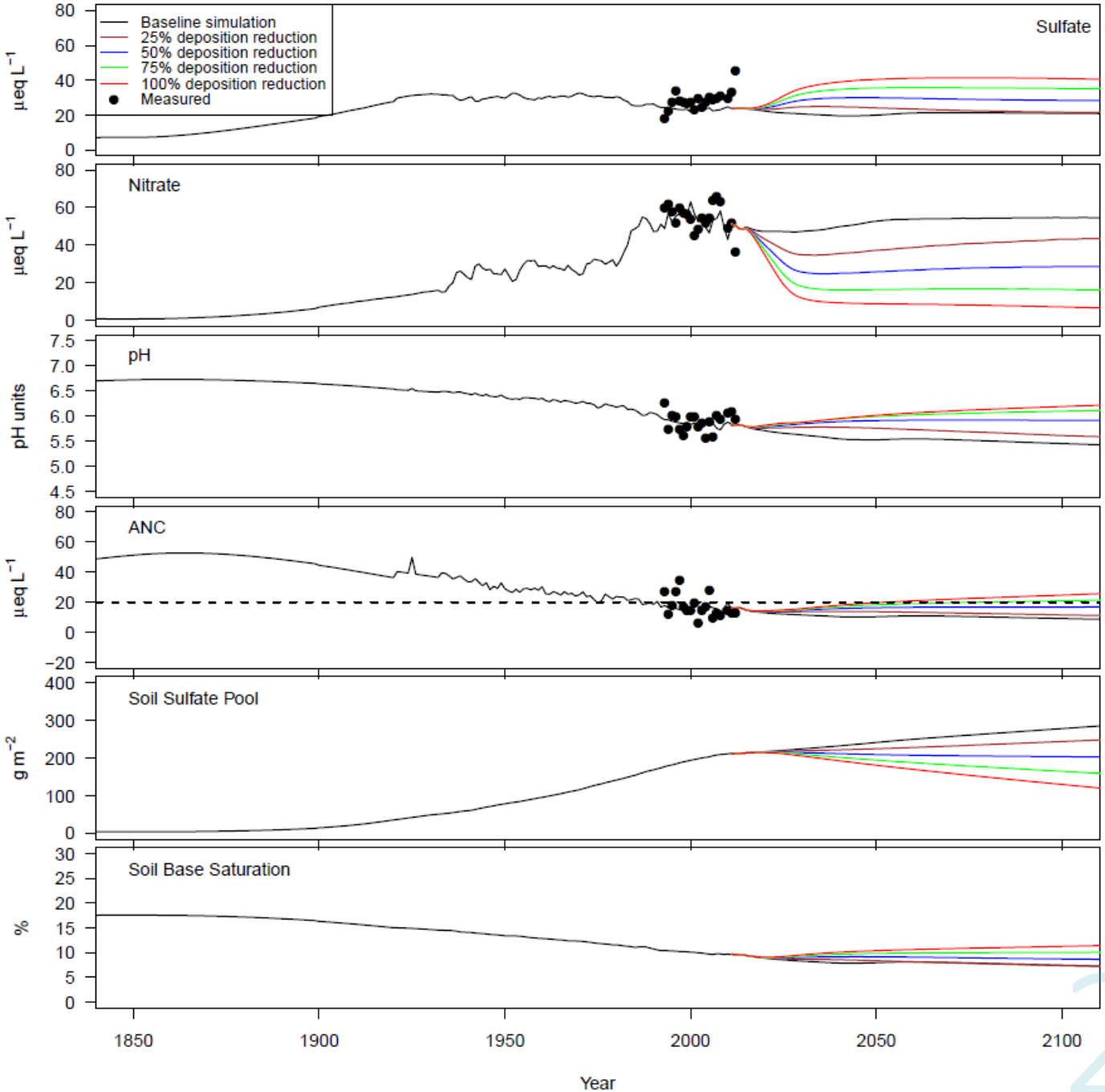


Acid deposition in Smoky Mountains

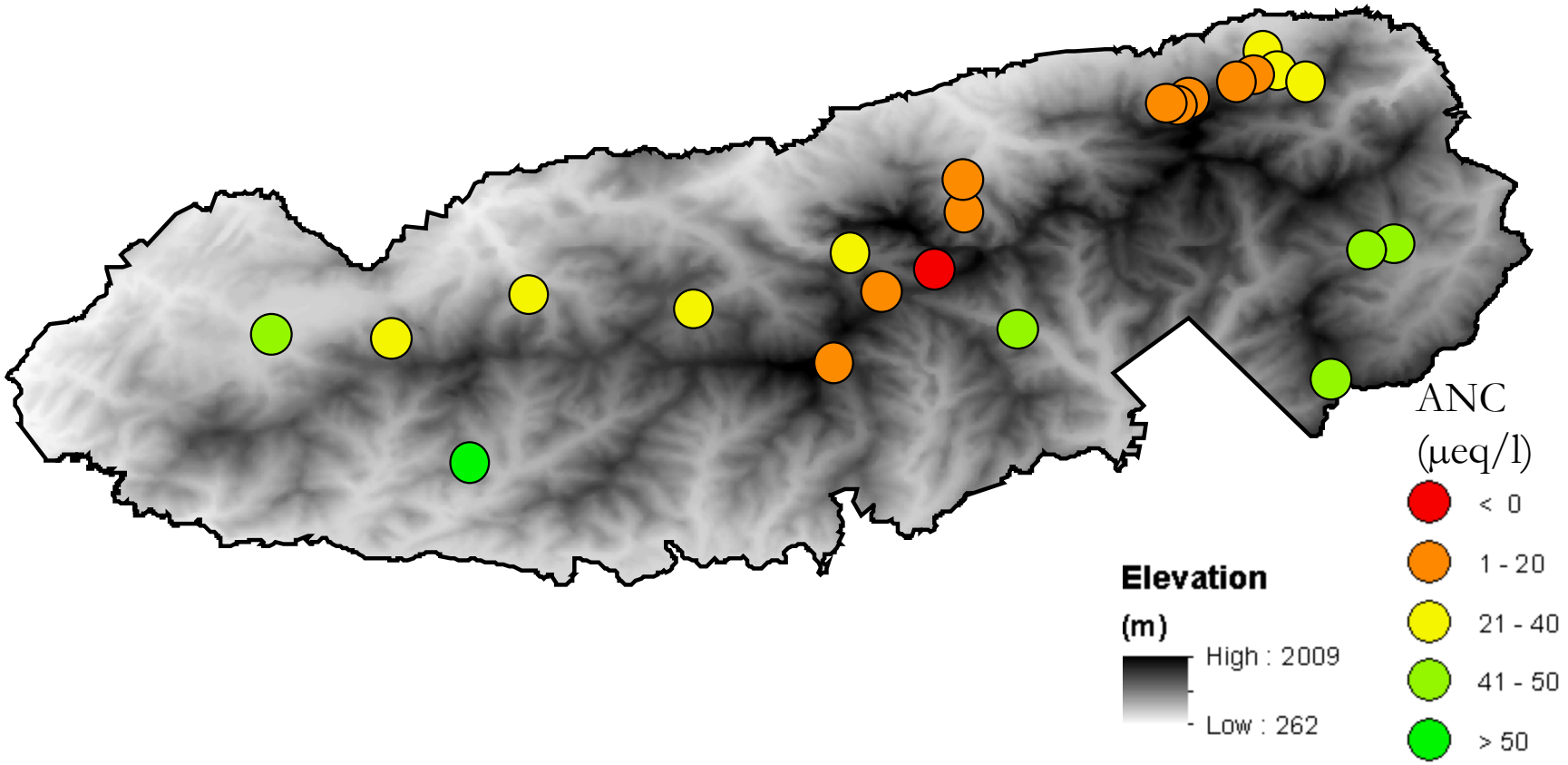




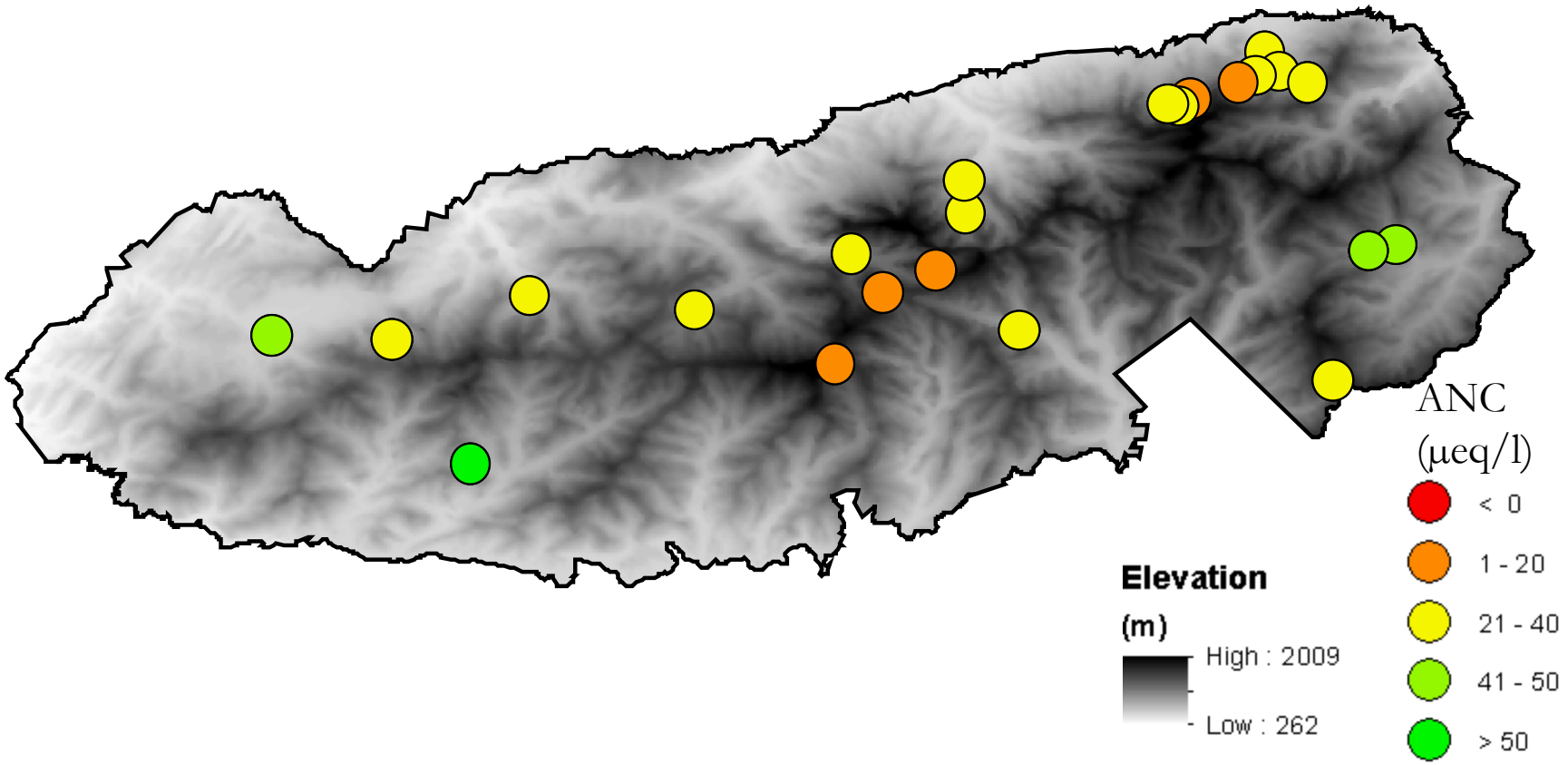
Model Projection for Upper Road Prong Stream



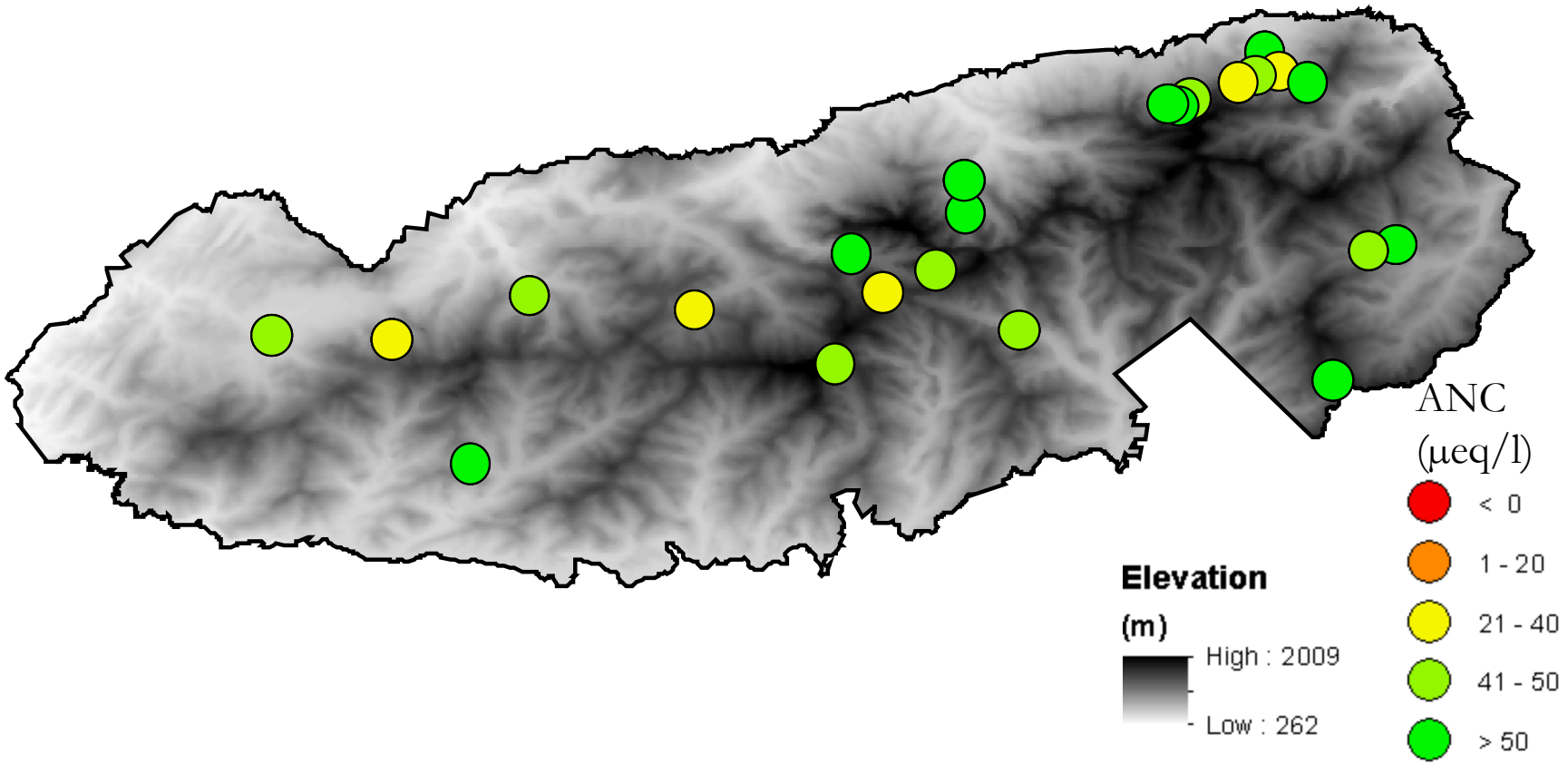
Measured ANC



Predicted ANC in 2050 with 100% control on emission



Predicted ANC in 2200 with 100% control on emission



Key messages

- Critical loads/ dynamic critical loads can be an effective approach to guide protection of ecosystems from air pollution
- Application of dynamic models can be provide important insights on ecosystem recovery from atmospheric deposition
- Additional ecosystem recovery will follow additional emission reductions, but the rate of recovery will be slow and pre-industrial conditions may not be achievable
- Examination of CLs across diverse ecosystems is necessary to establish a national program of air quality management to protect ecosystems

Future research suggestions

- Testing and application of organic acid algorithms
- Testing and application of algorithms for biological indicators
- Examination of CLs for multiple resources (e.g., forest, aquatic)
- Examine the effects of reduced N deposition
- Develop approaches for mercury CLs
- Better understanding the linkages between atmospheric deposition and climate change

Acknowledgements

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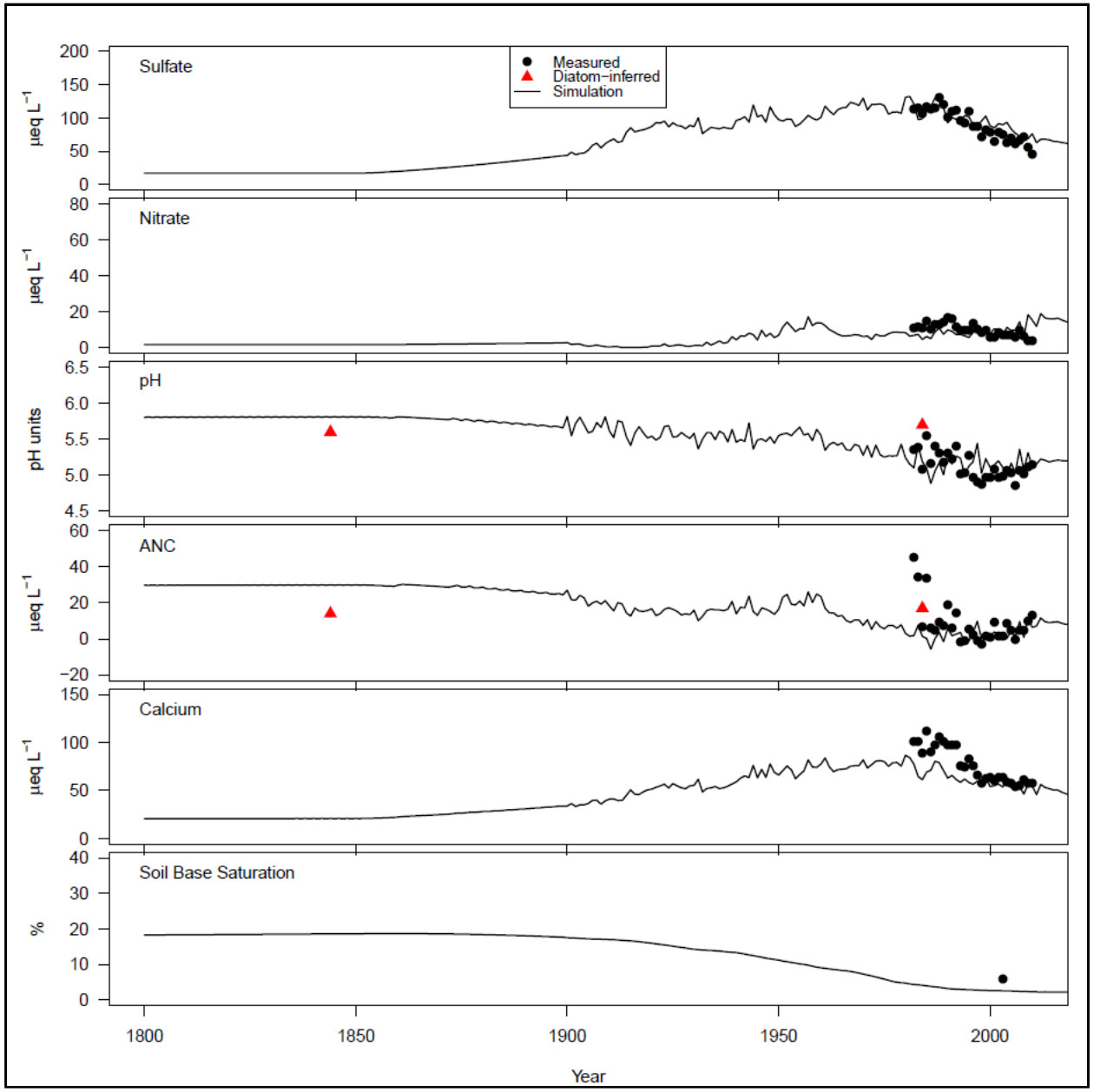
Carl Heilman

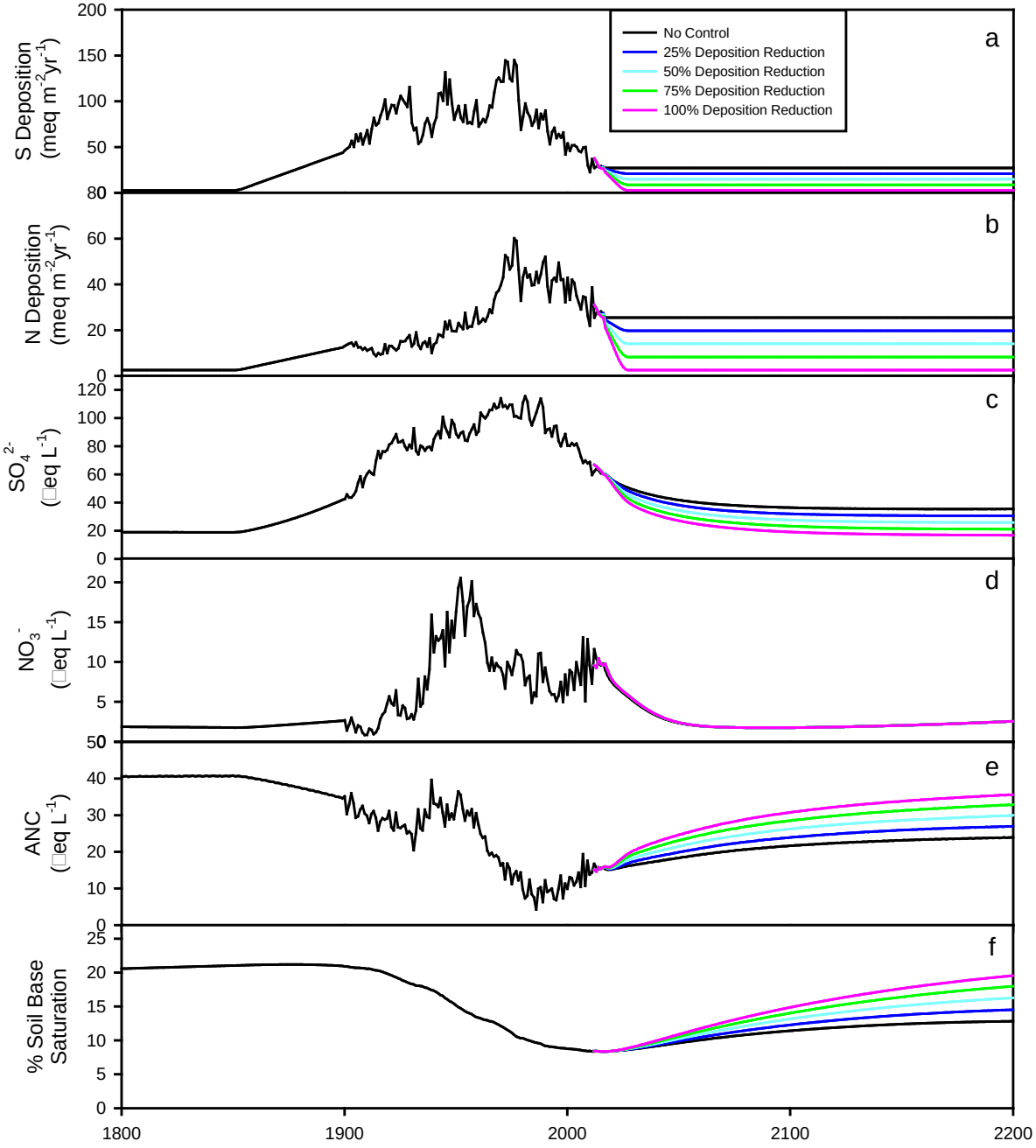
West Pond

Hindcast



Model simulated median values for lake chemistry and soil %BS for pre-industrial conditions and near-peak acidification measured values at 128 impaired lakes.

	Pre-industrial conditions (1850)	Current conditions (2000s)
SO_4^{2-} (μeq/L)	17.3	82.5
NO_3^- (μeq/L)	1.6	0.5
ANC (μeq/L)	40	0.0
pH	6.4	5.1
Soil %BS	18.6	7.9


No Control
25% Deposition Reduction
50% Deposition Reduction
75% Deposition Reduction
100% Deposition Reduction
a
S Deposition (meq m-2yr-1)
b
N Deposition (meq m-2yr-1)
c
SO4 2- (eq L-1)
d
NO3 - (eq L-1)
e
ANC (eq L-1)
f
% Soil Base Saturation
1800
1900
2000
2100
2200