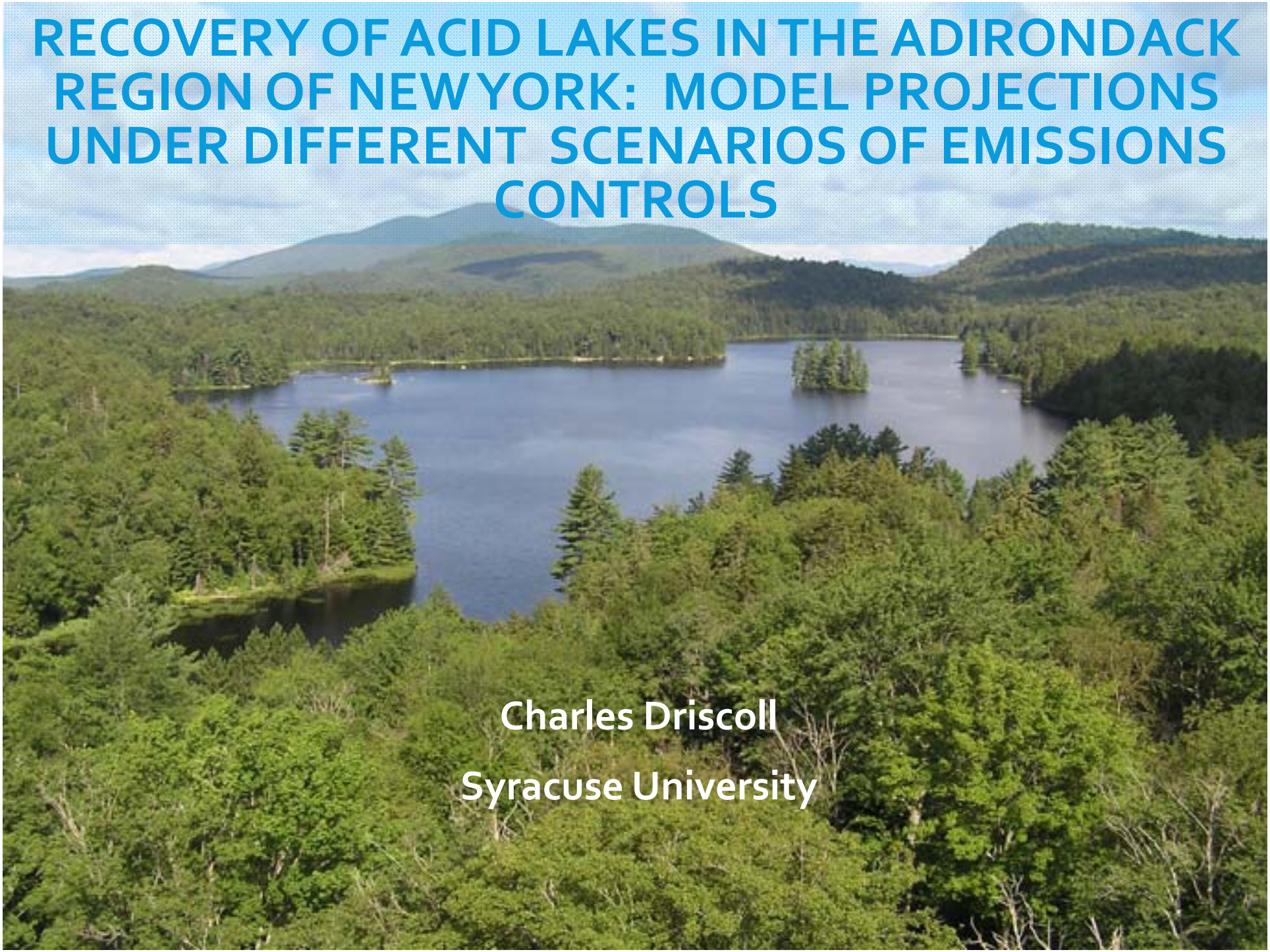
RECOVERY OF ACID LAKES IN THE ADIRONDACK REGION OF NEW YORK: MODEL PROJECTIONS UNDER DIFFERENT SCENARIOS OF EMISSIONS CONTROLS

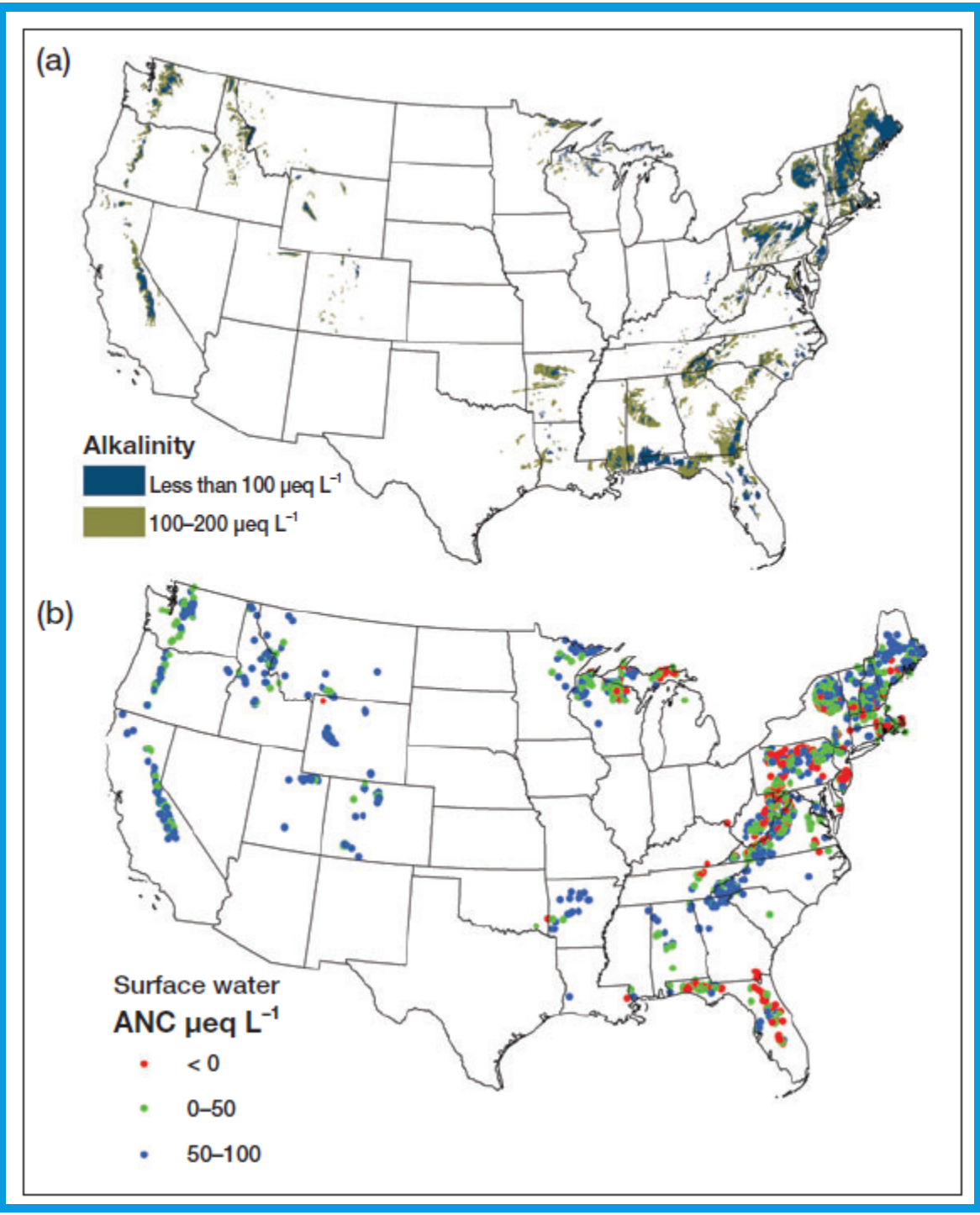


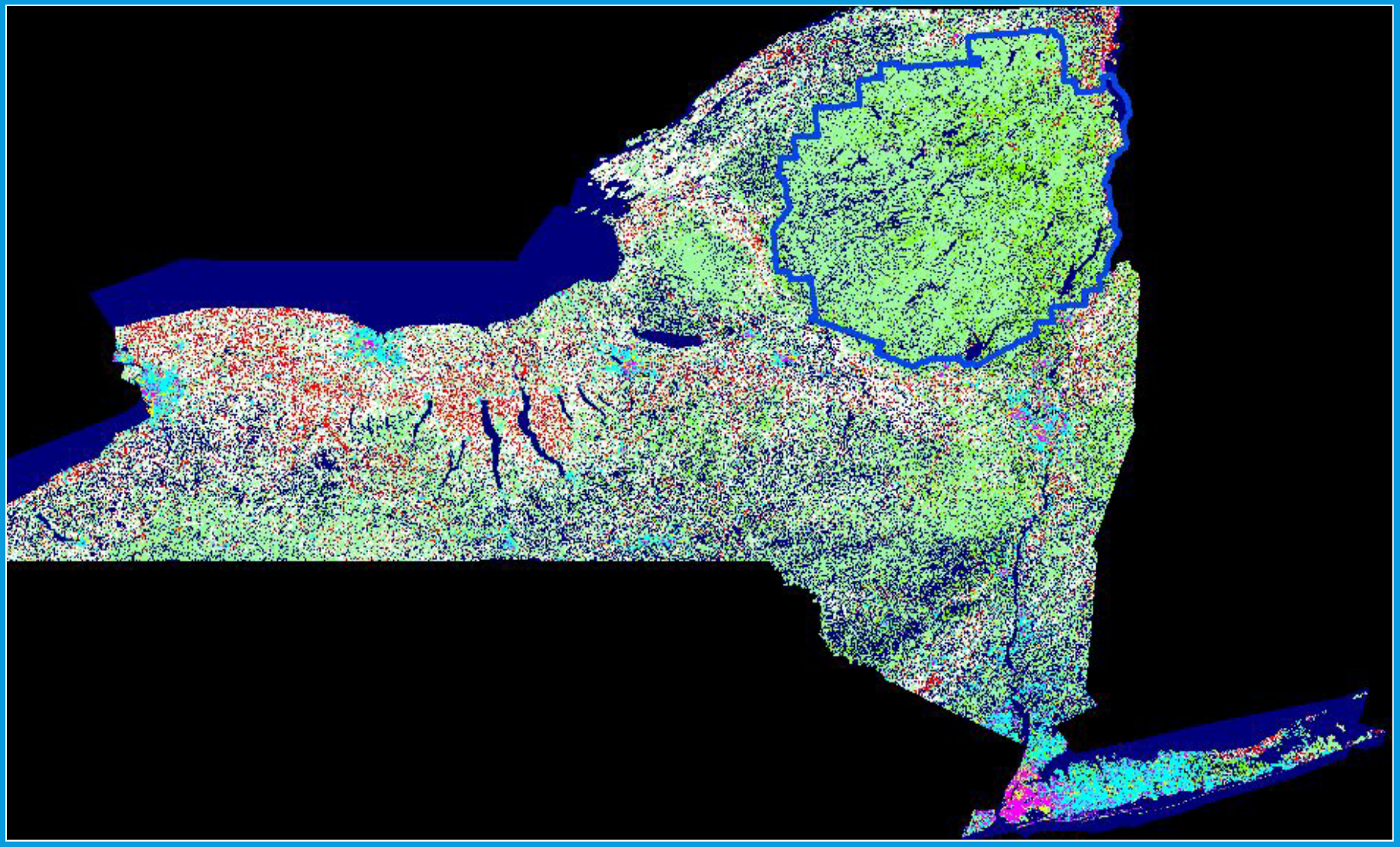
Charles Driscoll

Syracuse University

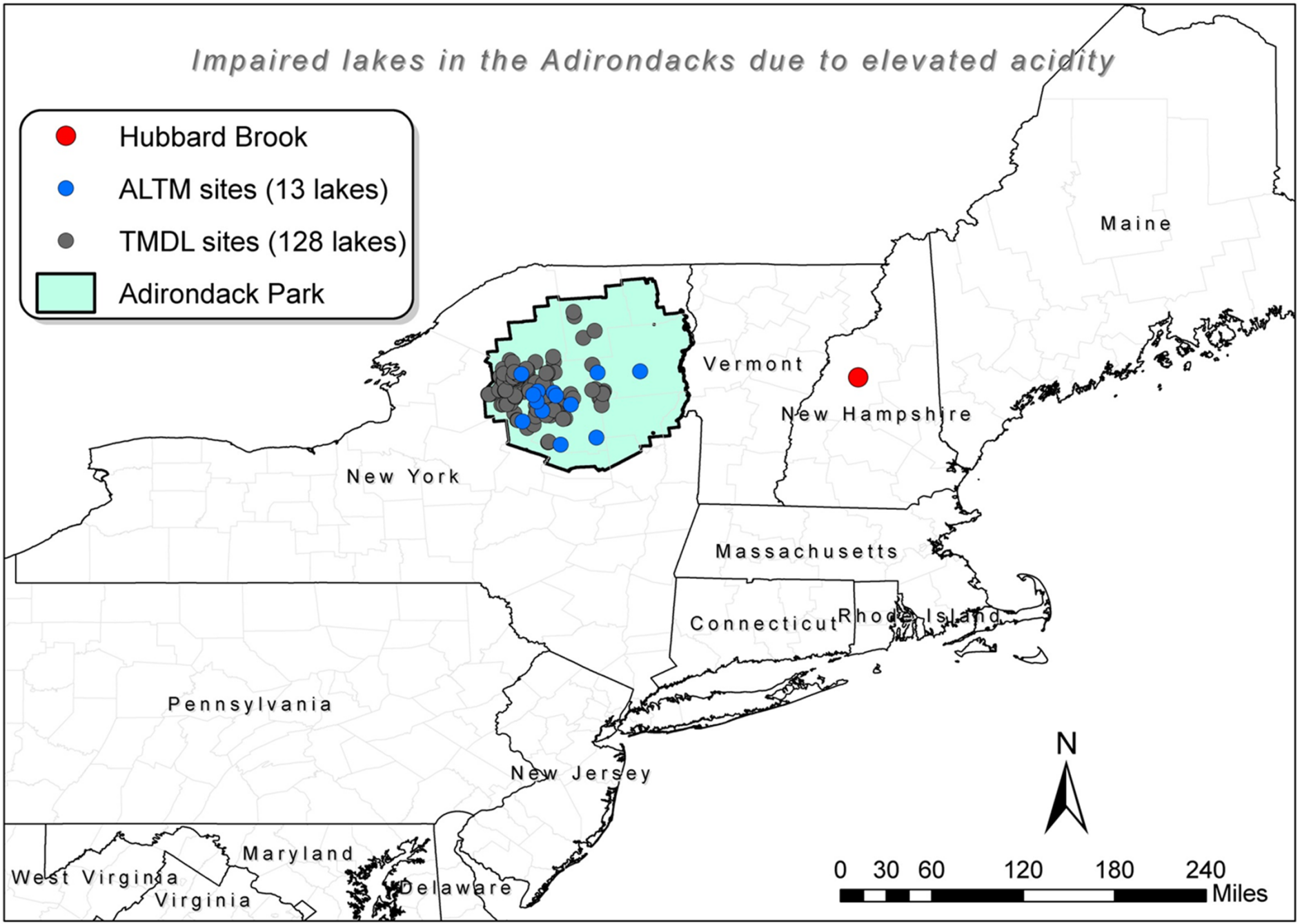
OUTLINE

- Background: Acid rain and the Adirondacks
- Acid rain and lake trends: recent and historical
- Total Maximum Daily Loads (TMDLs) for acid-impaired lakes
- Future initiatives
- Final thoughts


(a)
Alkalinity
Less than 100 µeq L⁻¹
100–200 µeq L⁻¹
(b)
Surface water
ANC µeq L⁻¹
< 0
0–50
50–100

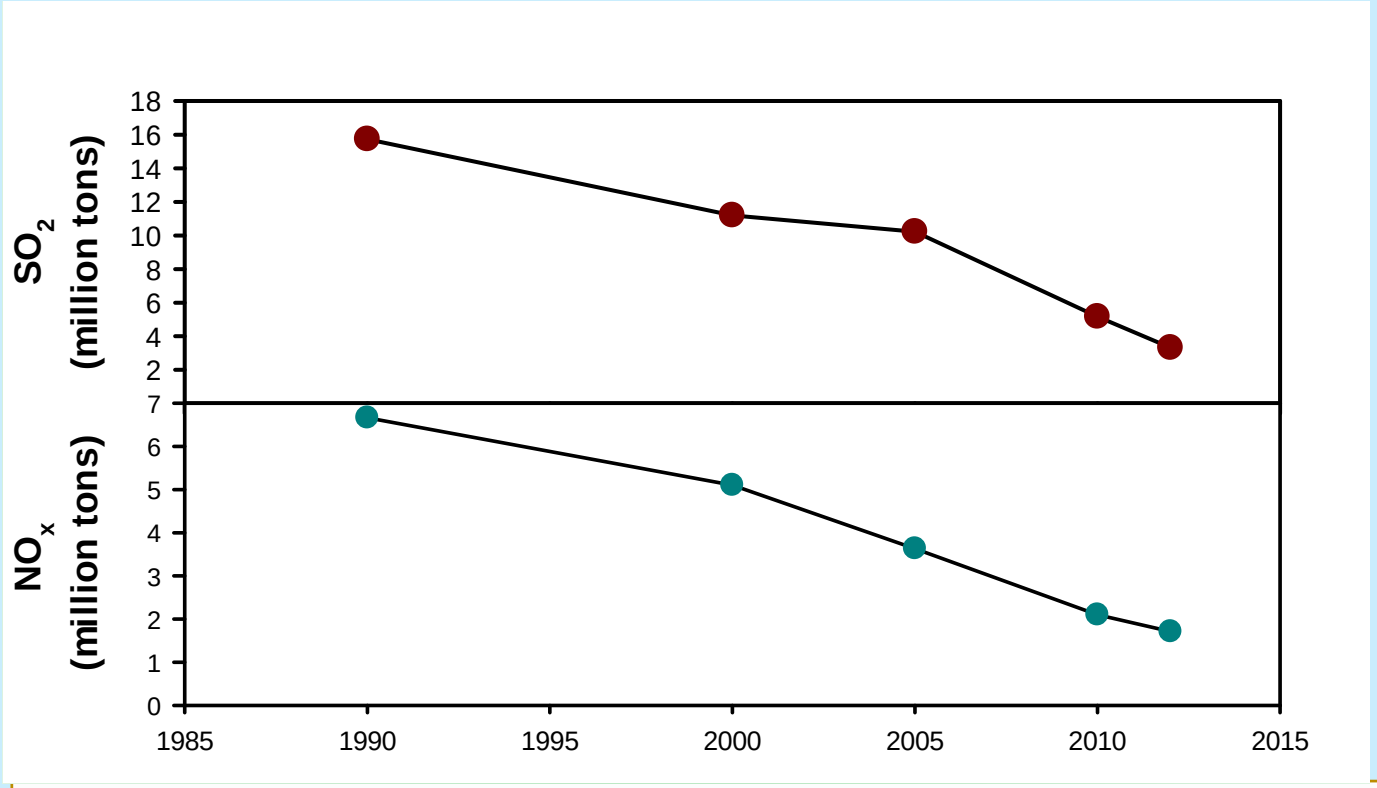


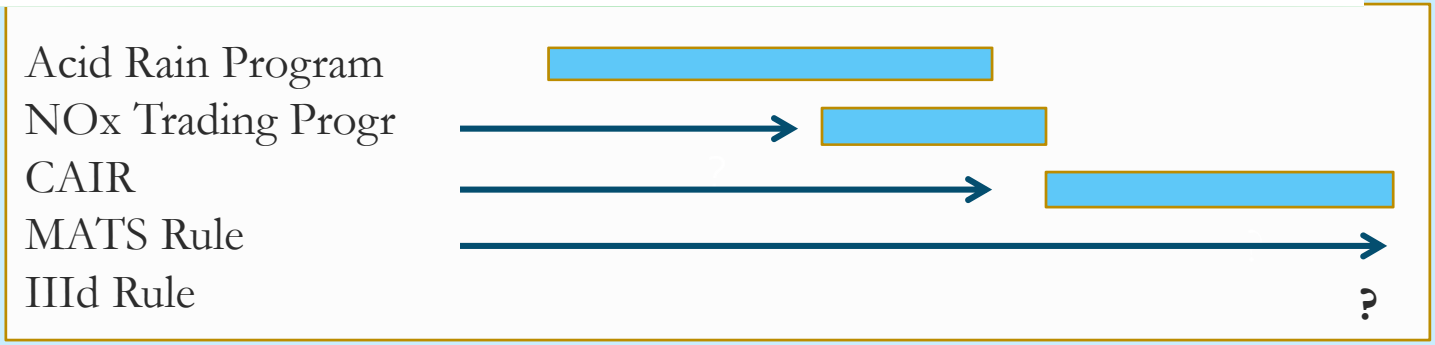
ARBUTUS LAKE – 48.2 HA

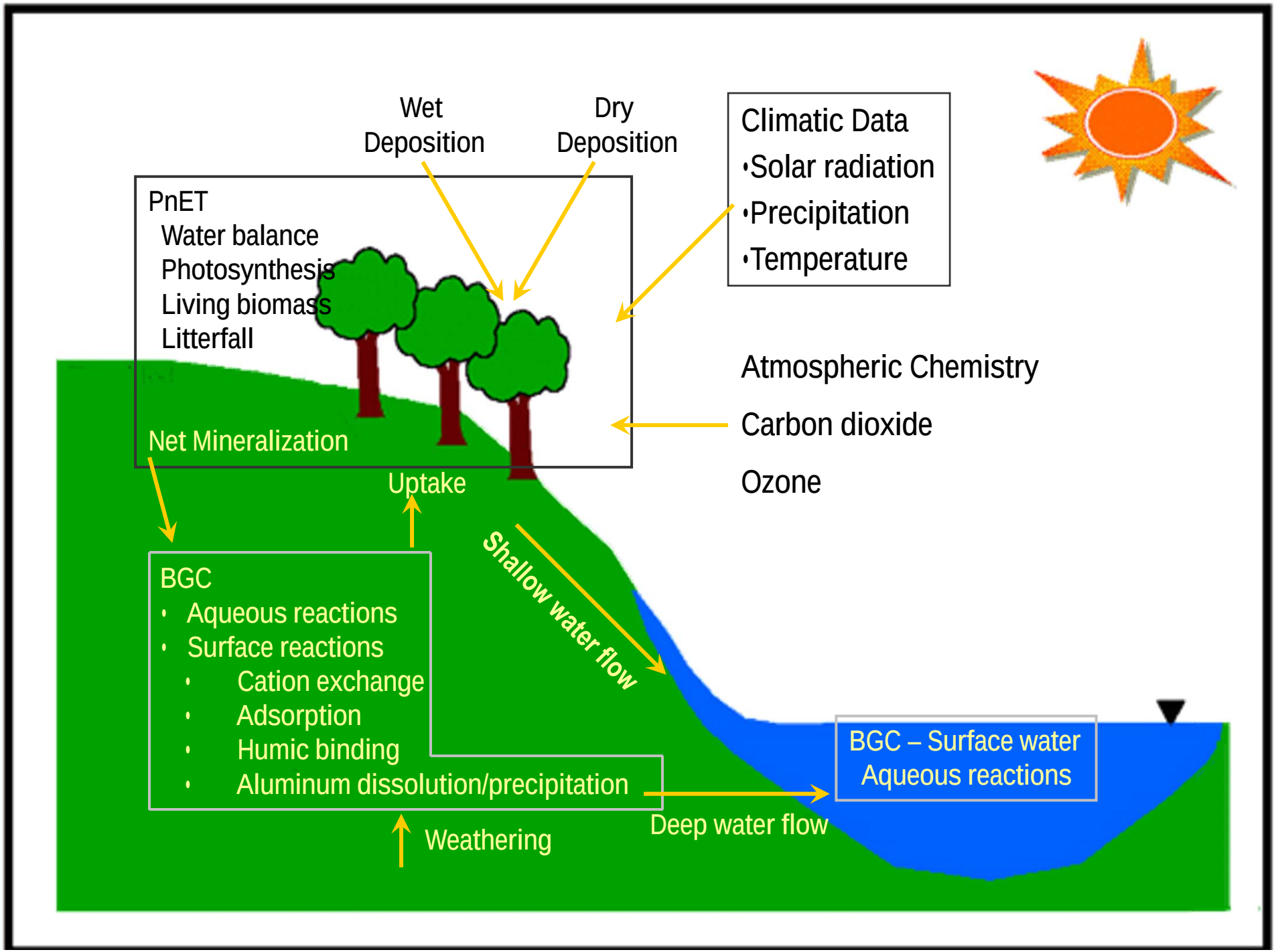

Impaired lakes in the Adirondacks due to elevated acidity
Hubbard Brook
ALTM sites (13 lakes)
TMDL sites (128 lakes)
Adirondack Park
Maine
Vermont
New Hampshire
New York
Massachusetts
Connecticut
Rhode Island
Pennsylvania
New Jersey
Maryland
West Virginia
Virginia
Delaware
N
0 30 60 120 180 240
Miles

OBJECTIVES

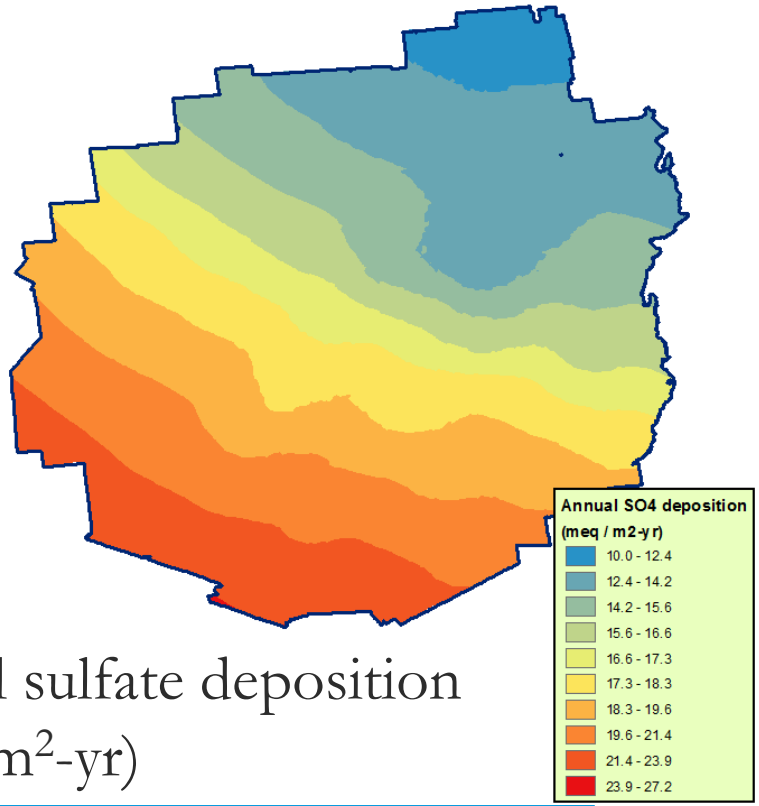
- Evaluate response and potential recovery of acid impaired Adirondack lake watersheds to past and future changes in acid deposition.
- Inform New York State in its development of a TMDL to alleviate acid impaired lakes.


SO2 (million tons)
18
16
14
12
10
8
6
4
2
NOx (million tons)
7
6
5
4
3
2
1
0
1985
1990
1995
2000
2005
2010
2015

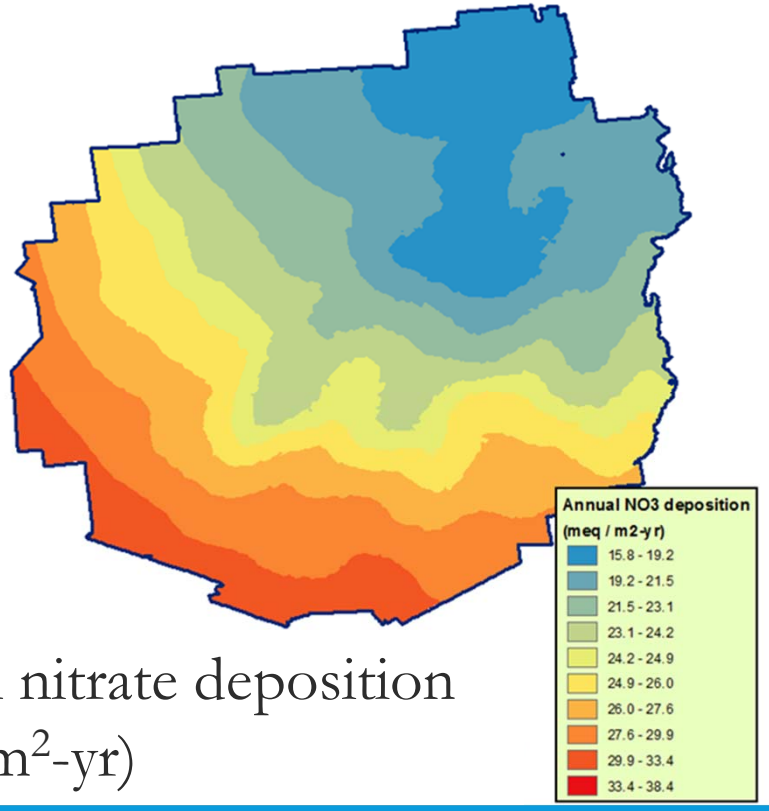

Acid Rain Program
NOx Trading Progr
CAIR
MATS Rule
IIId Rule
?


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
Weathering
Deep water flow
BGC – Surface water
Aqueous reactions

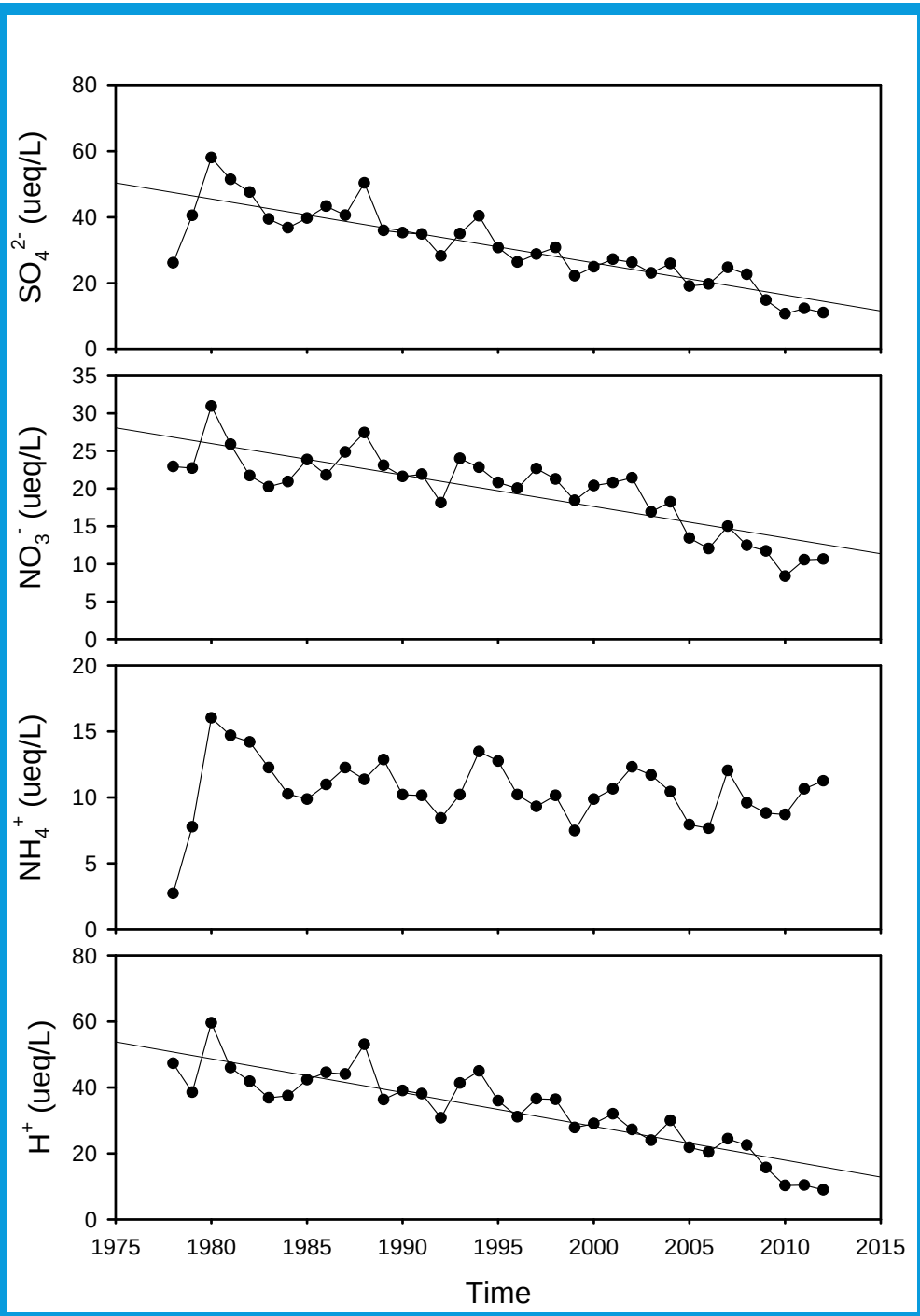
Spatial models for deposition



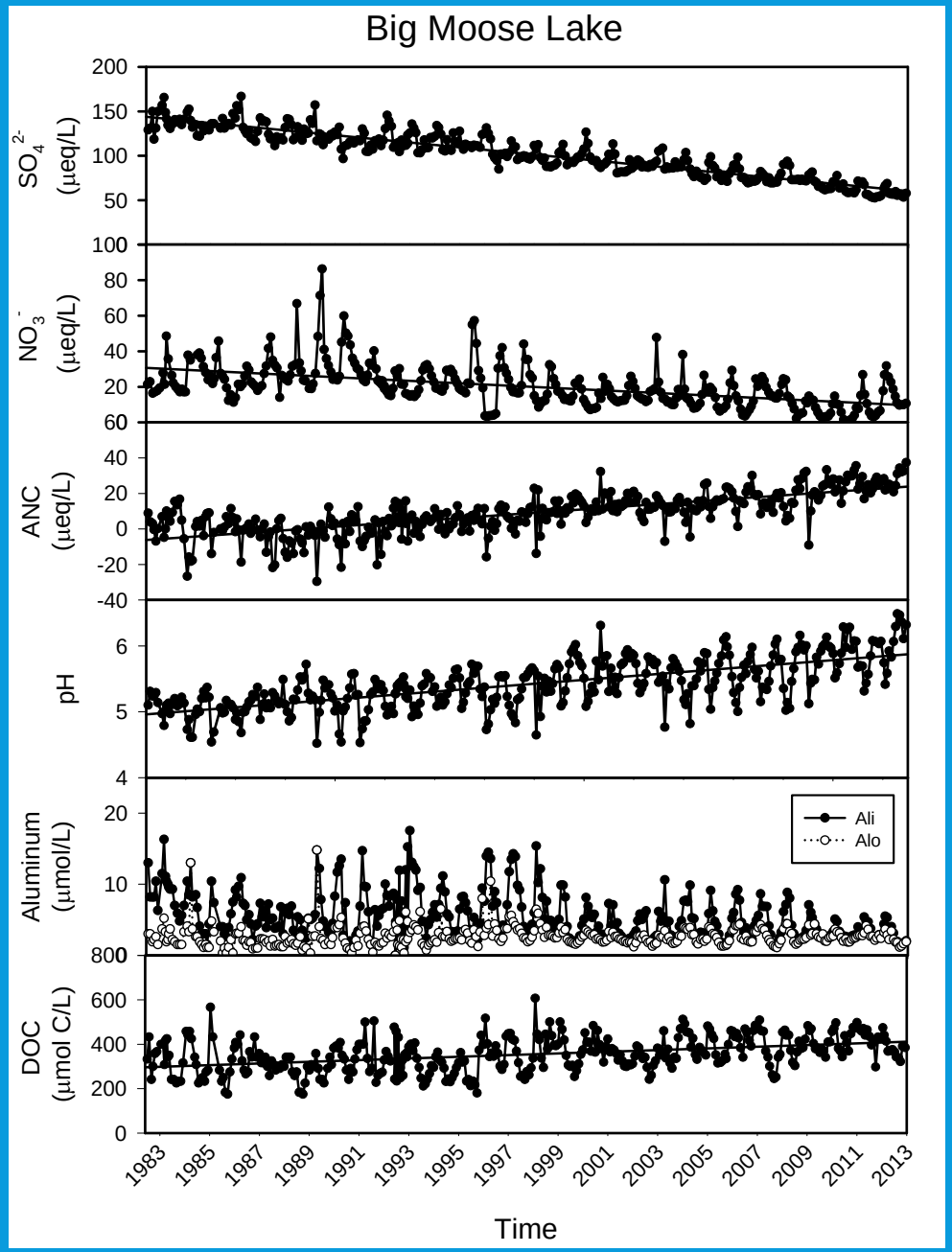
Annual sulfate deposition (meq/m^2-yr)

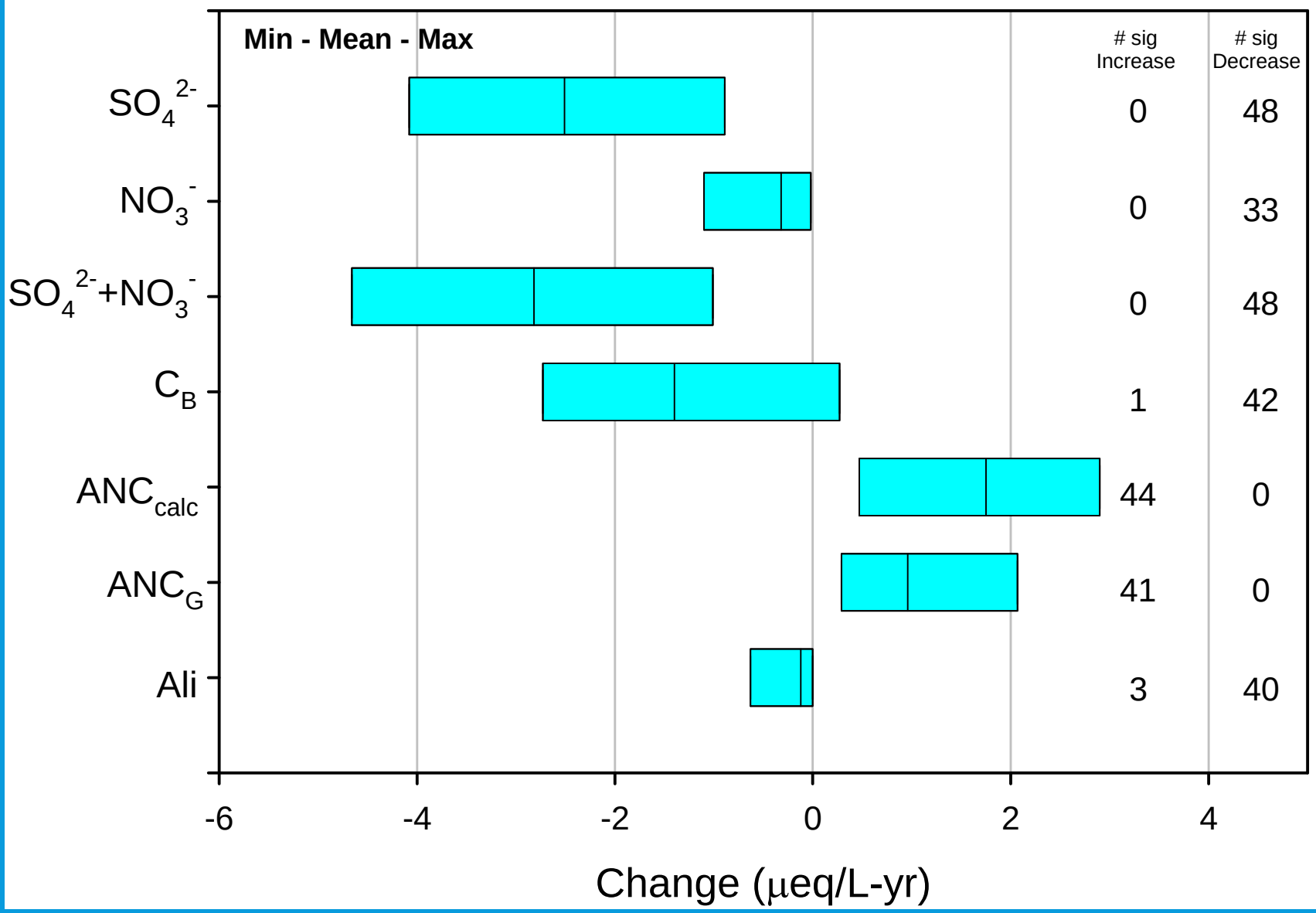


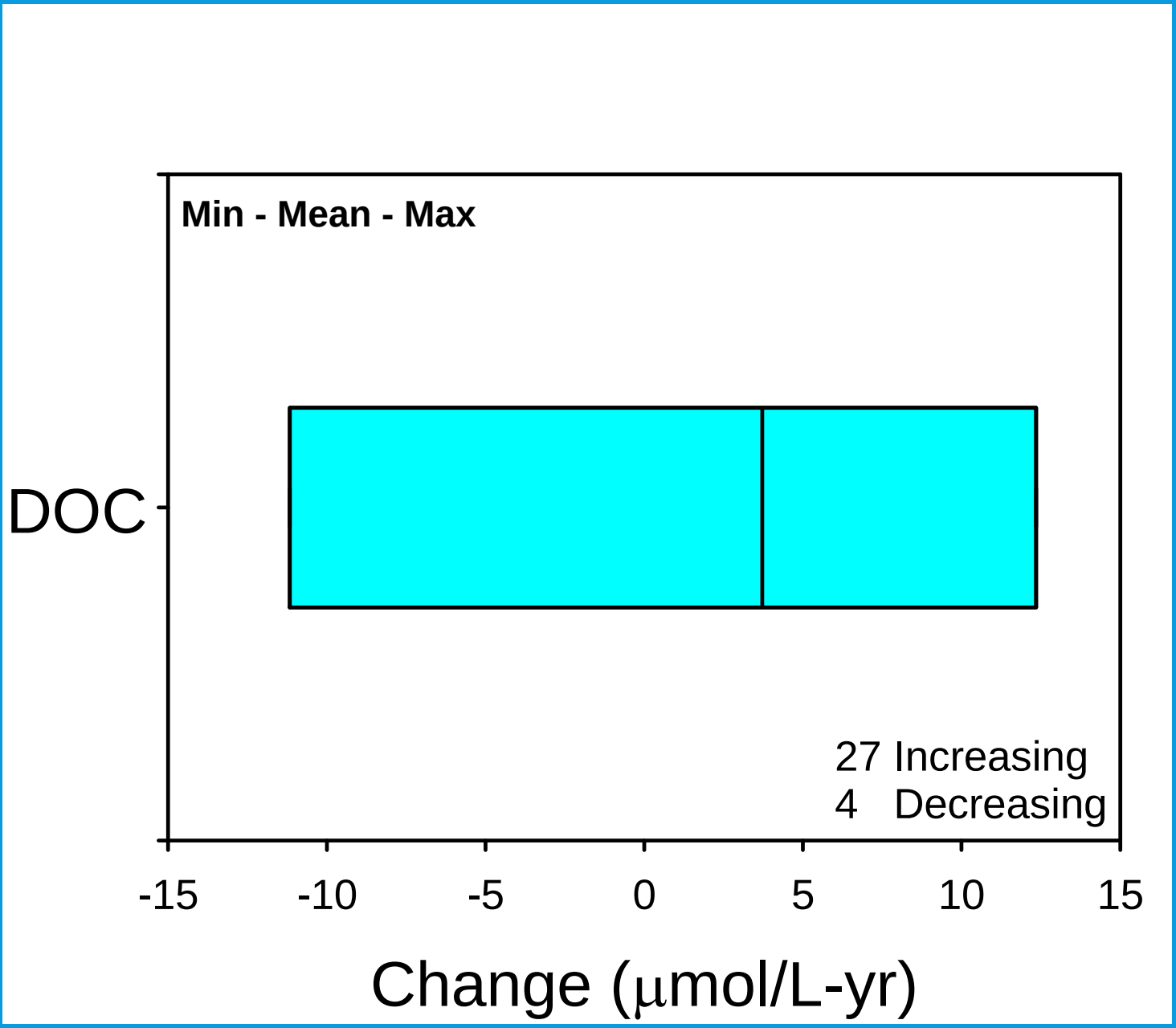
Annual nitrate deposition (meq/m^2-yr)


80
60
40
20
0
SO_4^{2-} (ueq/L)
35
30
25
20
15
10
5
0
NO_3^- (ueq/L)
20
15
10
5
0
NH_4^+ (ueq/L)
80
60
40
20
0
H^+ (ueq/L)
1975
1980
1985
1990
1995
2000
2005
2010
2015
Time

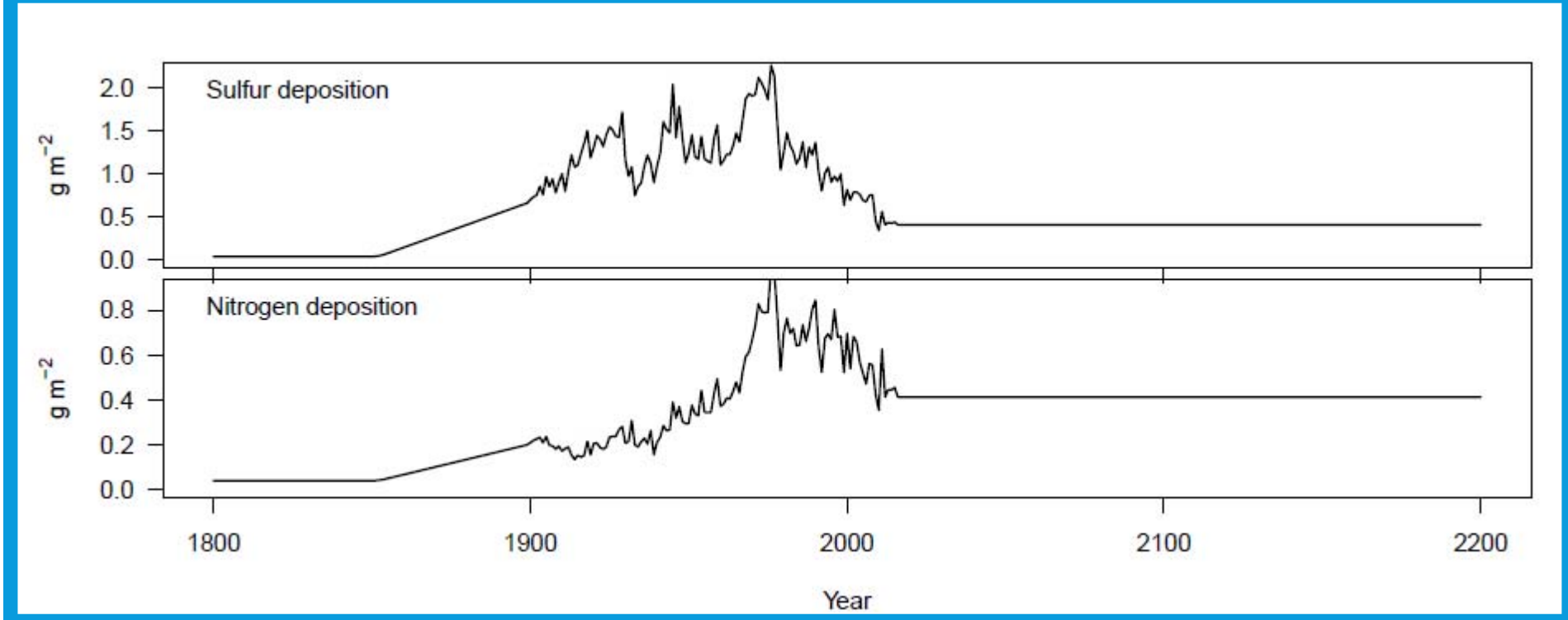
CURRENT AND HISTORICAL PATTERNS


Big Moose Lake
SO_4^{2-} (µeq/L)
200
150
100
50
100
NO_3^- (µeq/L)
80
60
40
20
60
ANC (µeq/L)
40
20
0
-20
-40
pH
6
5
4
Aluminum (µmol/L)
20
10
800
Ali
Alo
DOC (µmol C/L)
600
400
200
0
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
Time

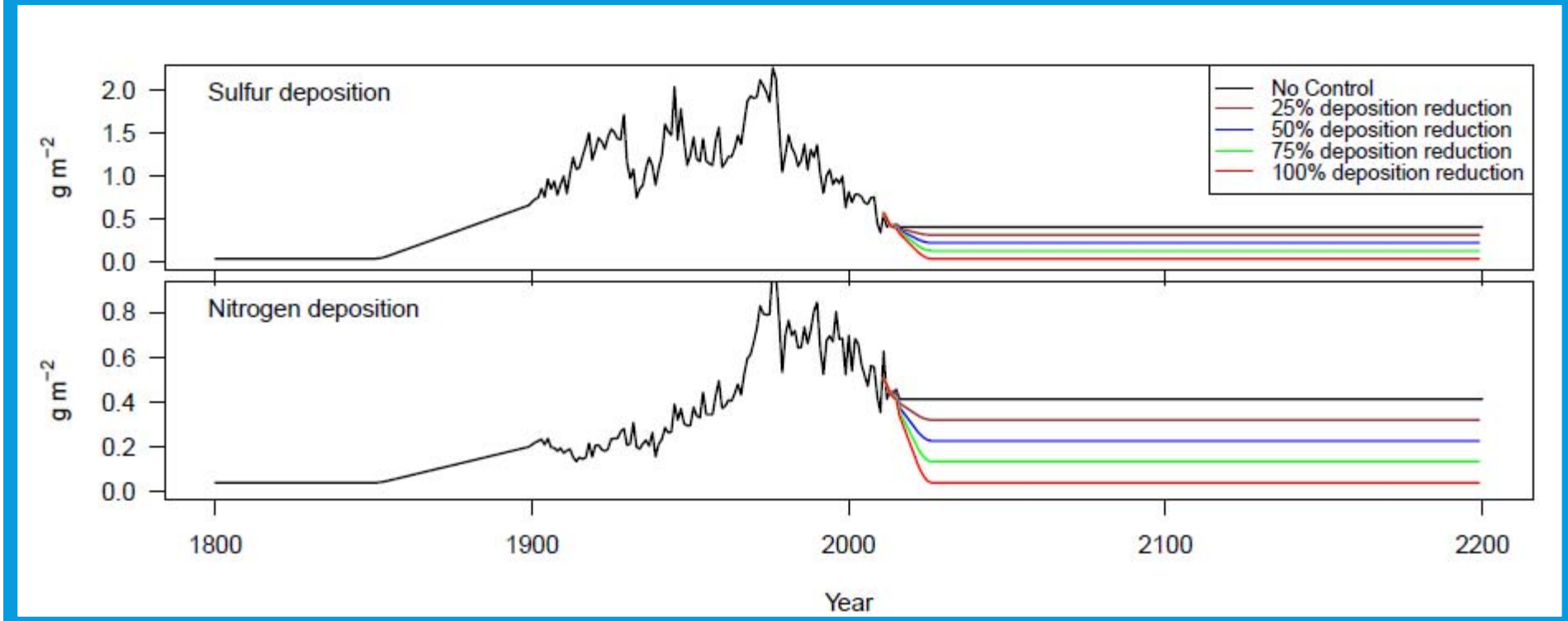

Min - Mean - Max
sig Increase
sig Decrease
SO_4^{2-}
NO_3^-
$SO_4^{2-}+NO_3^-$
C_B
ANC_{calc}
ANC_G
Ali
0
48
0
33
0
48
1
42
44
0
41
0
3
40
-6
-4
-2
0
2
4
Change (μeq/L-yr)


Min - Mean - Max
DOC
27 Increasing
4 Decreasing
-15
-10
-5
0
5
10
15
Change (μmol/L-yr)

Atmospheric Deposition of Sulfur and Nitrogen



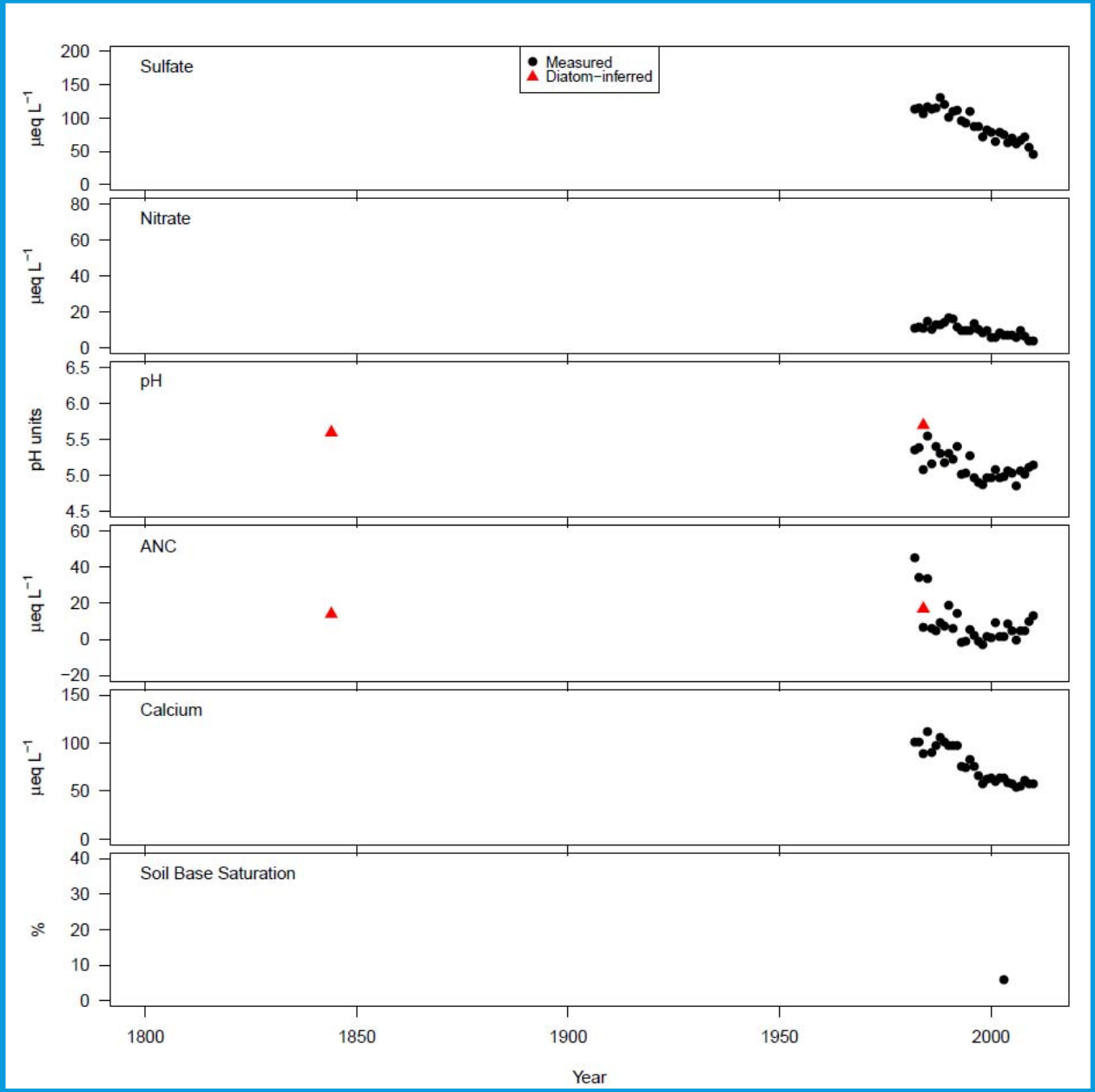
Hindcast and Forecast Scenarios



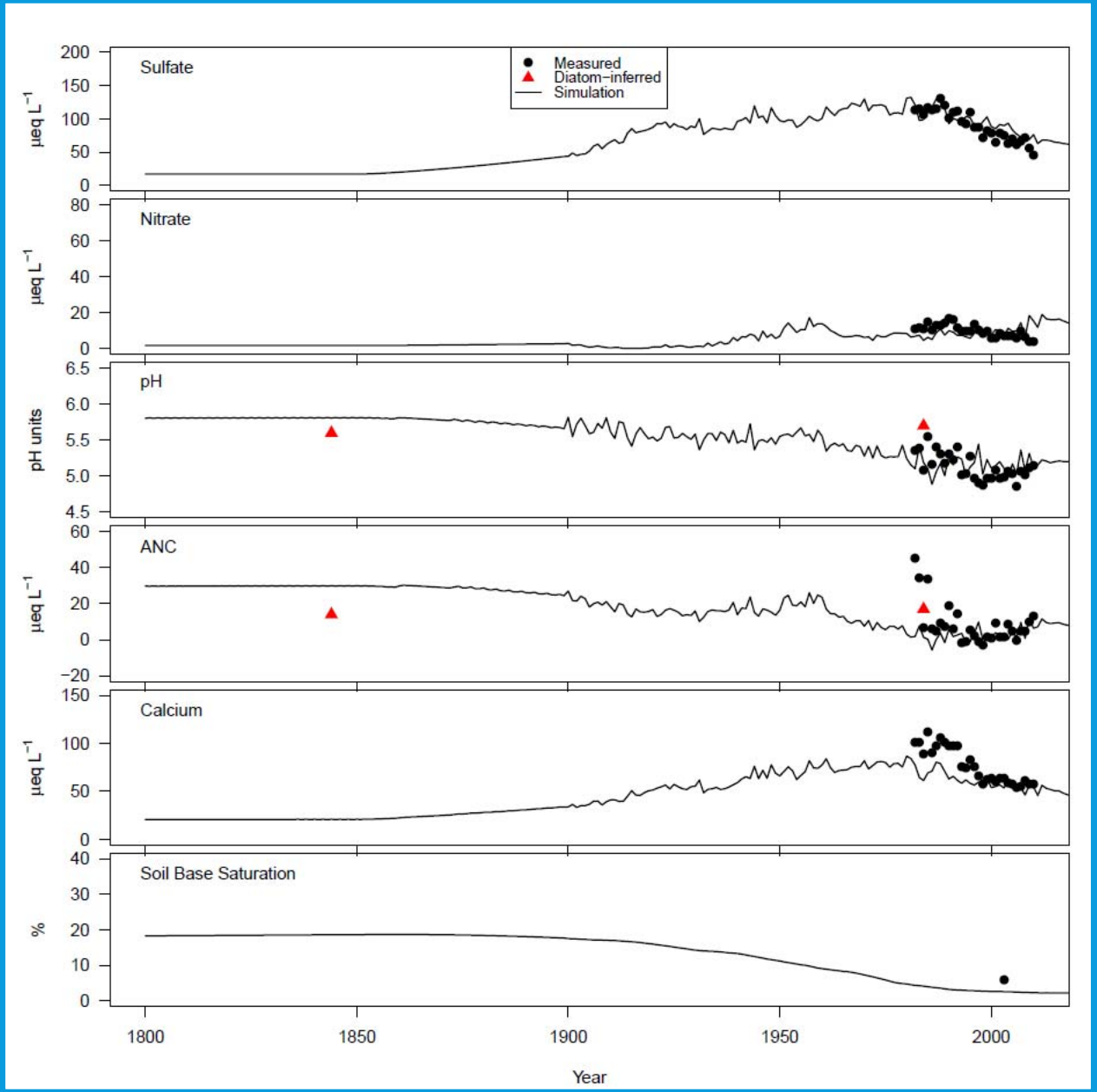
West Pond

West Pond

Measured



West Pond Hindcast



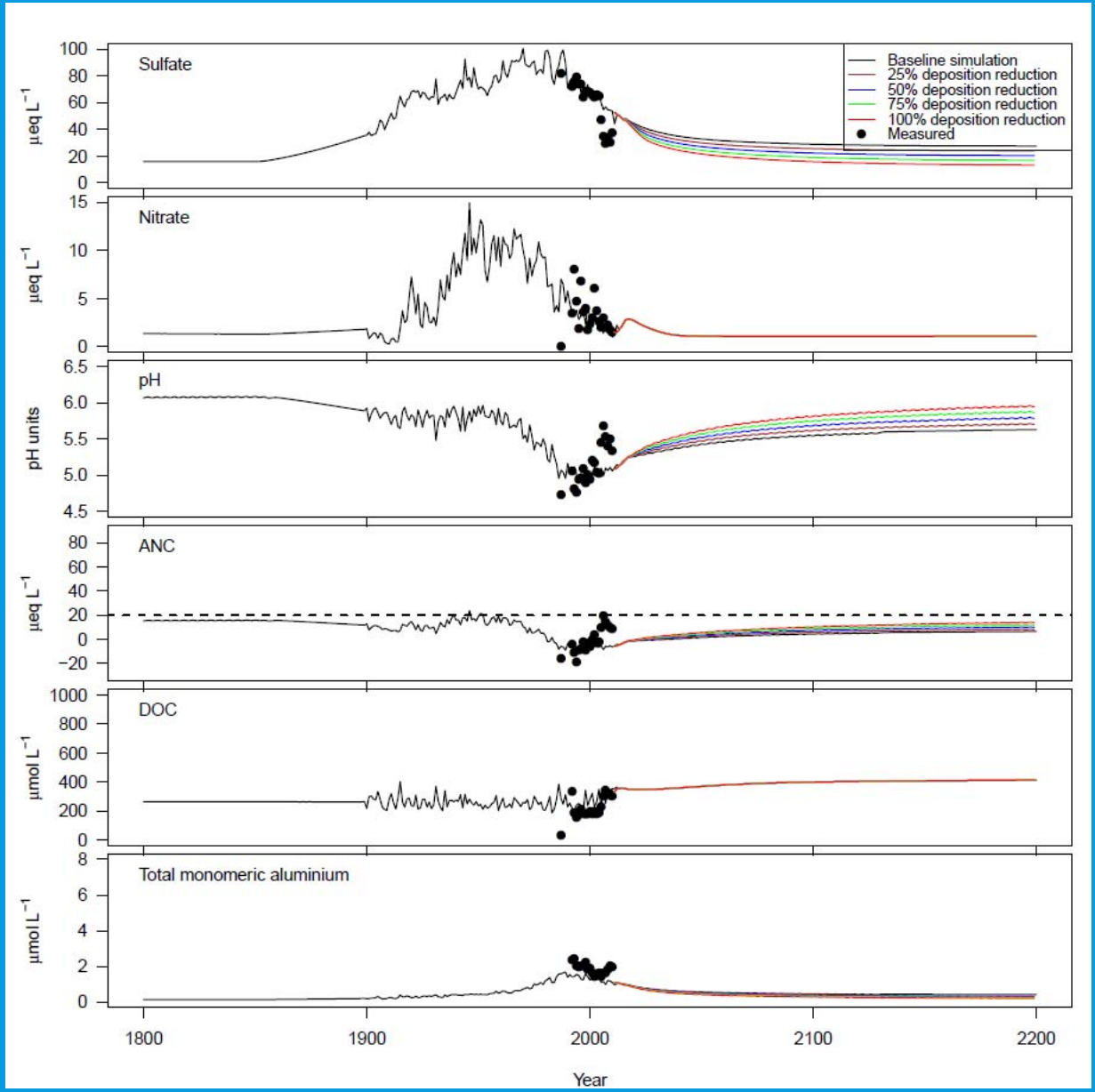
Model simulated median values for lake chemistry and soil %BS at the 128 TMDL sites for pre-industrial conditions and near-peak acidification measured values, as µeq/L, except pH and %BS.

	Pre-industrial conditions (1850)	**Near peak acidification conditions (1990)**
SO_4^{2-}	17.9	82.5
NO_3^-	1.6	15.7
ANC	39.7	0.3
pH	6.44	5.1
Soil %BS	18.6	7.9

SYSTEMATIC CLEAN WATER ACT FRAMEWORK

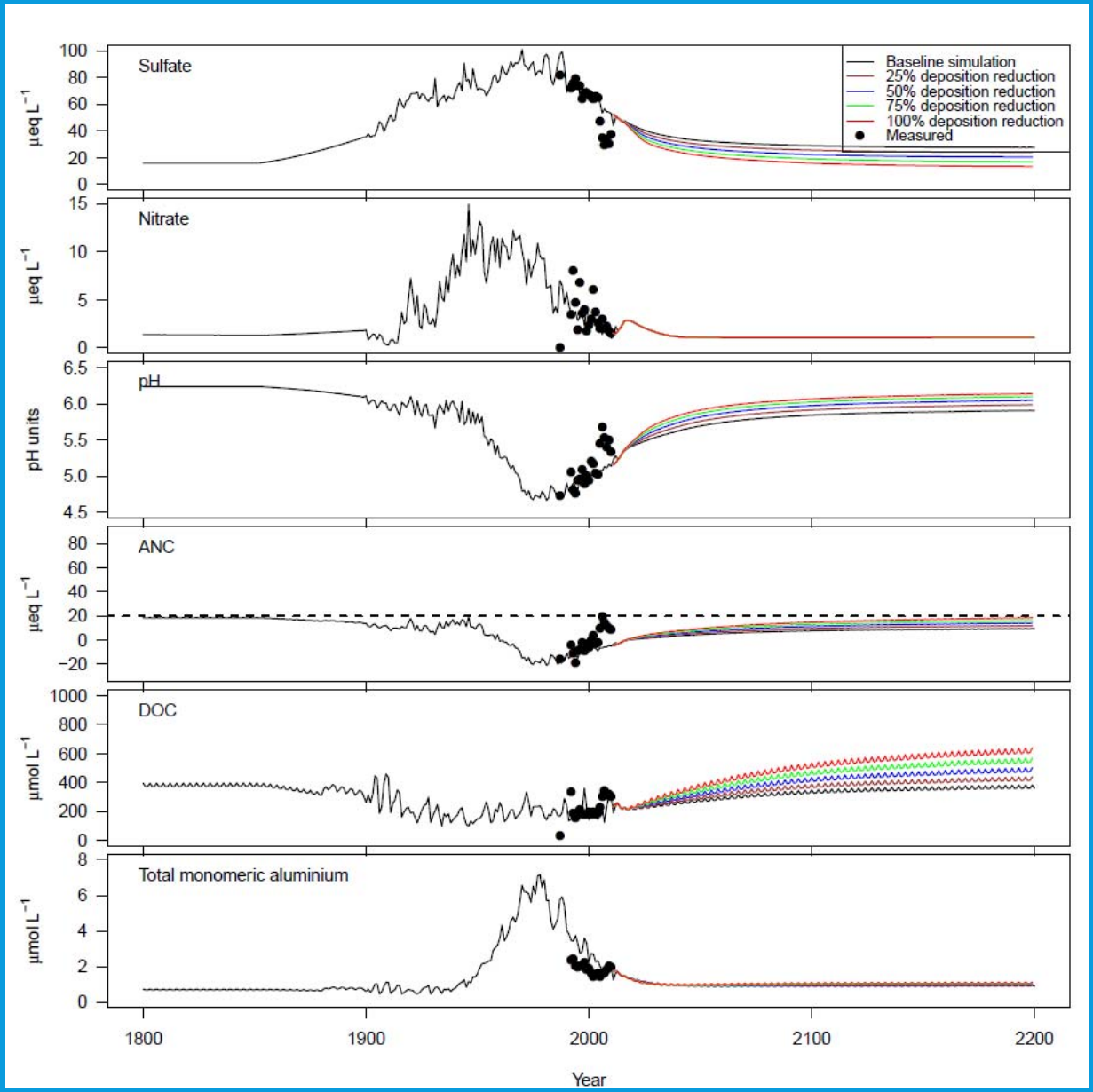
- Establish Water Quality Standards
- Assess Waters of the State
- Identify Impaired Waters on 303d List
- Conduct TMDL Analysis
- Implement TMDL
- Evaluate (Post-Audit)

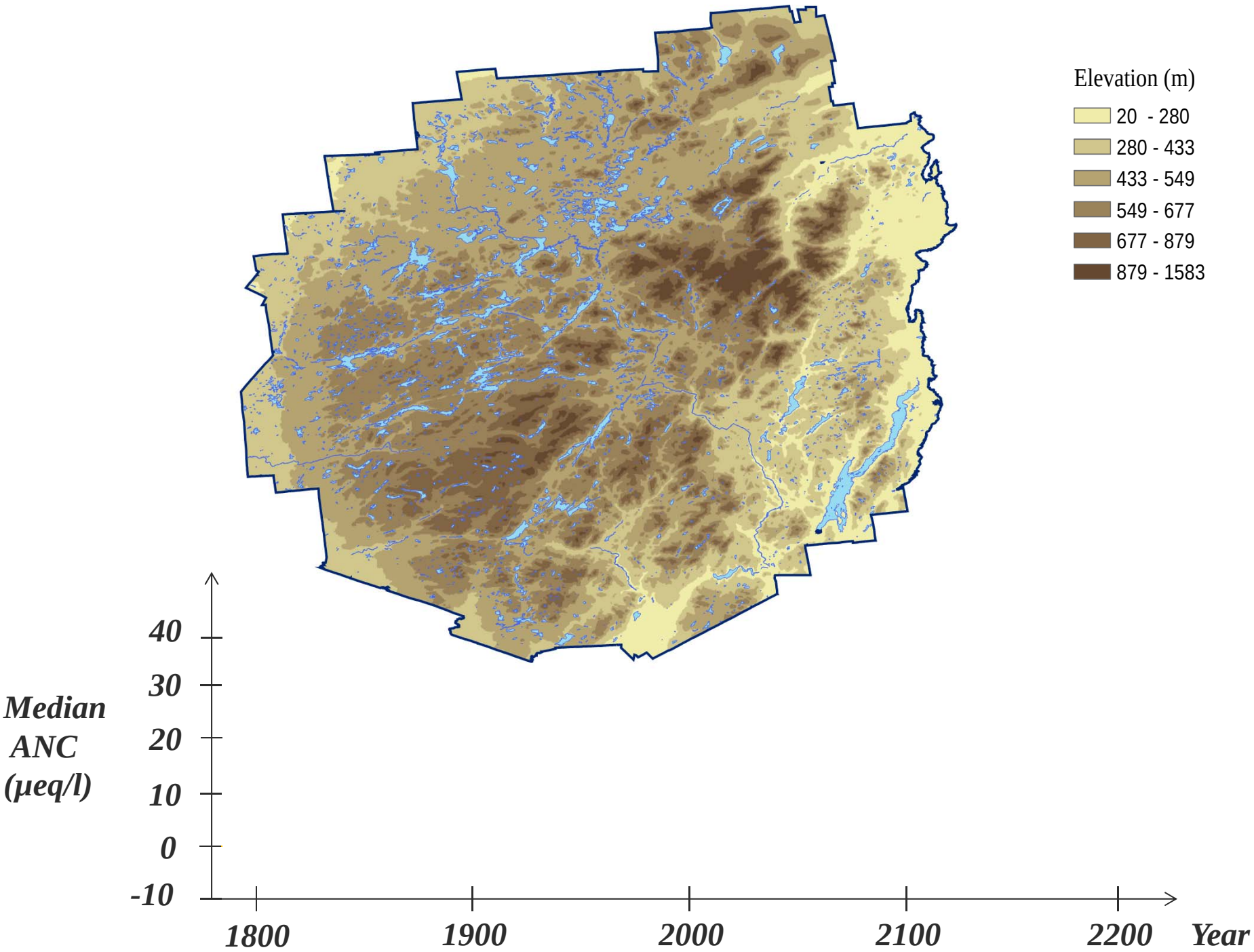
Carry Pond

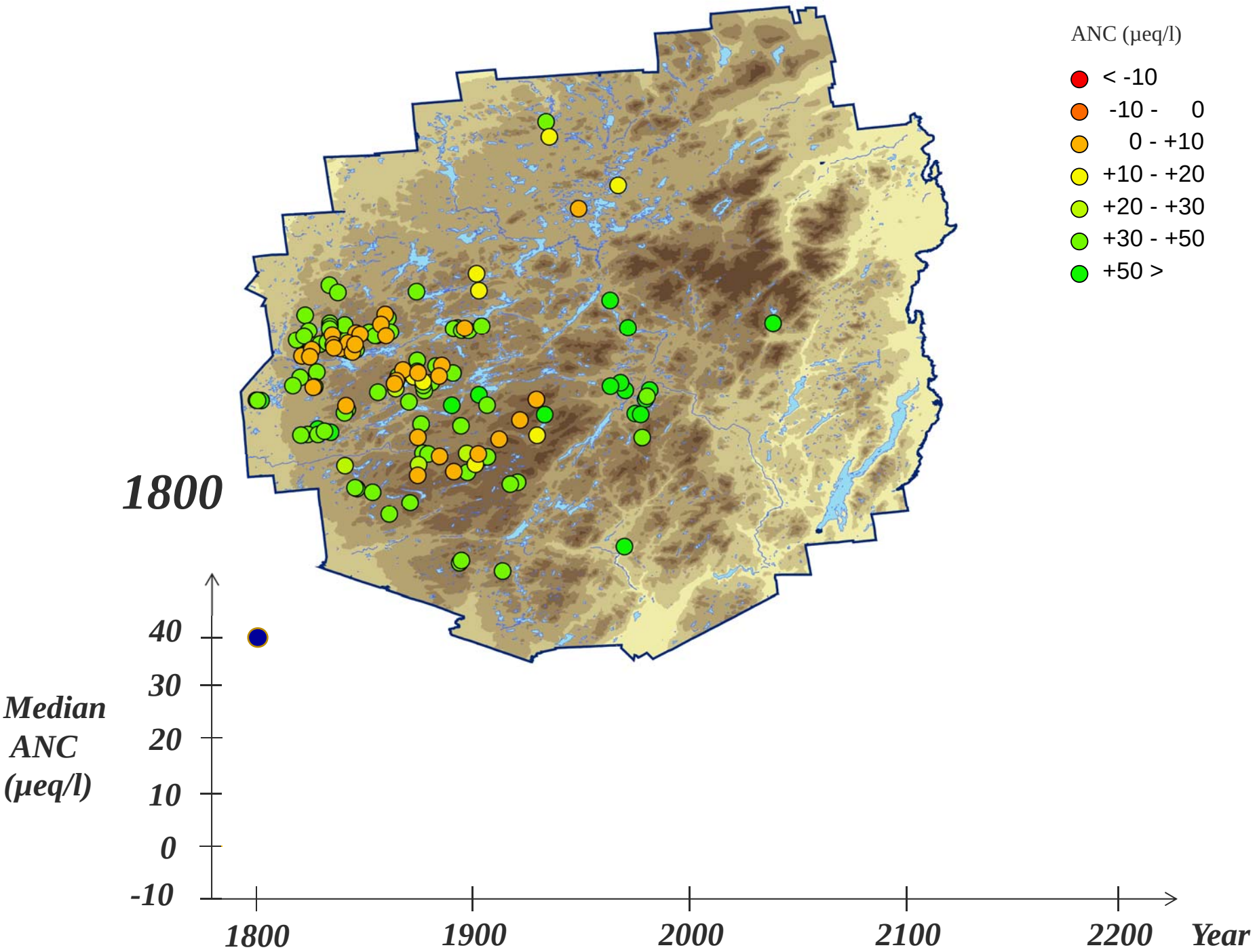

Sulfate
Nitrate
pH
ANC
DOC
Total monomeric aluminium
µeq L⁻¹
pH units
µmol L⁻¹
Baseline simulation
25% deposition reduction
50% deposition reduction
75% deposition reduction
100% deposition reduction
Measured
1800
1900
2000
2100
2200
Year

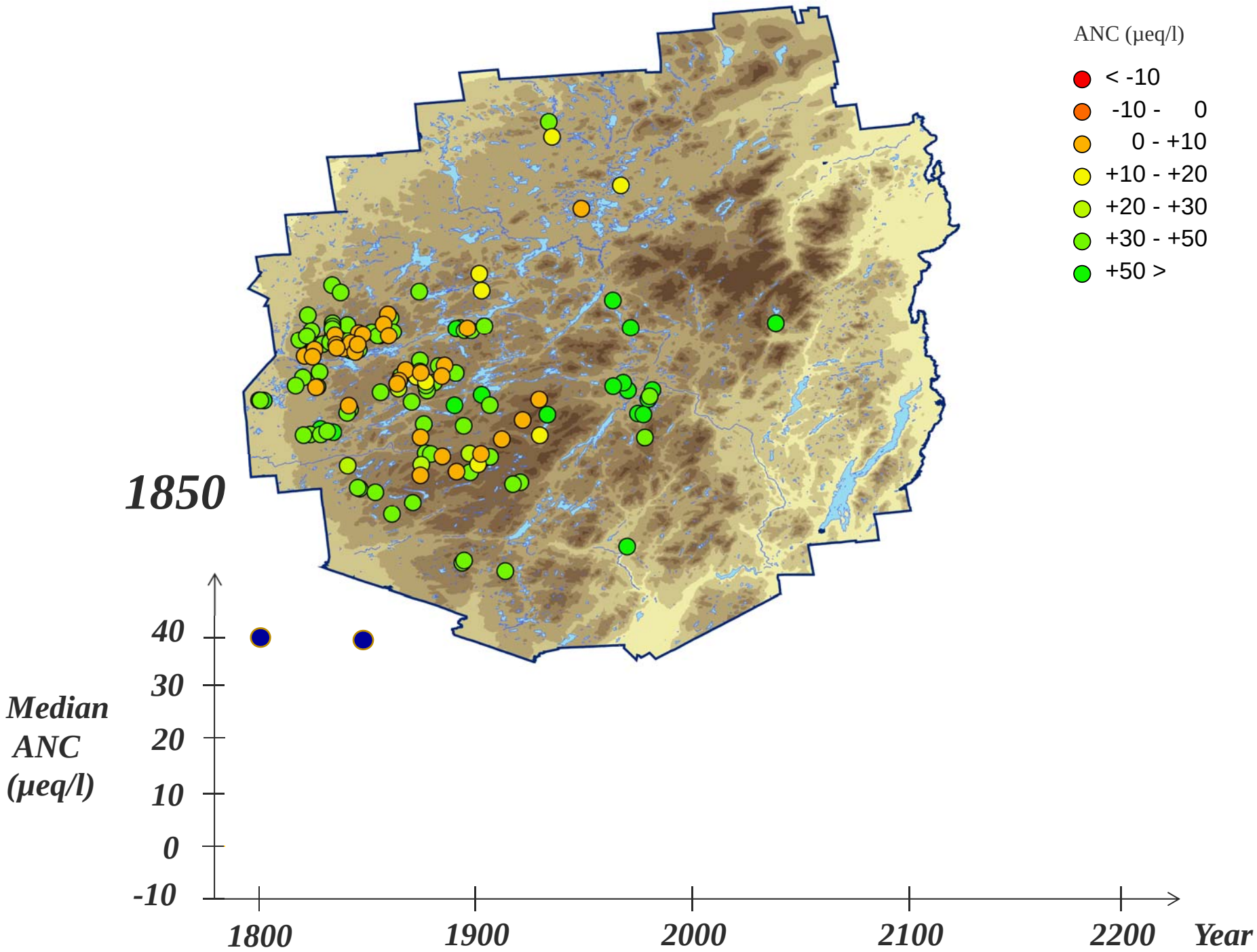
Carry Pond

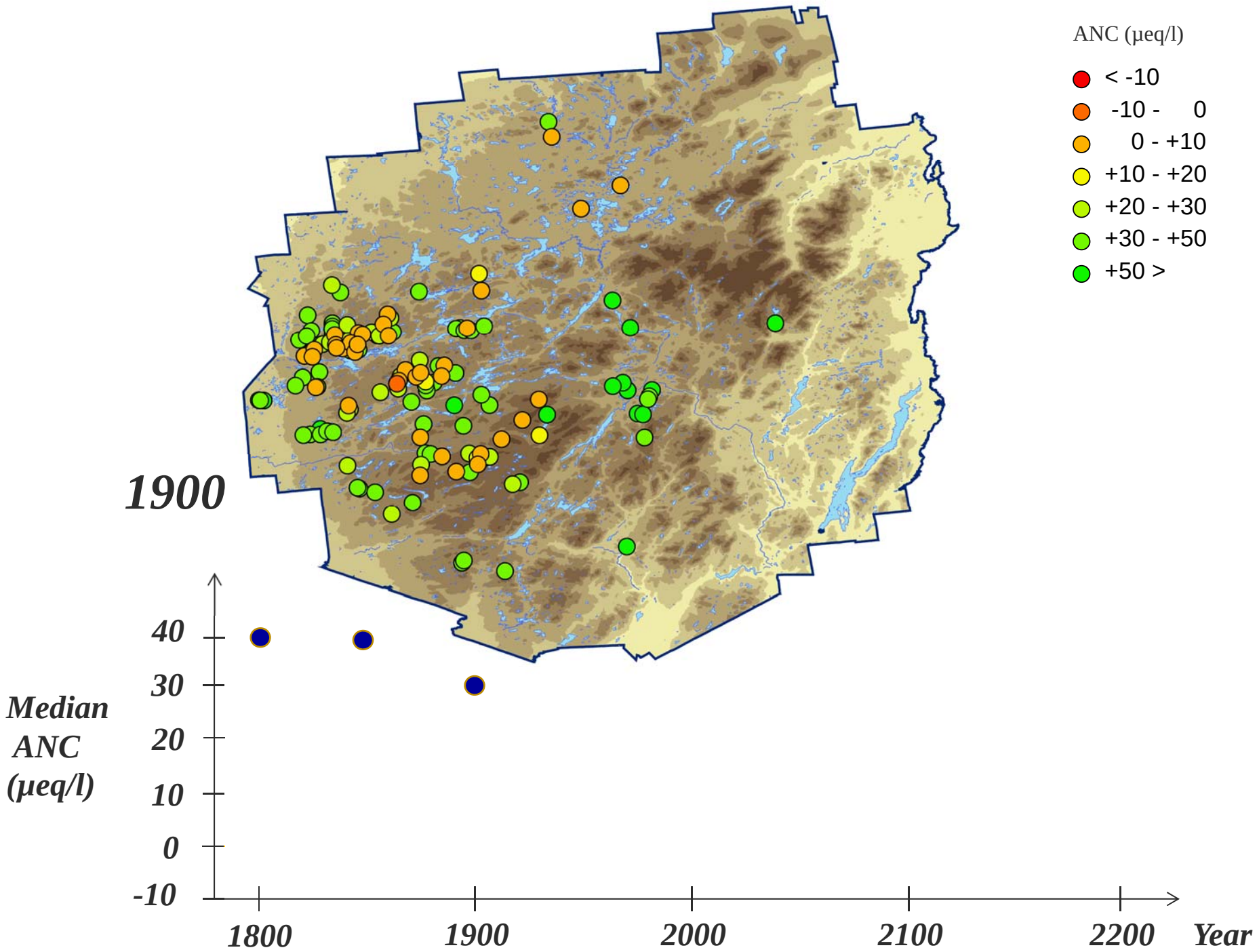
Simulation of Carry Pond with DOC algorithm

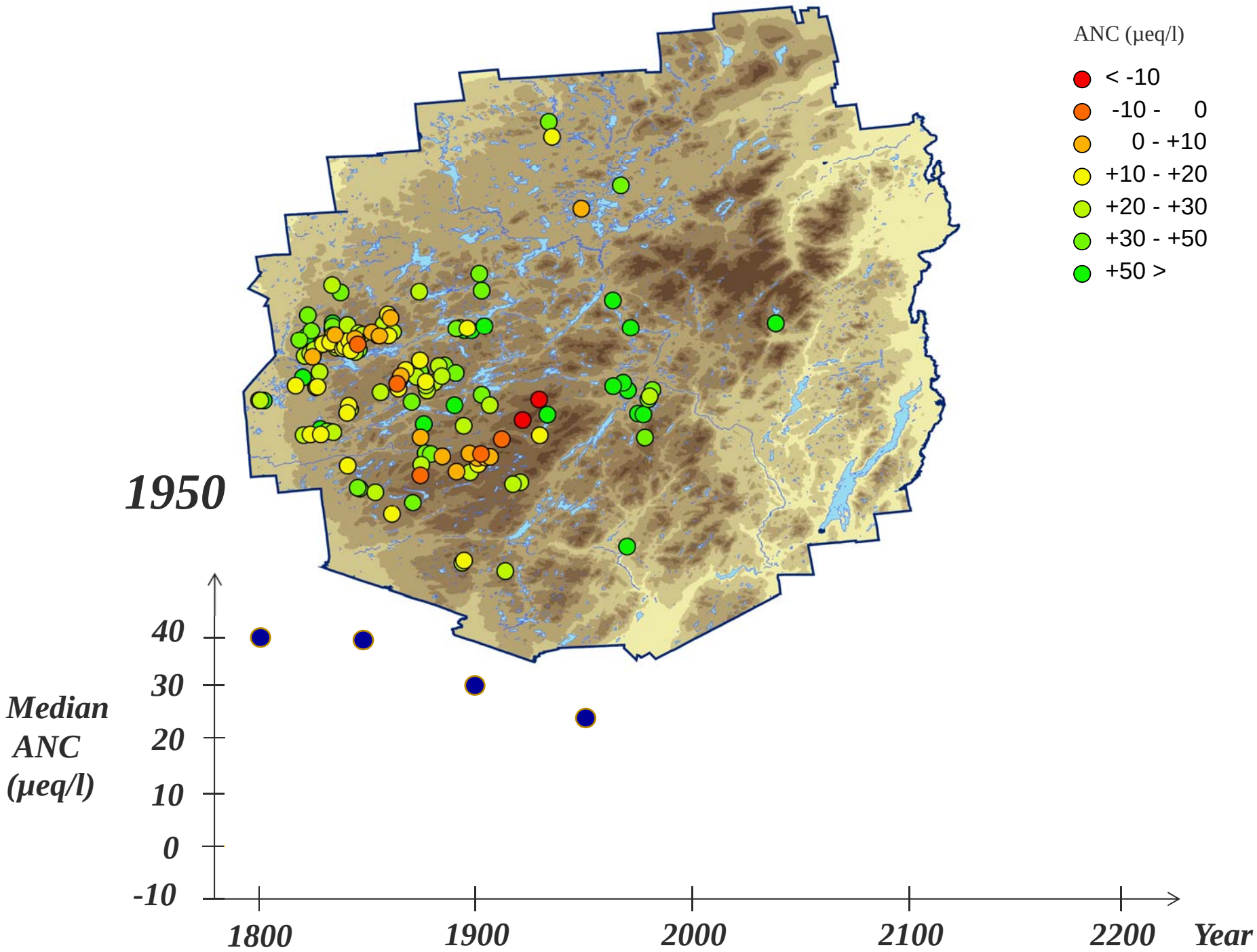


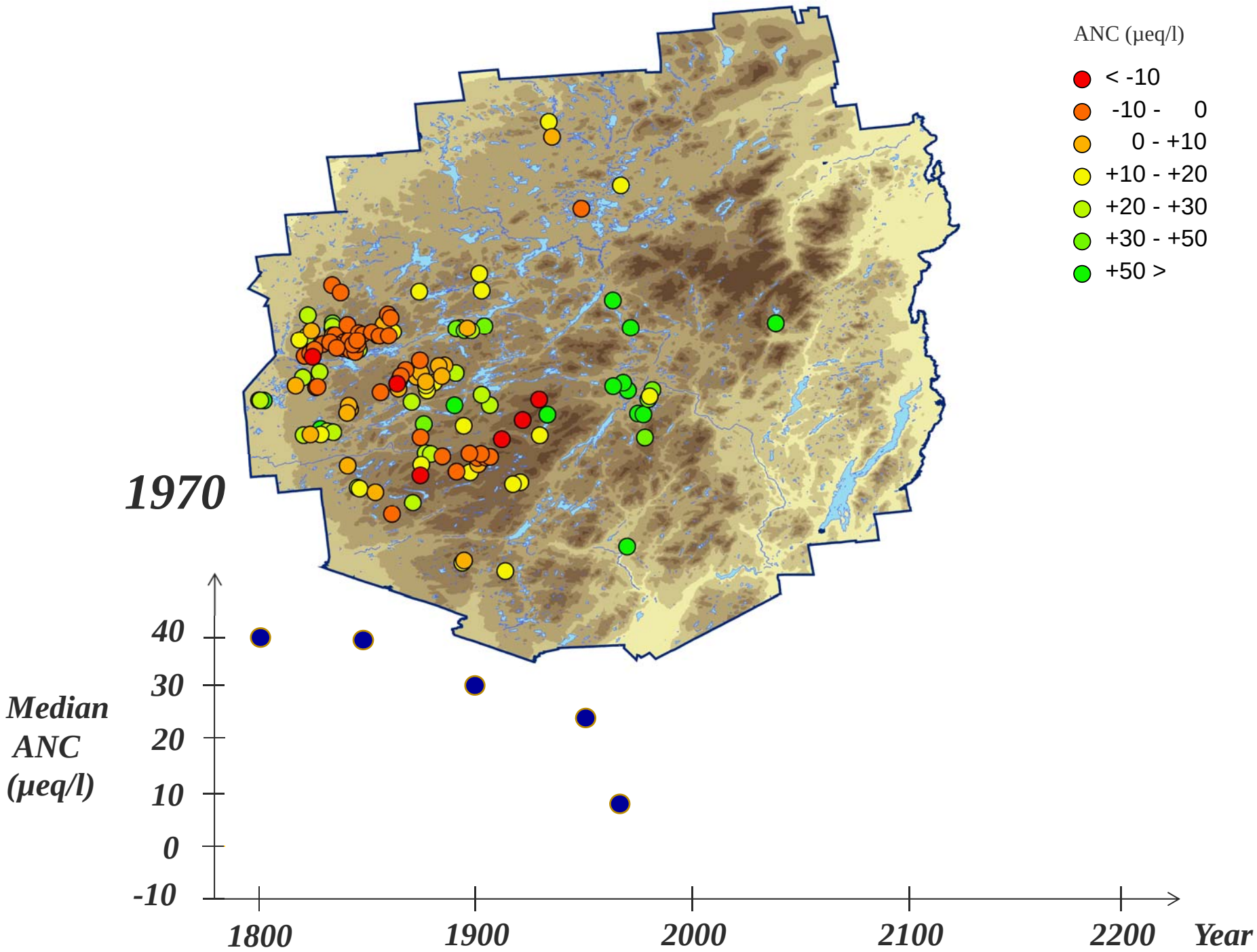

Elevation (m)
20 - 280
280 - 433
433 - 549
549 - 677
677 - 879
879 - 1583
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

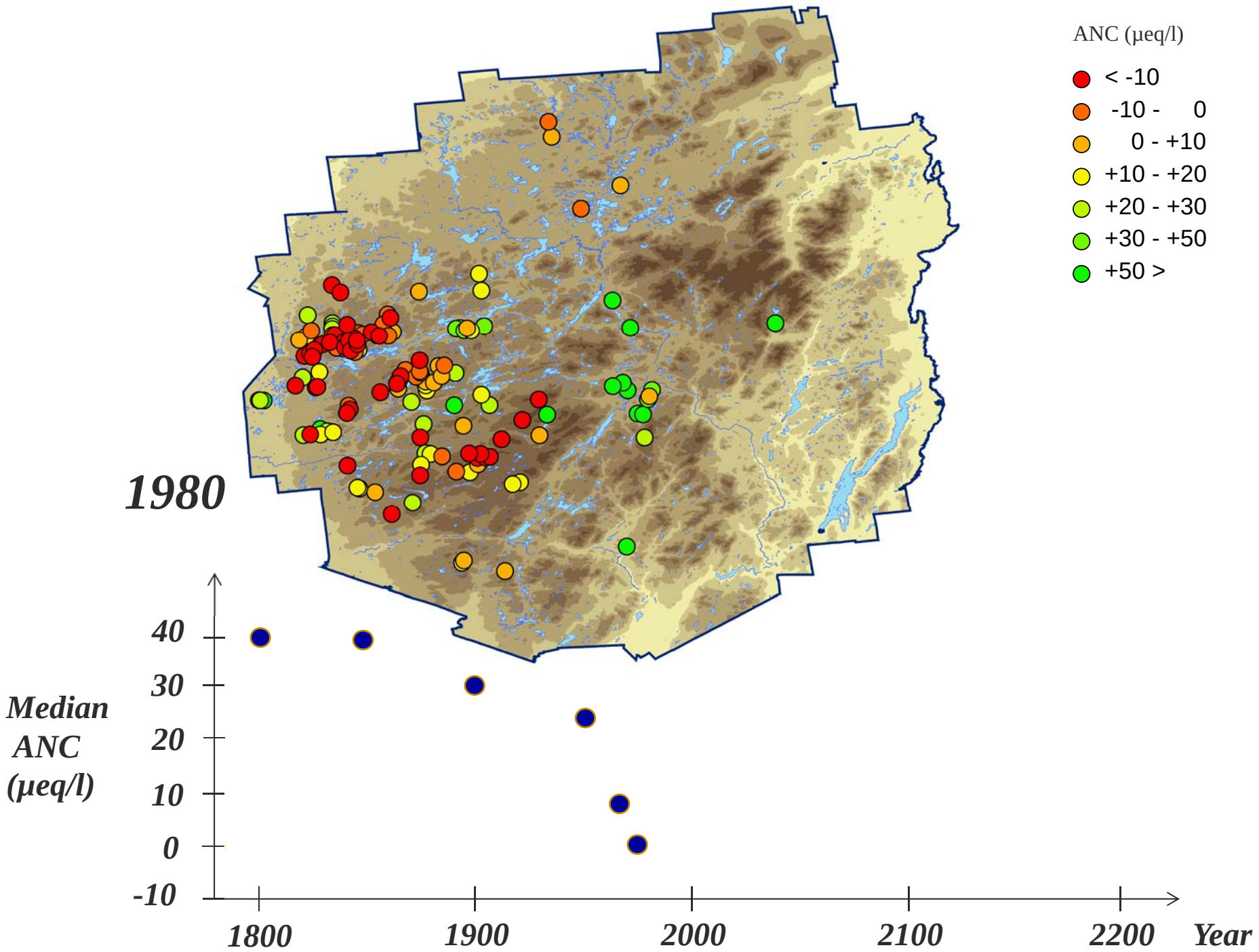

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1800
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

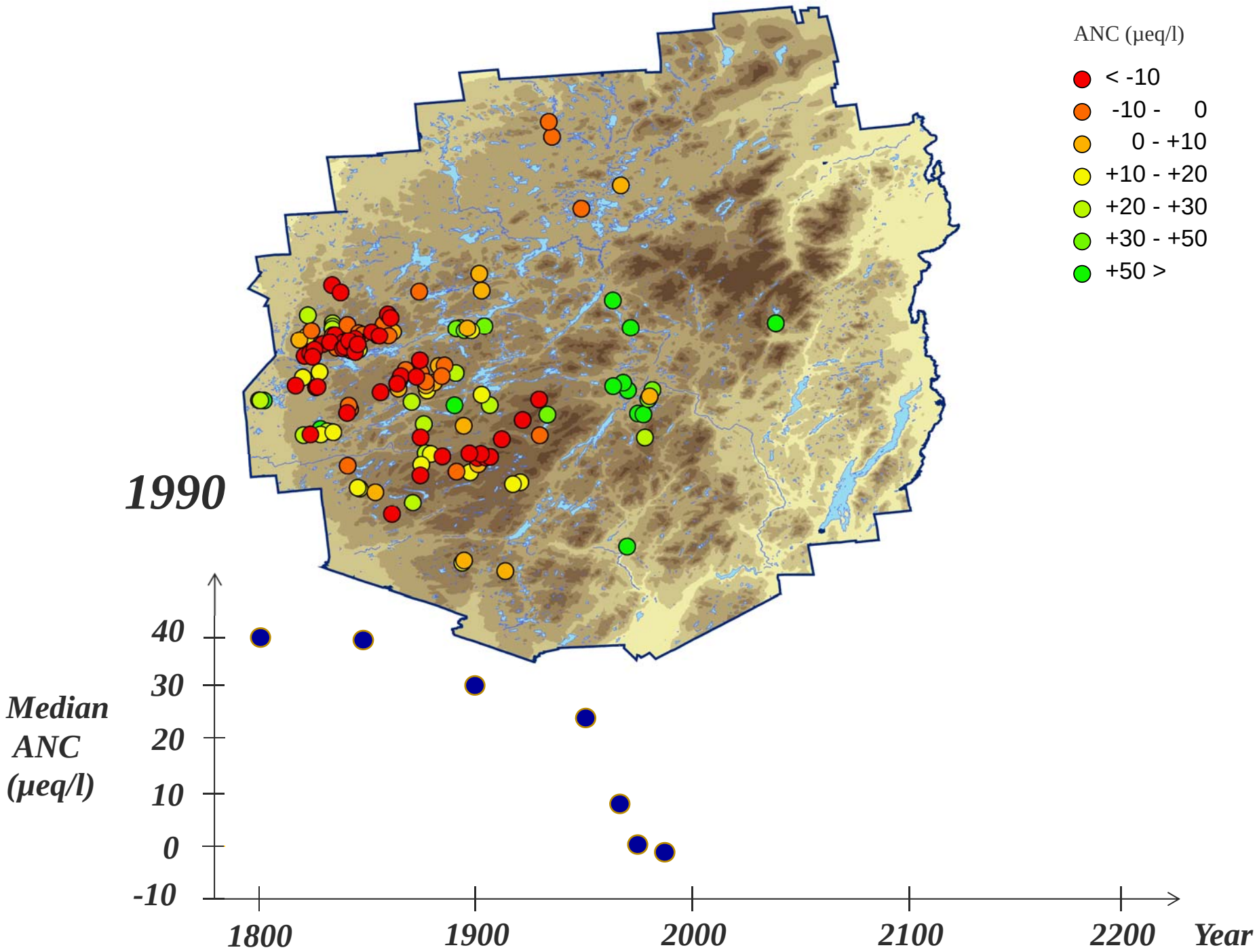

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1850
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

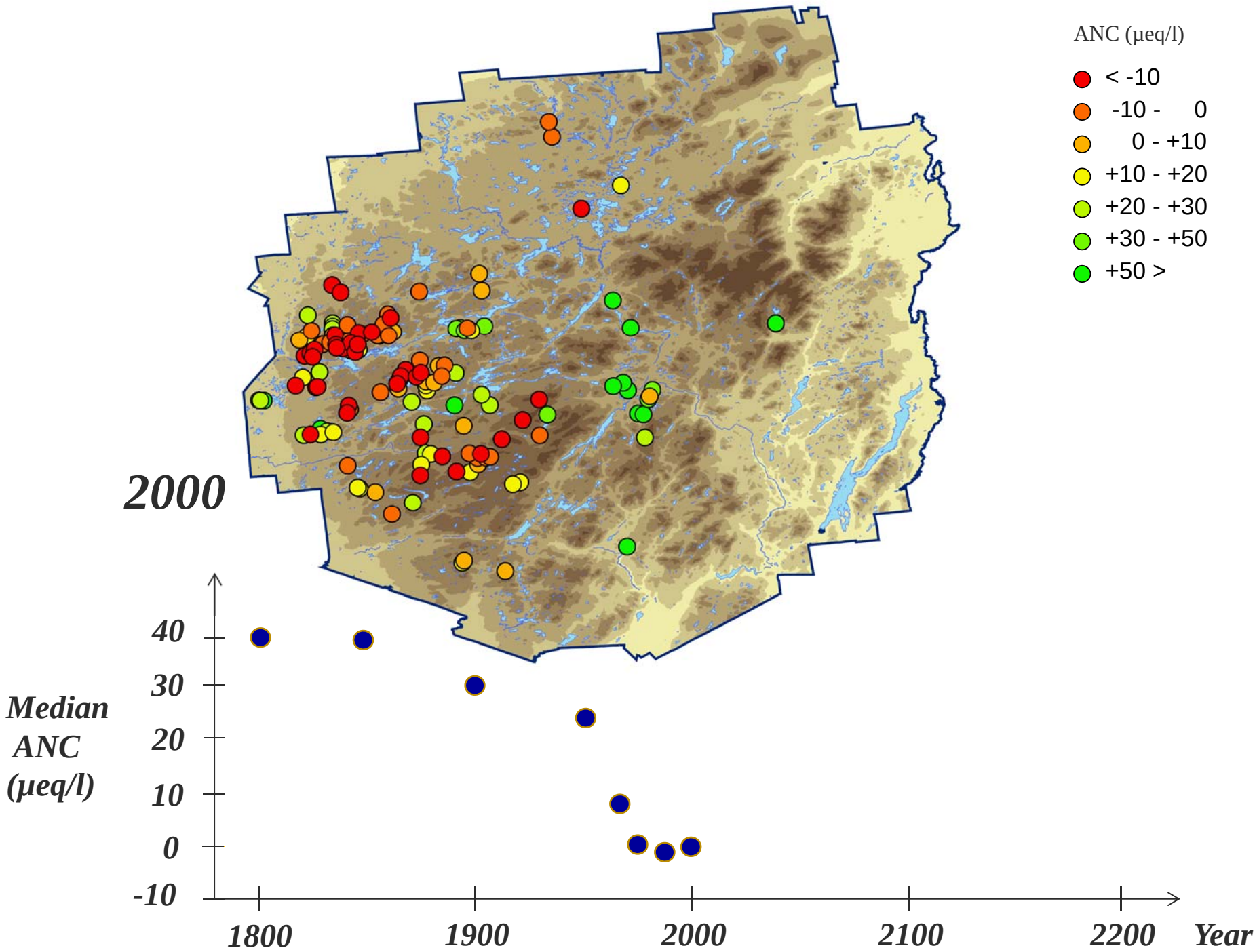

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1900
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

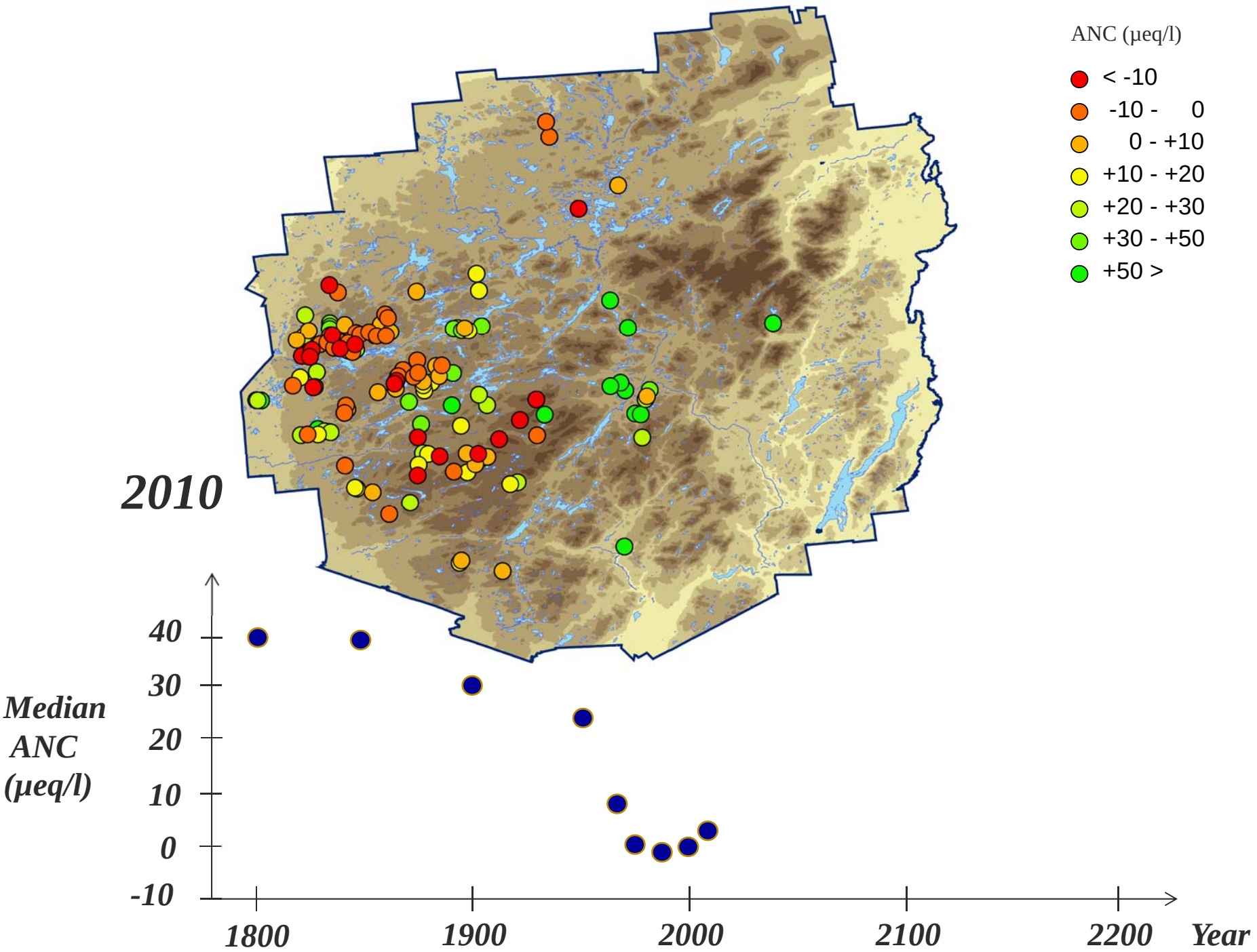

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1950
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

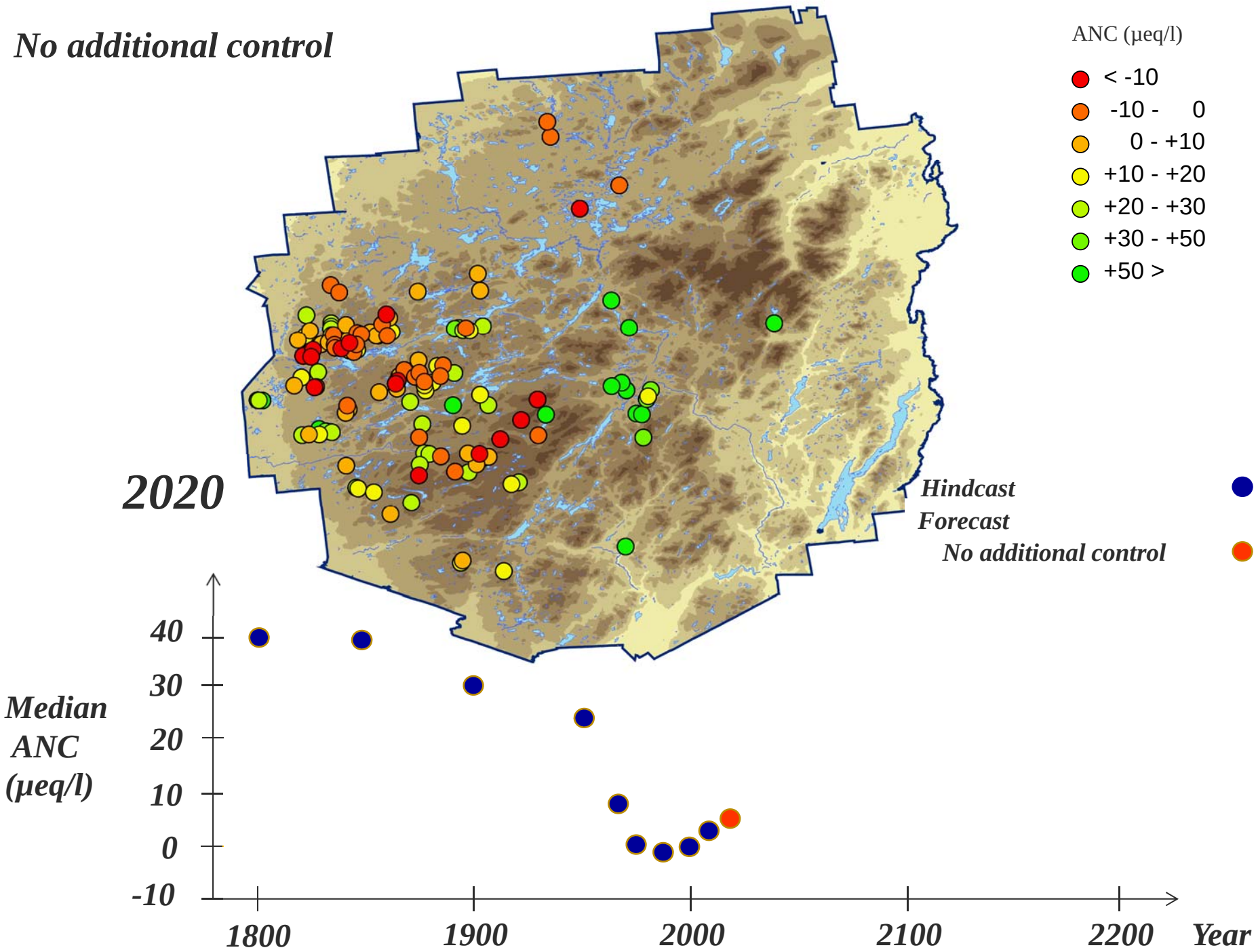

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1970
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

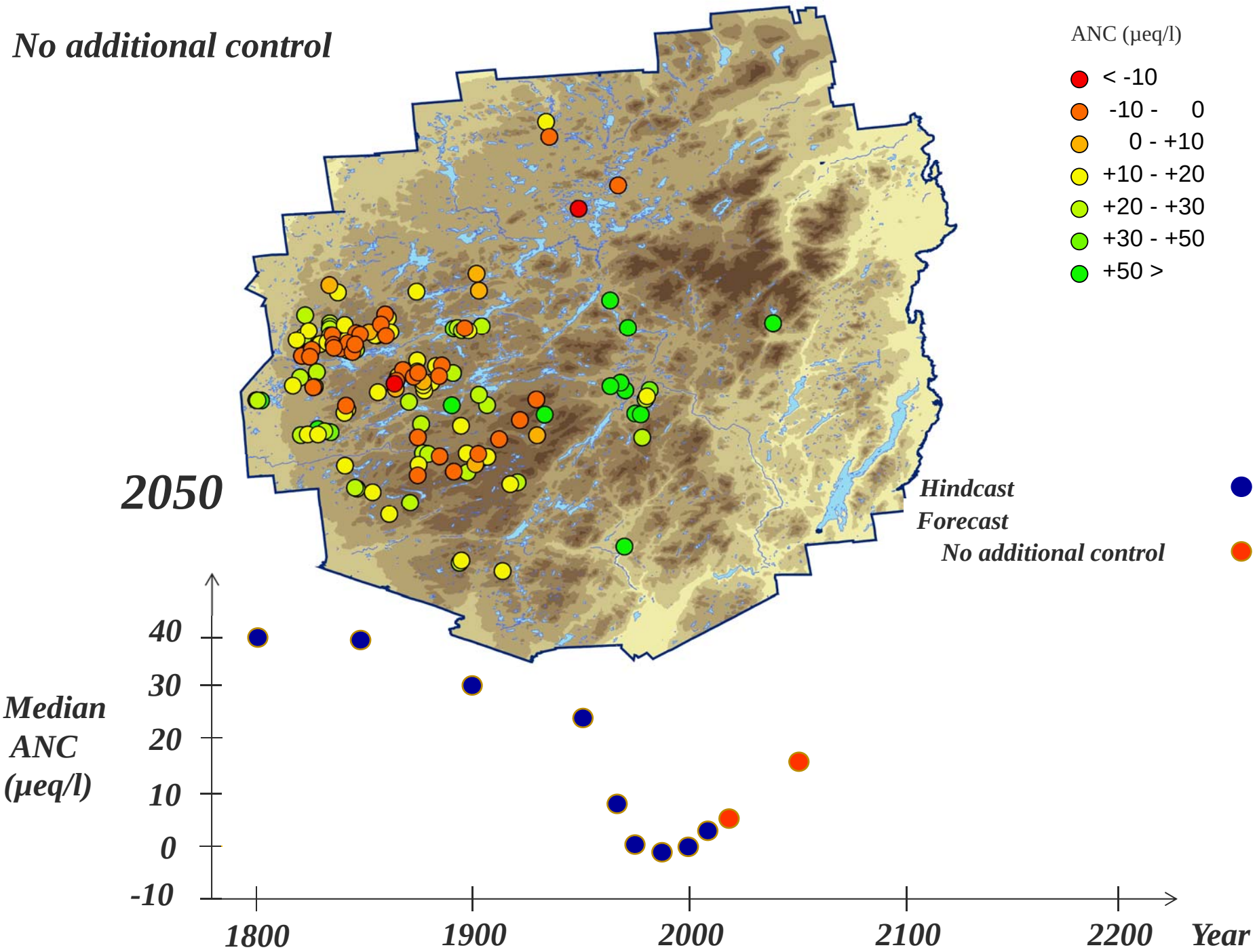

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1980
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

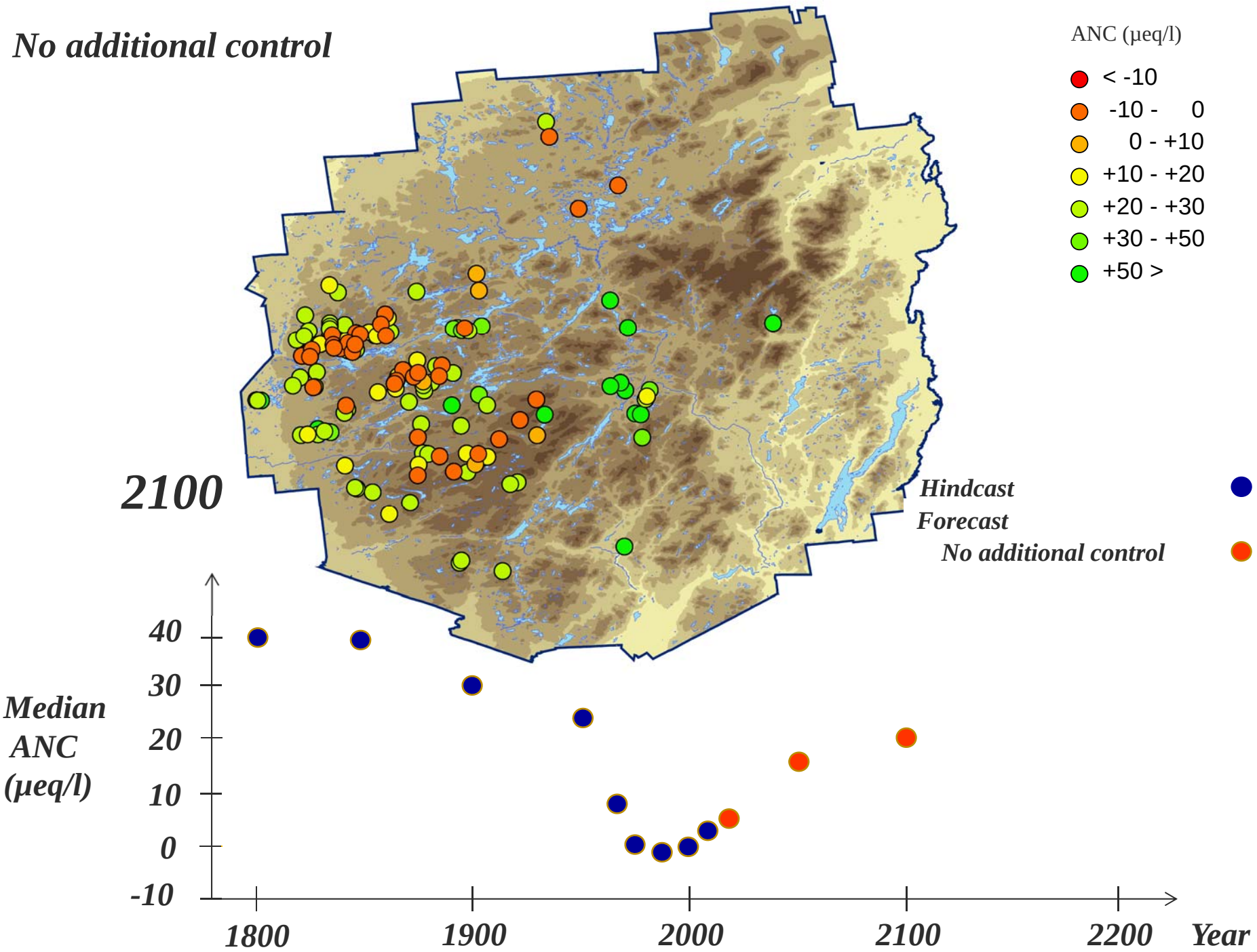

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
1990
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

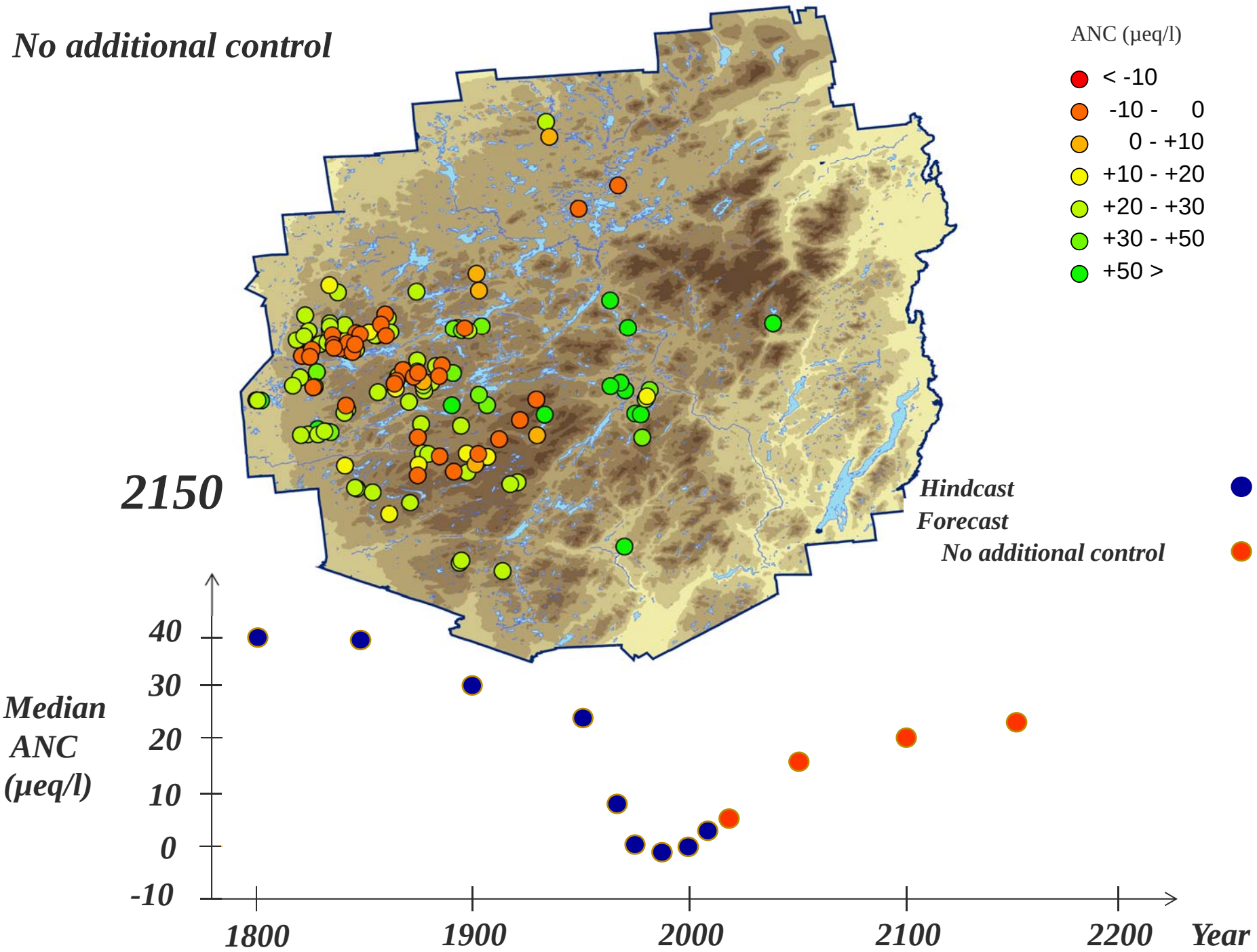

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2000
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

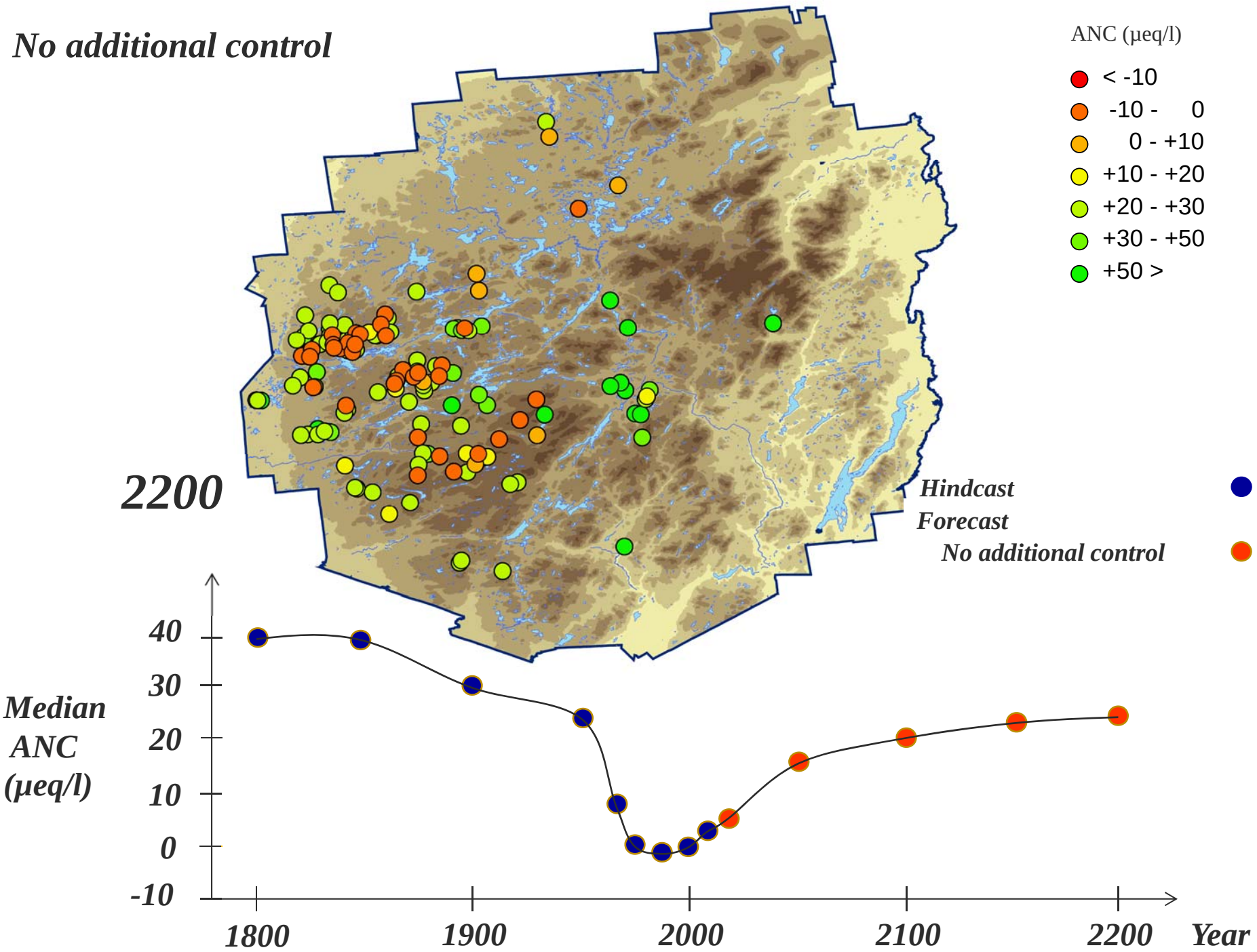

ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2010
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

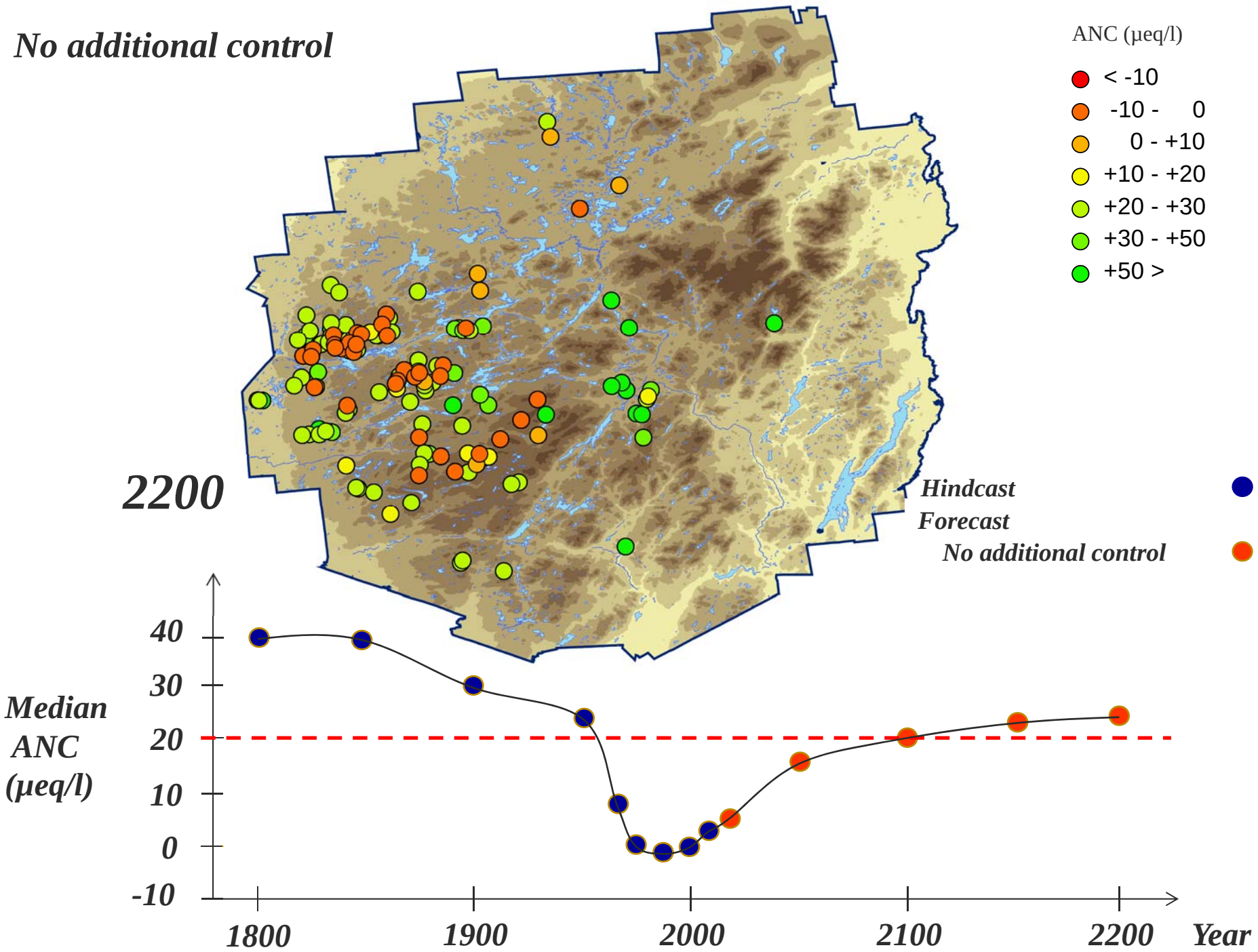

No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2020
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

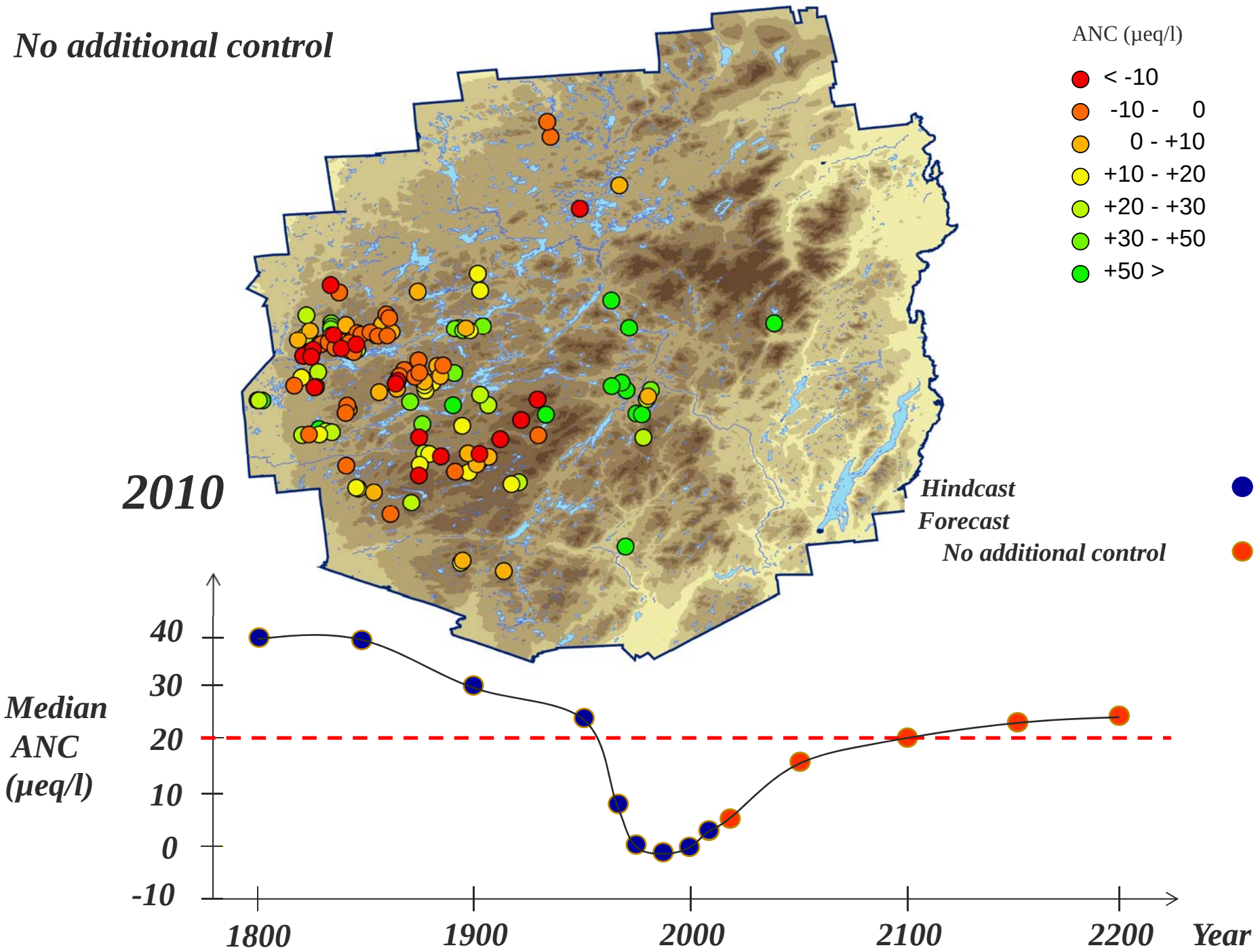

No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2050
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year


No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2100
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

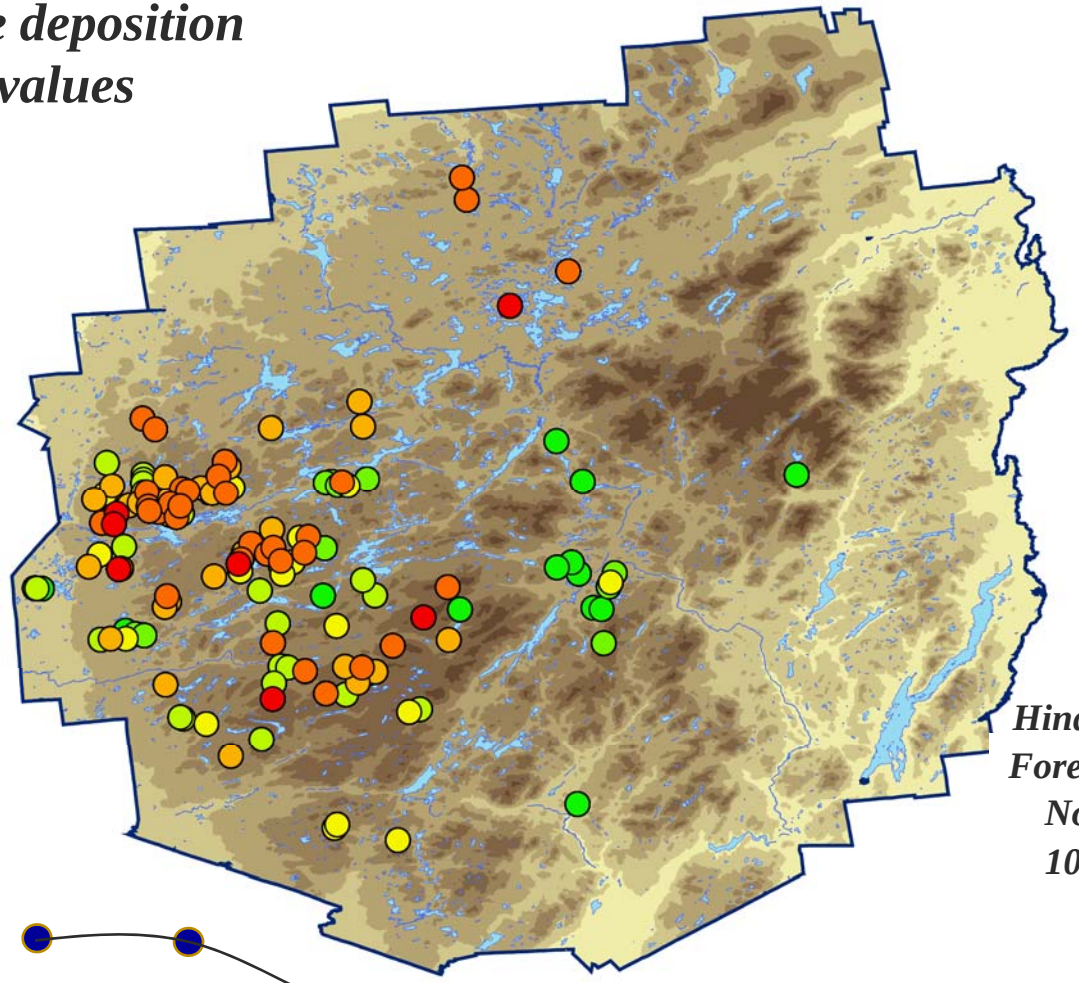

No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2150
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year


No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2200
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year


No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2200
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year


No additional control
ANC (µeq/l)
< -10
-10 - 0
0 - +10
+10 - +20
+20 - +30
+30 - +50
+50 >
2010
Hindcast
Forecast
No additional control
Median ANC (µeq/l)
40
30
20
10
0
-10
1800
1900
2000
2100
2200
Year

Decrease sulfate deposition to preindustrial values



ANC (µeq/l)

- < -10
- -10 - 0
- 0 - +10
- +10 - +20
- +20 - +30
- +30 - +50
- +50 >

2020

Hindcast

Forecast

No additional control

100% sulfate load control

Median ANC (µeq/l)

40

30

20

10

0

-10

1800

1900

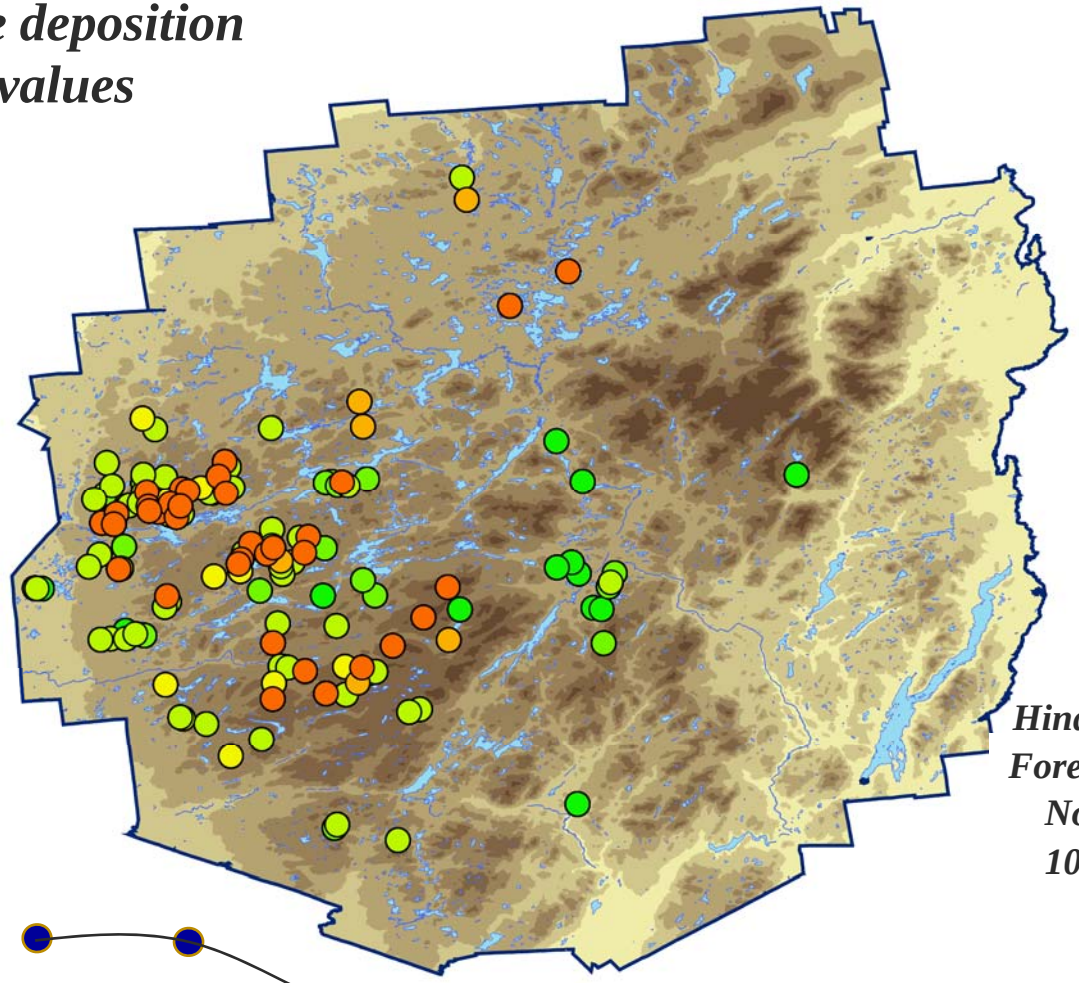
2000

2100

2200

Year

Decrease sulfate deposition to preindustrial values



ANC (µeq/l)

- < -10
- -10 - 0
- 0 - +10
- +10 - +20
- +20 - +30
- +30 - +50
- +50 >

2050

Hindcast

Forecast

No additional control

100% sulfate load control

Median ANC (µeq/l)

40

30

20

10

0

-10

1800

1900

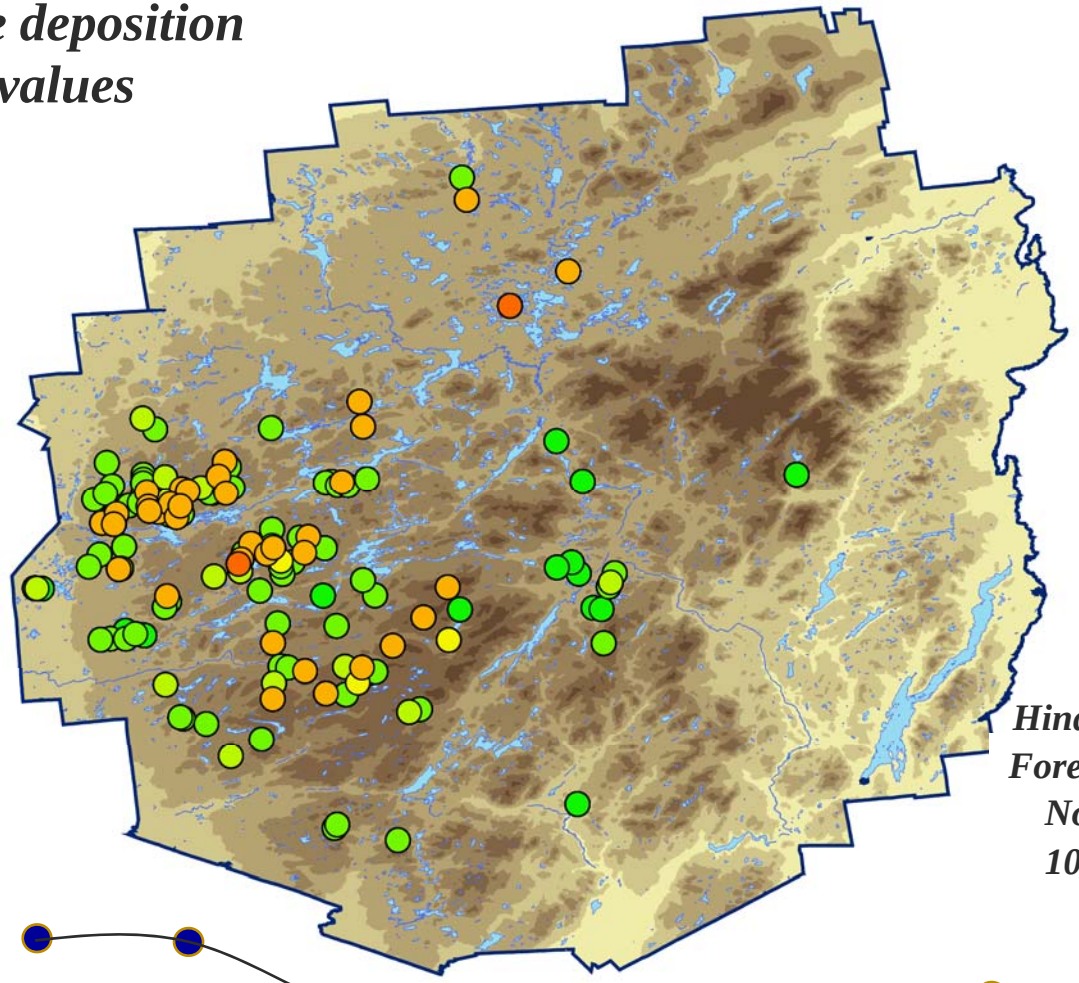
2000

2100

2200

Year

Decrease sulfate deposition to preindustrial values



ANC (µeq/l)

- < -10
- -10 - 0
- 0 - +10
- +10 - +20
- +20 - +30
- +30 - +50
- +50 >

2100

Hindcast

Forecast

No additional control

100% sulfate load control

Median ANC (µeq/l)

40

30

20

10

0

-10

1800

1900

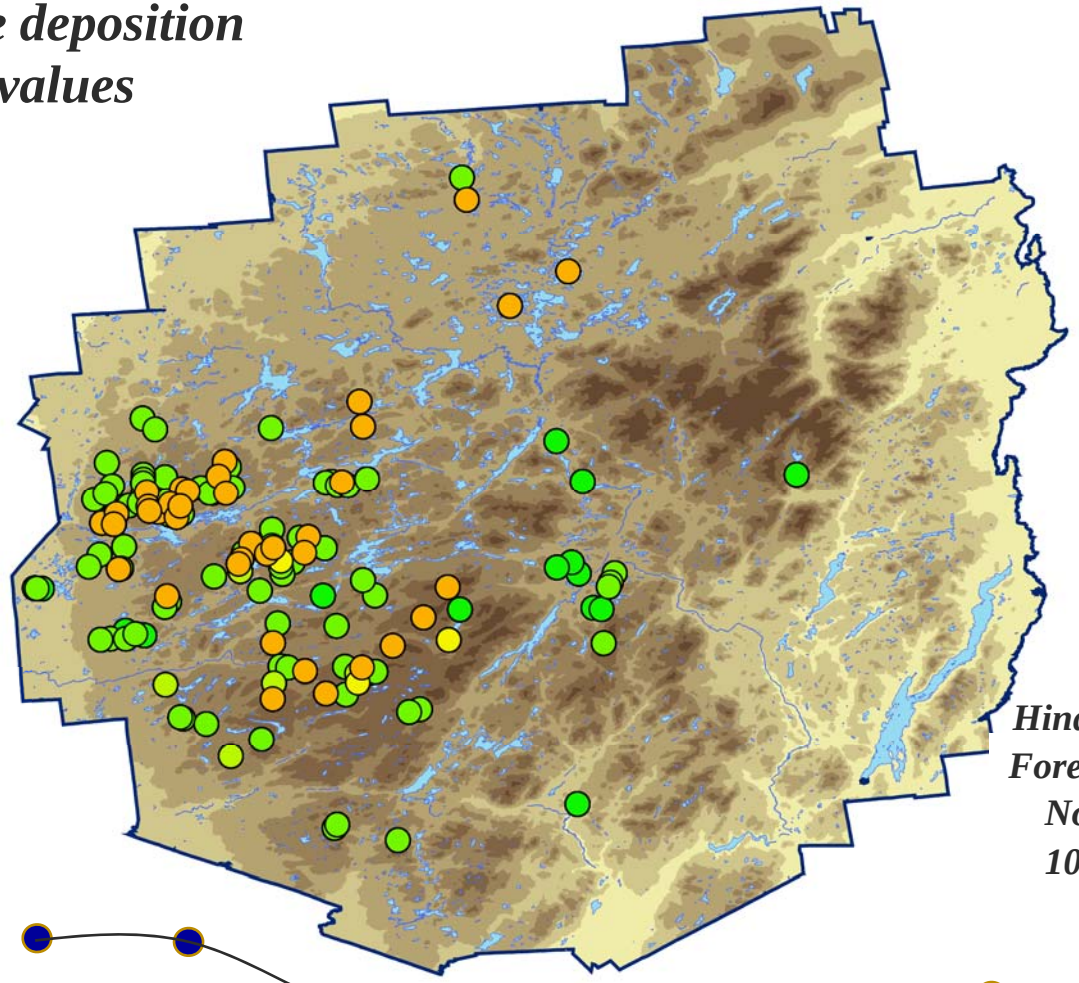
2000

2100

2200

Year

Decrease sulfate deposition to preindustrial values



ANC (µeq/l)

- < -10
- -10 - 0
- 0 - +10
- +10 - +20
- +20 - +30
- +30 - +50
- +50 >

2150

Hindcast

Forecast

No additional control

100% sulfate load control

Median ANC (µeq/l)

40

30

20

10

0

-10

1800

1900

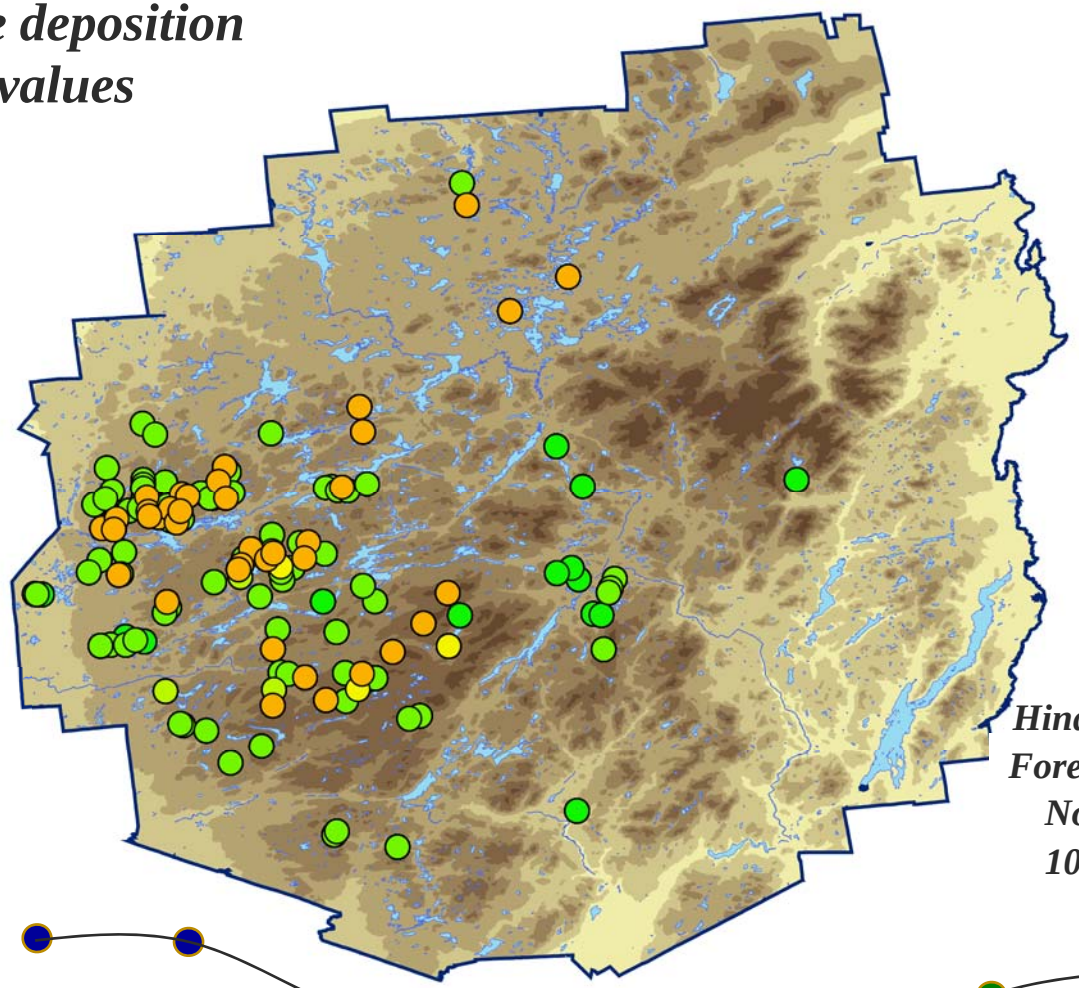
2000

2100

2200

Year

Decrease sulfate deposition to preindustrial values



ANC (µeq/l)

- < -10
- -10 - 0
- 0 - +10
- +10 - +20
- +20 - +30
- +30 - +50
- +50 >

2200

Hindcast

Forecast

No additional control

100% sulfate load control

Median ANC (µeq/l)

40

30

20

10

0

-10

1800

1900

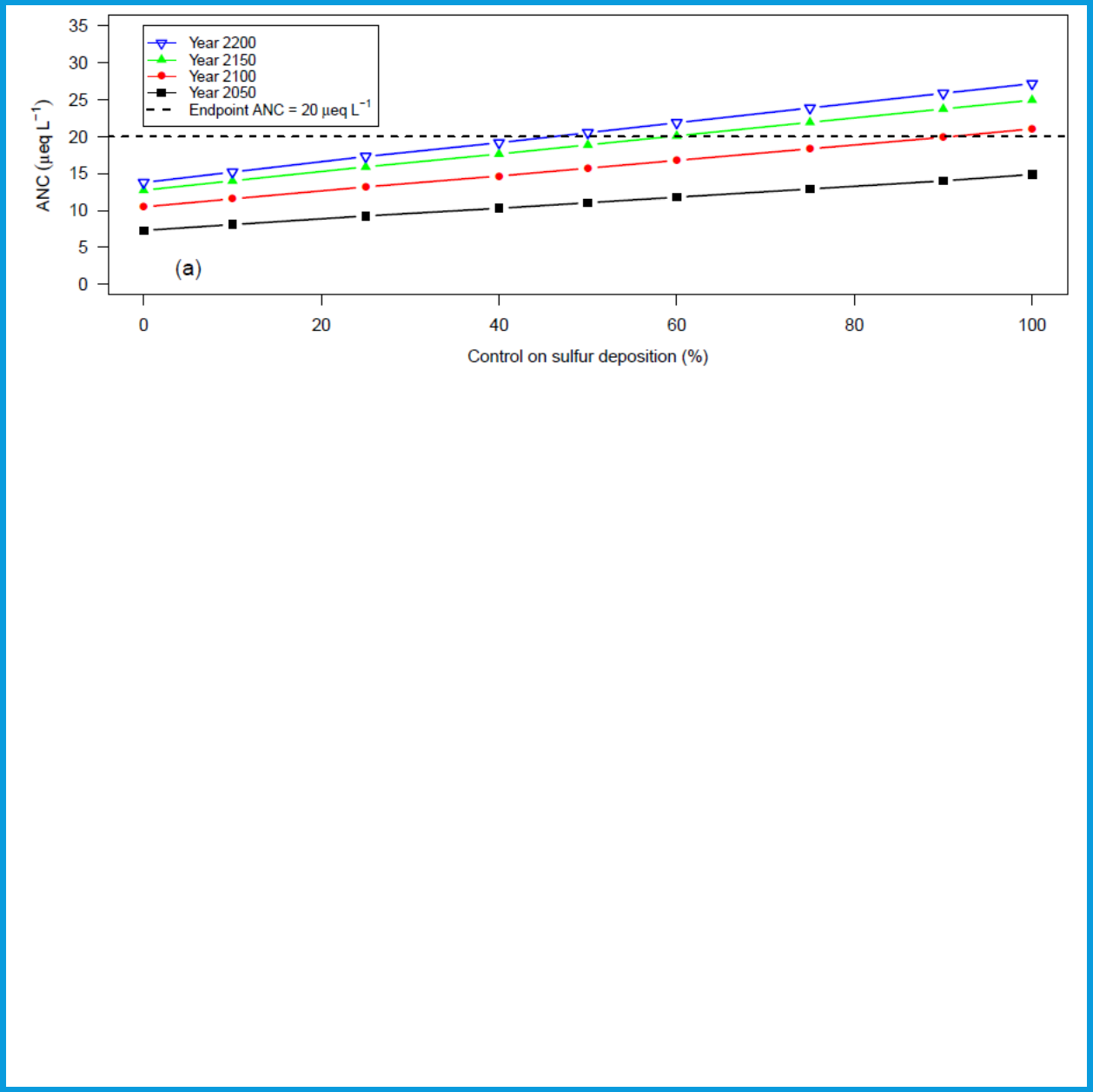
2000

2100

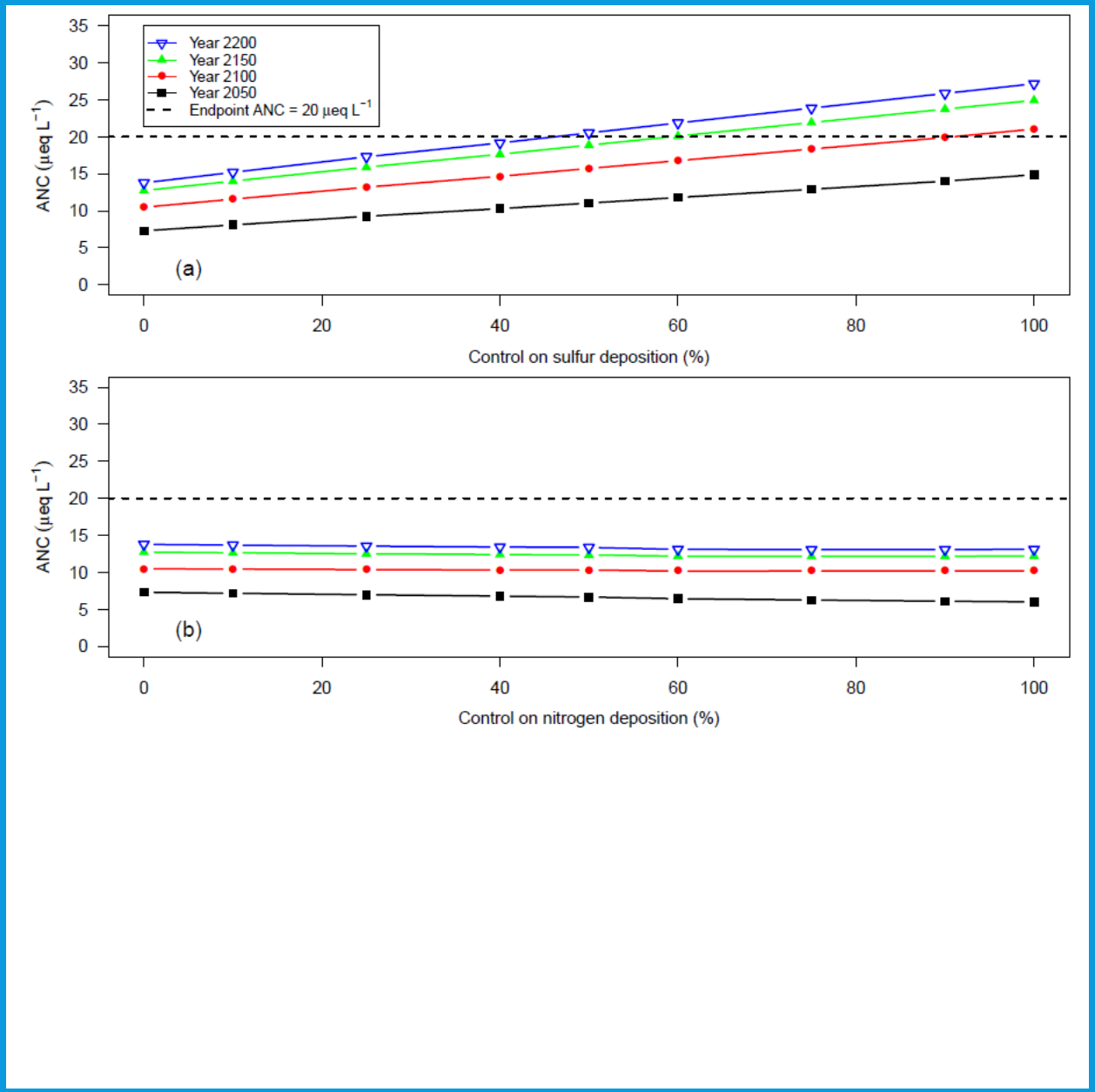
2200

Year

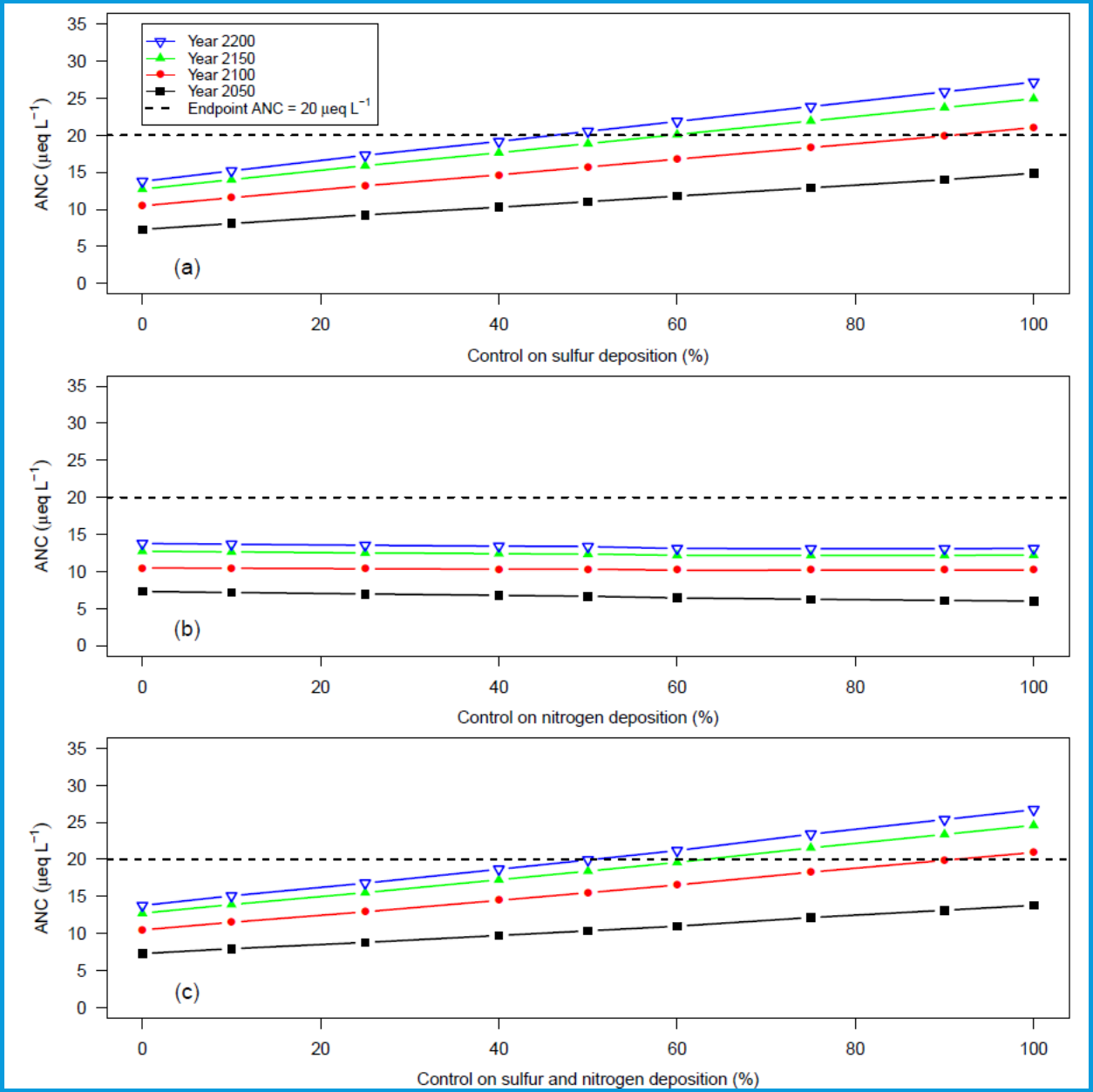
West Pond ANC in response to (a) Sulfur control



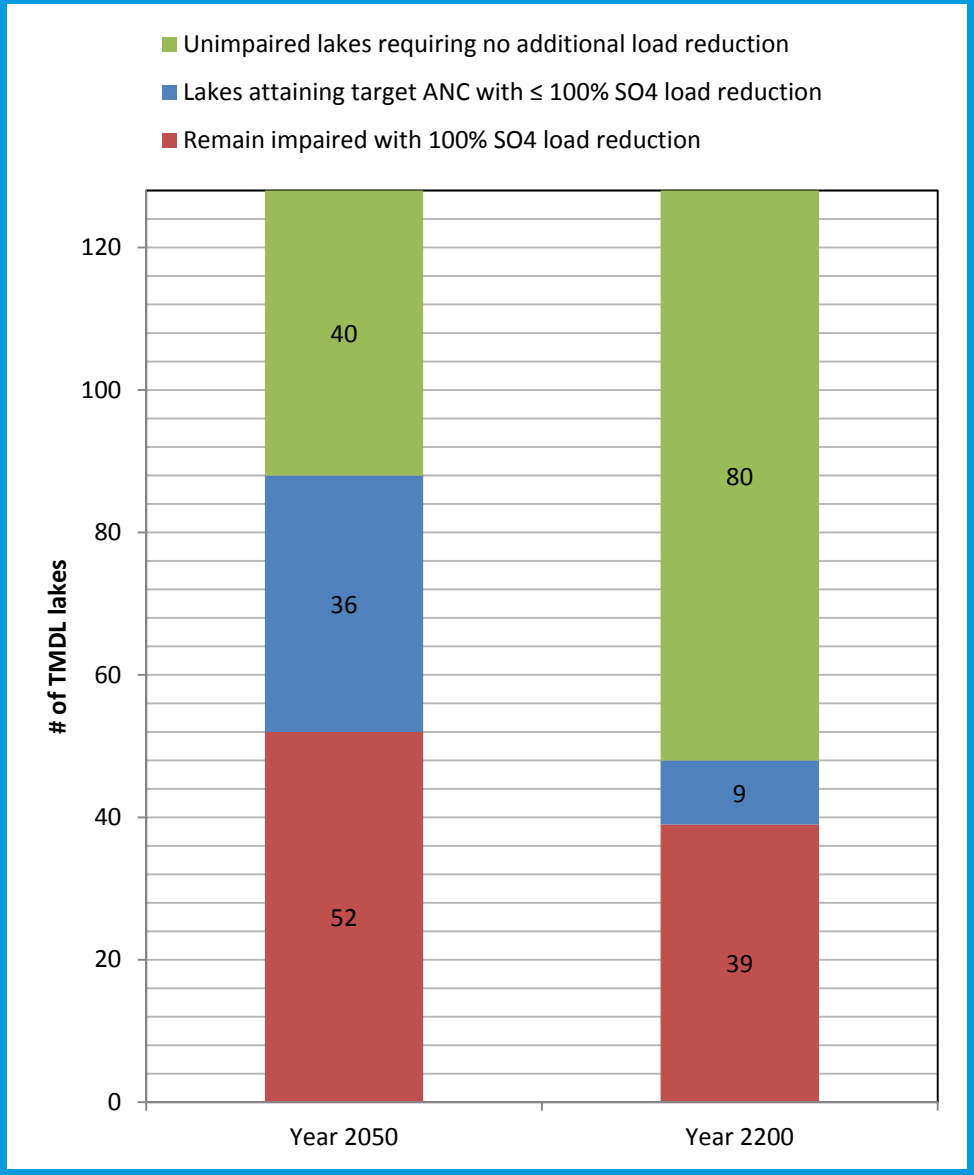
West Pond ANC in response to
(a) Sulfur control
(b) Nitrogen control



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



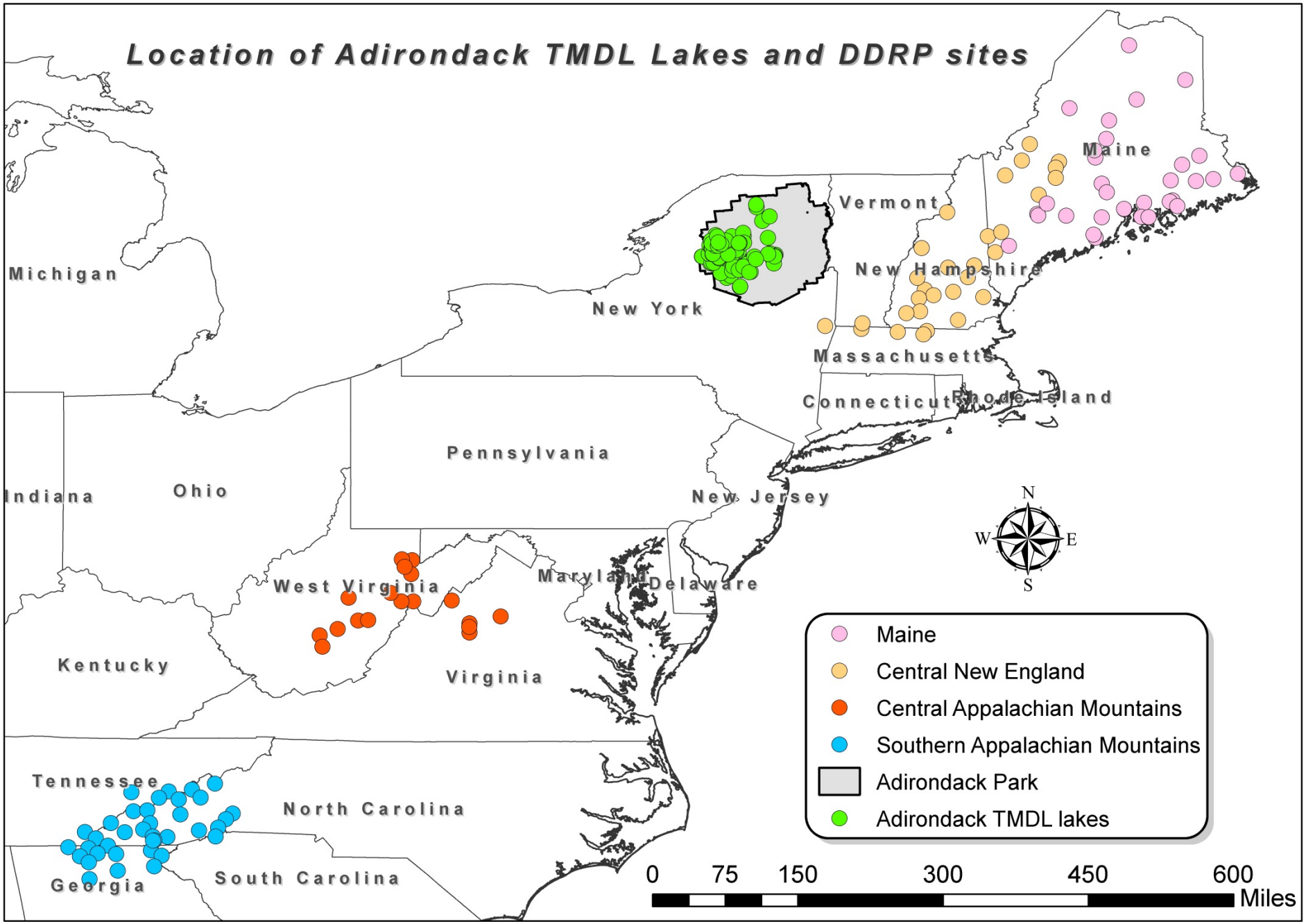
Number of lakes in three categories: not recoverable, recoverable and unimpaired lakes



Endpoint 20 (µeq/l)

FUTURE ACTIVITIES

- Inform additional state TMDL analysis (e.g., TN)
- Inform U.S. EPA review of NO_x-SO_x Secondary Standard
- Evaluate ecological co-benefits of proposed EPA carbon emission rule (111d rule)
- Assess interactions between changing climate and air pollution


Location of Adirondack TMDL Lakes and DDRP sites
Michigan
New York
Vermont
Maine
New Hampshire
Massachusetts
Connecticut
Rhode Island
Pennsylvania
New Jersey
Indiana
Ohio
West Virginia
Maryland
Delaware
Kentucky
Virginia
Tennessee
North Carolina
South Carolina
Georgia
N
W
E
S
Maine
Central New England
Central Appalachian Mountains
Southern Appalachian Mountains
Adirondack Park
Adirondack TMDL lakes
0
75
150
300
450
600
Miles

KEY MESSAGES

- Decreases in lake SO_4^{2-} and NO_3^- are widespread in the Adirondacks in response to decreases in emissions and atmospheric SO_4^{2-} and NO_3^- deposition
- There have been substantial improvements in the acid-base status of lakes in the Adirondacks, but some lakes exhibit increases in DOC which attenuates increases in ANC
- Acid impaired lakes will continue to recovery from current air emission control program, but recovery would be accelerated by additional controls; about a third of lakes impaired by acid deposition will not likely recover without additional mitigation
- TMDLs/ Critical Loads can be important tools to help guide air quality management to protect ecosystems

ACKNOWLEDGEMENTS

- Kim Driscoll, Habibollah Fakhraei, Myron Mitchell, Greg Lampman, Maureen Hale
- National Science Foundation LTER program, New York State Energy Research and Development Authority, U.S. Environmental Protection Agency, New York Department of Environmental Conservation, Adirondack Lakes Survey Corporation


Carl Heilman