Biogeochemical shifts and zooplankton responses in northeastern lakes:

The success of acid recovery, complexity of biological recovery, and value of long-term monitoring

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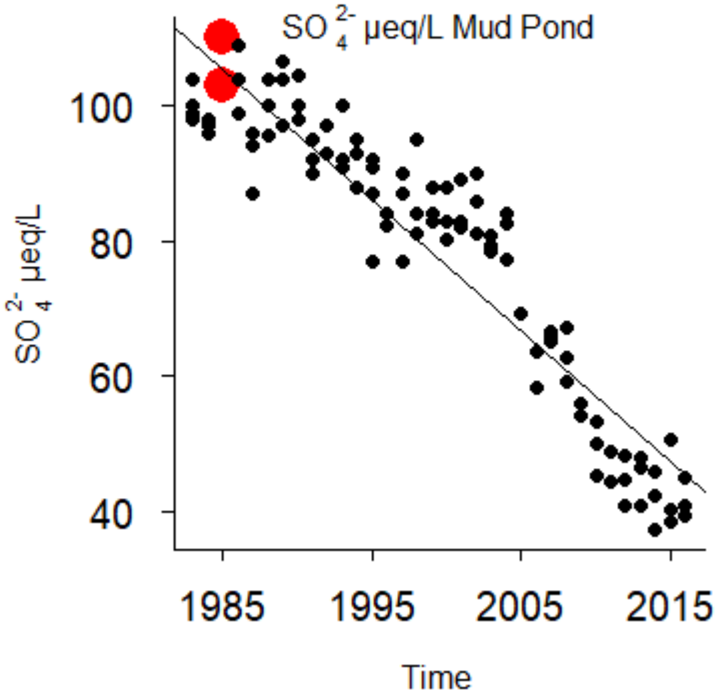
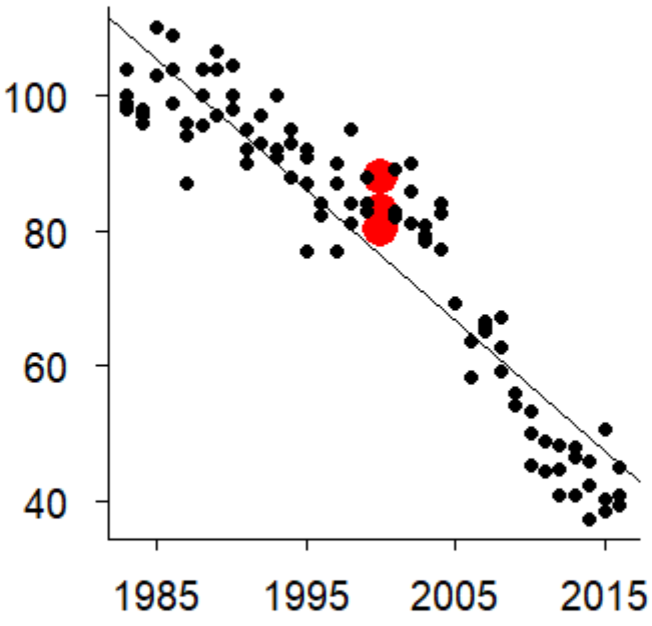
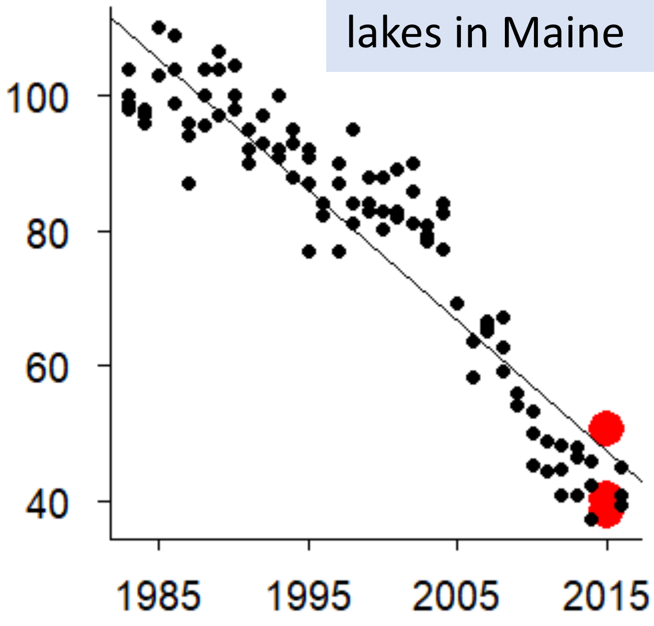
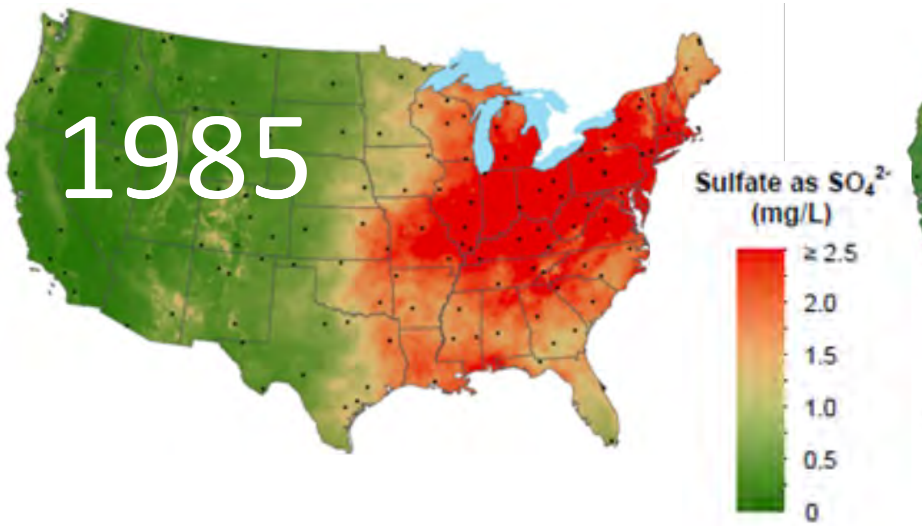
* presenting

US EPA – RLTM
lakes in Maine

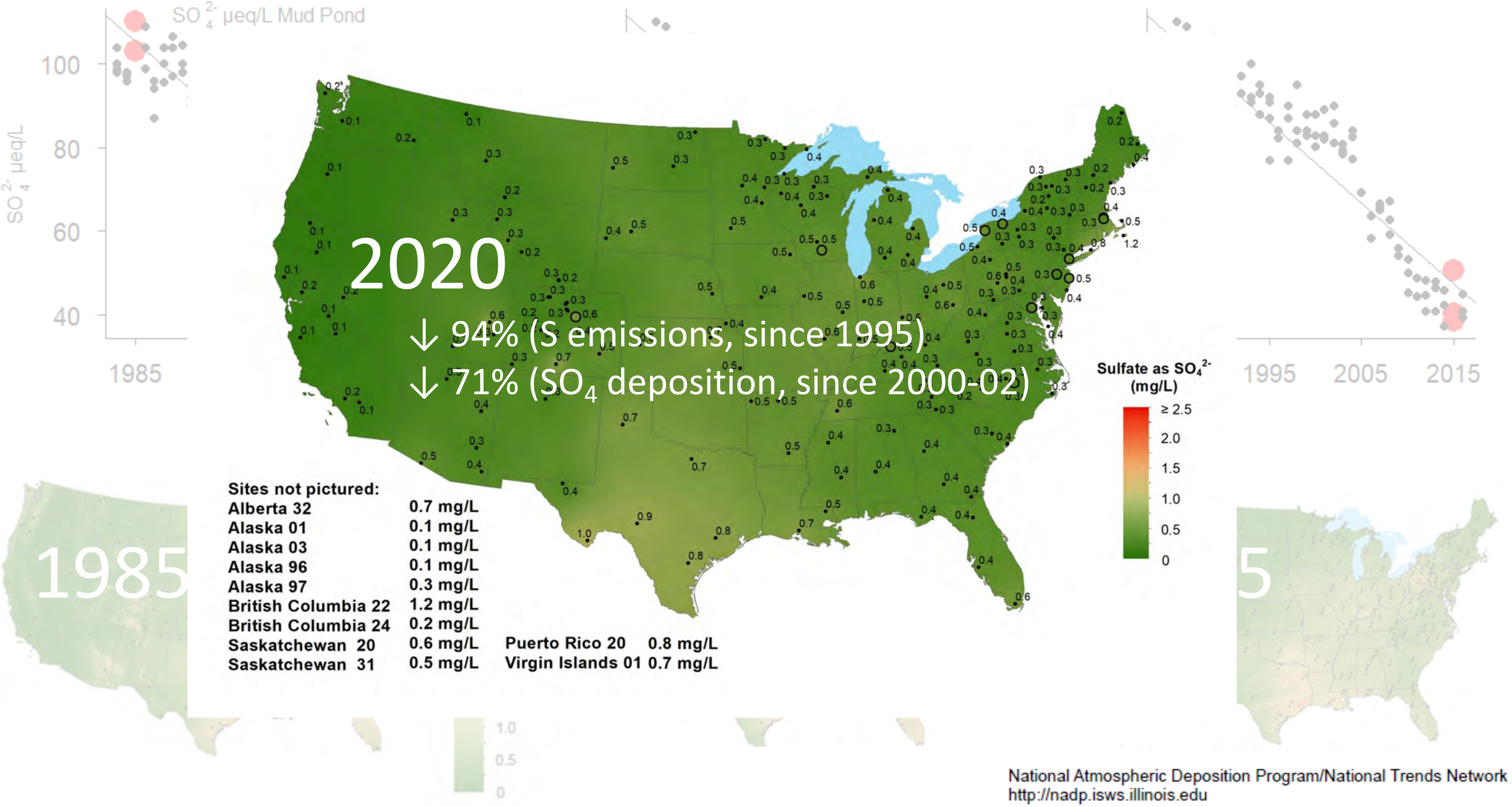






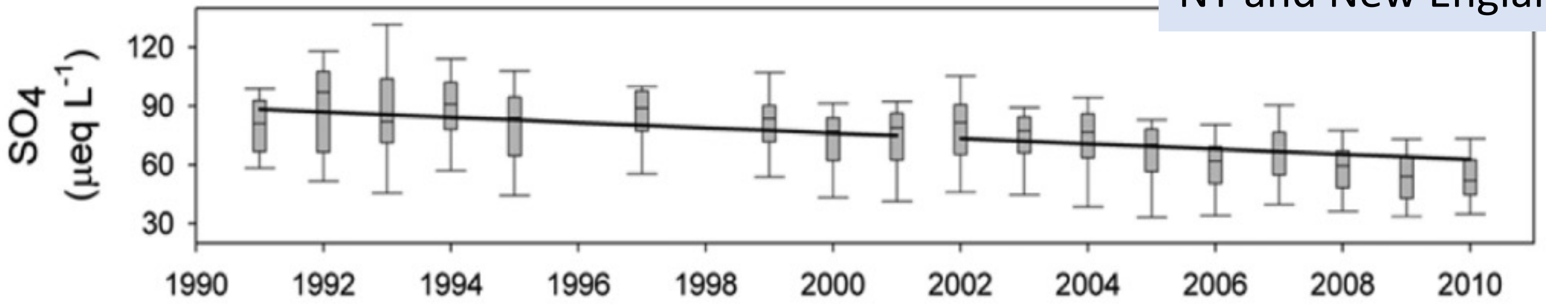


National Atmospheric Deposition Program/National Trends Network
http://nadp.isws.illinois.edu

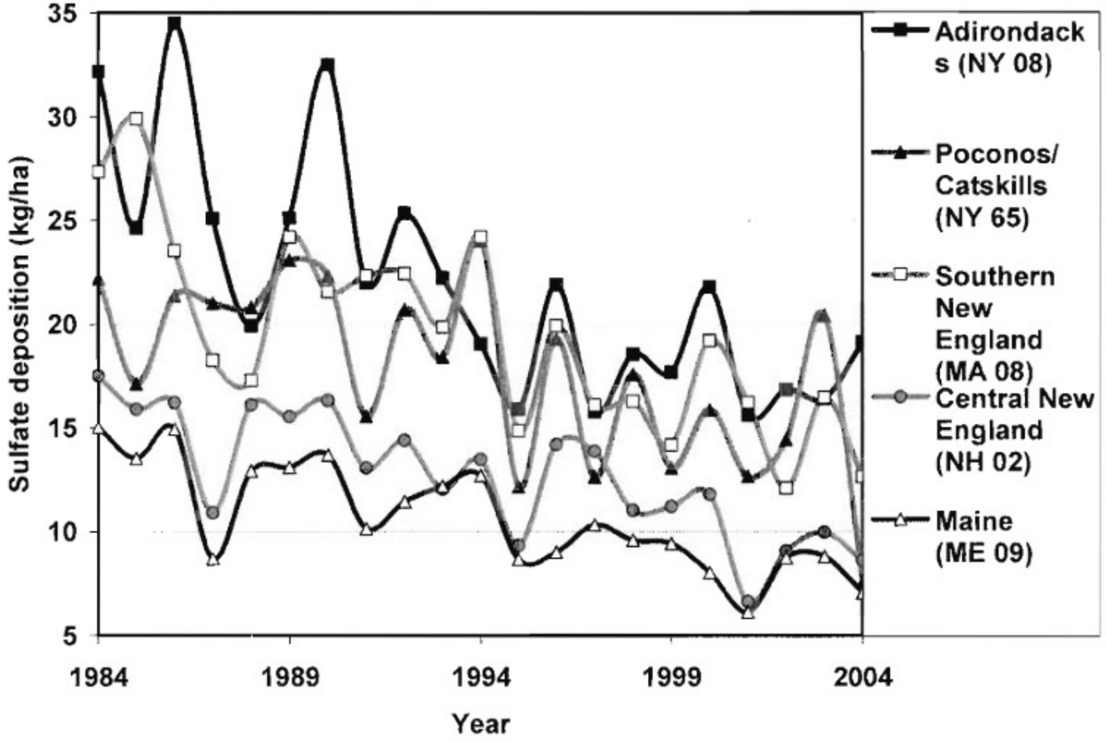

2020
↓ 94% (S emissions, since 1995)
↓ 71% (SO_4 deposition, since 2000-02)
SO_4^{2-} µeq/L Mud Pond
SO_4^{2-} µeq/L
1985
1995
2005
2015
Sulfate as SO_4^{2-} (mg/L)
≥ 2.5
2.0
1.5
1.0
0.5
0
Sites not pictured:
Alberta 32 0.7 mg/L
Alaska 01 0.1 mg/L
Alaska 03 0.1 mg/L
Alaska 96 0.1 mg/L
Alaska 97 0.3 mg/L
British Columbia 22 1.2 mg/L
British Columbia 24 0.2 mg/L
Saskatchewan 20 0.6 mg/L
Saskatchewan 31 0.5 mg/L
Puerto Rico 20 0.8 mg/L
Virgin Islands 01 0.7 mg/L
National Atmospheric Deposition Program/National Trends Network
http://nadp.isws.illinois.edu

EPA monitoring programs have documented reductions in sulfate in Northeastern lakes

US EPA – TIME lakes in NY and New England



US EPA – ELS lakes from PA to Maine



Declining SO_4^{2-} in lakes in New England and the Adirondack region (Strock et al., 2014, Rosfjord 2005)

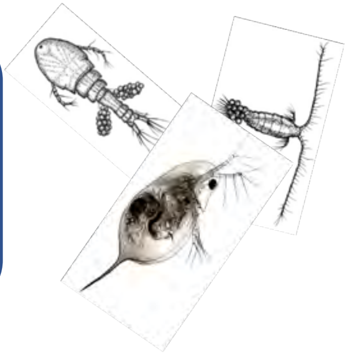

ELS-I:
768 acid sensitive lakes
Chemistry
1984

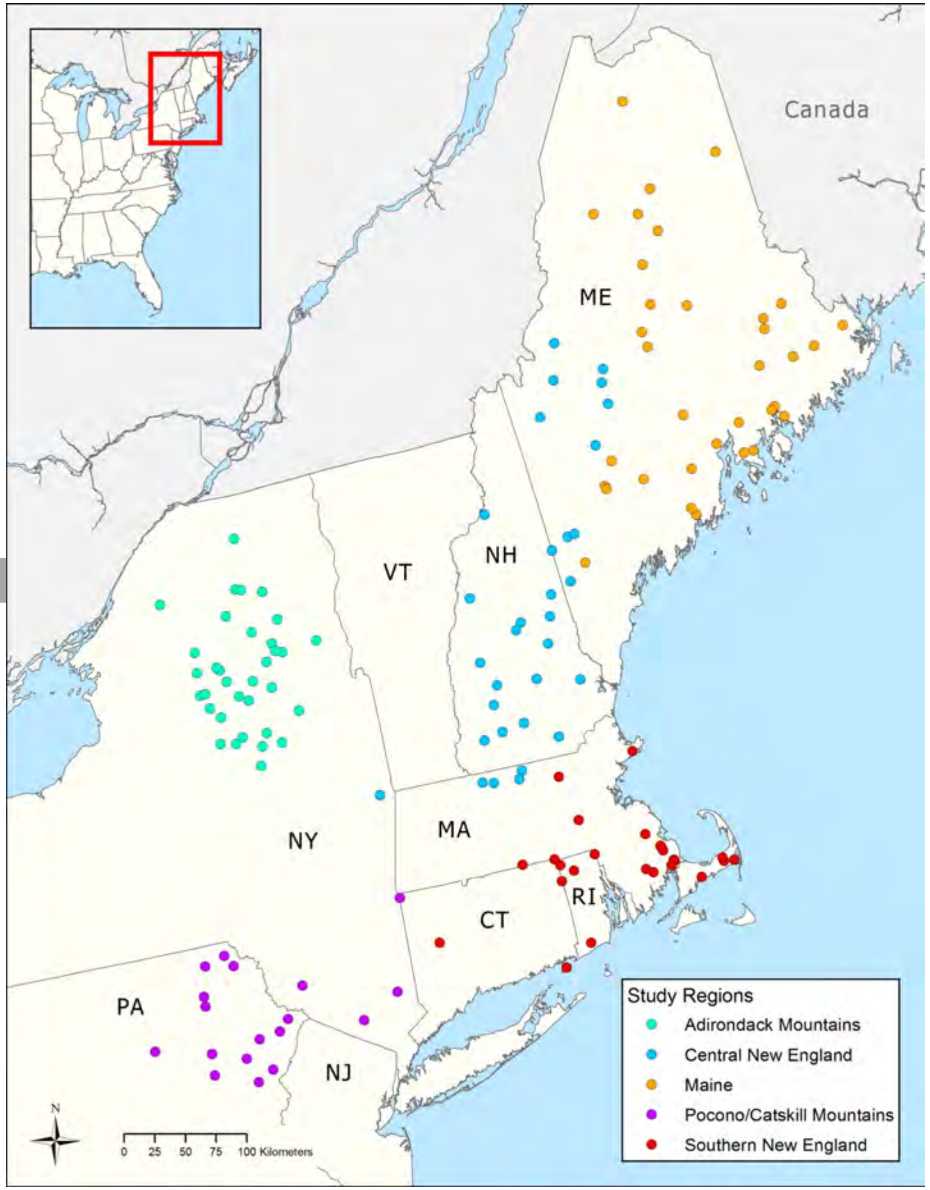
ELS-I:
768 acid sensitive lakes
Chemistry

1986

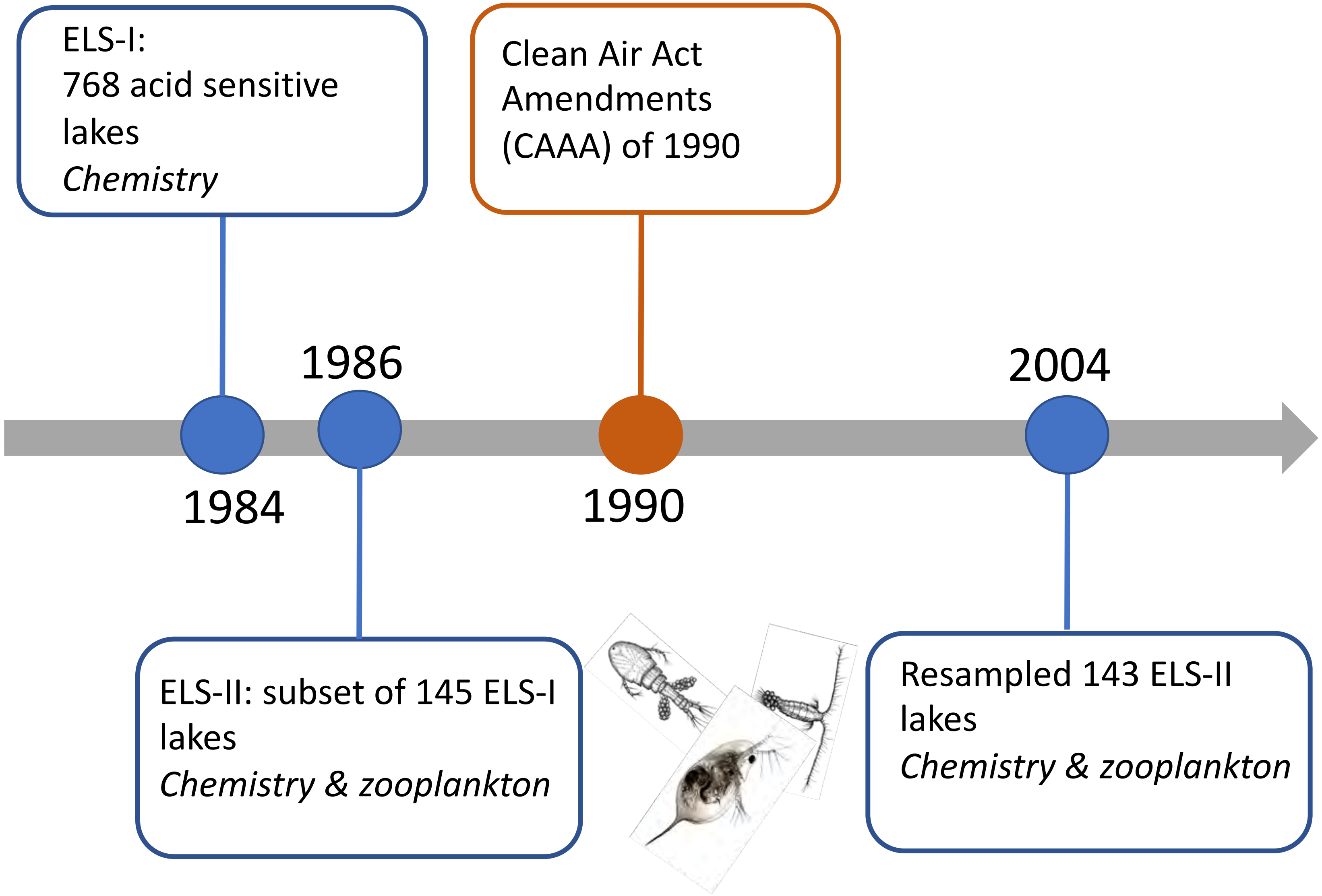
1984

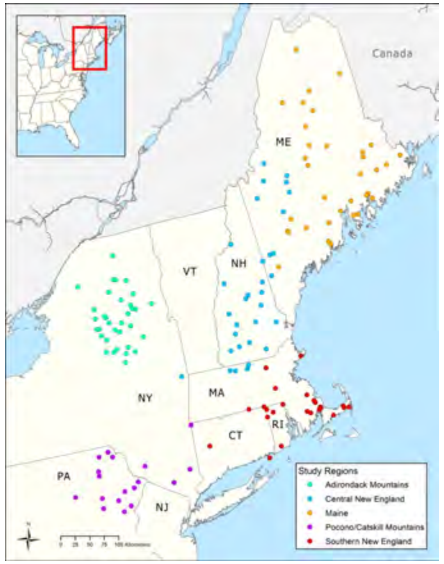
ELS-II: subset of 145 ELS-I lakes
Chemistry & zooplankton





Dykema et al. 2023


ELS-I:
768 acid sensitive lakes
Chemistry
Clean Air Act Amendments (CAAA) of 1990
1986
2004
1984
1990
ELS-II: subset of 145 ELS-I lakes
Chemistry & zooplankton
Resampled 143 ELS-II lakes
Chemistry & zooplankton


Canada
ME
VT
NH
NY
MA
RI
CT
PA
NJ
Study Regions
Adirondack Mountains
Central New England
Maine
Pocono/Catskill Mountains
Southern New England

Salting our freshwater lakes

Hilary A. Dugan[a,b,1], Sarah L. Bartlett[c], Samantha M. Burke[d], Jonathan P. Doubek[e], Flora E. Krivak-Tetley[f],
Nicho
Derek

[a]Center
Freshw
Canada

USGS
science for a changing world

Historical Changes in Lake Ice-Out Dates as Indicators of Climate Change in New England, 1850-2000

Changes in v
supplies and
is studying t
Maine and N
munity, and t

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Water Resources Research

RESEARCH ARTICLE

10.1029/2017WR020963

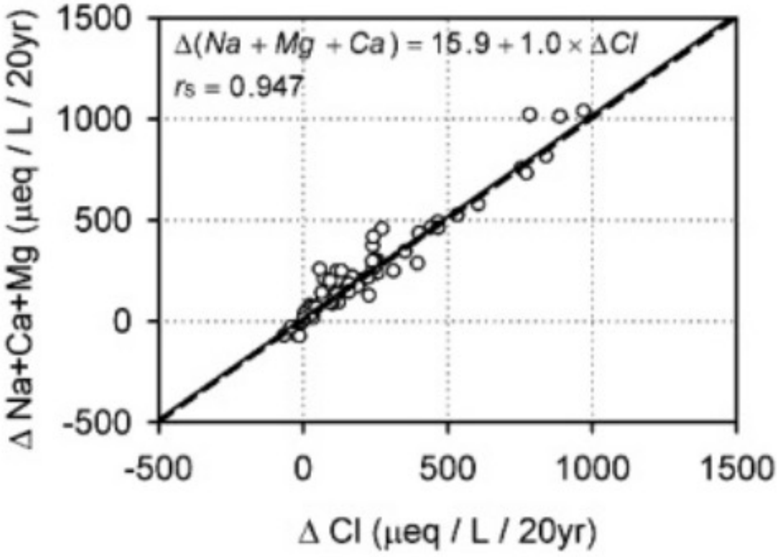
Acidification and Climate Linkages to Increased Dissolved Organic Carbon in High-Elevation Lakes

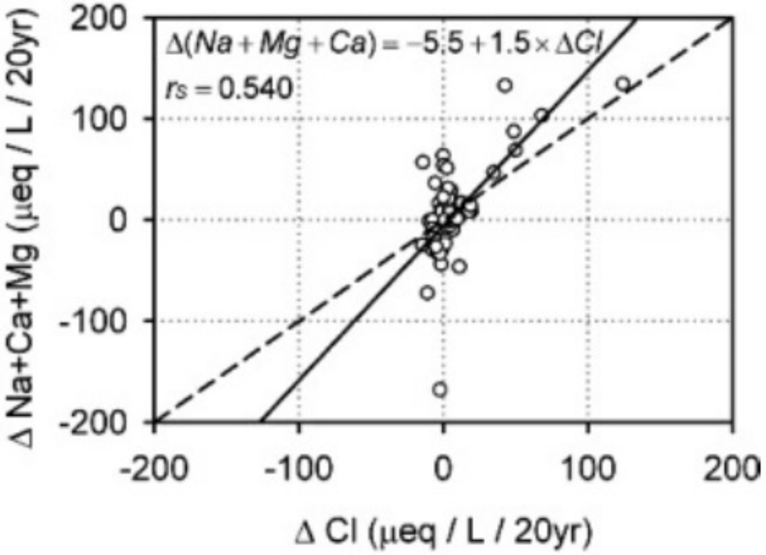
A. L. Gavin[1], S. J. Nelson[1,2], A. J. Klemmer[1,3], I. J. Fernandez[2,4], K. E. Strock[5], and W. H. McDowell[6]

[1]Ecology and Environmental Sciences, University of Maine, Orono, ME, USA, [2]School of Forest Resources, University of Maine, Orono, ME, USA, [3]School of Biology and Ecology, University of Maine, Orono, ME, USA, [4]Climate Change Institute, University of Maine, Orono, ME, USA, [5]Environmental Science Department, Dickinson College, Carlisle, PA, USA

Special Section:
Responses to Environmental Change in Aquatic Mountain Ecosystems

ELS Lakes: Anthropogenic sources of salt complicates regional patterns of recovery from acidification



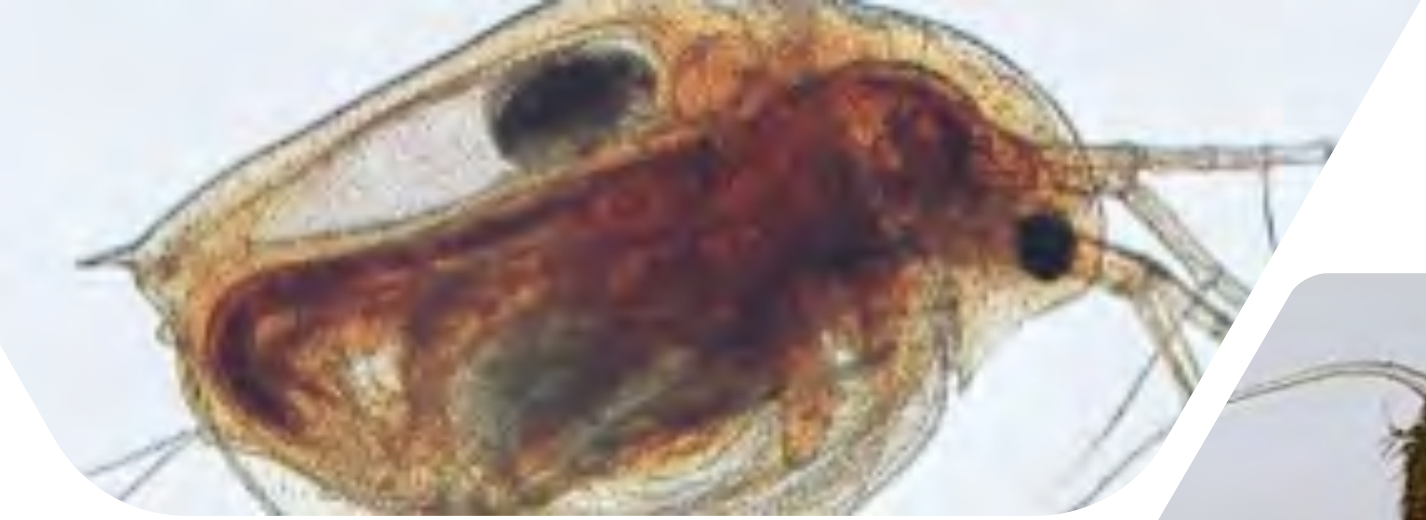


Rosfjord et al., 2007

Anthropogenic sources of salt complicates regional patterns of recovery from acidification

- Cation exchange in soil releases Ca + Mg to lakes
- Ca + Mg base cations buffer acidity

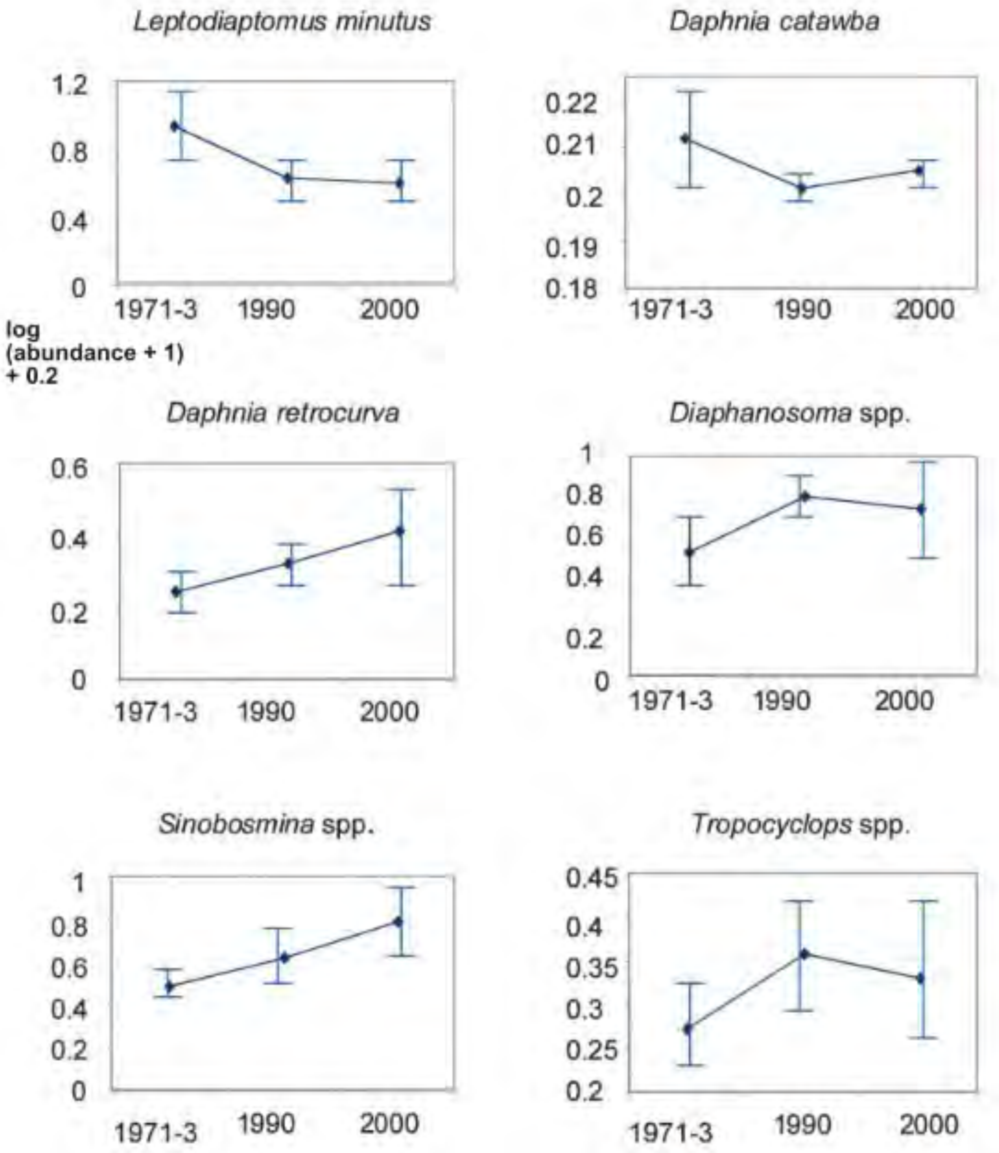
Huffpost.com



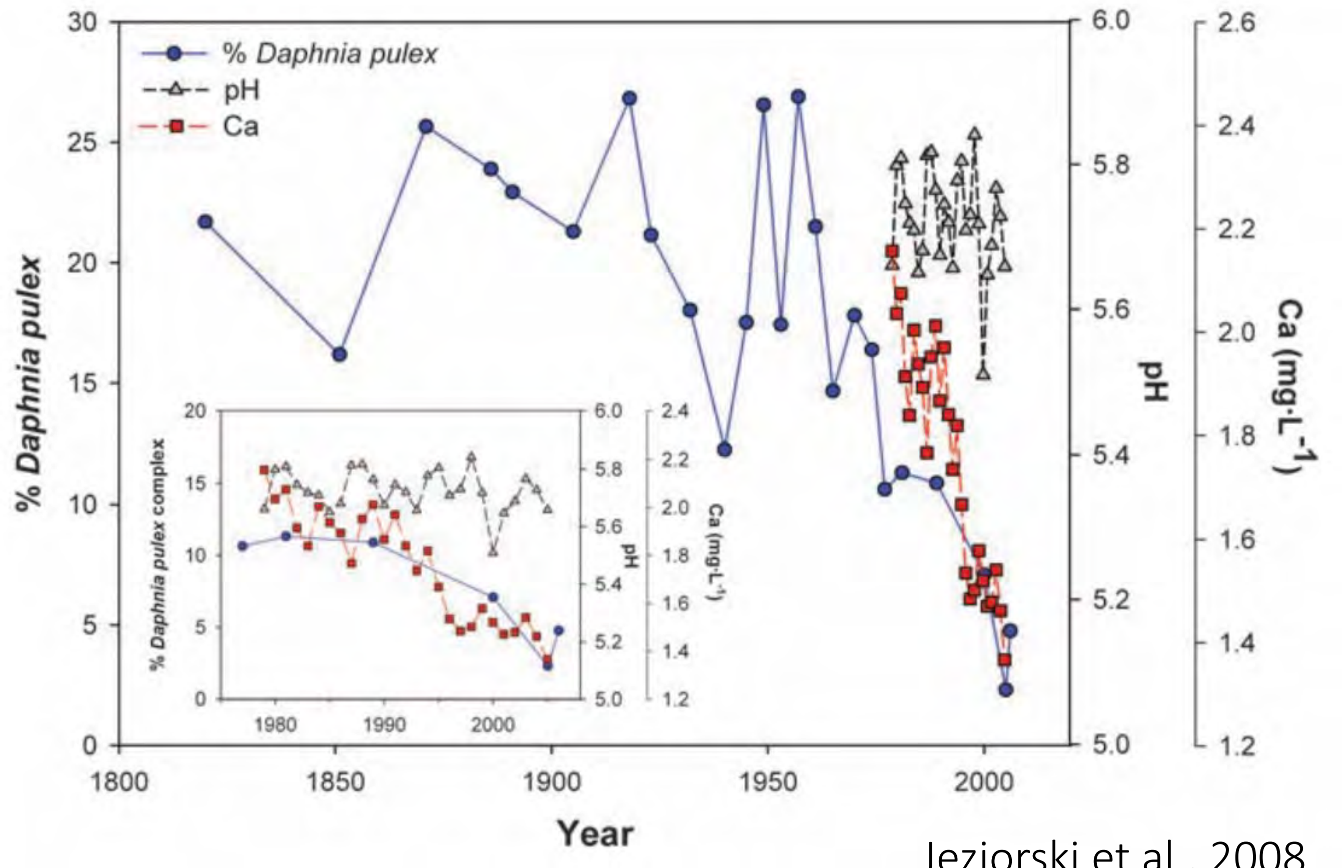
What about zooplankton?

Zooplankton communities shift in response to acid recovery

Holt & Yan, 2003

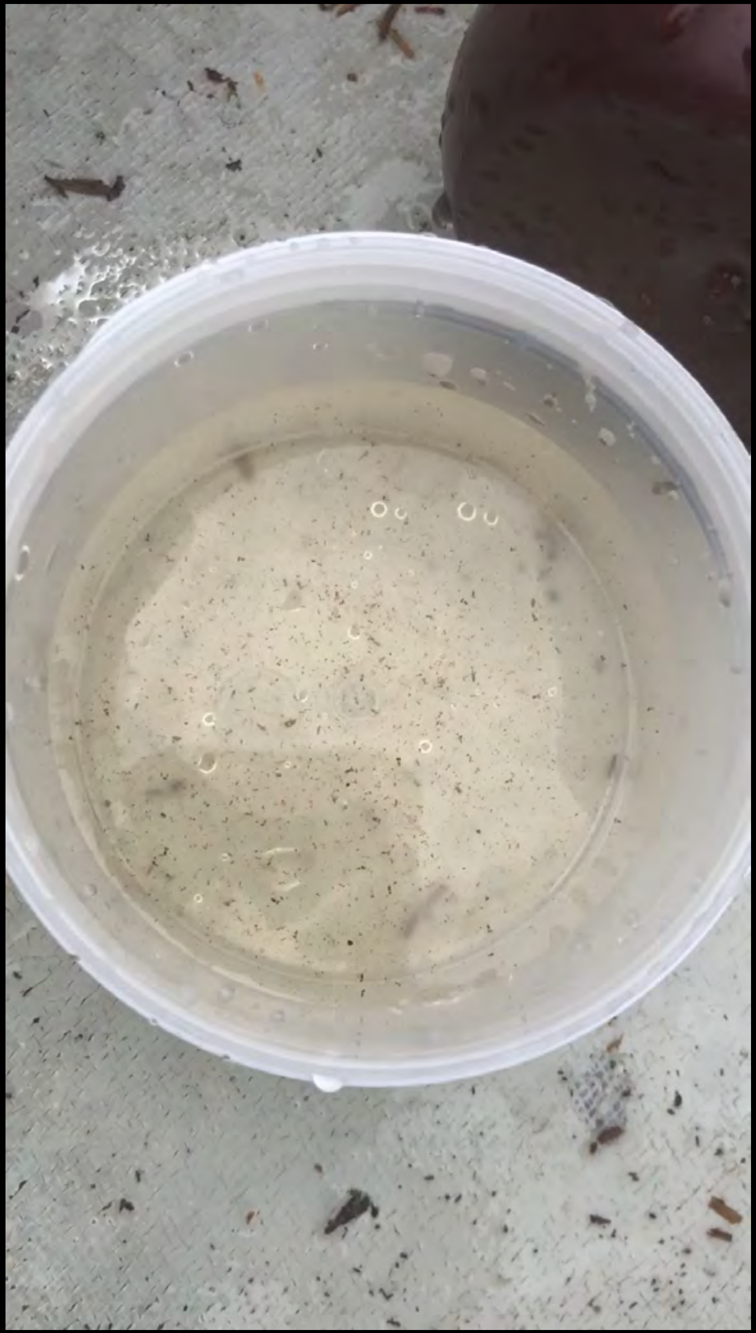


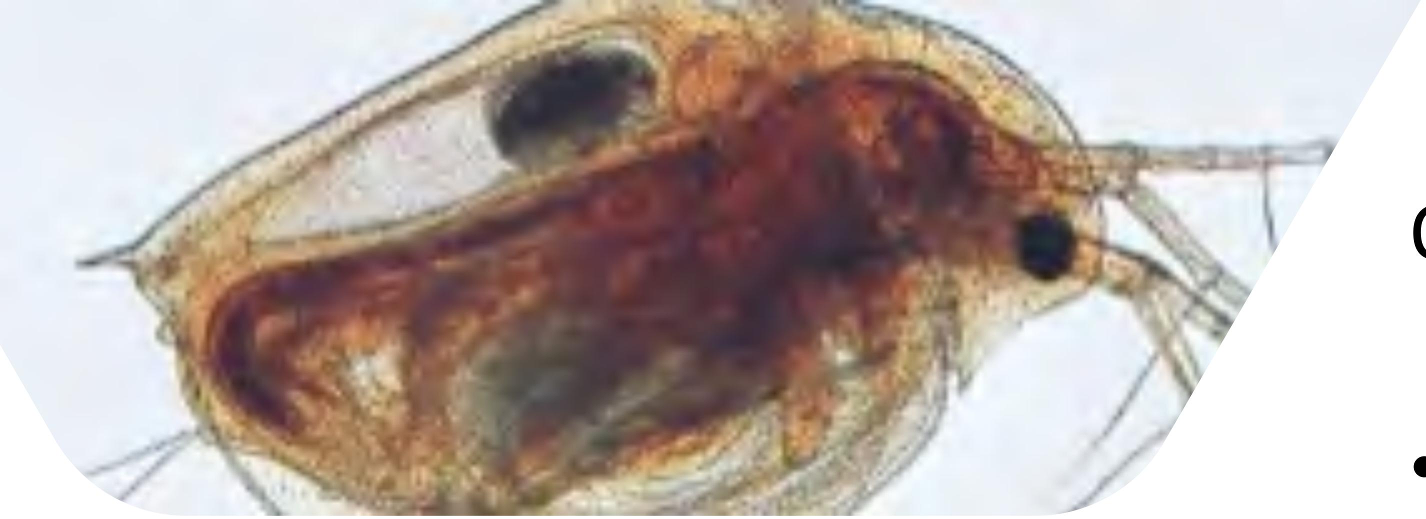
Cladoceran species have high Calcium requirements



Jeziorski et al., 2008

- Vertical zooplankton tows from 143 lakes in the Northeast in 1986 and 2004
- Abundance counts and body length estimates

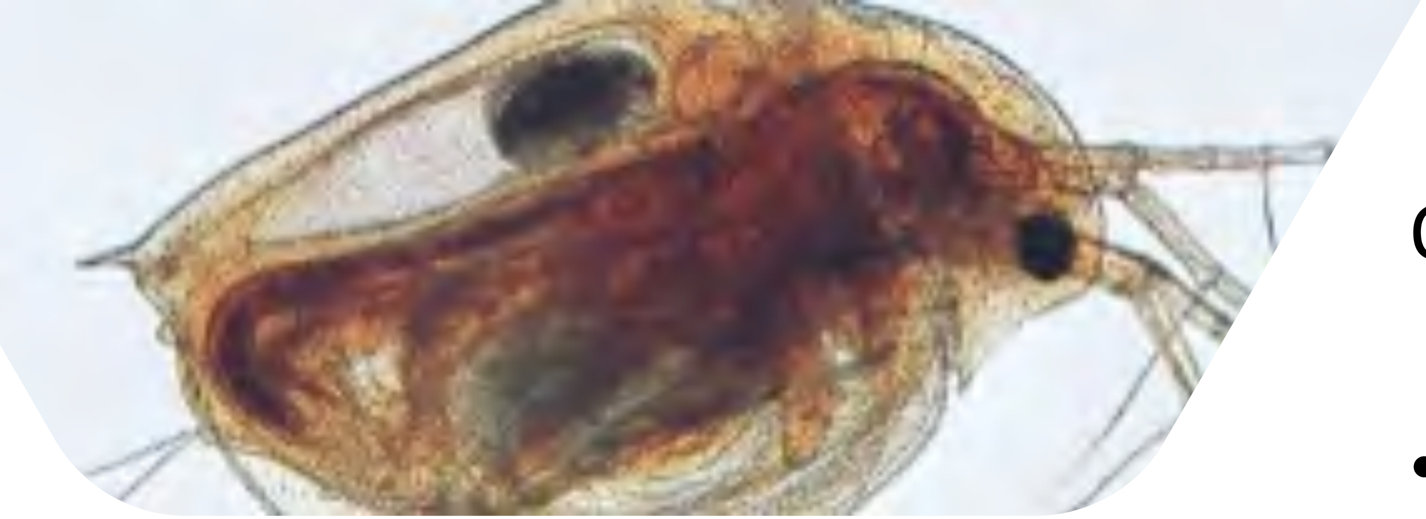




Questions:

- Did zooplankton body size increase?
  - Were increases driven by biogeochemistry?

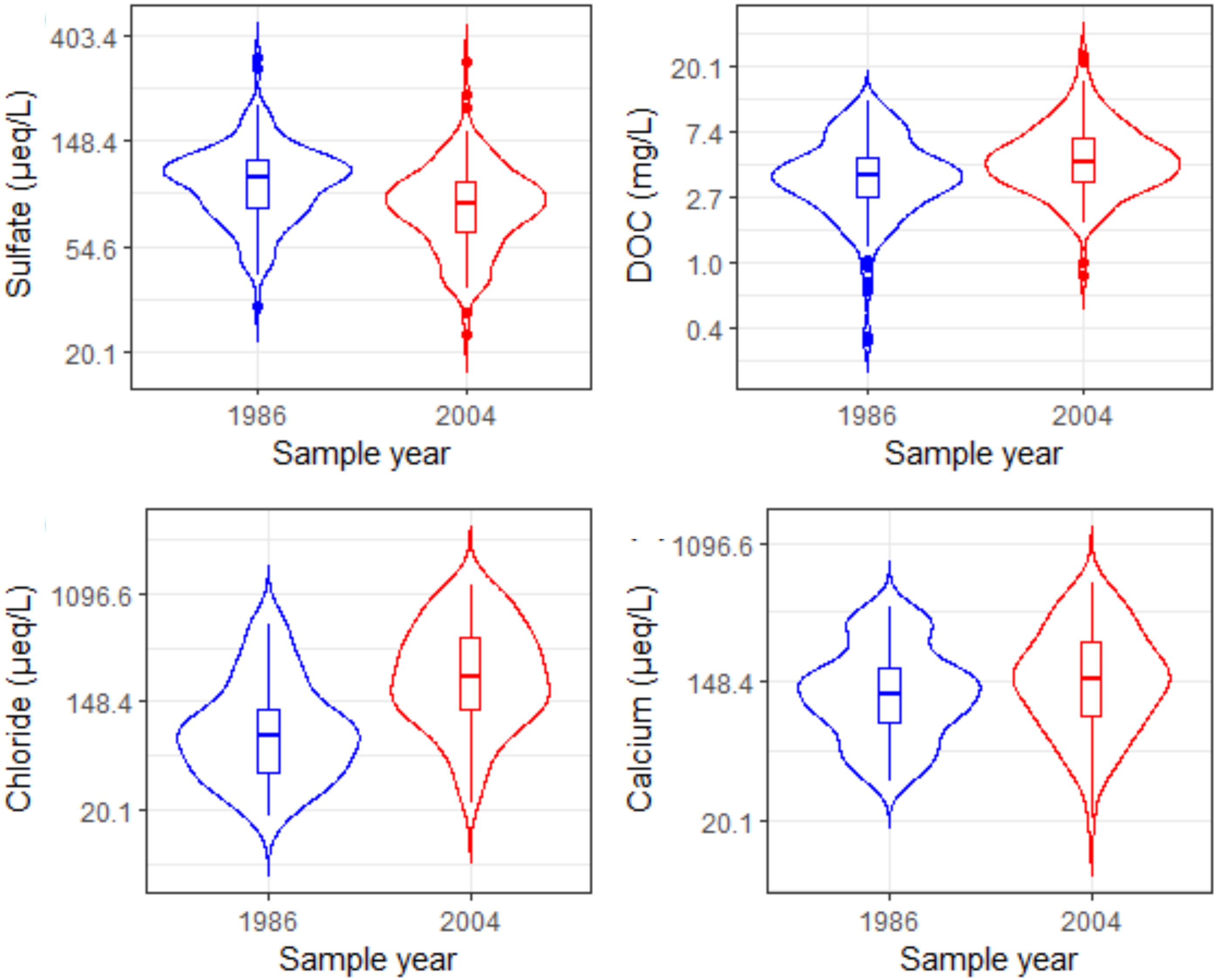
Body size ~ ANC, pH, DOC, Ca + Mg, Cl, SO_4^{2-}



Questions:

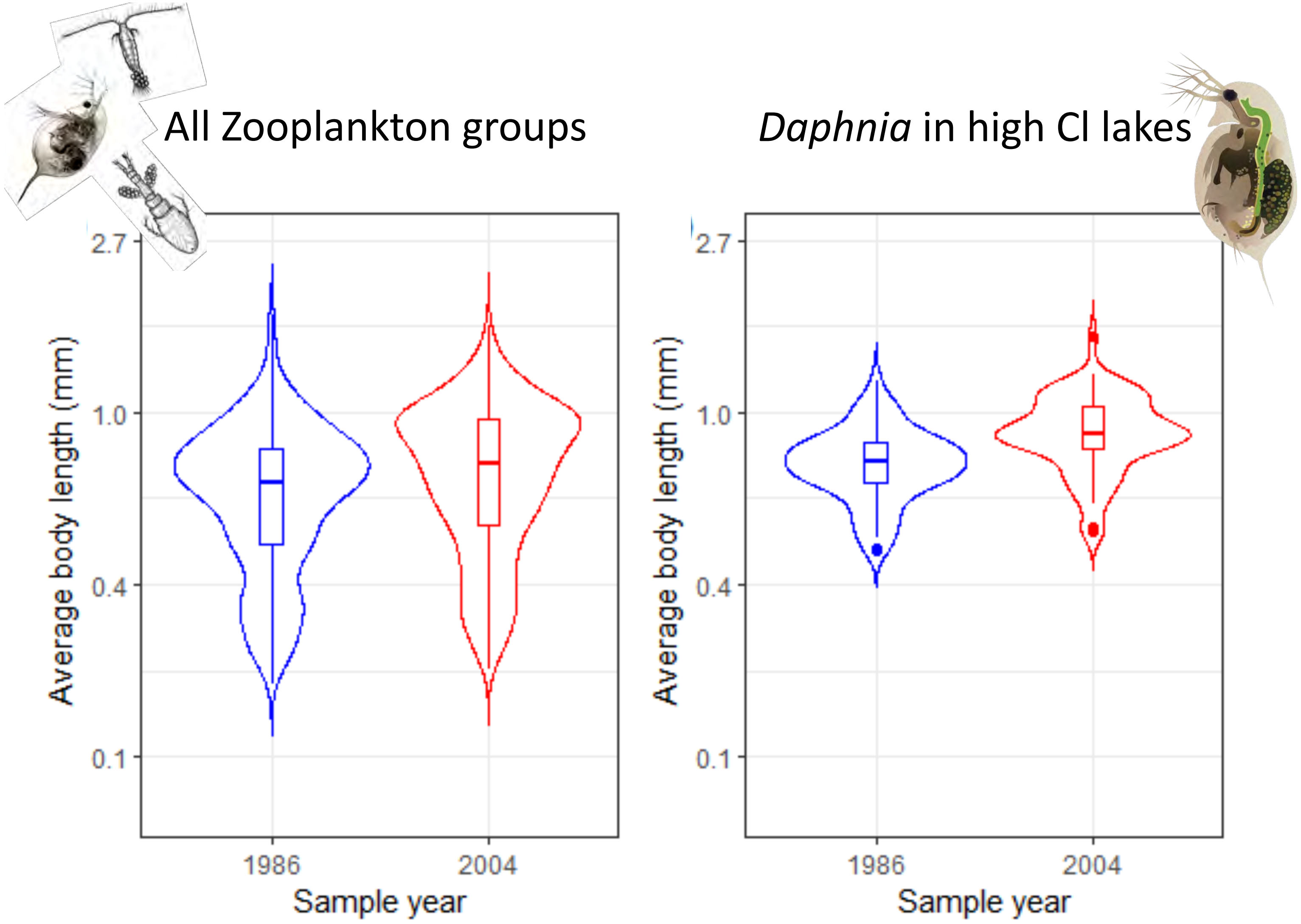
- Was community composition driven by variability in water chemistry?
  - NMDS
  - ANOSIM
  - Mantel
  - Indicator species test

Geochemistry shifted between 1986 and 2004 ($p < 0.001$)



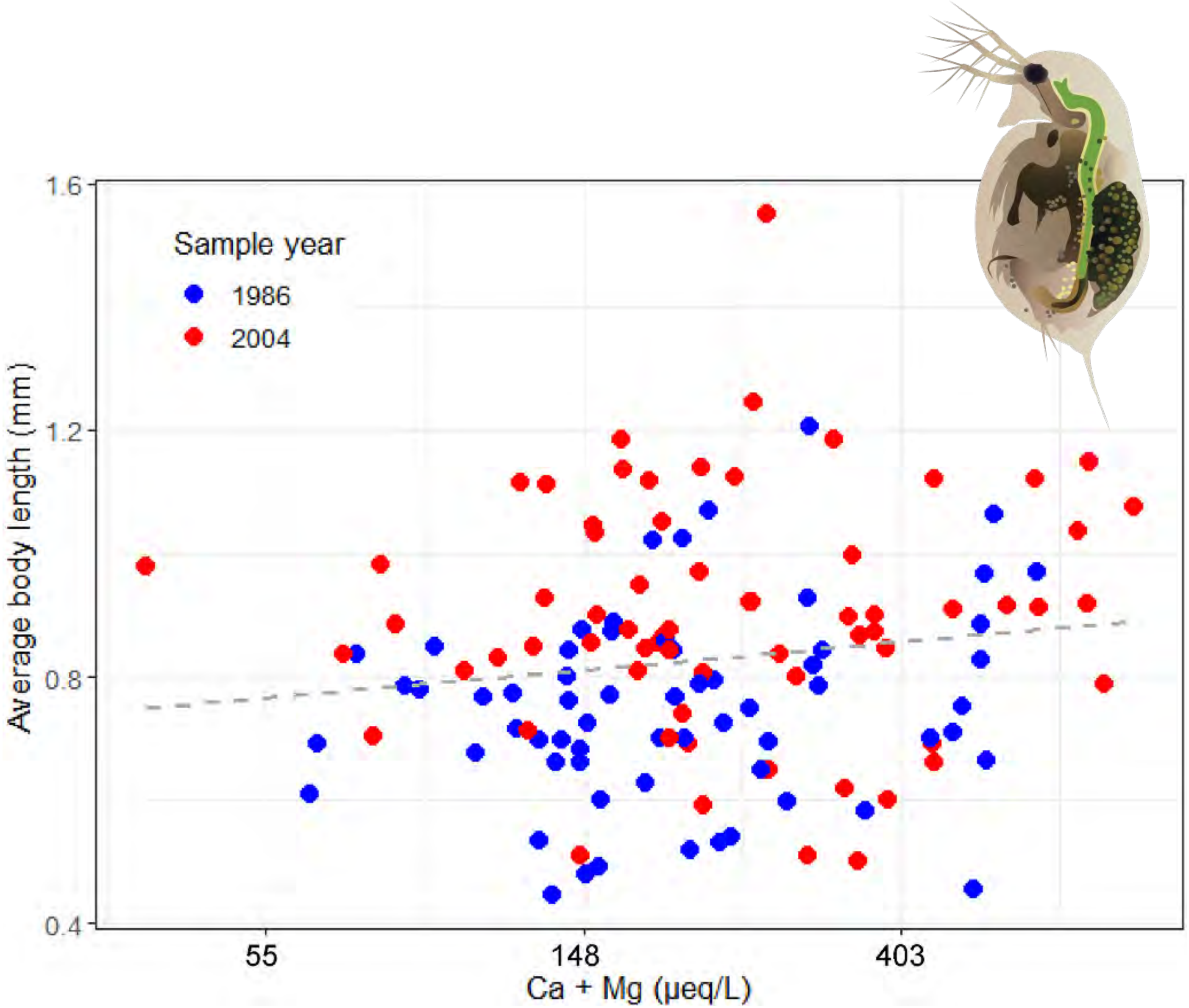
Did zooplankton body size increase?

Average body lengths **increased** significantly from between 1986 and 2004 ($p<0.001$)



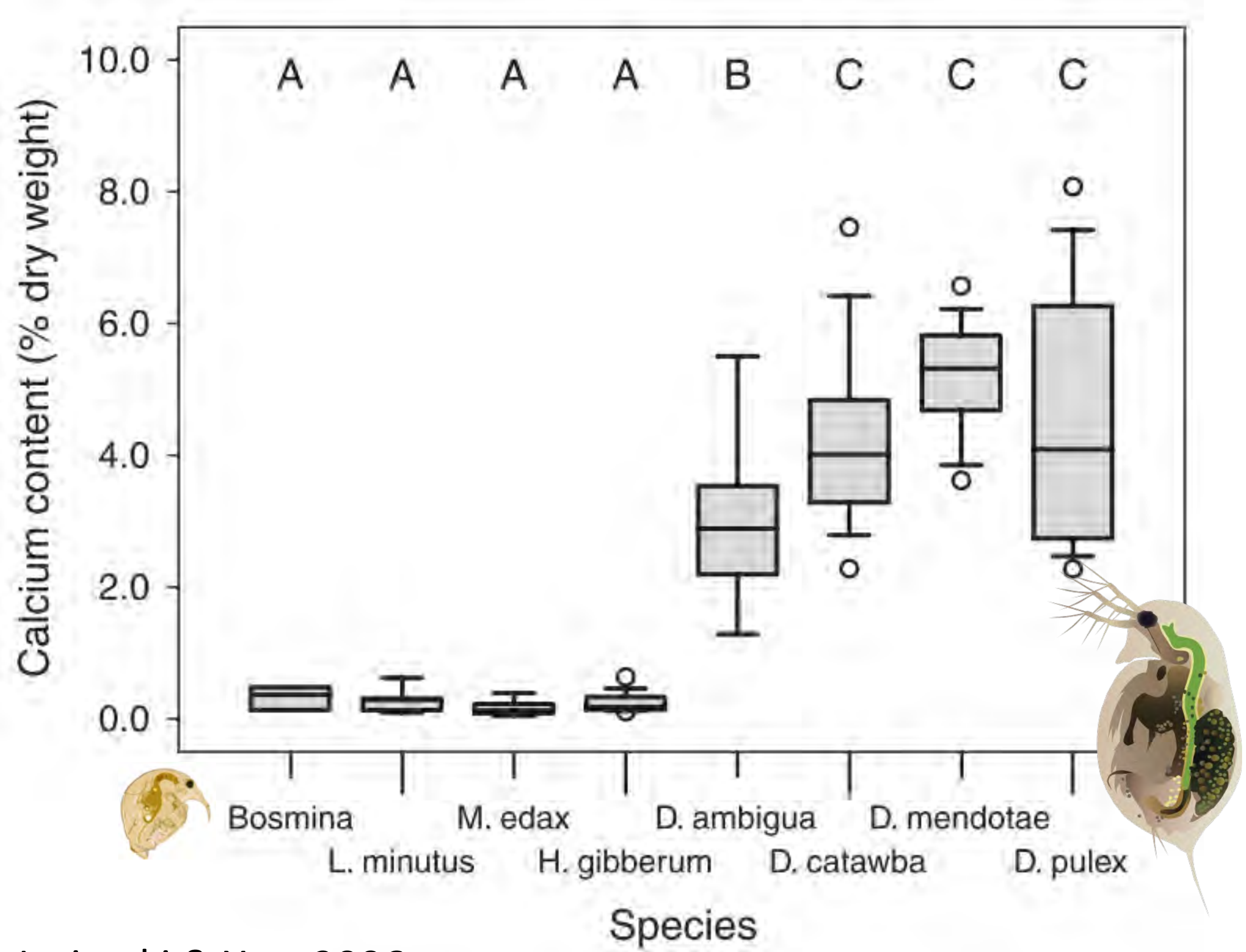
Were increases driven by biogeochemistry?

Variability in **Ca + Mg** explains variability in *Daphnia spp.* ($p<0.1$) in salt affected lakes



Larger bodied *Daphnia* species have higher Ca requirements than smaller bodied *Daphnia*

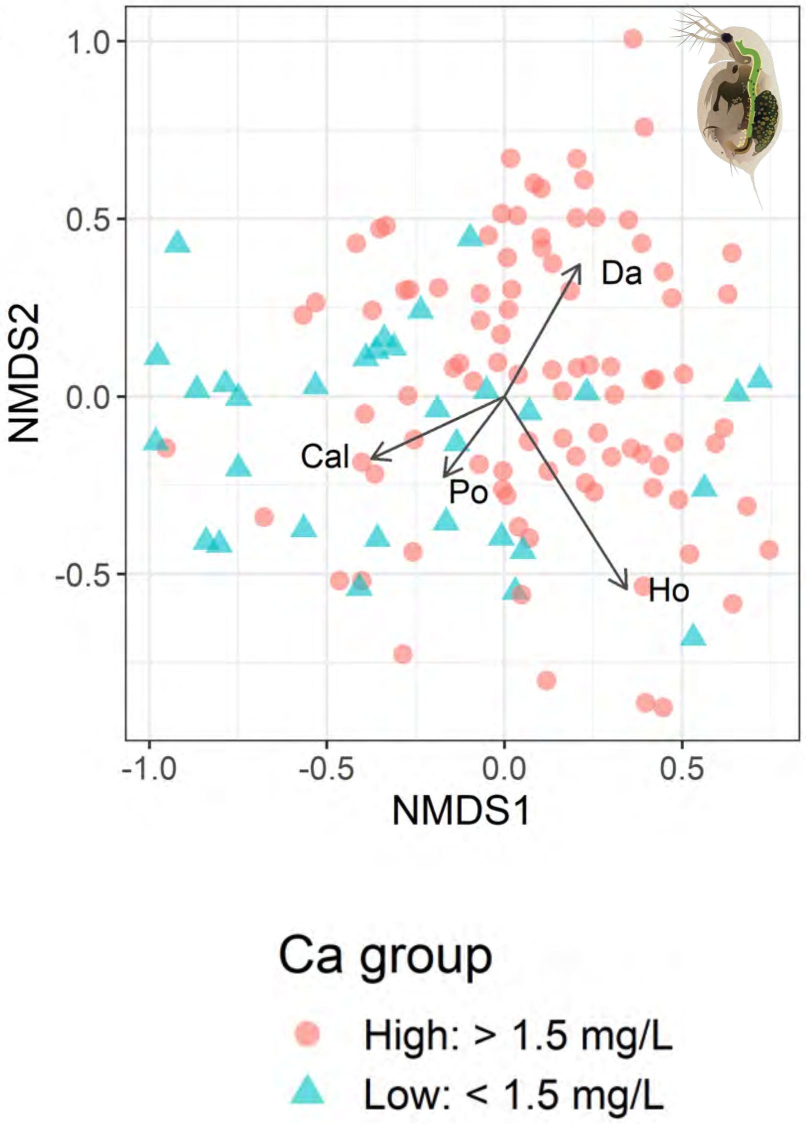
Calcium content of zooplankton species



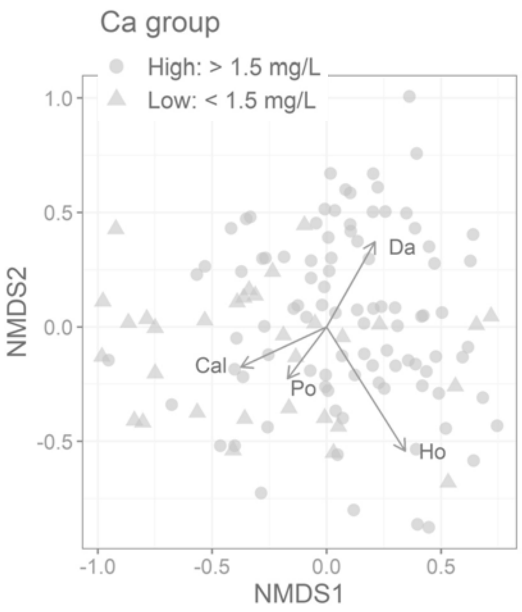
Jeziorski & Yan, 2006

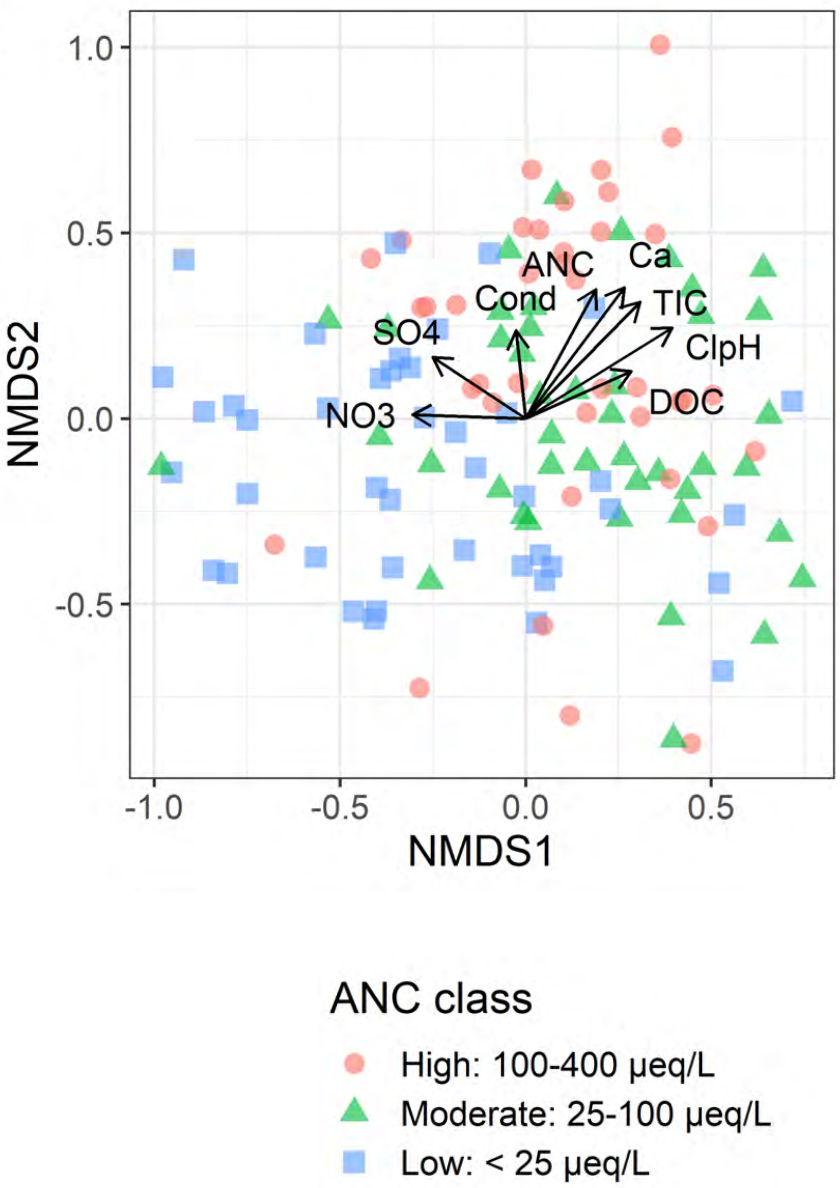
Was community composition driven by variability in water chemistry?

Ca drives variation in community and *Daphnia* are associated with high Ca sites



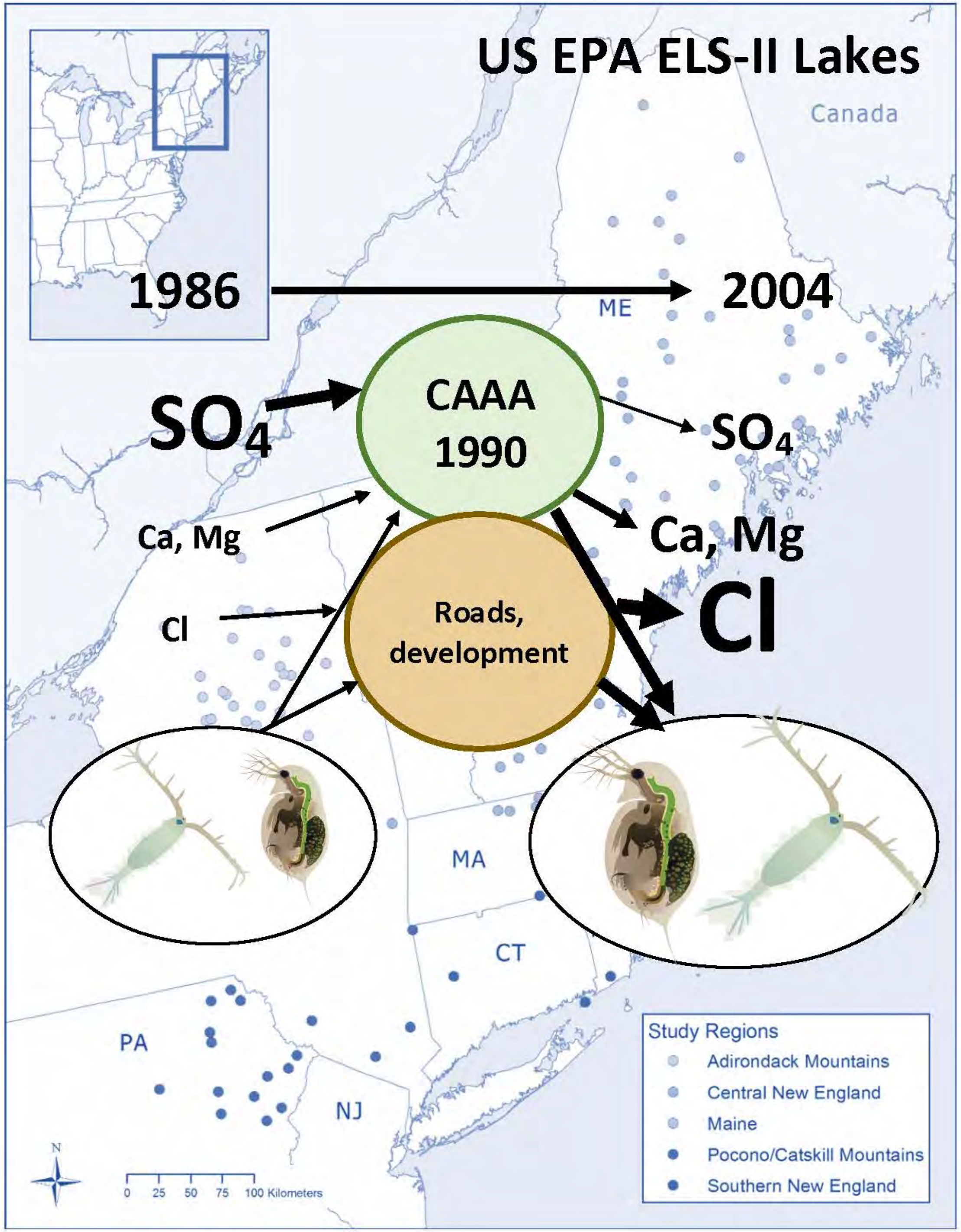
Was community composition driven by variability in water chemistry?





Significance tests implicate **SO_4^{2-} and ANC class** as most important drivers of community variability ($p < 0.001$)

- Reduced acidity, increasing Ca elicited changes in the zooplankton community
  - Zooplankton size increased overall; *Daphnia* size increased with calcium
  - Lake acidity affected zooplankton community structure in 2004 cross-lake comparison
- Biological recovery from acidification is confounded by other biogeochemical change
  - Chloride and calcium increased in lakes near roads and development
  - Novel climate, land use, and chemistry preclude return to pre-acidification status



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- D. Anderson (UMaine), S. Capone (ALSC), J. Haney (UNH), R. Stemberger (Dartmouth)

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- University of Maine, MAFES (ME41507 and ME084767-02)
- UMaine Graduate Student Government Grants Program

Publication:

- Dykema et al. 2023 https://www.sciencedirect.com/science/article/abs/pii/S1352231022005799

Images of Zooplankton:
https://ian.umces.edu/media-library/daphnia-pulex-water-flea/
https://ian.umces.edu/media-library/acartia-spp-copepod/
http://cfb.unh.edu/cfbkey/html/index.html

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EPA United States Environmental Protection Agency

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