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Effectiveness and longevity of Al treatment for lake restoration: results and recent advances

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Al treatment of lakes

Al has been used for 50 years to reduce internal P loading

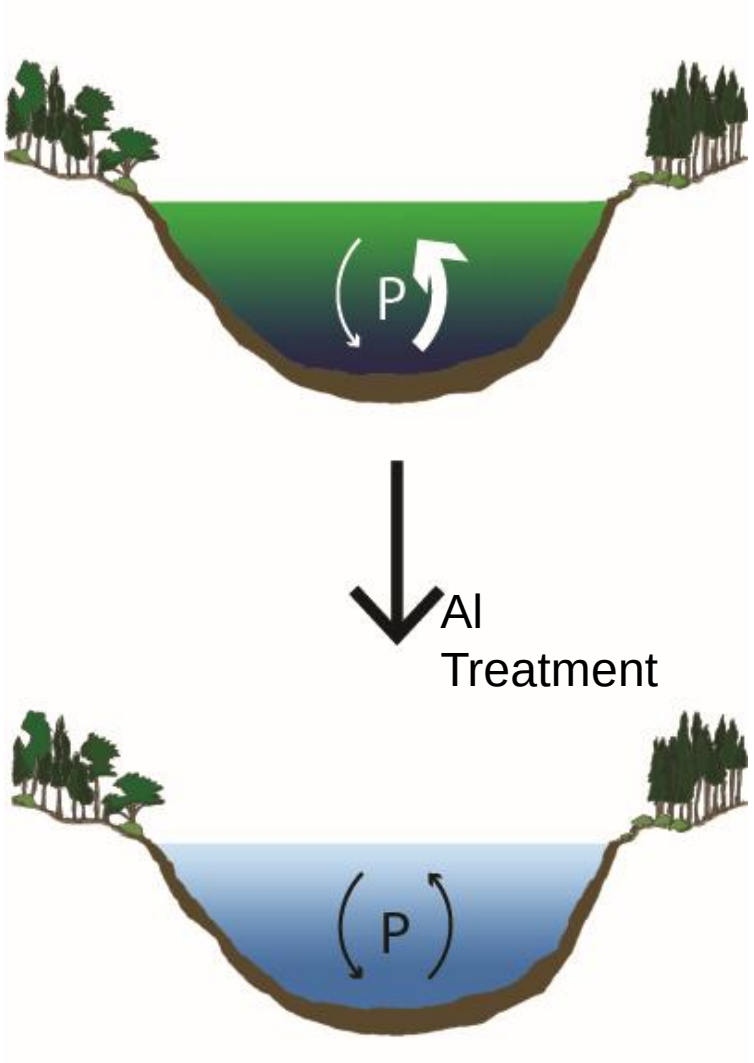
- First lake treated in Sweden (Långsjön) in 1968
- Hundreds of lakes have been treated
- Drinking water treatment (200+ years)

Most common metal in the earth's crust

- We eat 7-25 mg every day
- Found in antacids, baking powder, etc
- Does not bioaccumulate

Why do we add Al?

- Excess P has been added to lake without natural binding metals
- Fe and Ca can be used, but have limitations
- Forms a natural mineral $Al(OH)_3$ already found in soil and sediment



Aluminum Chemistry

Metals like Al, Fe, and Ca are effective at different pH ranges

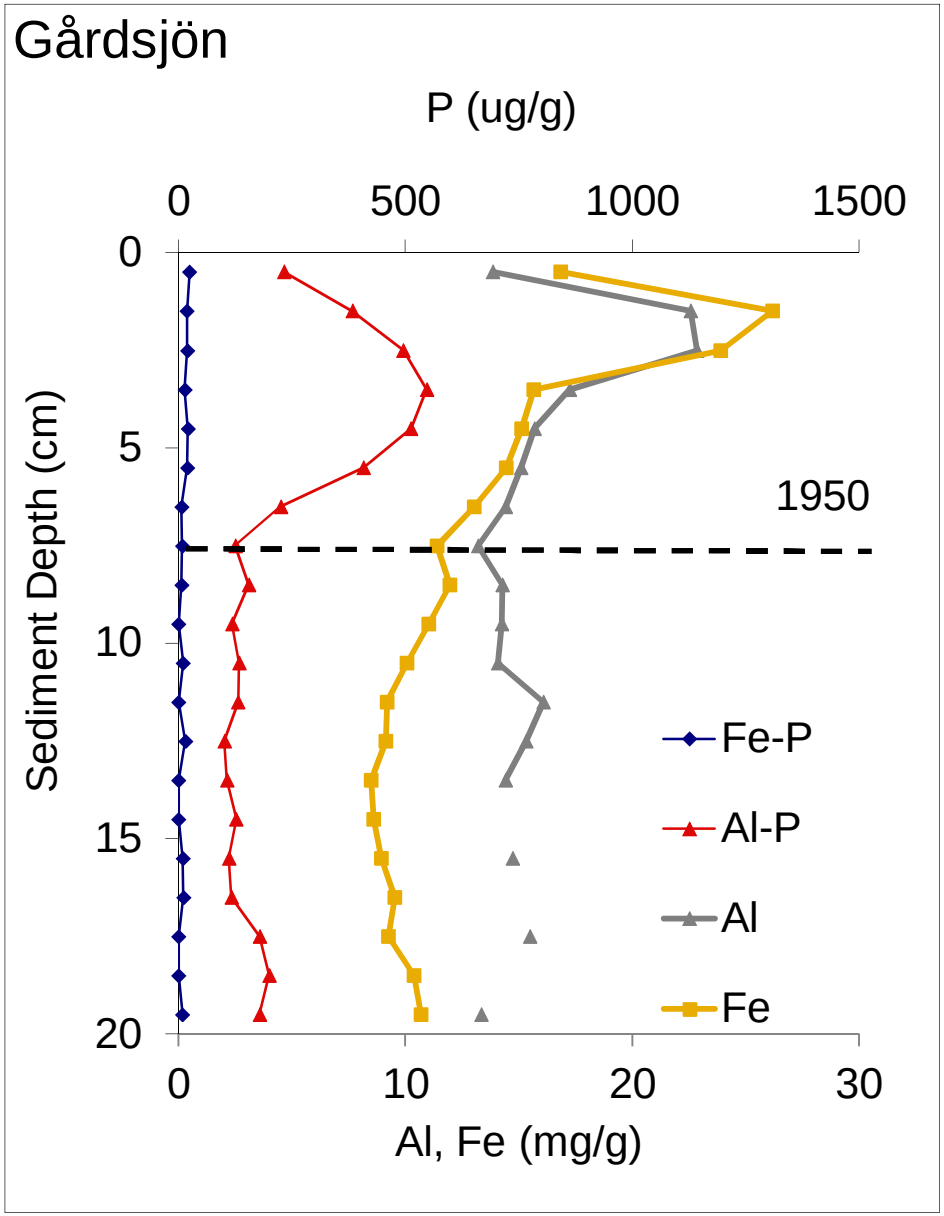
Surface water pH often greater than that at sediment surface

- Also generally decreases after restoration

Sediment buffering processes keep pH near neutral

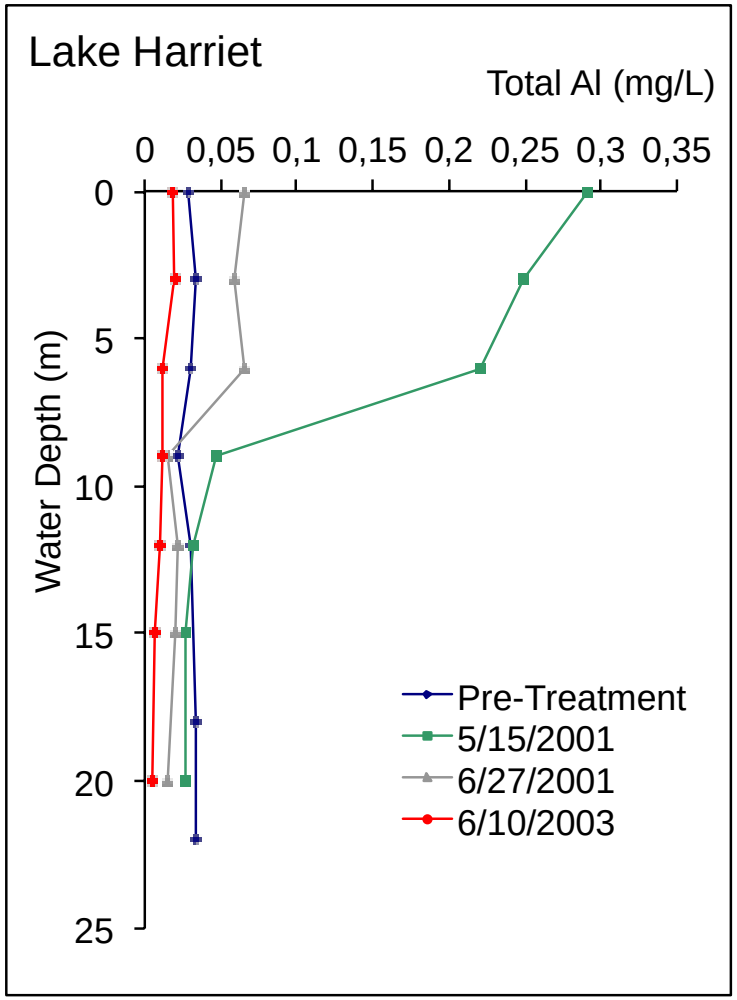
- Reduction of sulfate, nitrate, etc.

Al and Fe precipitate and remain in sediment, even in acidified lakes

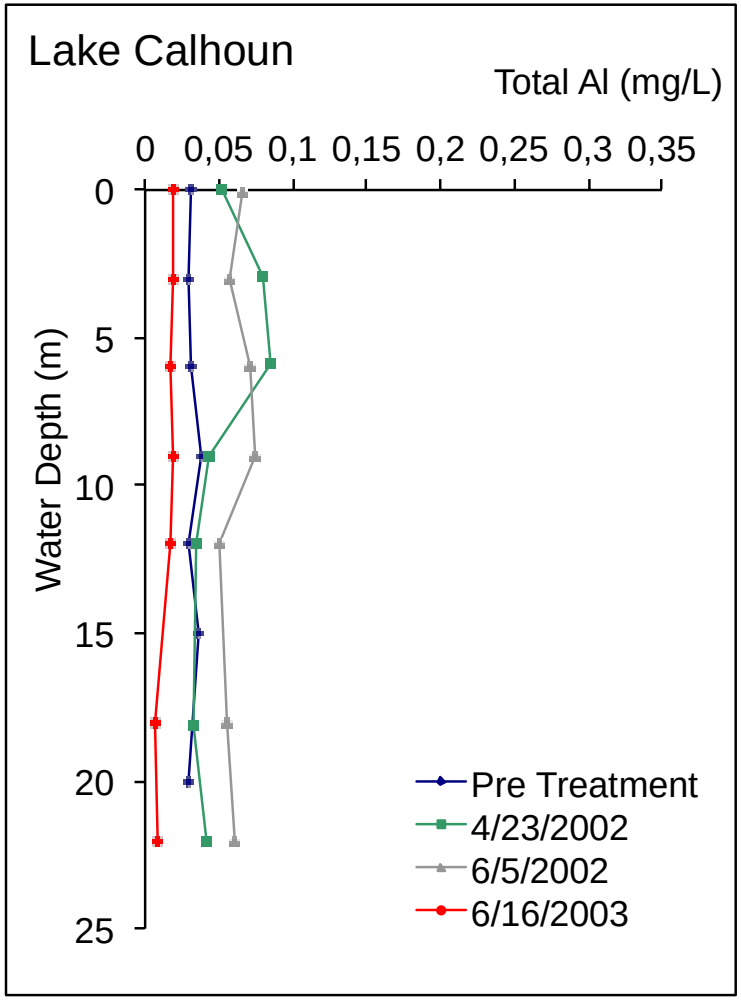


Al is lower in lakes after Al addition

Lake Harriet
Al Dose 32 g/m2

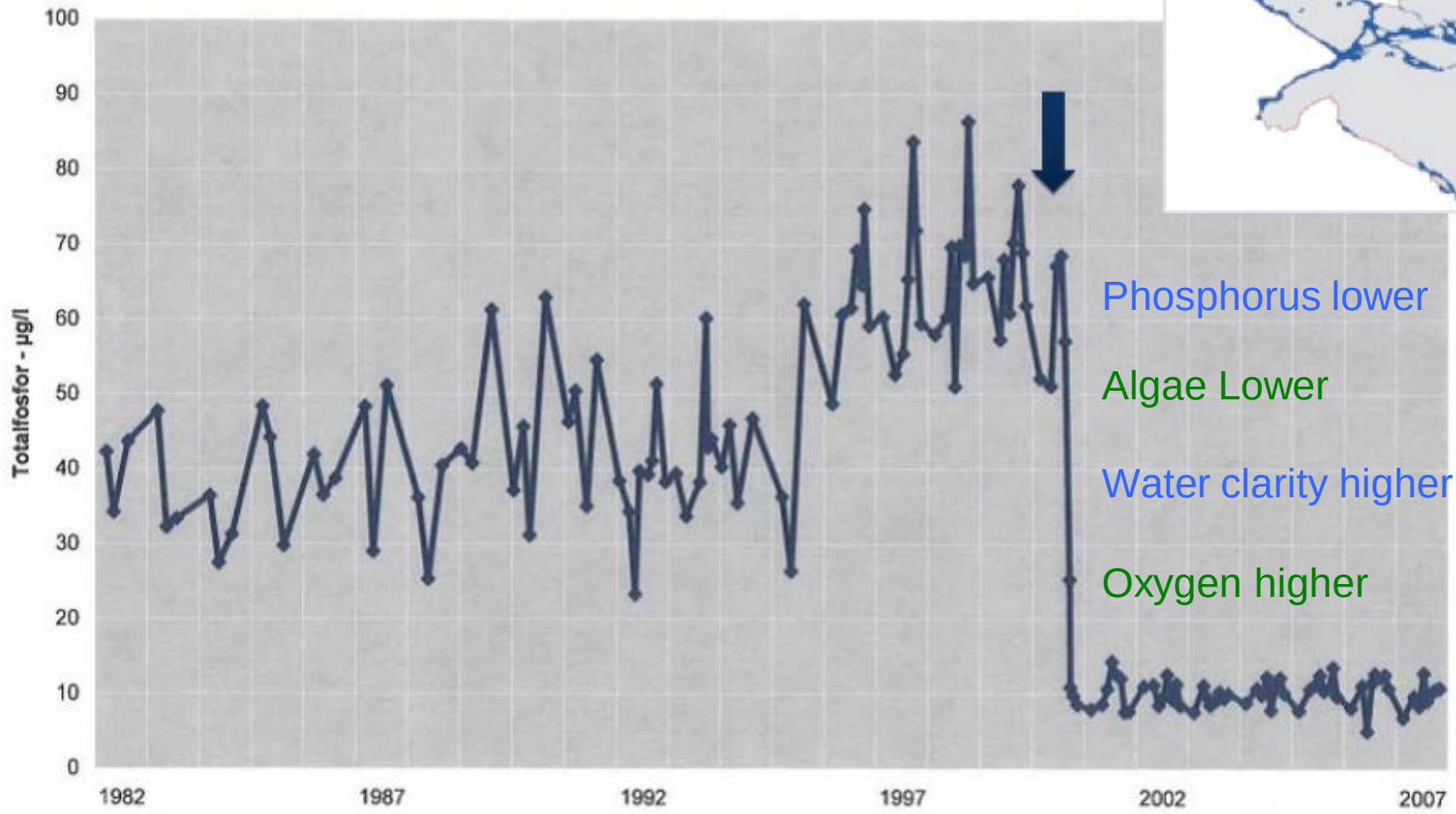


Lake Calhoun
Al Dose 42 g/m2



Does Al treatment work?

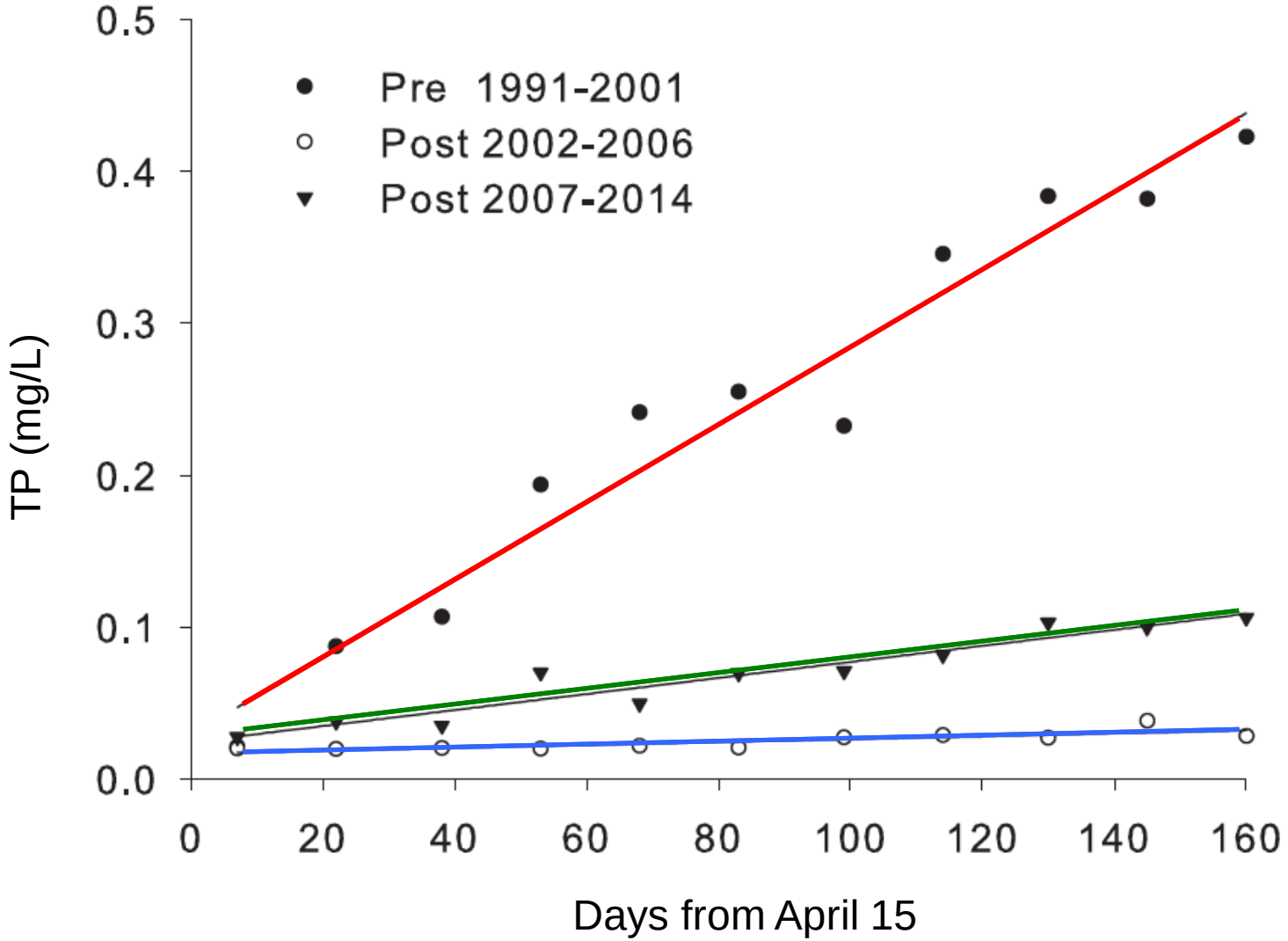
Flaten 2000, treatment in Sweden



Stockholm vatten AB

Does it work?

Internal loading (hypolimnetic water)
Lake Calhoun, USA (2001 treatment)



Is it permanent?

Medical Lake, USA

- Treated in 1977
- 120 g/m^2 (based on alkalinity)

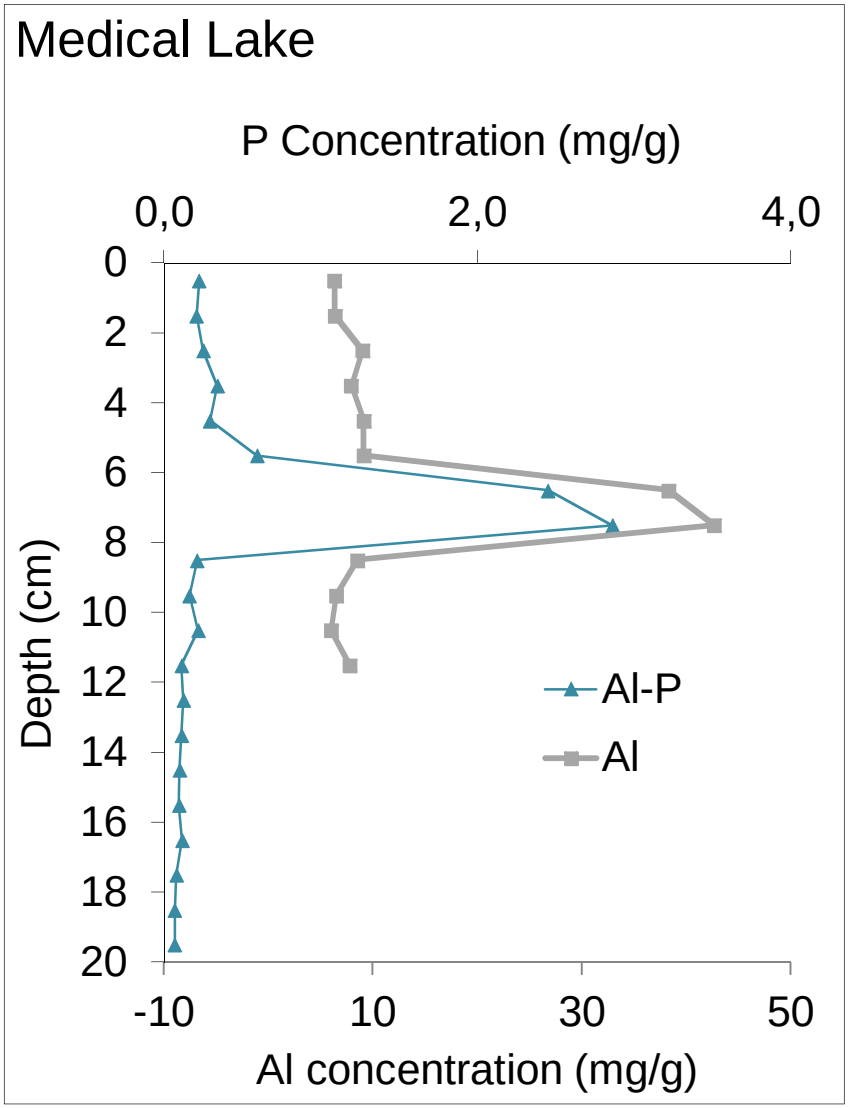
Al and Al-P remain in sediment 20 years after treatment

- Buried by new sediment

Complete reversal of eutrophication

Treatment expected to last over 100 years

- Due to nearly complete reduction of external P sources



Rydin et al. 2000

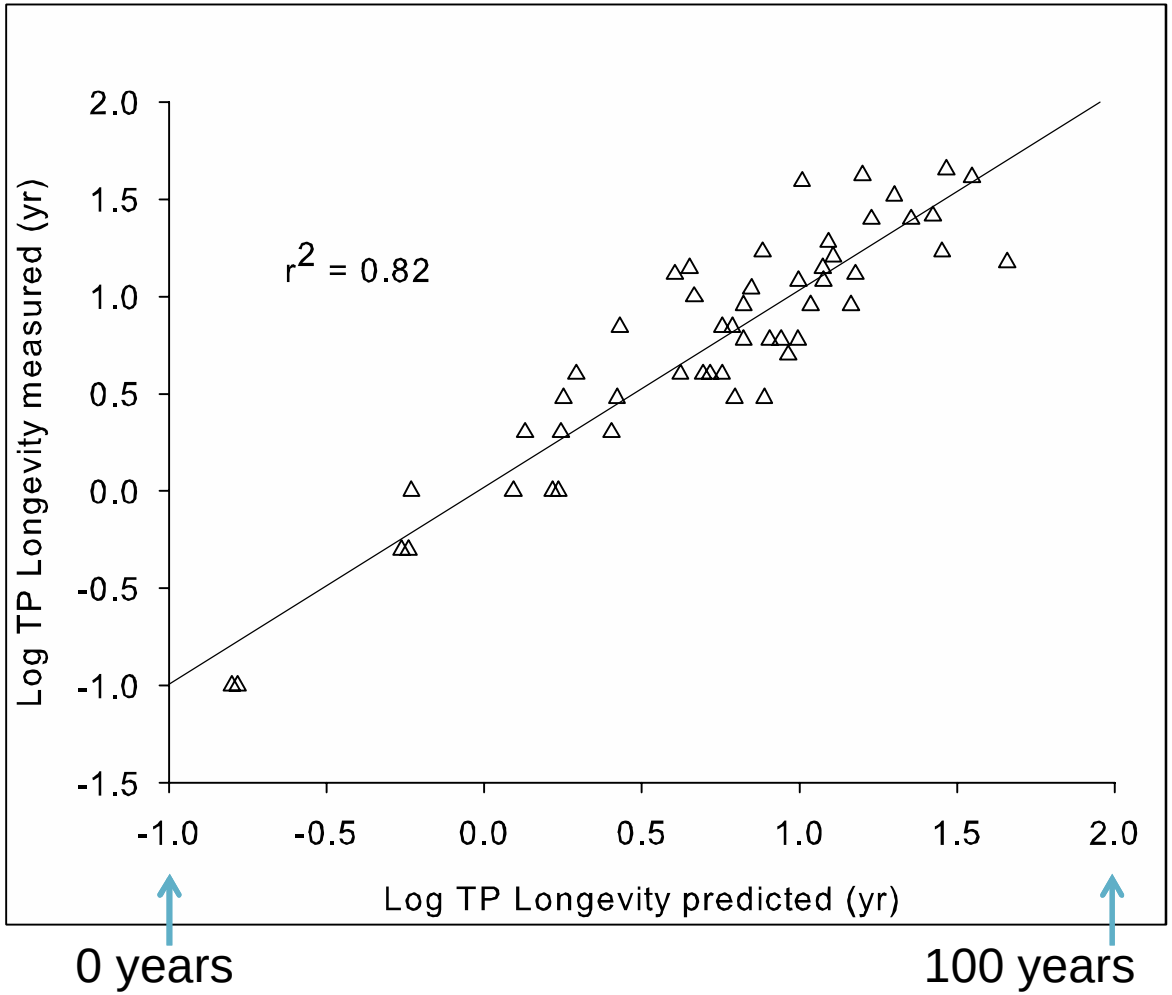
What affects treatment effectiveness?

- Recent study of Al treated lakes around the world (114 lakes)
  - Average longevity – 15 years (based on of surface TP)
  - Shallow, polymictic lakes – 6 years
  - Deep, stratified lakes – 21 years
  - **Based on a 50% reduction of TP in the surface water**

- Most lakes were dosed using out-dated/old methods
  - Dosing was either a guess or not based on sediment P
  - Common for recent treatments to last > 20 years, some are expected to last at least 100 years

Predicting treatment longevity

Huser et al. Water Research, 2016



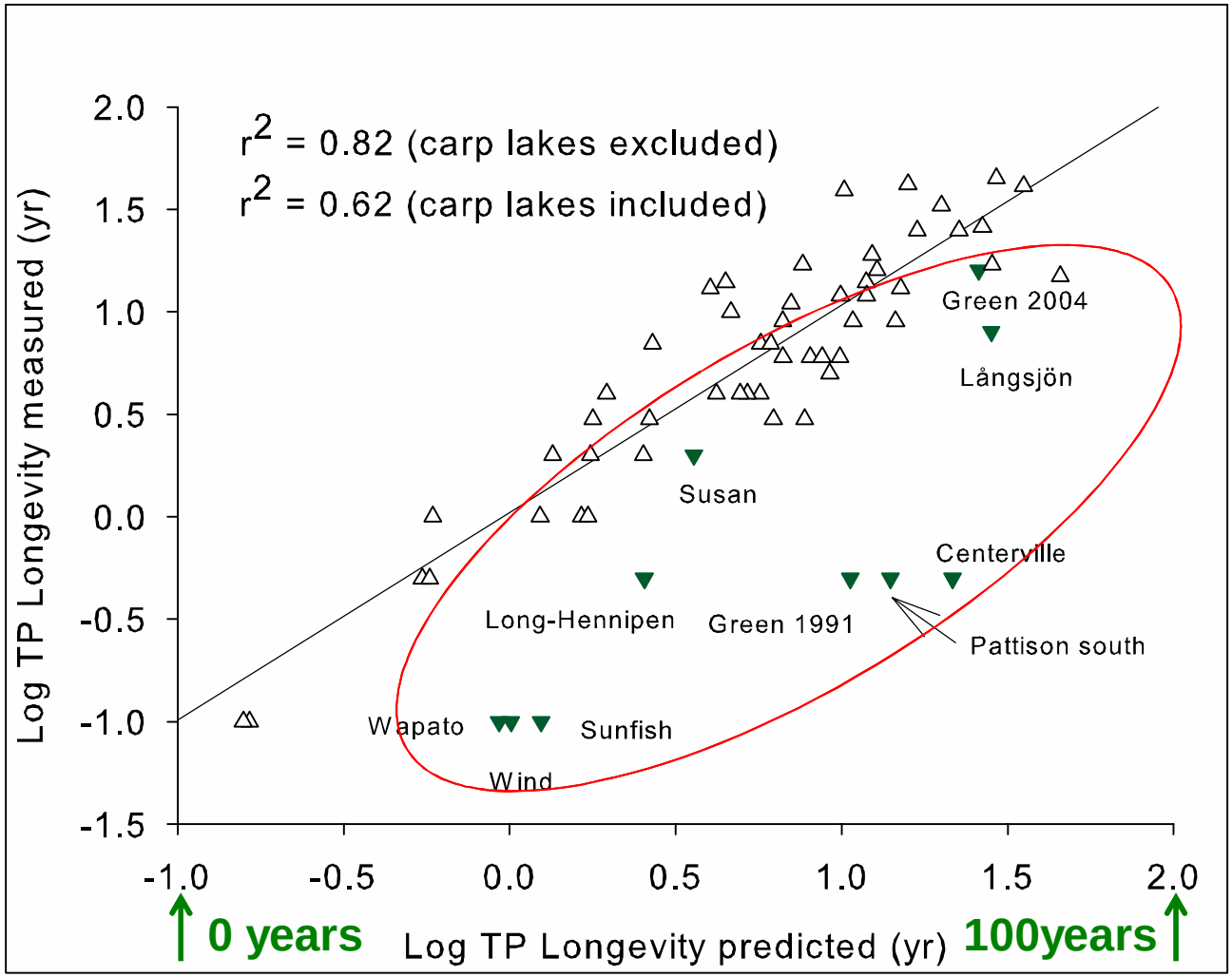
Treatment Longevity = Lake morphology (OI), WA:LA, Al dose

Huser et al. Water Research, 2016

Factors affecting longevity

- Lake morphology
  - Higher Osgood Index = deeper/stratified lake = greater longevity of treatment
- Shallow lakes
  - Lower Al doses added = lower longevity
    - Limited alkalinity to buffer treatment
  - Typically more sediment P is bound in the organic form
    - This degrades over time and becomes mobile P
- Biological (and physical) processes also important
  - Macrophytes
  - Faster transfer of sediment P to surface waters in shallow lakes
    - Less sediment P release needed to decrease water quality
  - Benthic feeding fish

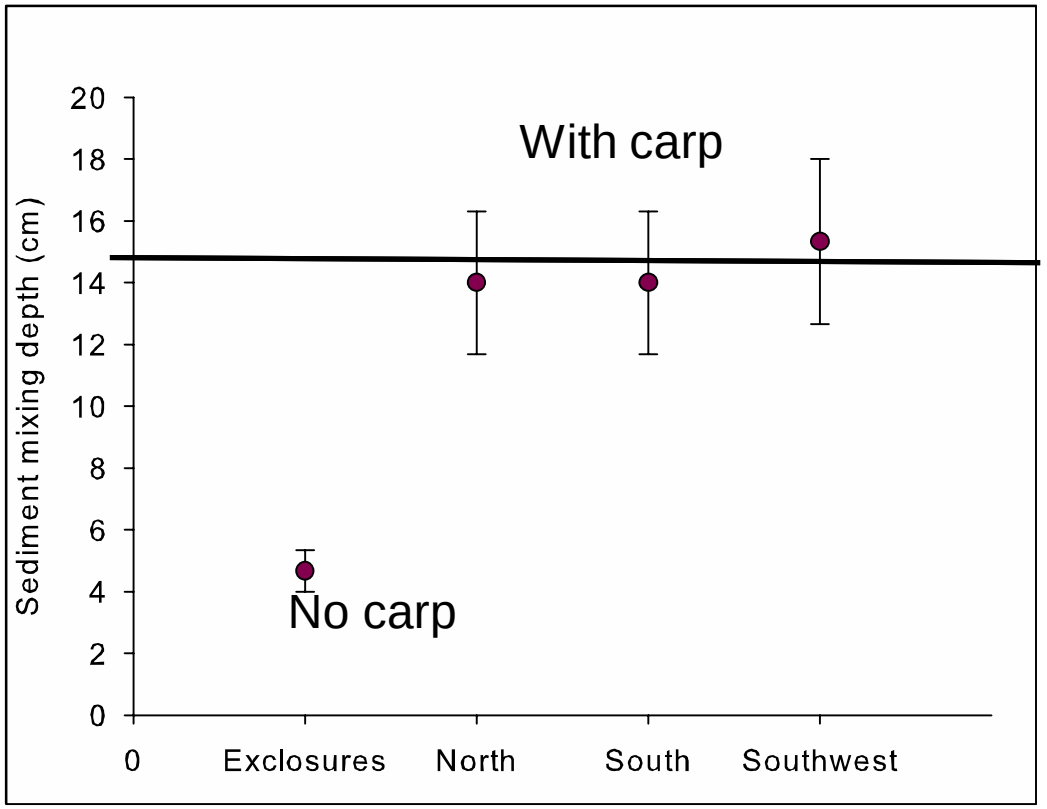
Benthic fish affect treatment



Moderate to high densities of benthic fish = less than expected treatment longevity

Benthic fish and sediment mixing

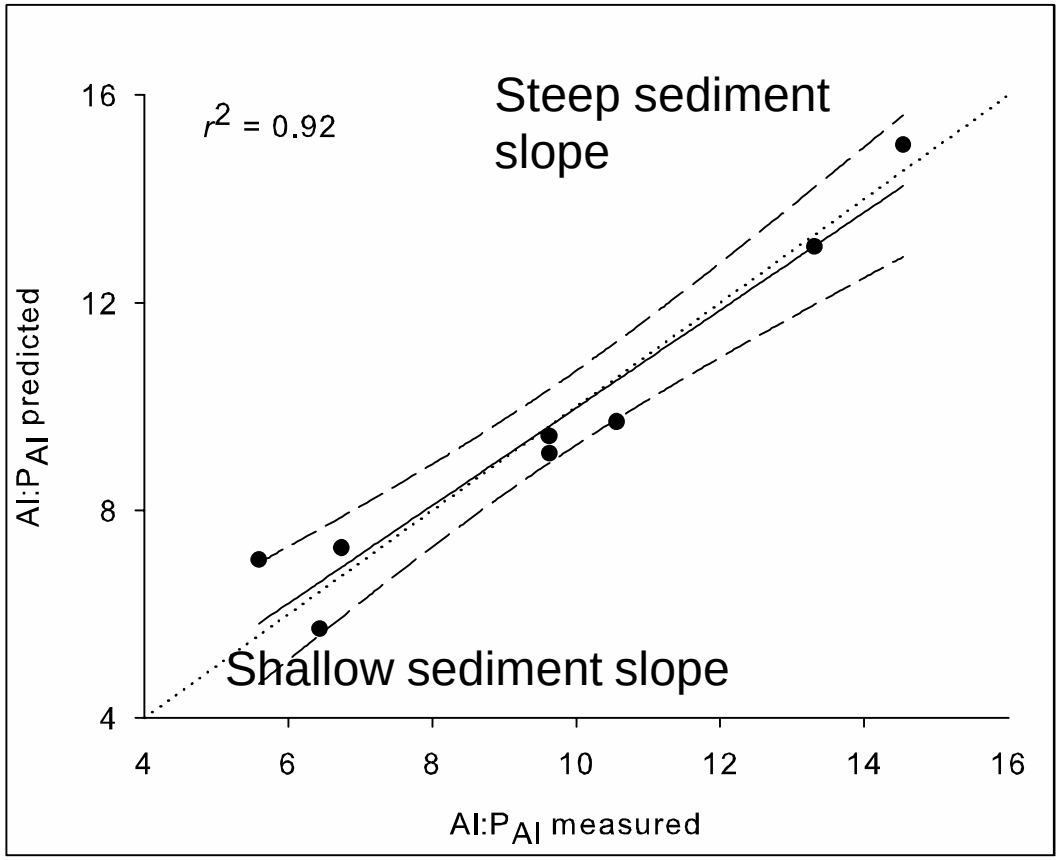
- Kohlman Lake, (US)
  - Carp (3.4 kg average weight, 180kg/ha)
  - Sediment mixing depth increased from 5 to 15 cm with carp present
- Mobile sediment P
  - Increase in sediment mixing doubled potentially available P
- Shows that both sediment P and biology are important



Huser et al. Hydrobiologia, 2016

Other morphological effects

- Crystallization affects binding efficiency
  - $Al:P_{Al}$ binding ratios range from 2 to 20
  - Crystalizes in absence of P = lower binding efficiency (de Vicente et al. 2008)
- Lakes with steep slopes and high Al doses
  - Al translocates (moves) from shallow to deep areas
- Model developed can maximize binding effectiveness
  - **Need for splitting doses**



Huser. Water Research, 2012

Factors affecting longevity- Watershed to Lake area ratio

- Greater WA:LA (watershed to lake area ratio = lower longevity

- External P sources may play a larger role than internal
  - Likely that external P sources were not well controlled in all the study lakes (especially urban lakes)

  - If external sources of P are not controlled before Al treatment, internal P loading will increase

  - Most methods used to decrease internal loading will be affected by this in the same manner

Factors affecting longevity- Al dose

- 1970 (Kennedy and Cooke 1982)
  - Based on alkalinity, which has nothing to do with P or eutrophication
- 1990 (Kennedy et al. 1987)
  - Based on internal loading of P rate, but impossible to know how many years of internal loading in the sediment
- 2000 (Rydin and Welch 1999)
  - Based on mobile P in the sediment, eliminates nearly all mobile P
- 2014 (Huser and Pilgrim 2014)
  - ‘Dynamic’ model using previously (lab) determined binding ratios
  - Can calculate a dose based on a goal for internal P loading reduction

Cost of treatment

- Euro per kg of Al-P formed (or kg mobile P inactivated)

- Surface water application

	Mean	Range
Shallow lakes	52	40-82
Deep (stratified) lakes	43	13-67

- Sediment injection

	Mean	Range
All types (N=2)	118	106-129

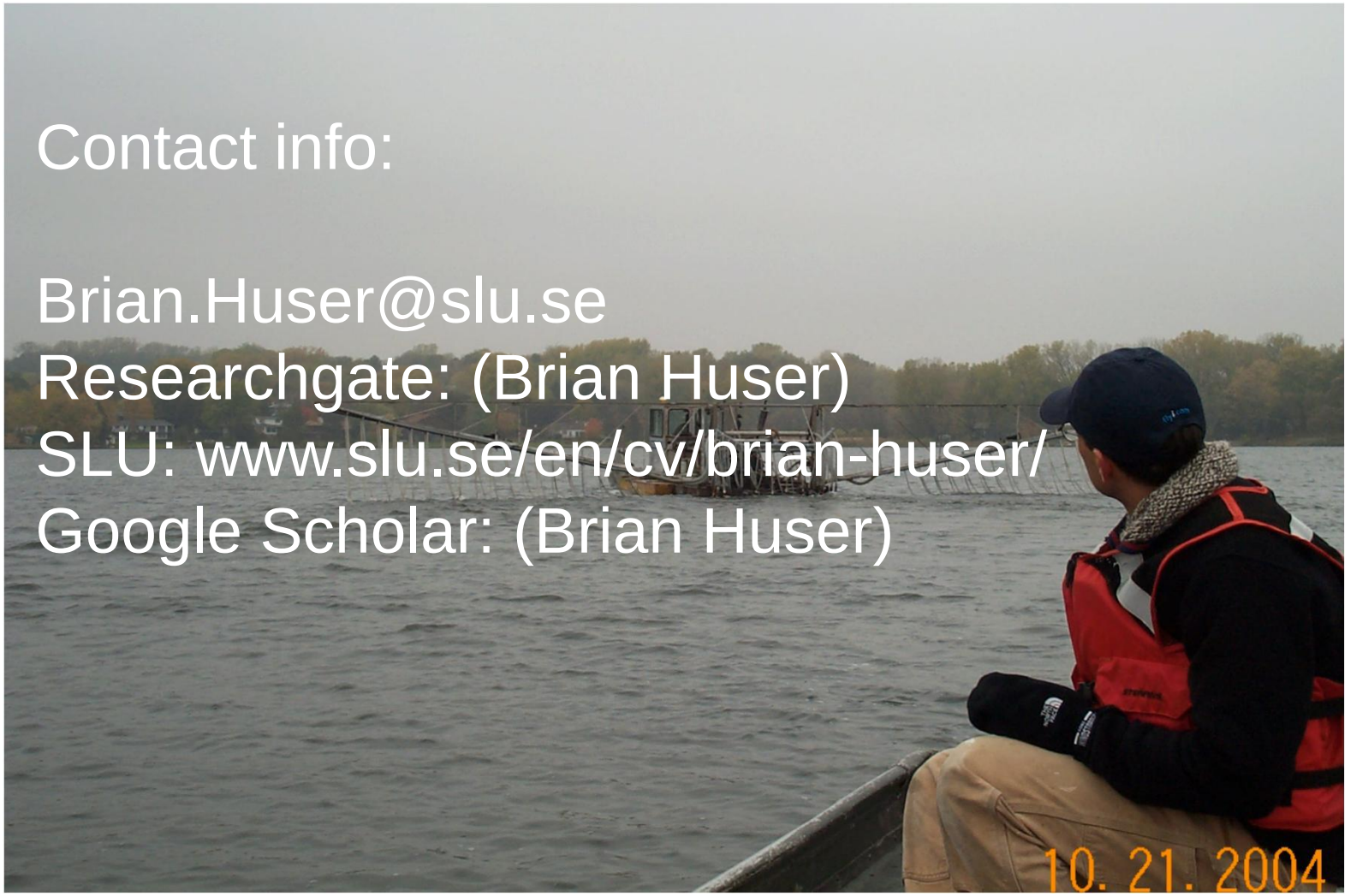
Some ongoing work

- Organic P degradation importance for timing for split Al doses
- Other factors affecting binding efficiency
  - Range of 2-20 (Al:Al-P) likely affected by other factors besides morphology and Al dose (sediment organic matter, DOC, Al form, etc.)
- Estimation of natural/background internal loading during growing season
  - Need a goal for restoration and it usually isn't 0
- Development of a common monitoring plan for lake modeling and restoration
  - EU Life project (2017-2024)
  - Water and sediment
  - Minimize monitoring costs while maximizing information and modeling accuracy

Summary

- Al treatment = adding a natural, mineral binder of P to the lake to neutralize excess, historical P inputs
- Minimal negative effects except in cases of equipment failure or design errors (e.g. pH drops below 6)
  - Easy to fix, for example geochemical modeling of treatment
- Al works. ‘Failed’ treatments mainly due to poor dosing and/or treatment design (e.g. external loading dominates)
- Dosing must be done carefully to maximize binding effectiveness and limit short-term effects on biota
- **Good data collection and lake modeling are needed to ensure success of any restoration project**

Questions?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Google Scholar: (Brian Huser)
10. 21. 2004

P forms in sediment