The Shootout at the ~~OK~~ N-P ~~Corral~~ Lagoon

D. W. Schindler

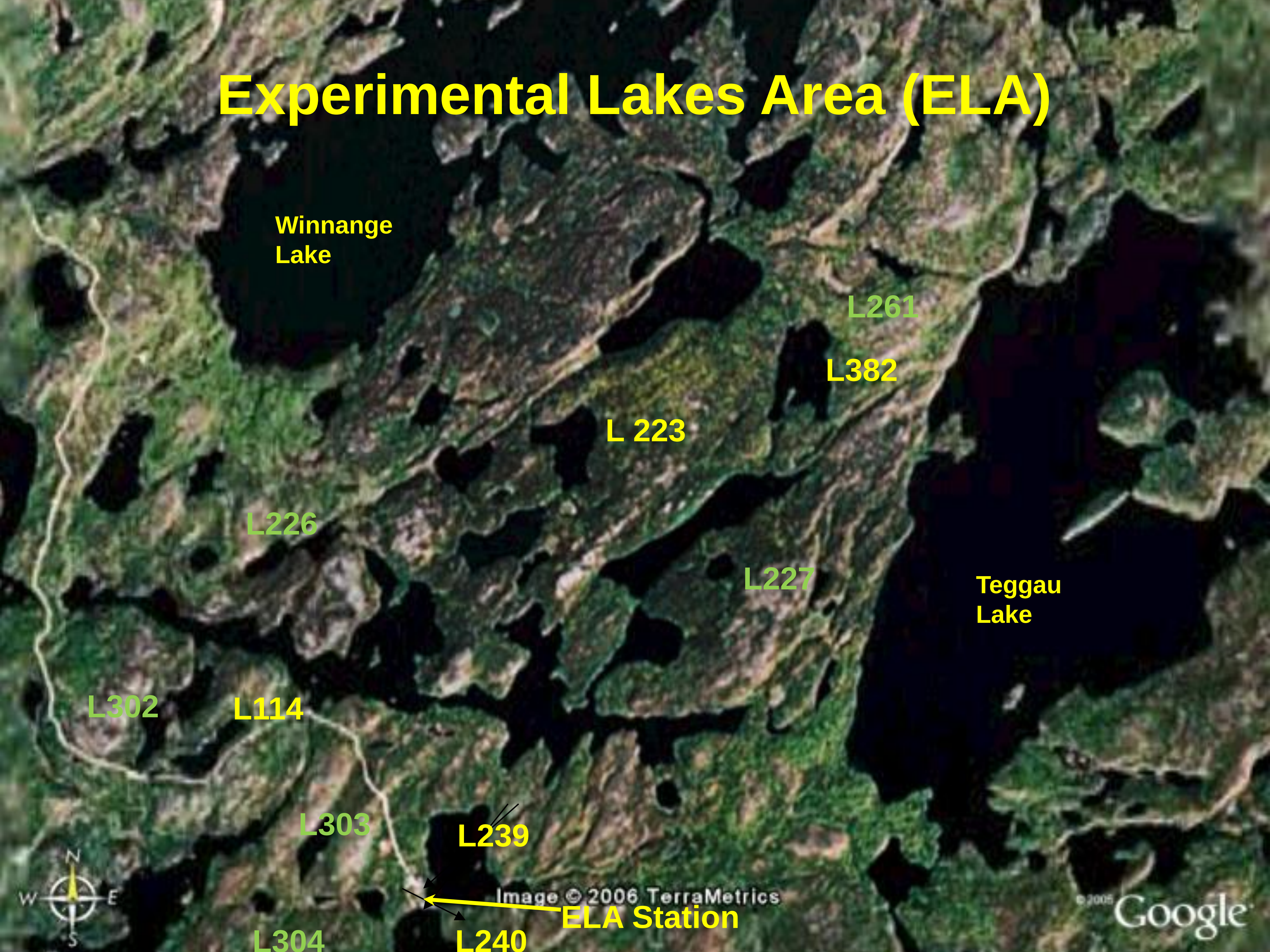
Dedicated to Val Smith

Redfield Ratio

16N:1P (moles), 7N:1P (wt)

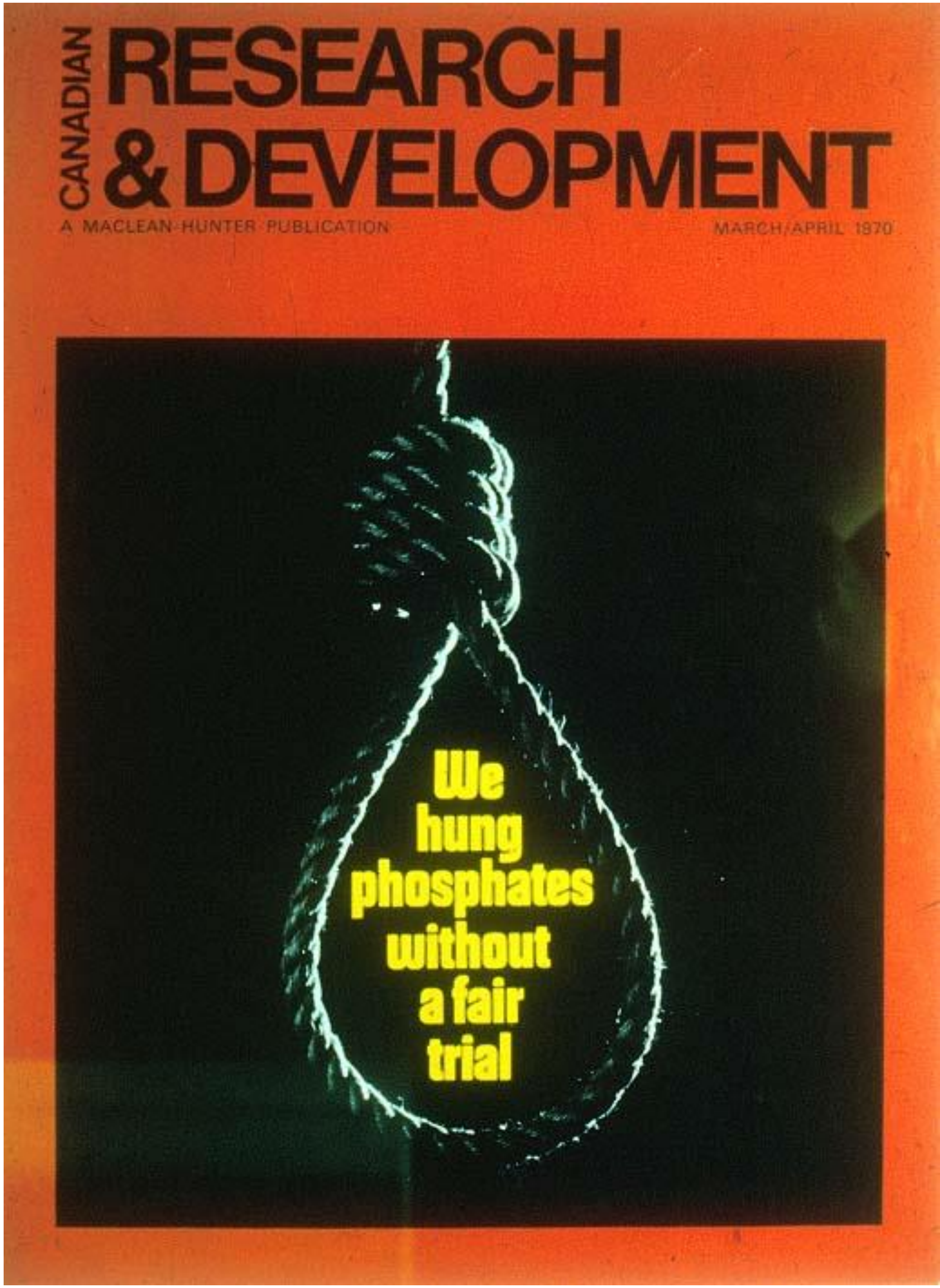
Redfield, A.C., The biological control of chemical factors in the environment, *American Scientist*, 1958

Experimental Lakes Area (ELA)



ASLO 1971
Shootout at the C-P Lagoon

The detergent industry promoted the view that carbon, not phosphorus caused eutrophication, based on bottle, mesocosm and nutrient ratio studies that showed carbon to be limiting.

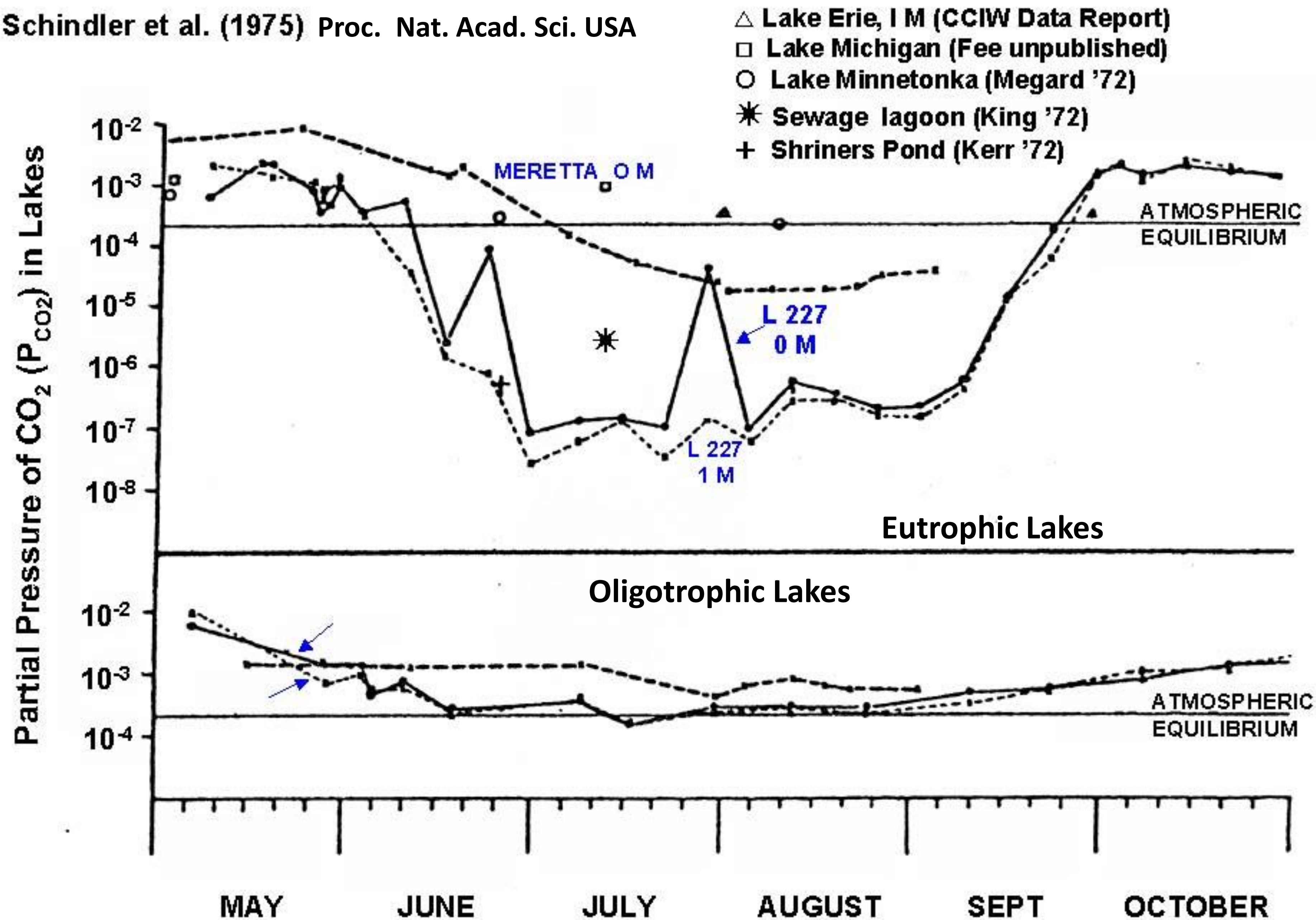


Lake 227

Before nutrient addition

After adding P+N (1969-1988) or P alone (1989-2014)

Schindler et al. (1975) Proc. Nat. Acad. Sci. USA



Carbon limitation did not mean that Carbon control was necessary.

First Shootout at the N-P Lagoon-SIL 1974

Schindler Science 1974

ELA Whole-Lake Nutrient Experiments
Total 79 Lake-Years of nutrient additions

Increased Loading

Phosphorus, no N
- Lake 261, 1973-1976
- Lake 227, 1989-2014

Nitrogen , no P
- Lake 226SW, 1973-1980
- Lake 302N, 1981-1986
- Lake 304, 1973-74

Phosphorus + nitrogen
- Lake 227, 1969-1988
- Lake 304, 1971-1972 &75-76
- Lake 303, 1975-1976
- Lake 226NE, 1973-1980

Reductions in Loading

Phosphorus
- Lake 303, 1977-
- Lake 261, 1977-
- Lake 304, 1973-4, 1977-
- Lake 226NE, 1981-

Nitrogen
- Lake 227, 1989-2014
- Lake 302N, 1987-
- Lake 226SW, 1981-

ELA Lakes-Summary of Responses

Additions

Adding N +P gave rapid positive response.

Adding N-deficient N+P gave slower positive response.

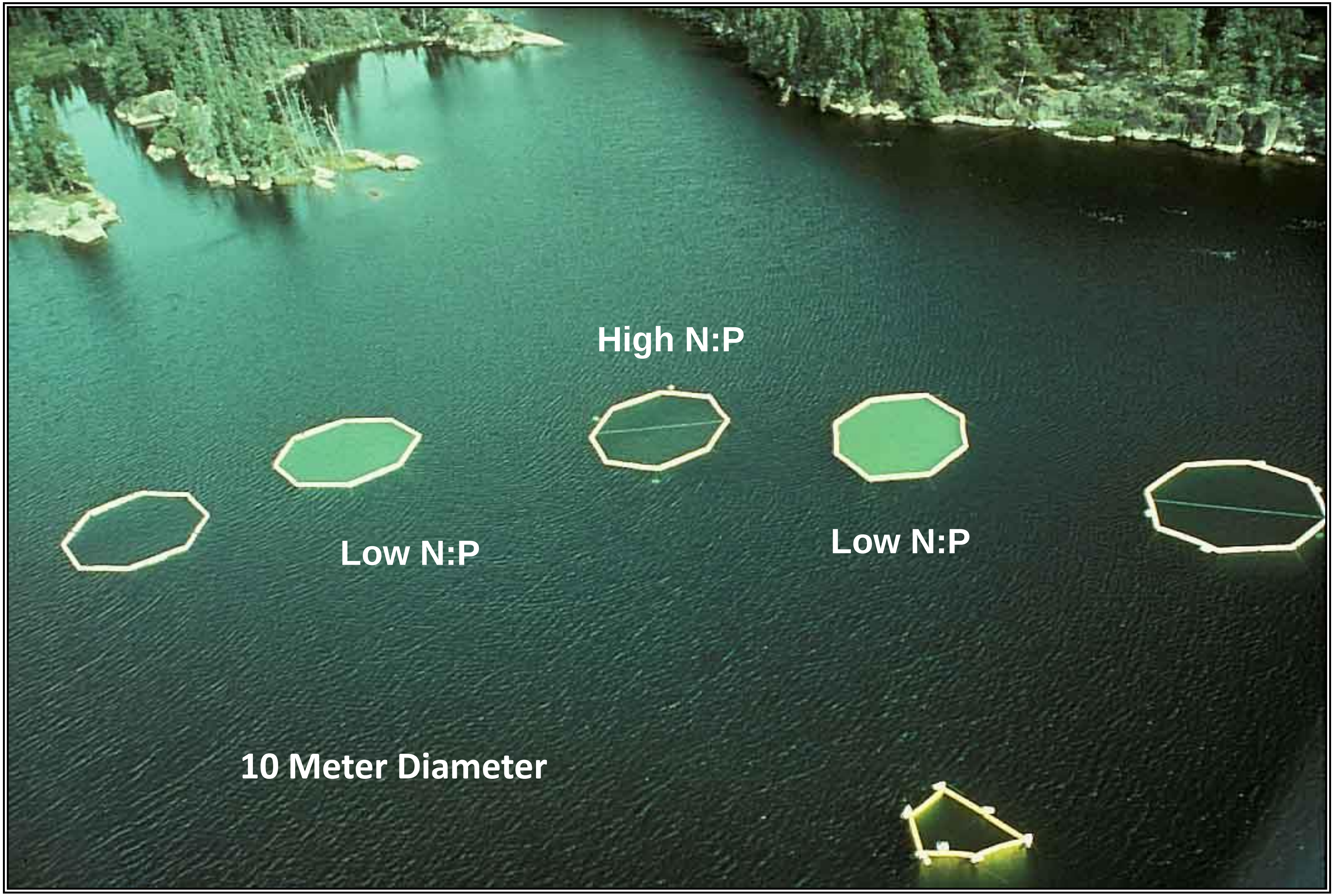
Adding P alone gave very slow, but positive response.

Adding N without P did *not* cause a response.

Deletions

If P or P+ N was reduced, algae tracked the decline in P, leaving excess NO3 (denitrified).

If N alone was reduced, no change occurred in biomass.



Levine and Schindler 1992 Limnol. Oceanogr. 37: 917-935.

Nitrogen Control Theory Resurfaces like a Phoenix in the New Millenium

Control of Lacustrine Phytoplankton by Nutrients: Erosion of the Phosphorus Paradigm. W. M. Lewis, Jr. and W. A. Wurtsbaugh 2008. Internat. Rev. Hydrobiol. 93 (4–5) 446–465.

Controlling eutrophication: Nitrogen and phosphorus. DJ Conley et al. 2009. Science 323: 1014-1015.

Algal blooms: Noteworthy nitrogen. H. Paerl et al. 2014. Nature 346: 175.

Where P control has worked – partial list of case histories

Lake Erie
Lake Ontario
Lake Michigan
Lake Huron
Lake Superior
Lake Onondaga, NY
Lake Geneva, Switzerland
Lake Lucerne, Switzerland
Lake Zurich, Switzerland
Lake Constance, Switzerland
Lake Norrviken, Sweden
Lake Malaren, Sweden
Lake Hjalmaren, Sweden
Lake Vattern, Sweden
Lake Vanern, Sweden
Lake Mjosa, Sweden
Gravenhurst Bay, Muskoka
Kootenay Lake, BC
Moses Lake, Washington
Several ELA lakes
Stockholm Archipelago -G. Brat tberg, *Vatten* **42**, 141-153 (1986)

There are *NO* examples of where decreasing nitrogen loading has successfully reduced eutrophication of a lake!

Conclusion: P paradigm has *increased* in strength, not eroded!
Schindler 2012 Proc. Roy. Soc. London (B) 279: 4322-4333.

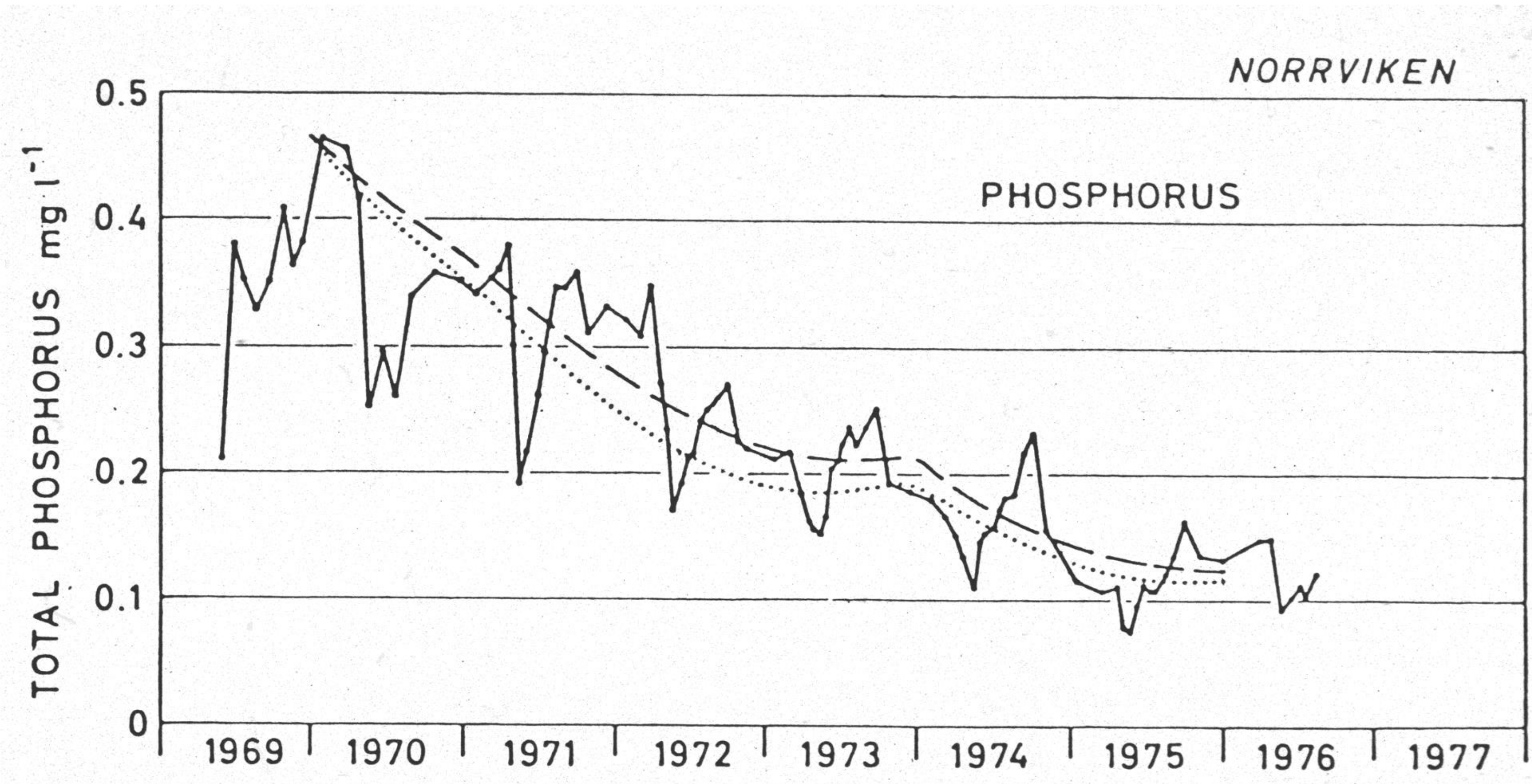
Moses Lake Washington

"Long-term, whole lake experiments in which the nutrient inputs are manipulated and the lake response *in situ* is observed are the only reliable way to judge the relative importance of each nutrient."

"…. Targeting both N and P may not only be much costlier than necessary, but may even promote blooms of N-fixing cyanobacteria, especially in cases of high internal P loading."

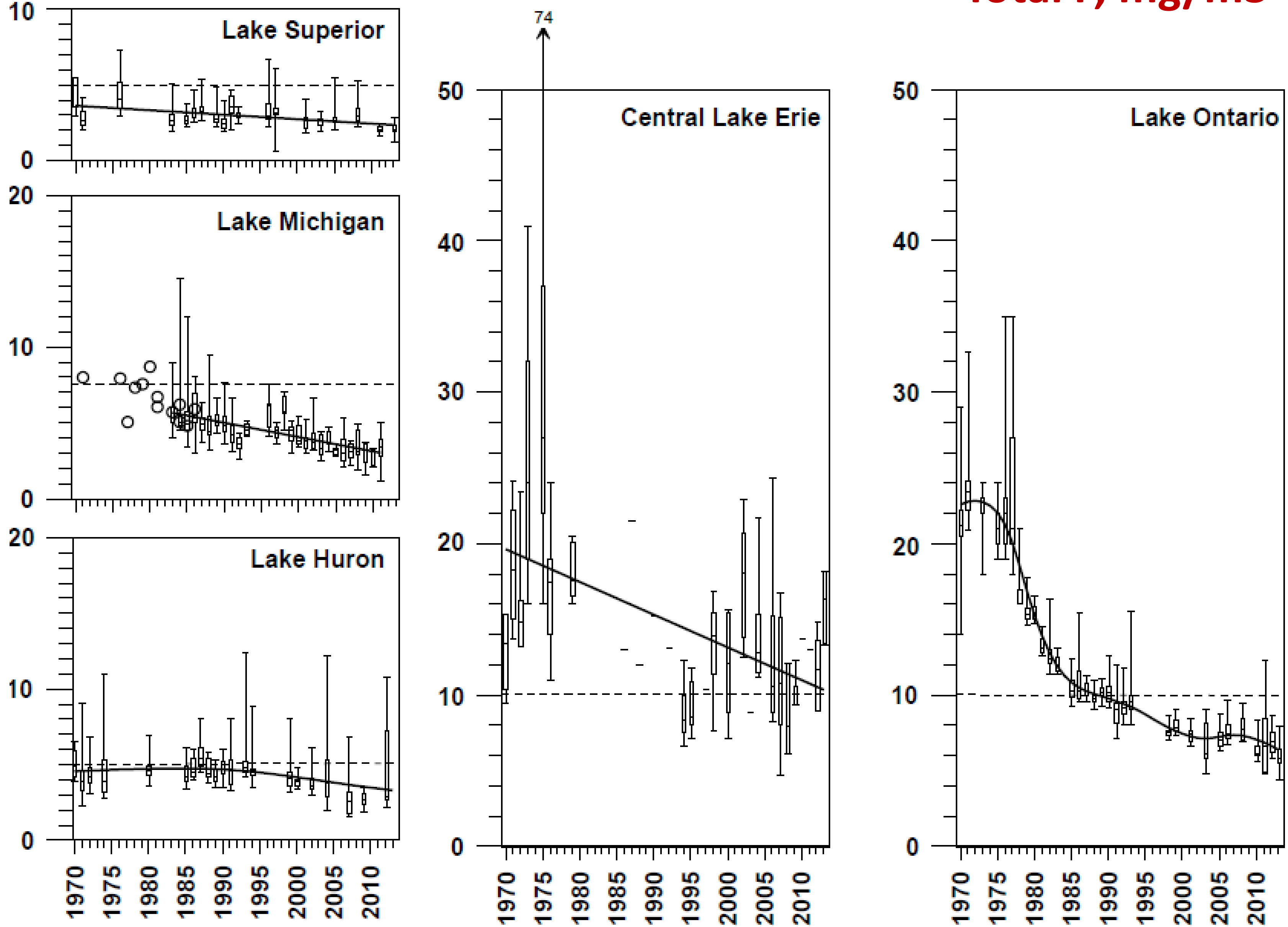
E. B. Welch 2009 Lake Reserv. Manage.

Mean phosphorus concentrations in Lake Norrviken after diversion of sewage effluents in 1969. I. Ahlgren 1977.



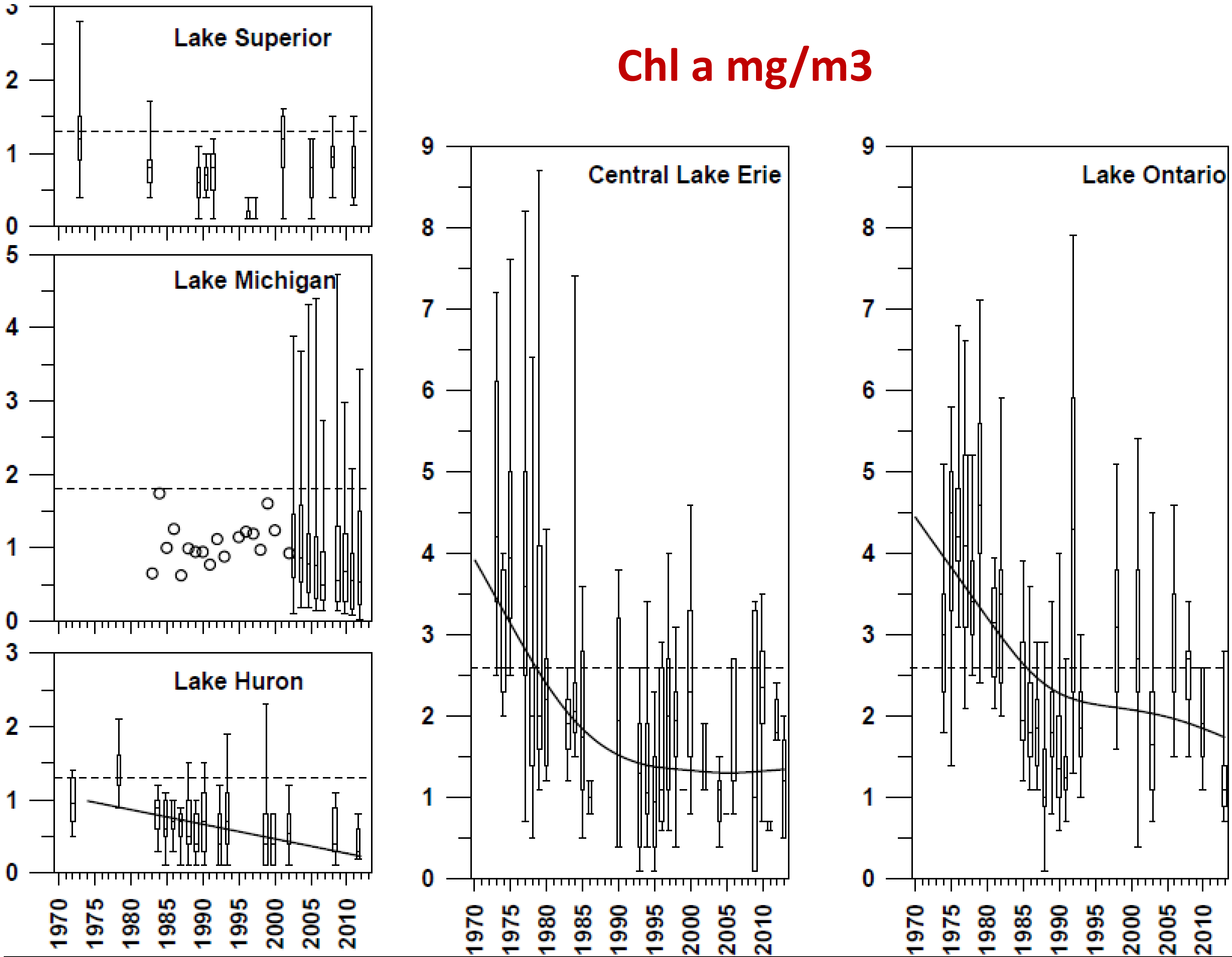
Dove and Chapra 2015 Limnol. Oceanogr. 60(2) (in press)

Total P, mg/m3



Great Lakes do not need N control!

Chl a mg/m3



Dove and Chapra 2015 Limnol. Oceanogr. 60(2) (in press)

Proximate nutrient limitation- **where nutrient addition stimulates a biological process, such as productivity.**

Ultimate nutrient limitation- **where additions of a nutrient can change ecosystem properties.**

Vitousek et al. 2010. Terrestrial phosphorus limitation: mechanisms, implications,and nitrogen–phosphorus interactions. *Ecological Applications* 20(1): 5–15.

The Message for Limnologists and Oceanographers:

Results of short-term bioassays (hours to months) are proximate measures. They are unlikely to accurately predict the long-term response of ecosystems to nutrient addition or removal.

Using results from nutrient *additions* to predict the results of nutrient *removal* may not be valid, due to hysteresis.

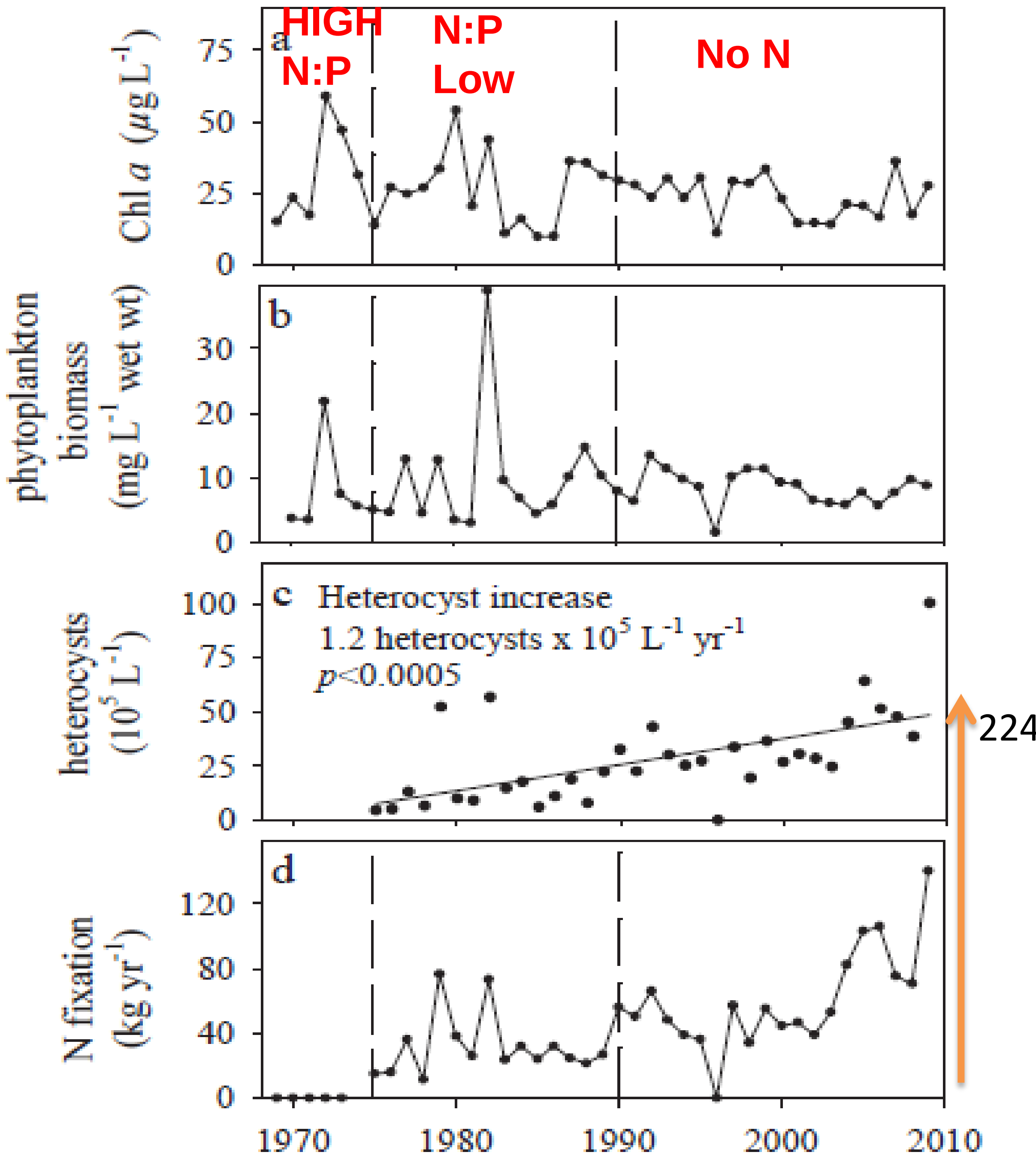
Twisted Nitrogen Logic in Proximate Assays:

1. When carbon was limiting in bottle bioassays, we didn't conclude that carbon must be controlled.
2. If silica was limiting, we didn't conclude that silica must be controlled.
3. Then *why* do we conclude that if nitrogen is limiting, it must be controlled?

A culturally-eutrophic lake is proximately nitrogen-limited because it has been over-fertilized with *phosphorus*.

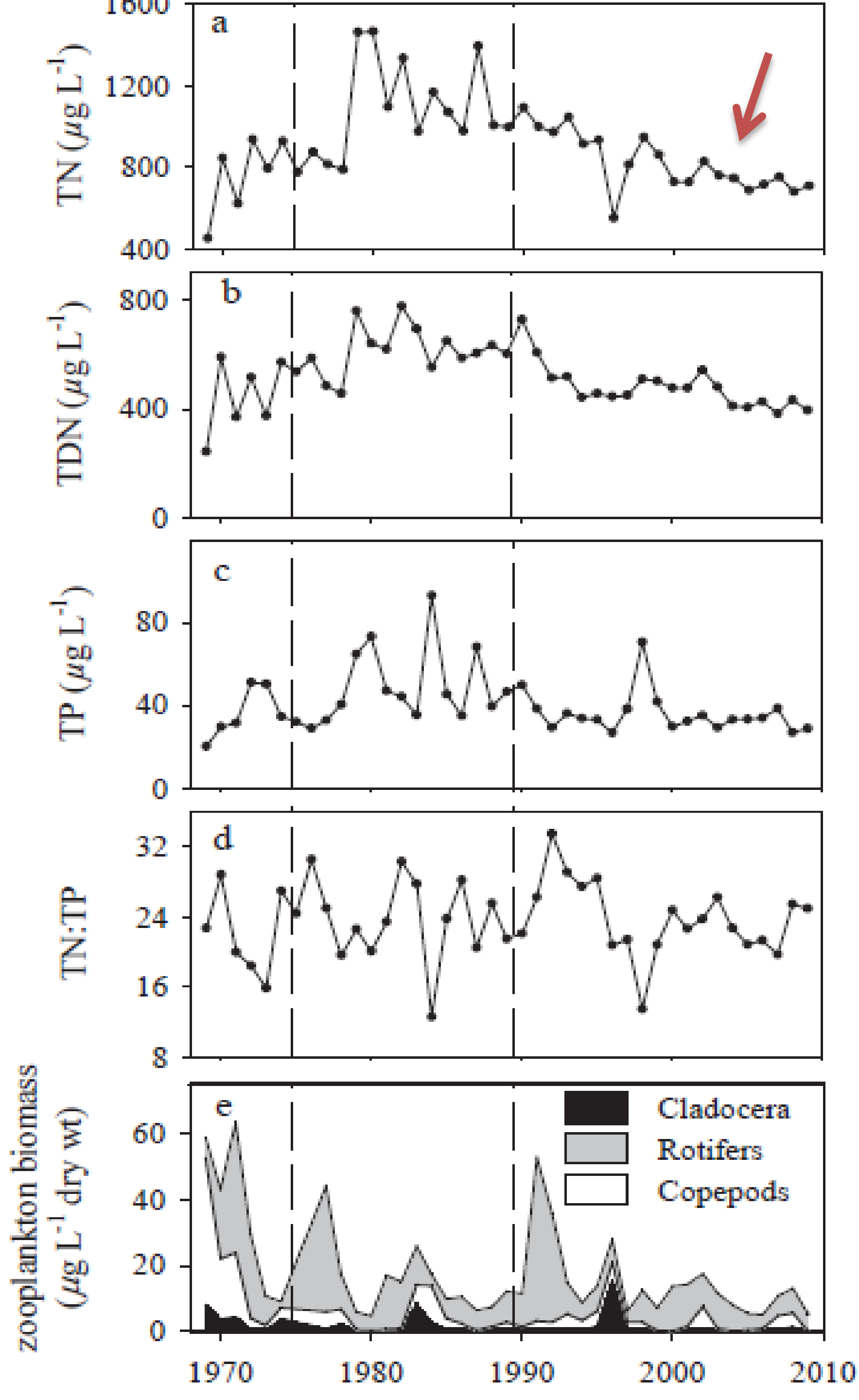
Schindler et al 2008
PNAS 105: 11254-11258,

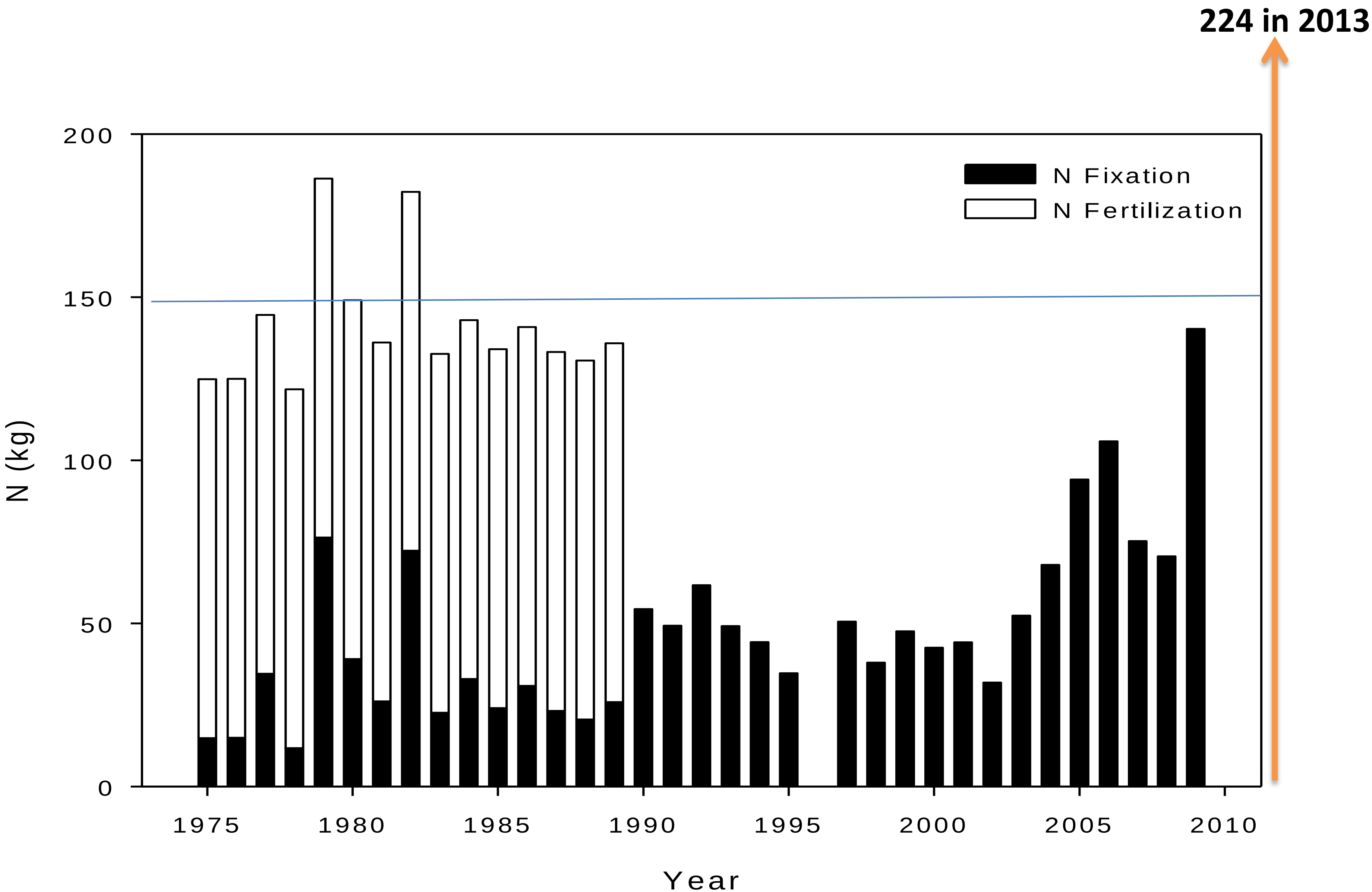
Paterson et al. 2011
L&O 56: 1545-1547.



Refuting more nonsense.

Decrease in N is entirely due to the DON fraction, not denitrification





Fixation is now similar to the sum of fertilizer+ fixation in the 1980s, and is still increasing.

Lake 227 Nitrogen Flux to Water Column. Lehnherr 2013.

Nitrogen Source	Flux during 2011 summer stratification period (kg N)	%
Profundal Sediments (5-10 m)	102	23
Littoral Sediments (0-2.5 m)	37	9
Total Return of DIN from Sediments	139	33
N_2-Fixation	224	52
Atmospheric Deposition (2004-2007 mean)	13	3
Runoff (2004-2007 mean)	51	12
	Total 427	

Denitrification is unmeasurable. No measurable nitrate is present in summer. N:P in Total Nutrient Load = 427/24.5 = 17.4 (wt)

Lessons from the Experimental Lakes

Short-term nitrogen limitation does not mean that nitrogen must be controlled, it means the lake has been overfertilized with phosphorus.

Bottle bioassays tell us nothing about the long-term (years) processes that correct deficiencies of nitrogen and carbon in whole lakes. Meta-Analyses do not make them ecosystem scale.

Mesocosms can tell some features of a lake's response, but still underestimate slow biogeo-chemical processes and successional changes.

The Costs of a Mistake are Huge

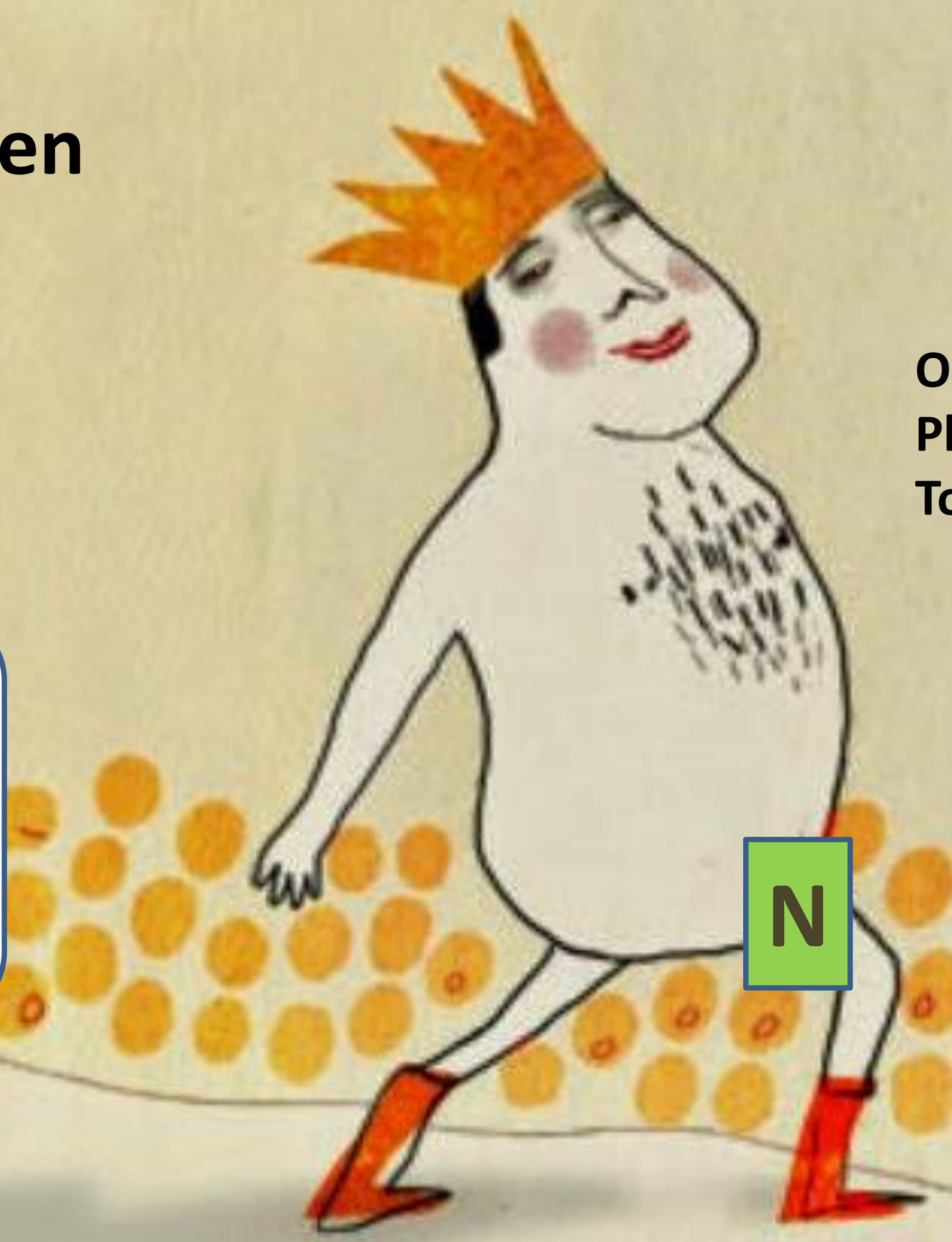
Baltic Sea

"The costs to reduce 15,016 t/yr of P and 133,170 t/yr of N according to HELCOM would be 3300 million Euro/yr (0.45 trillion $US). That is 2900 million Euro/yr higher than the "optimal" strategy advocated in this work." (P alone control = 400 million Euros). Lars Hakanson 2009.

Lake Winnipeg (5% of P loading)

New treatment costs to remove N and P from Winnipeg sewage = $365 Million.

Emperor Nitrogen is very scantily clad!



On close inspection, Phoenix turns out To be Icarus.

You are living in a House of Cards, Boys!

Proposal: A NEW SHOOTOUT AT THE N-P LAGOON: A POSSIBLE SOLUTION FOR VANILLA ASLO MEETINGS?

Rules:

Only ecosystem scale experiments or case histories where N or P has been decreased for several years.

Bottles, mesocosms and nutrient ratio data are prohibited.

Each paper 40 min, followed by 20 minutes of debate.

Lakes at first shootout, coastal waters at second.

Any hands not holding a weapon will be tied, to prevent hand- waving!

Mesocosm Experiments-Deficiencies

- **Cannot assess ecosystem phenomena that require months or years to adapt, ie some successional and new sediment-water equilibria.**
- **Are difficult to scale to properly assess sediment-water and hypolimnion-epilimnion exchanges.**

Conclusion: Can point the direction of response if properly scaled (a big if).