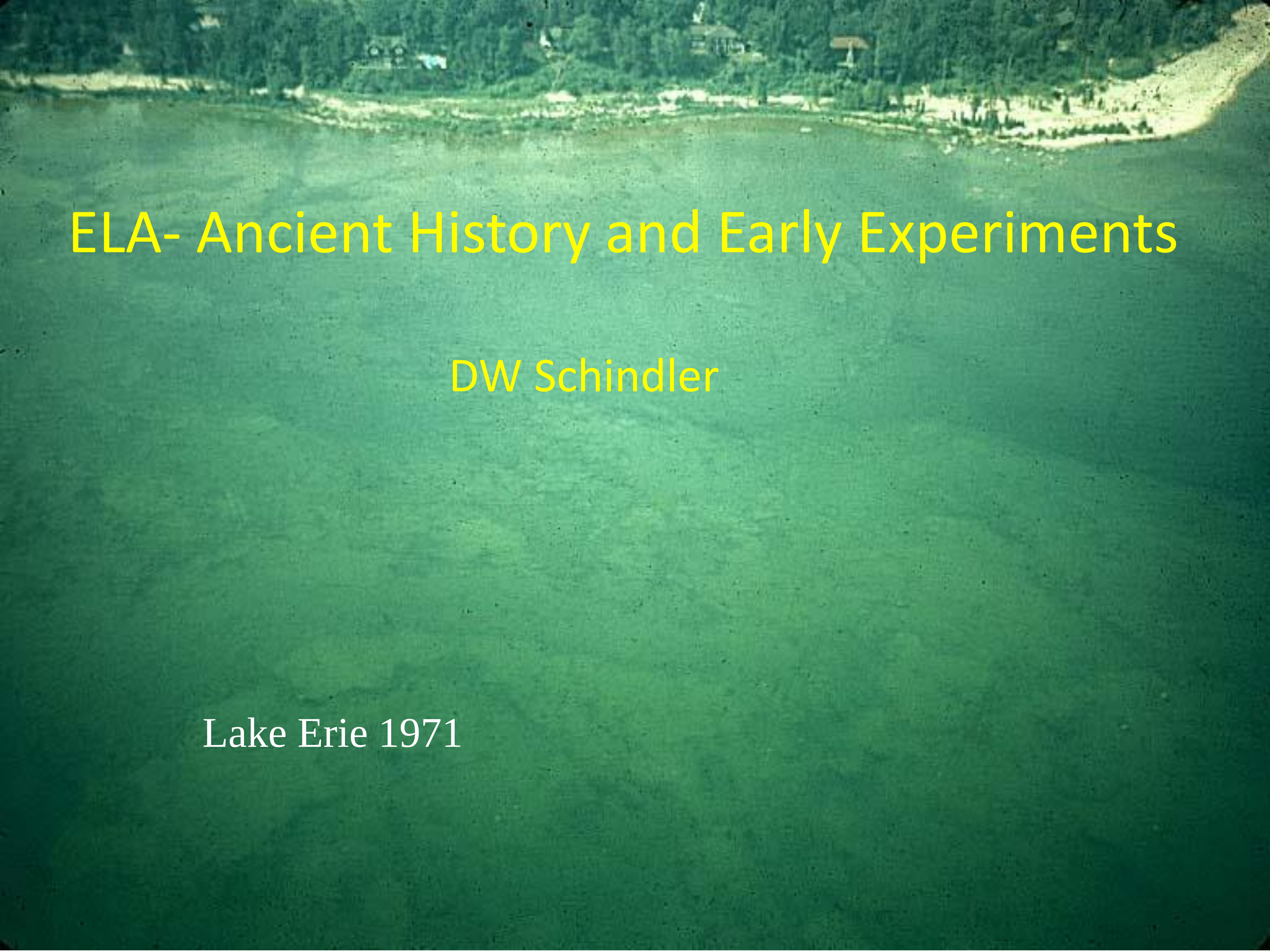
ELA- Ancient History and Early Experiments

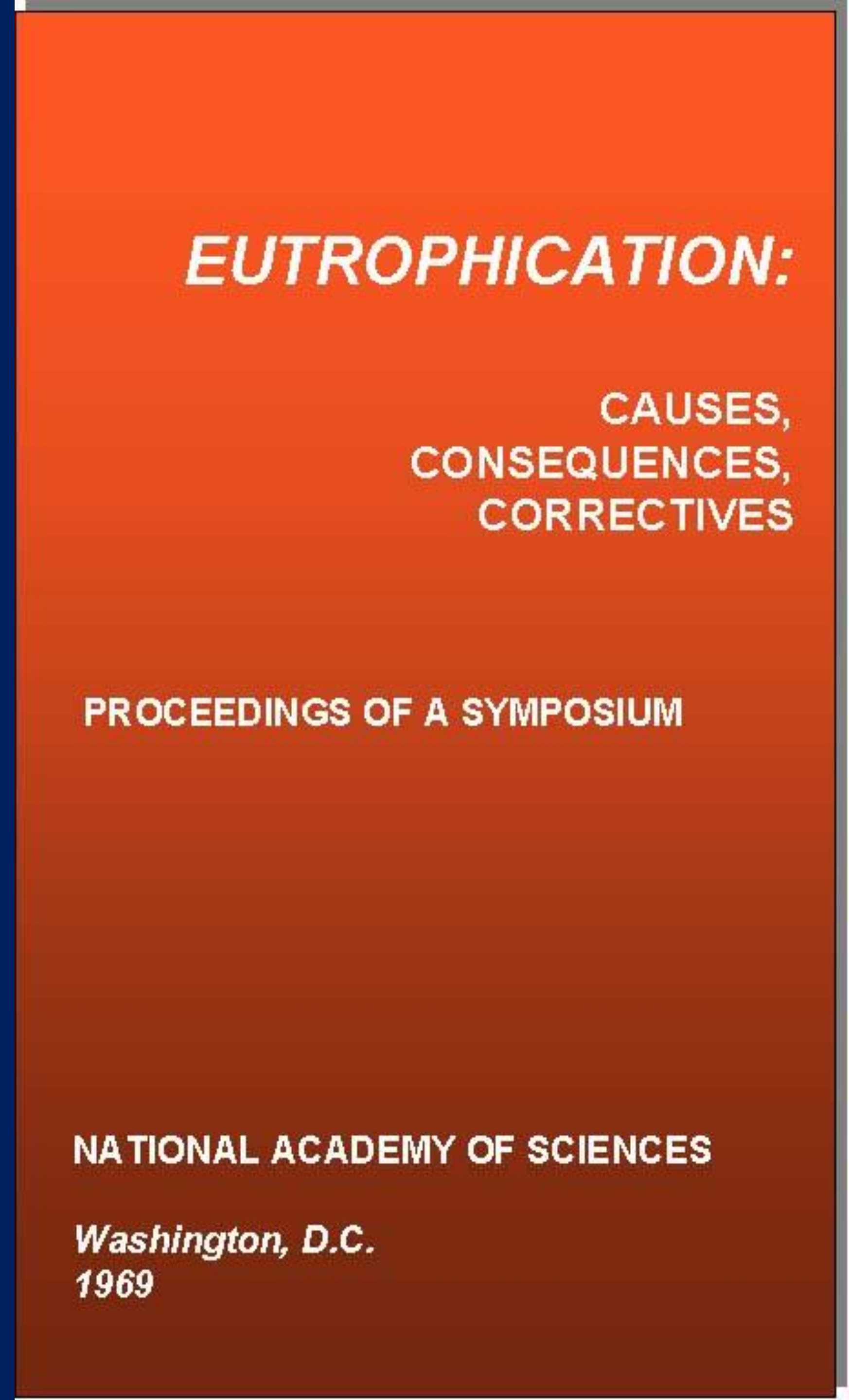
DW Schindler

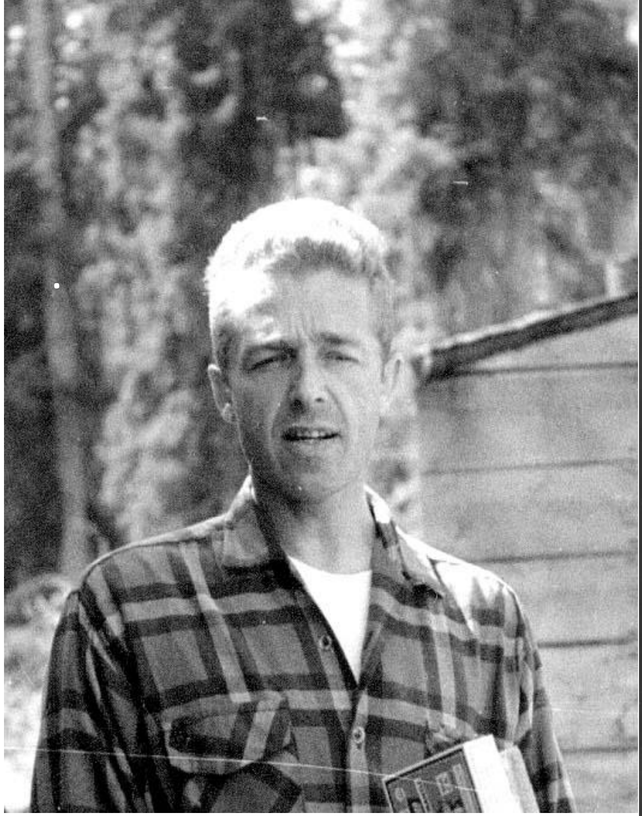


Lake Erie 1971

ELA Origin and Early History

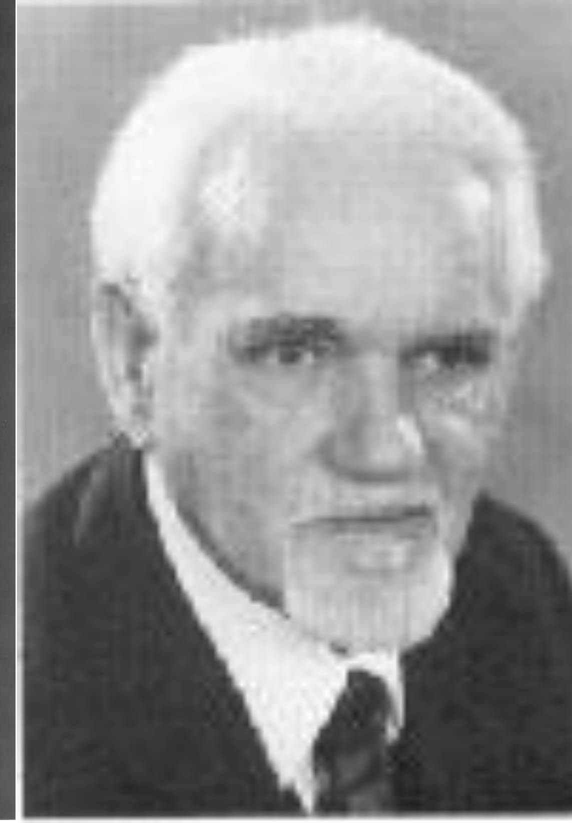
1965- IJC Report on Gt Lakes Pollution
1966-CCIW and FWI open
WE Johnson Director
JR Vallentyne Eutrophication
1967- Surveys of three areas for
experimental lake site
1968-Current area selected, surveys
begin. D Schindler arrives.
1969- Camp at permanent location
First lake experiment, L 227
1973- L226 Experiment begins
Windstorm
1974-First Forest Fire
1976- Mandate broadened
L 223 acid expt. begins



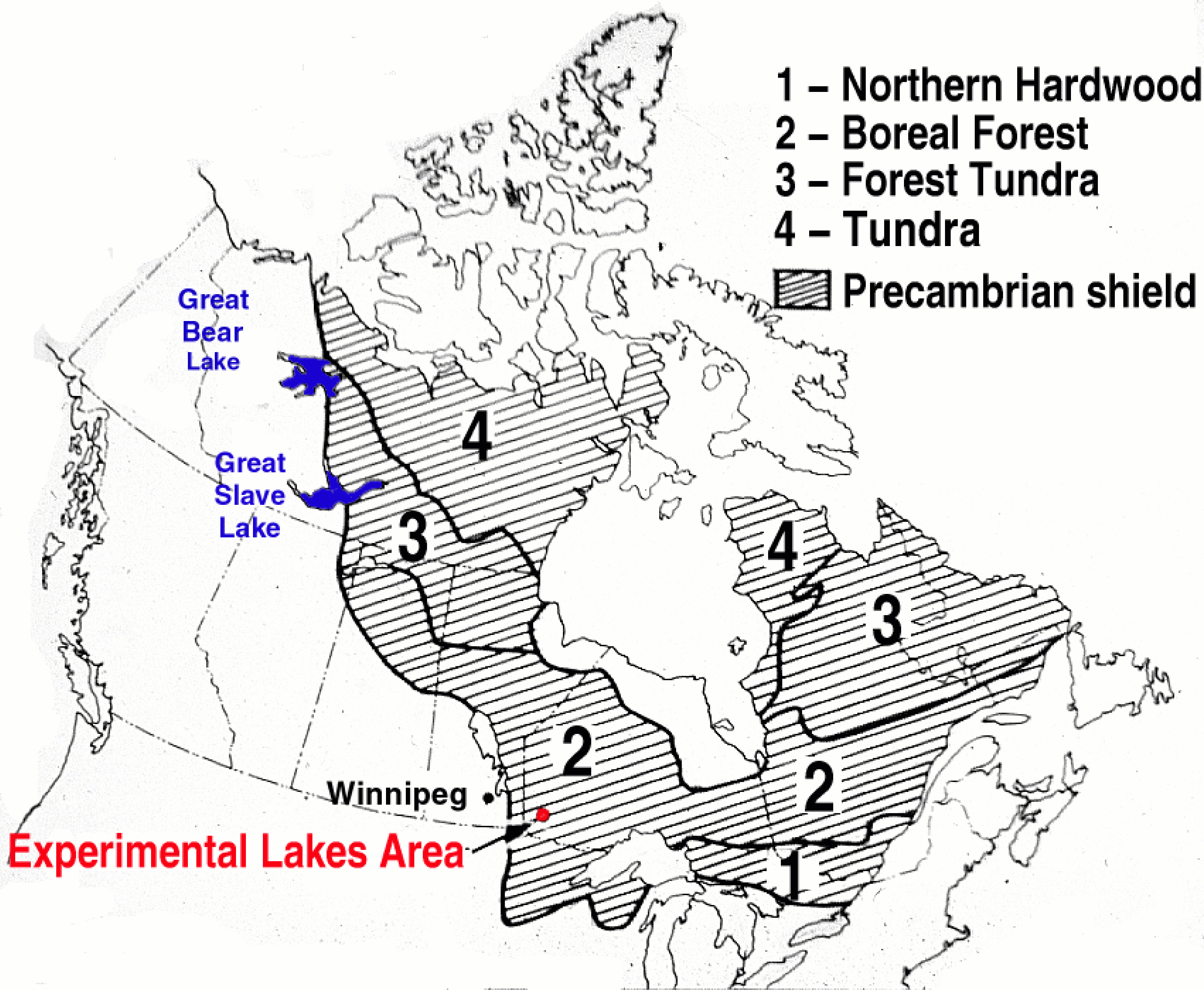


Wally Johnson

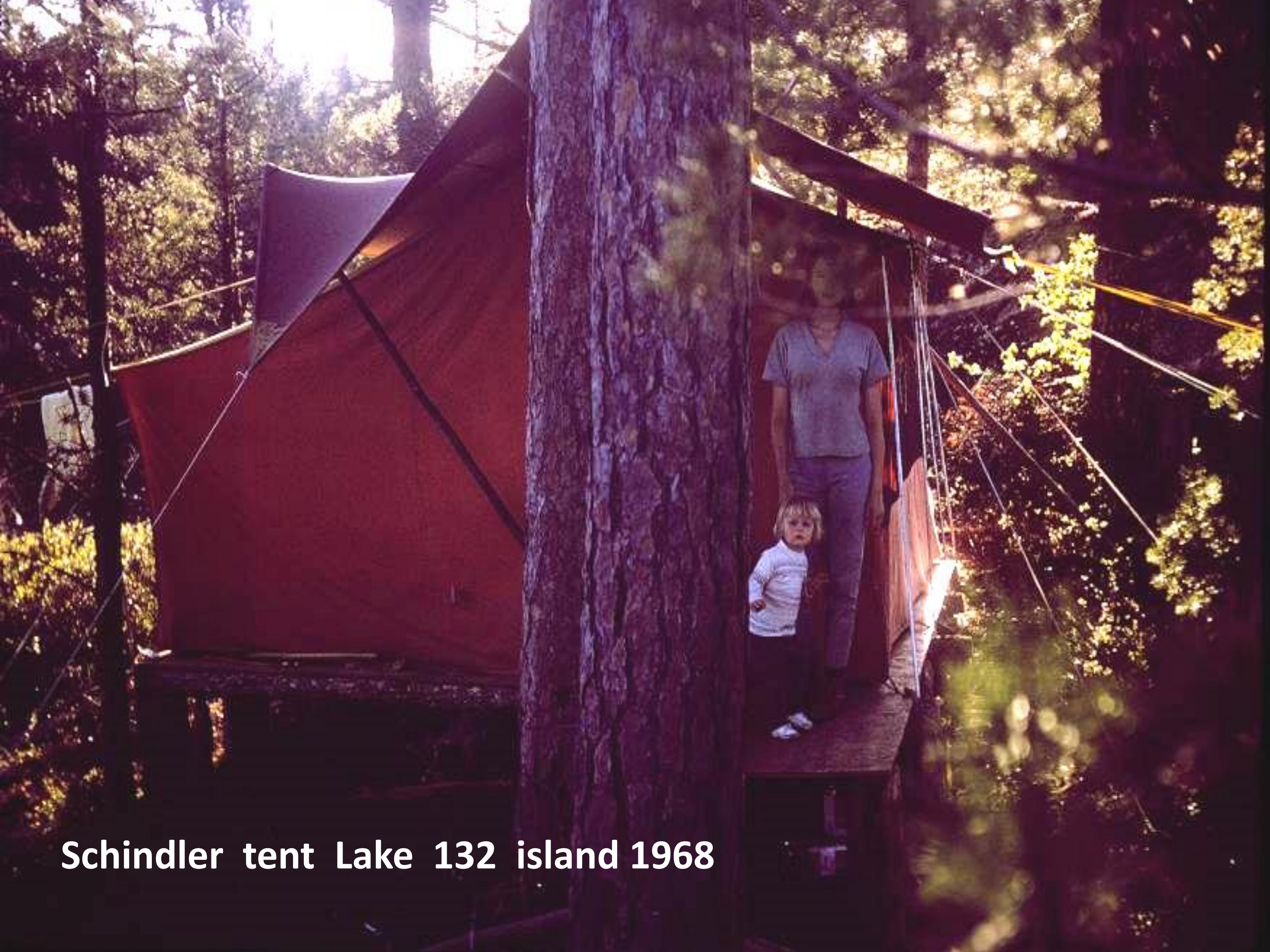
Jack Vallentyne



Richard Vollenweider


1 – Northern Hardwood
2 – Boreal Forest
3 – Forest Tundra
4 – Tundra
Precambrian shield
Great Bear Lake
Great Slave Lake
Winnipeg
Experimental Lakes Area
4
3
2
4
3
2
1

Experimental Lakes Area (ELA)


Schindler tent Lake 132 island 1968

ELA Camp January 1969

Summer 1969

Schindler Cabin Summer 1969

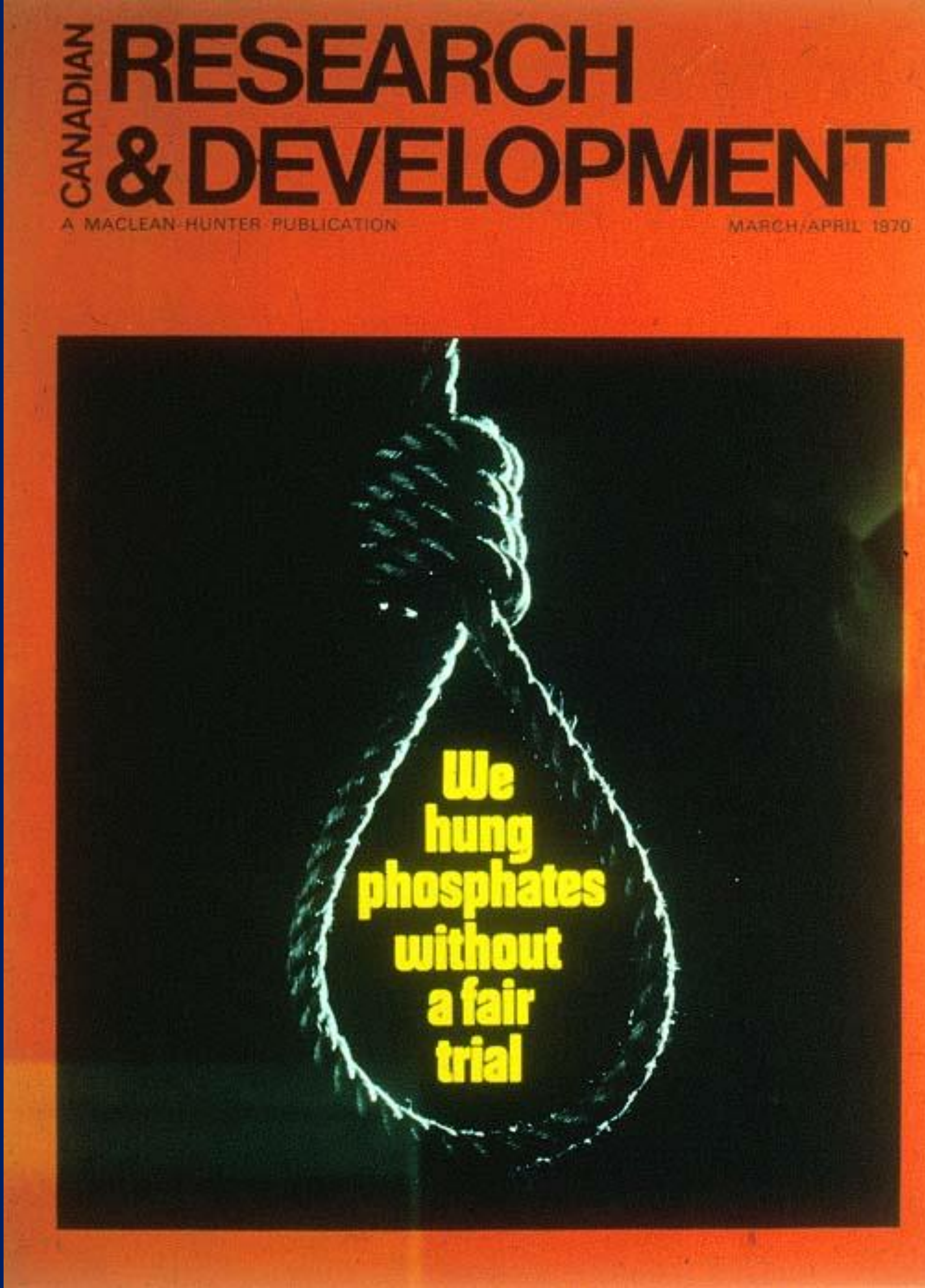
24 June 1974


L 239 Basin 1975


Early June 1980


July 1980

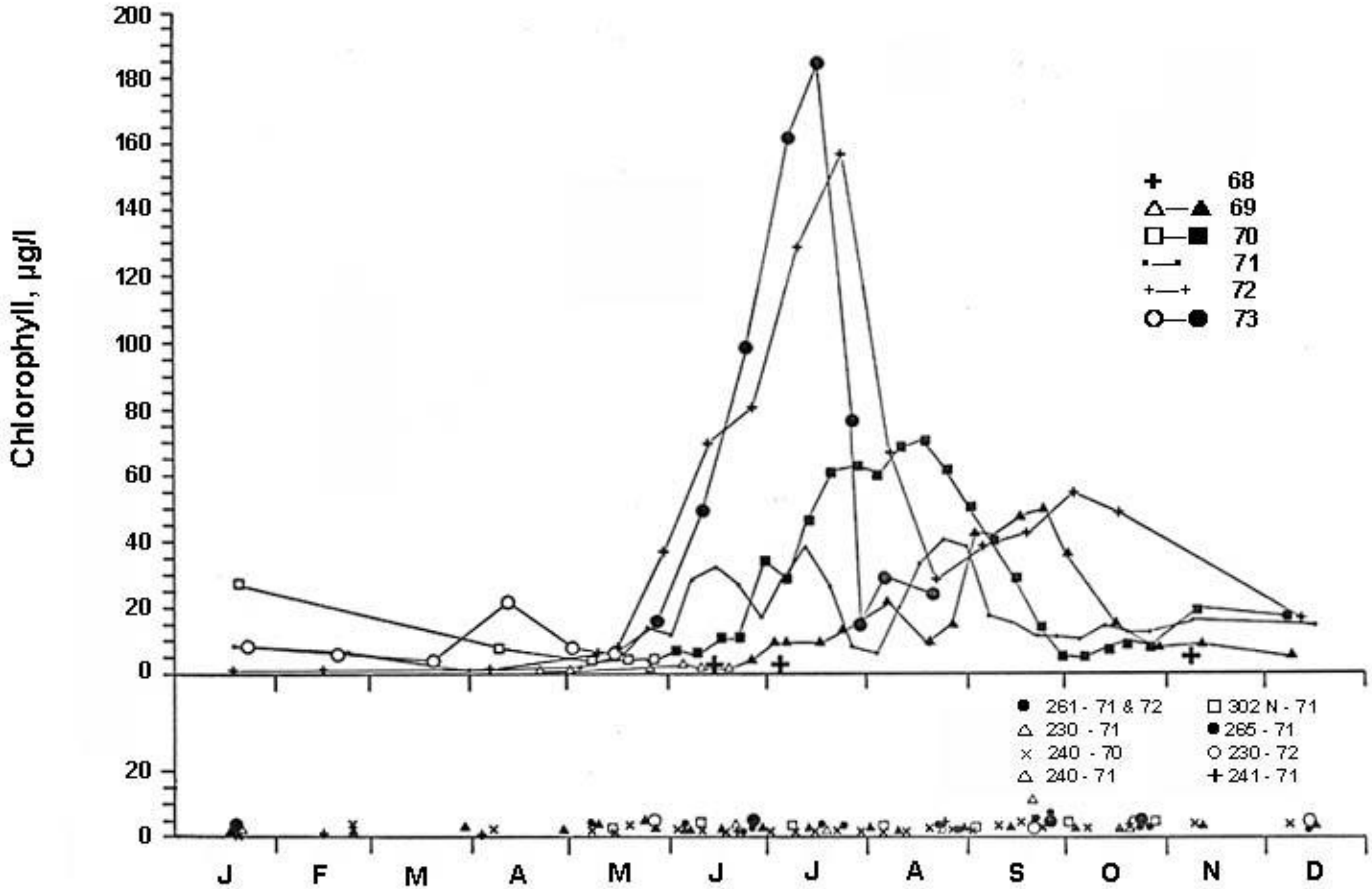
THE CARBON LIMITATION THEORY 1967-1971



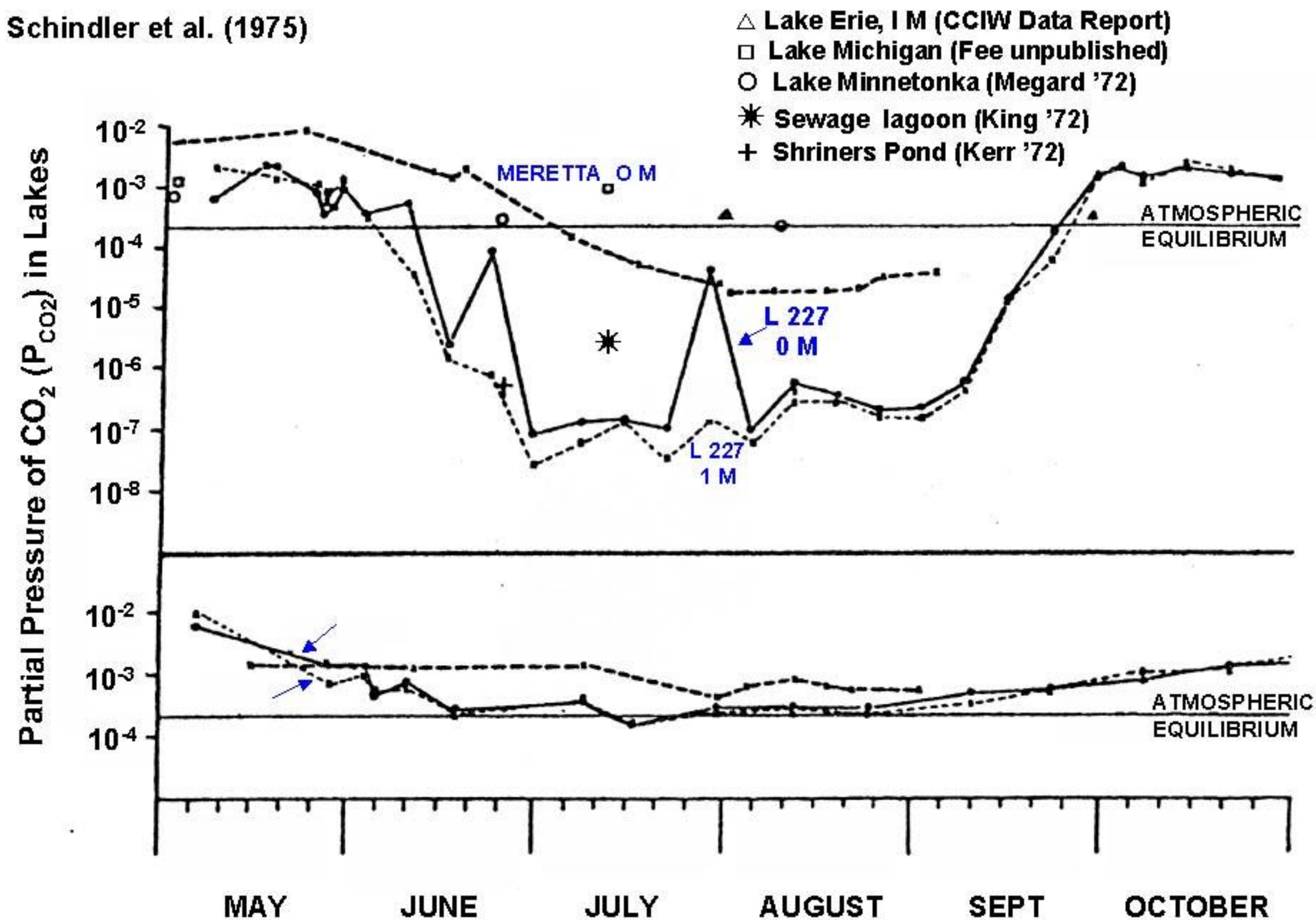
Lake 227

Before nutrient addition

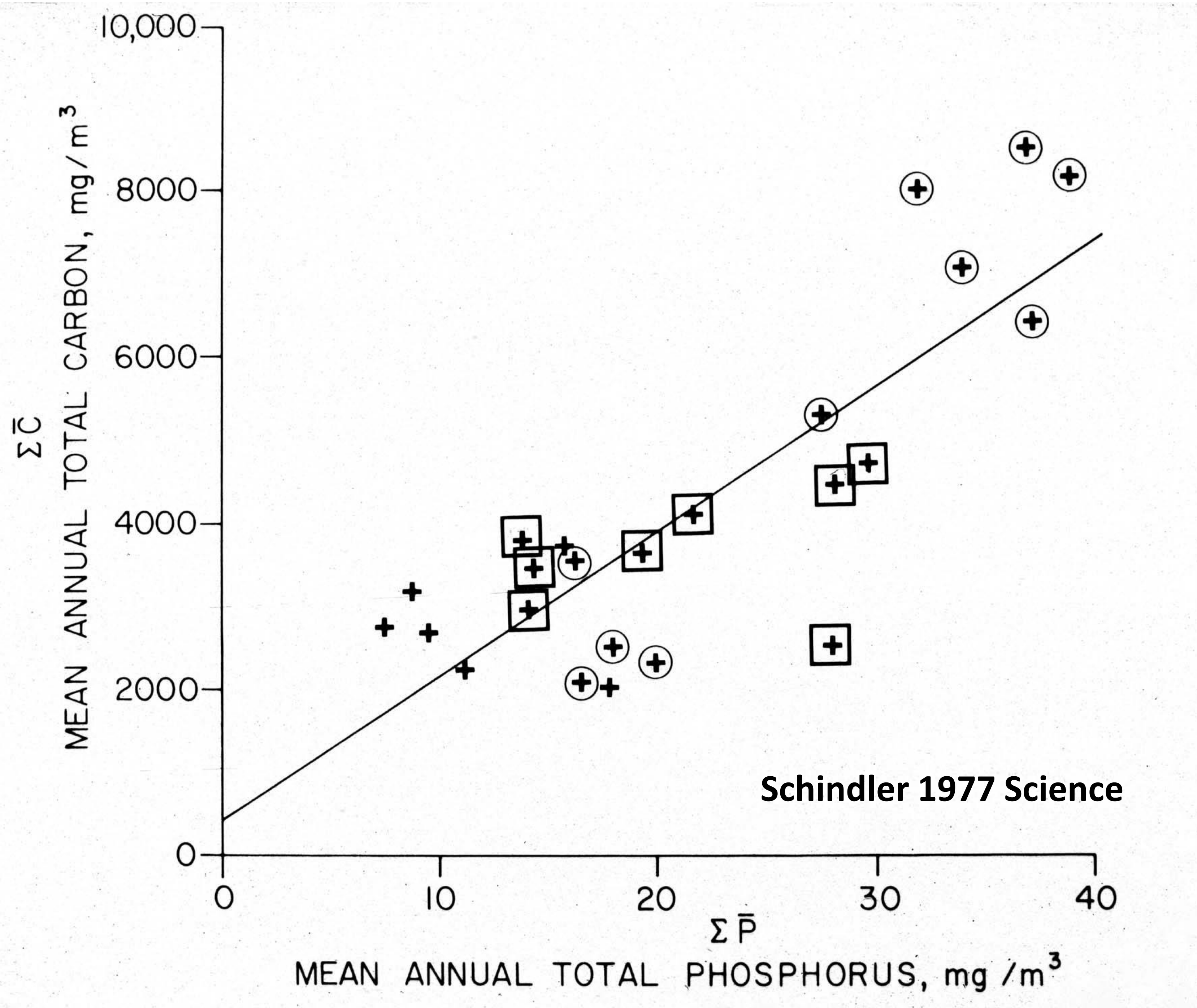
After adding P+N

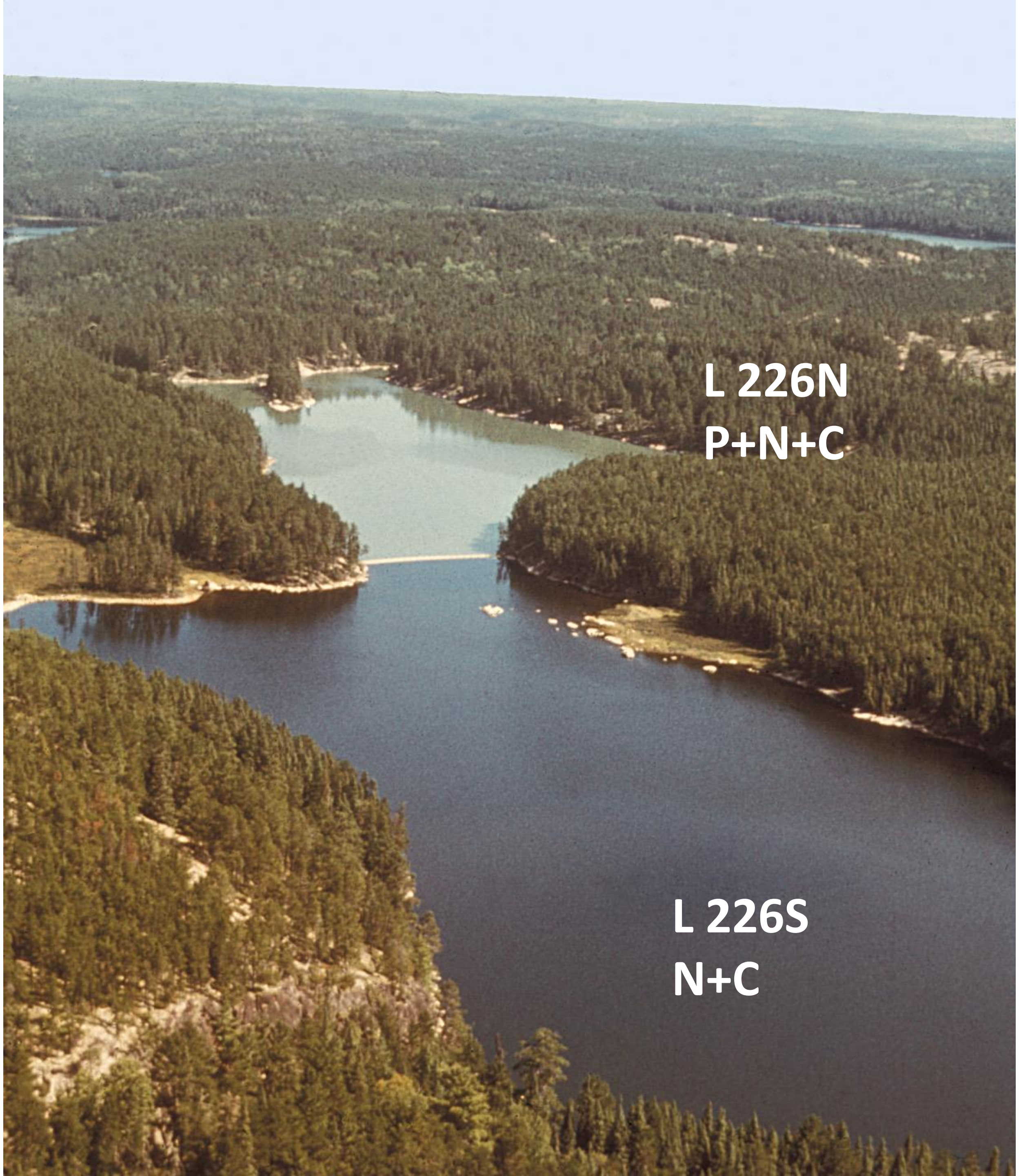


Schindler and Fee (1974)

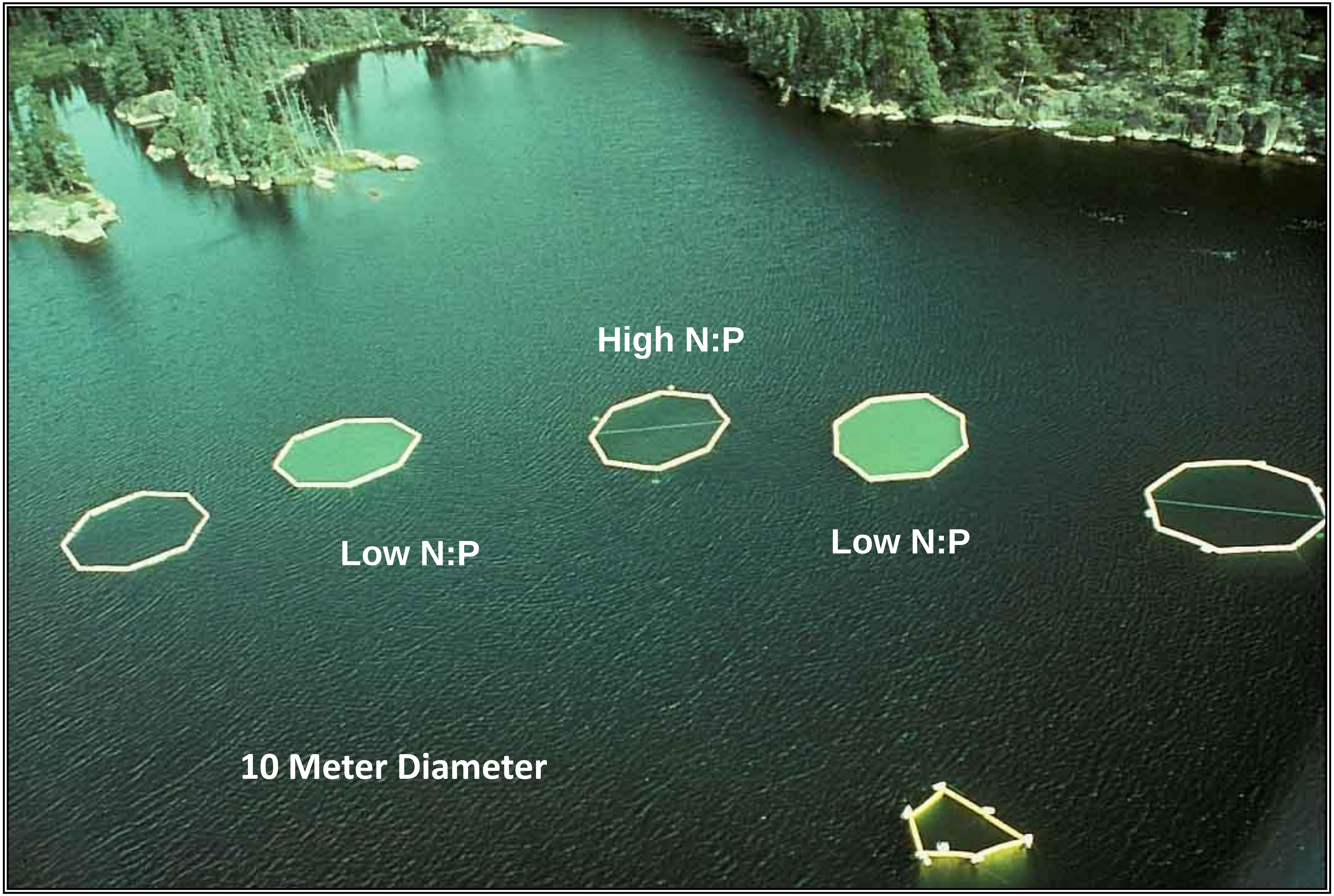


Schindler et al. (1975)
△ Lake Erie, I M (CCIW Data Report)
□ Lake Michigan (Fee unpublished)
○ Lake Minnetonka (Megard '72)
✱ Sewage lagoon (King '72)
+ Shriners Pond (Kerr '72)
Partial Pressure of CO_2 (P_{CO_2}) in Lakes
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
MERETTA O M
ATMOSPHERIC EQUILIBRIUM
L 227 0 M
L 227 1 M
MAY
JUNE
JULY
AUGUST
SEPT
OCTOBER


10,000
8000
6000
4000
2000
0
ΣC̄
MEAN ANNUAL TOTAL CARBON, mg/m3
0
10
20
30
40
ΣP̄
MEAN ANNUAL TOTAL PHOSPHORUS, mg/m3
Schindler 1977 Science



Schindler Science 1974



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

ELA Whole-Lake Nutrient Experiments
Total 81 Lake-Years of whole-lake 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

Reduced 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-

Nitrogen Control Theory resurfaces like a Phoenix in the New Millenium

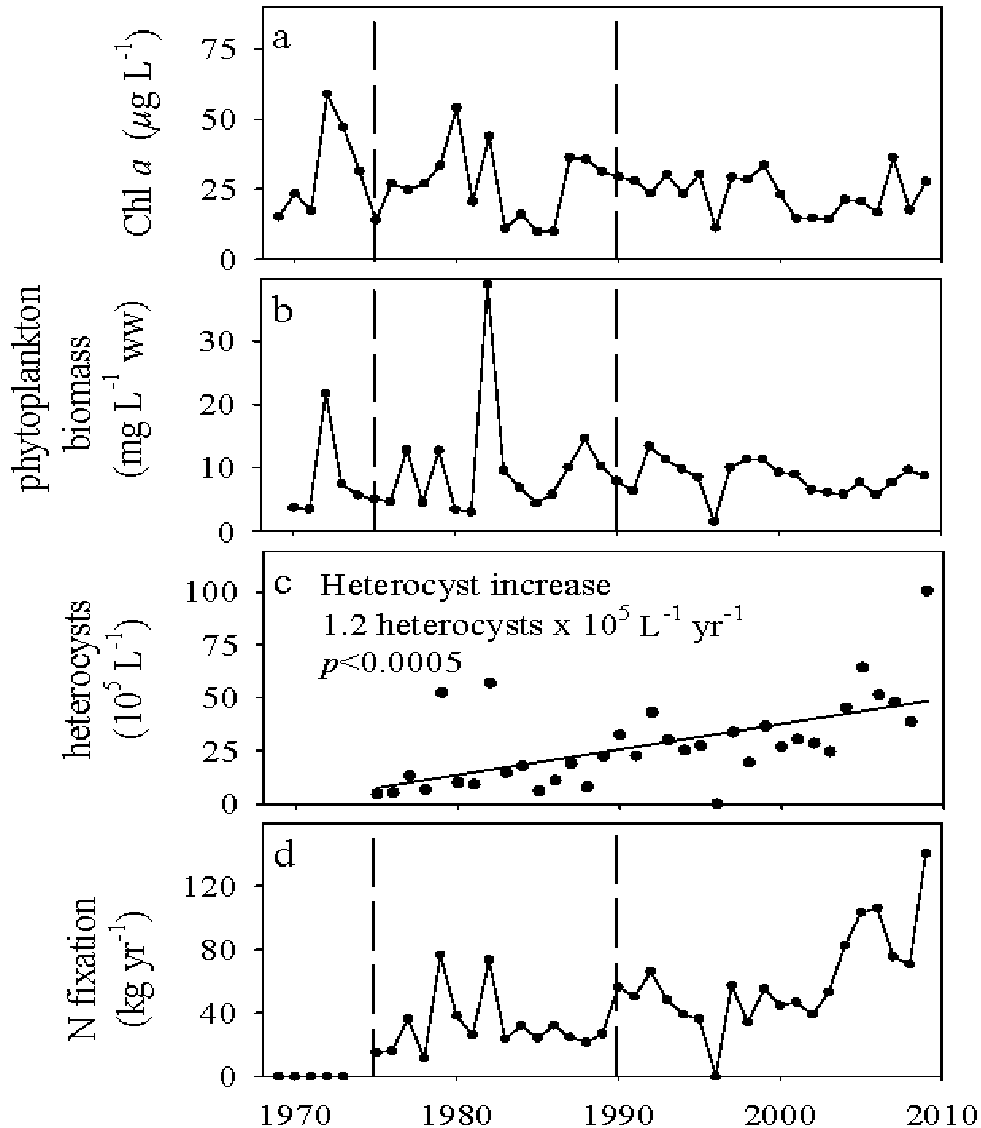
Control of Lacustrine Phytoplankton by Nutrients: Erosion of the Phosphorus Paradigm. W. M. Lewis, Jr. and W. A. Wurtsbaugh. 2008. Internat. Rev. Hydrobiol. 93 (4–5) 446–465.

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

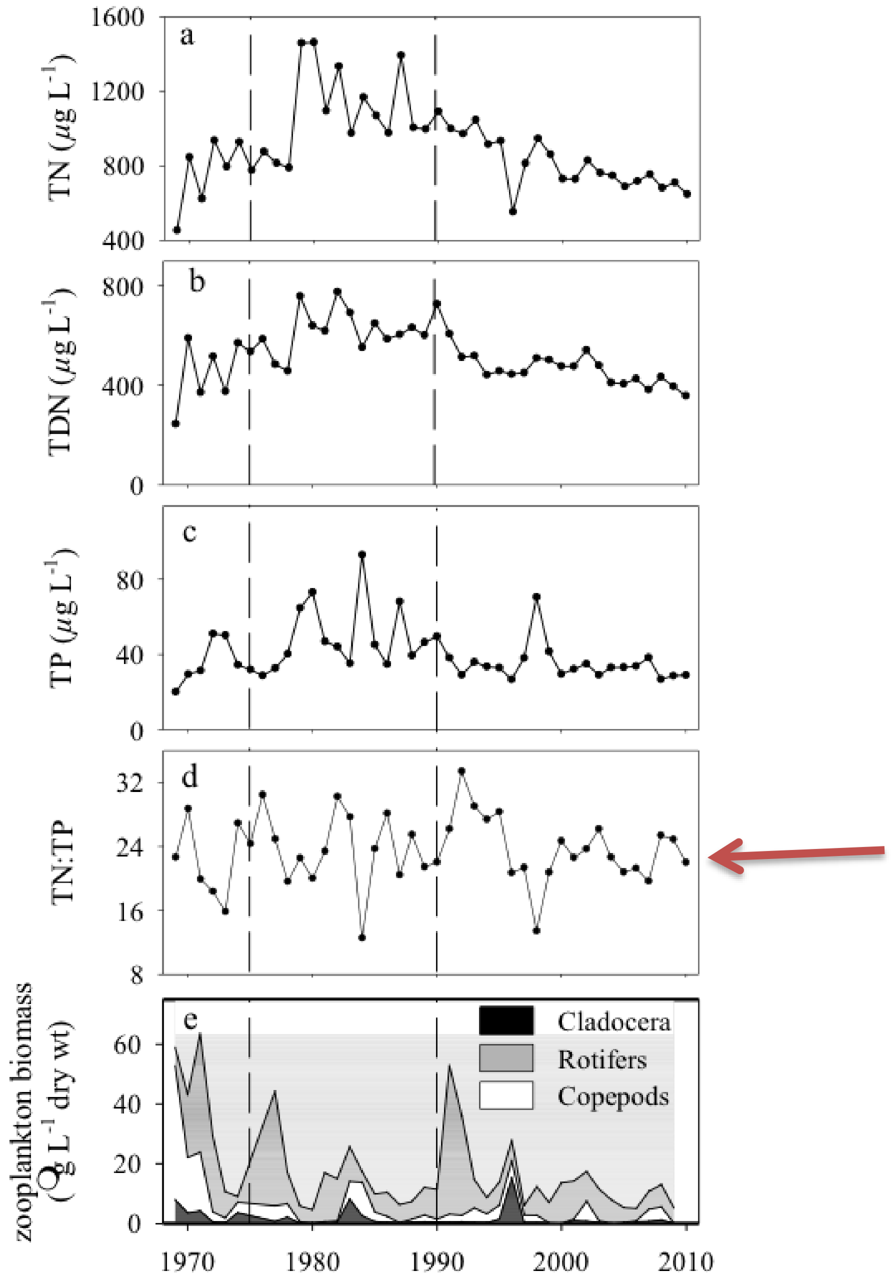
Algal blooms: Noteworthy nitrogen. H. Paerl et al. 2014. Nature 346: 175.

It takes two to tango: When & where dual nutrients (N & P) reductions are needed to protect lakes and downstream ecosystems. H. Paerl et al. 2016. Env. Sci. Technol. ***

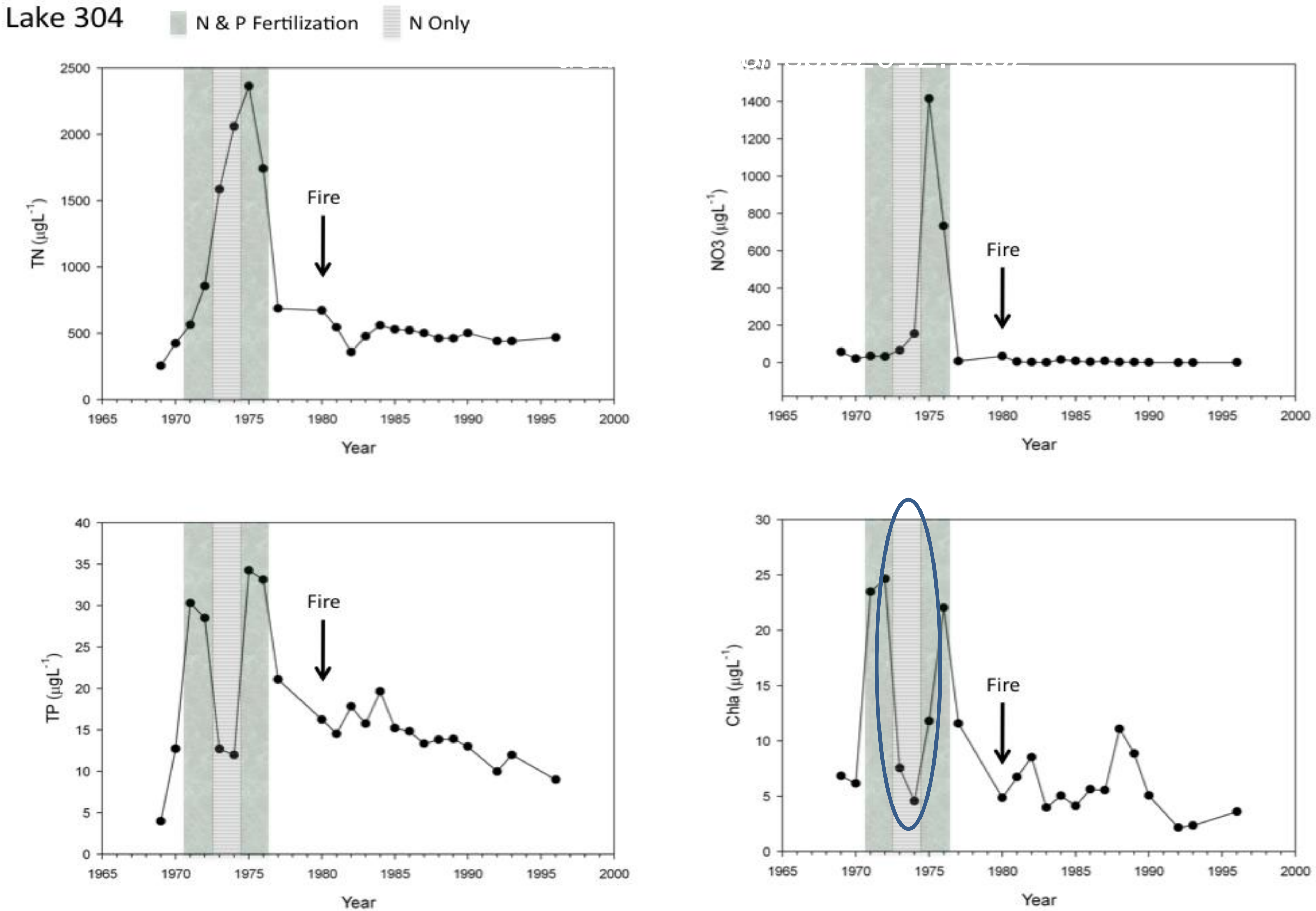
L227



Paterson et al. 2010 Limnol. Oceanogr.



a
b
c
d
e
TN (μg L^{-1})
TDN (μg L^{-1})
TP (μg L^{-1})
TN:TP
zooplankton biomass
(μg L^{-1} dry wt)
Cladocera
Rotifers
Copepods
1600
1200
800
400
0
80
40
32
24
16
8
60
20
1970
1980
1990
2000
2010

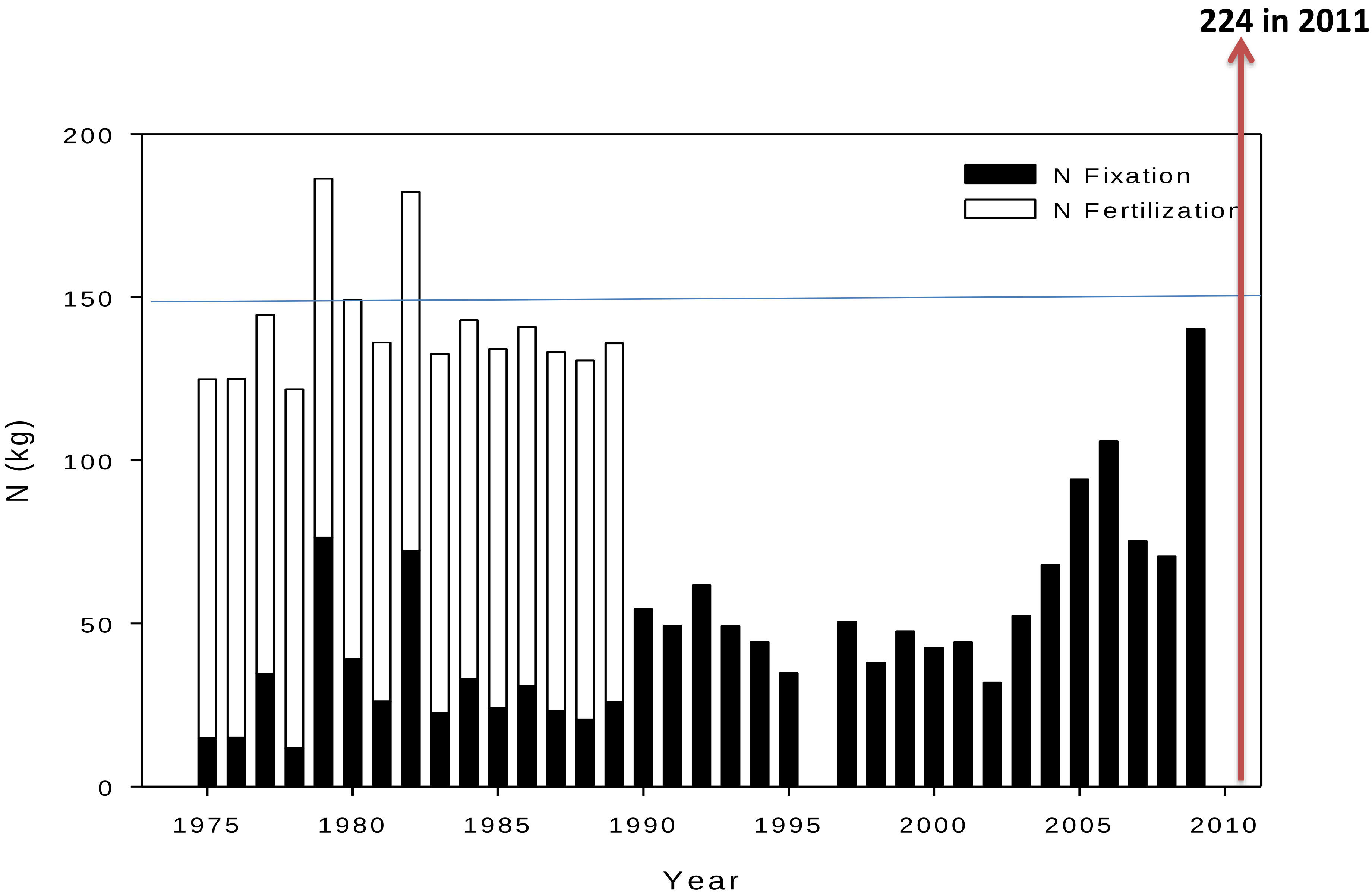


Cutting P without cutting N causes rapid decline in chl a in L 304
NO3 declined rapidly (denitrified). Schindler 2012 Proc. Roy. Soc. B

Lake 227 Nitrogen Flux to Water Column. Lehnherr 2013.

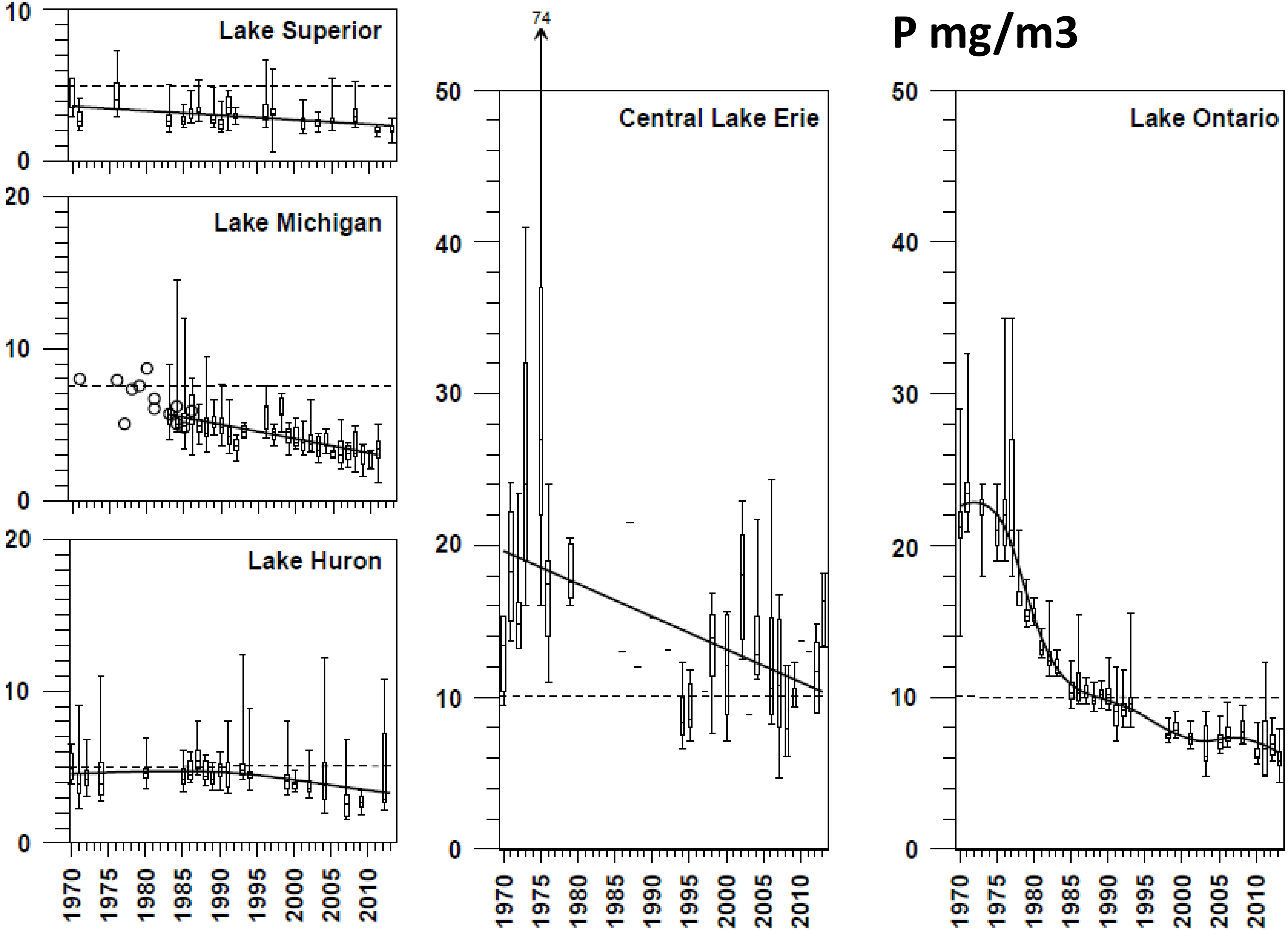
Nitrogen Source	Flux during 2011 summer stratification period (kg N)
Profundal Sediments (5-10 m)	102
Littoral Sediments (0-2.5 m)	37
Total Return of DIN from Sediments	139
N_2-Fixation	224
Atmospheric Deposition (2004-2007 mean)	13
Runoff (2004-2007 mean)	51

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



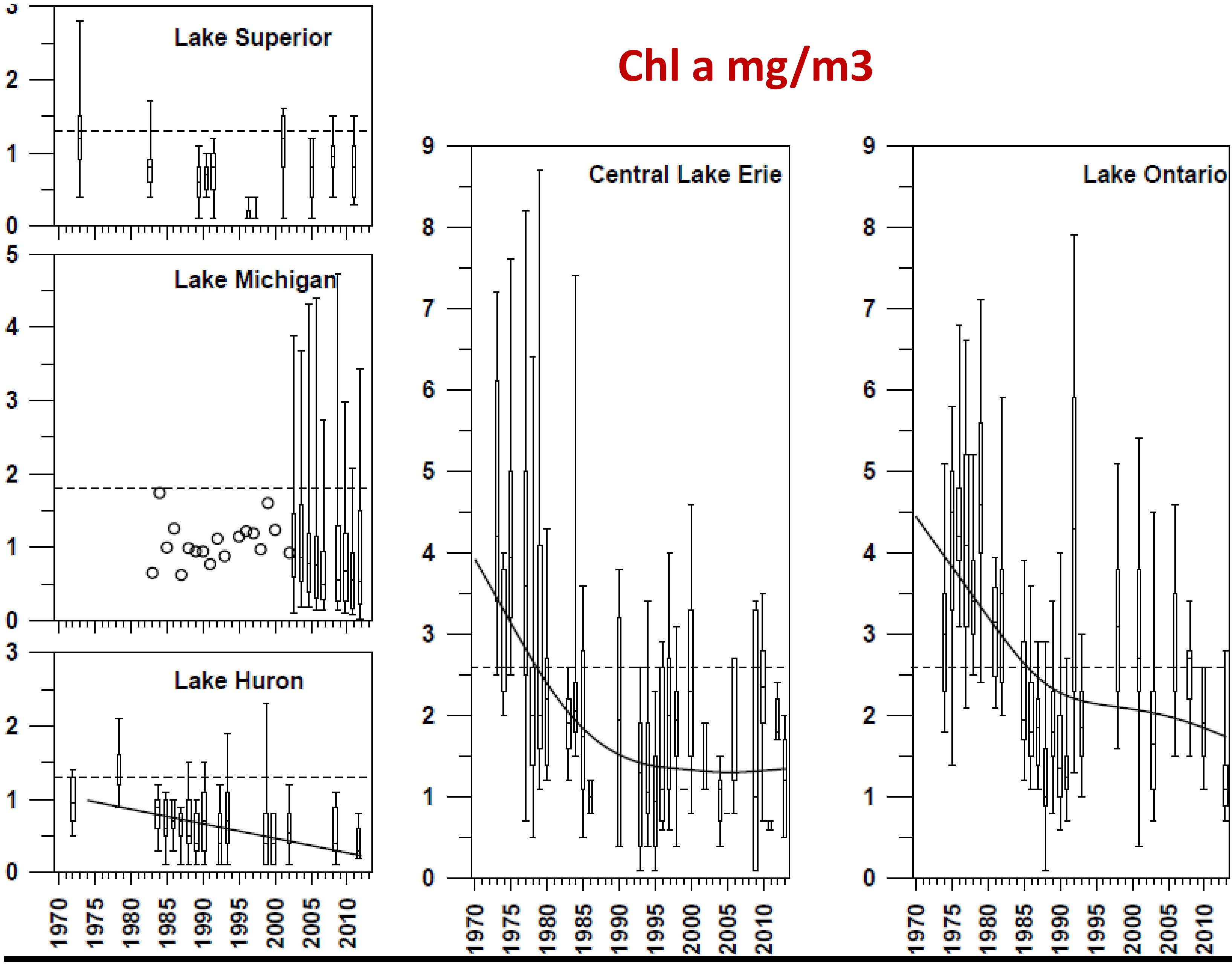
N-fixation is now equal to or greater than the sum of fertilizer+ n-fixation in the 1980s, and is still increasing.

P mg/m3



Dove and Chapra L & O 2015

Chl a mg/m3



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

There are numerous case histories and experiments showing that P control has reduced eutrophication .

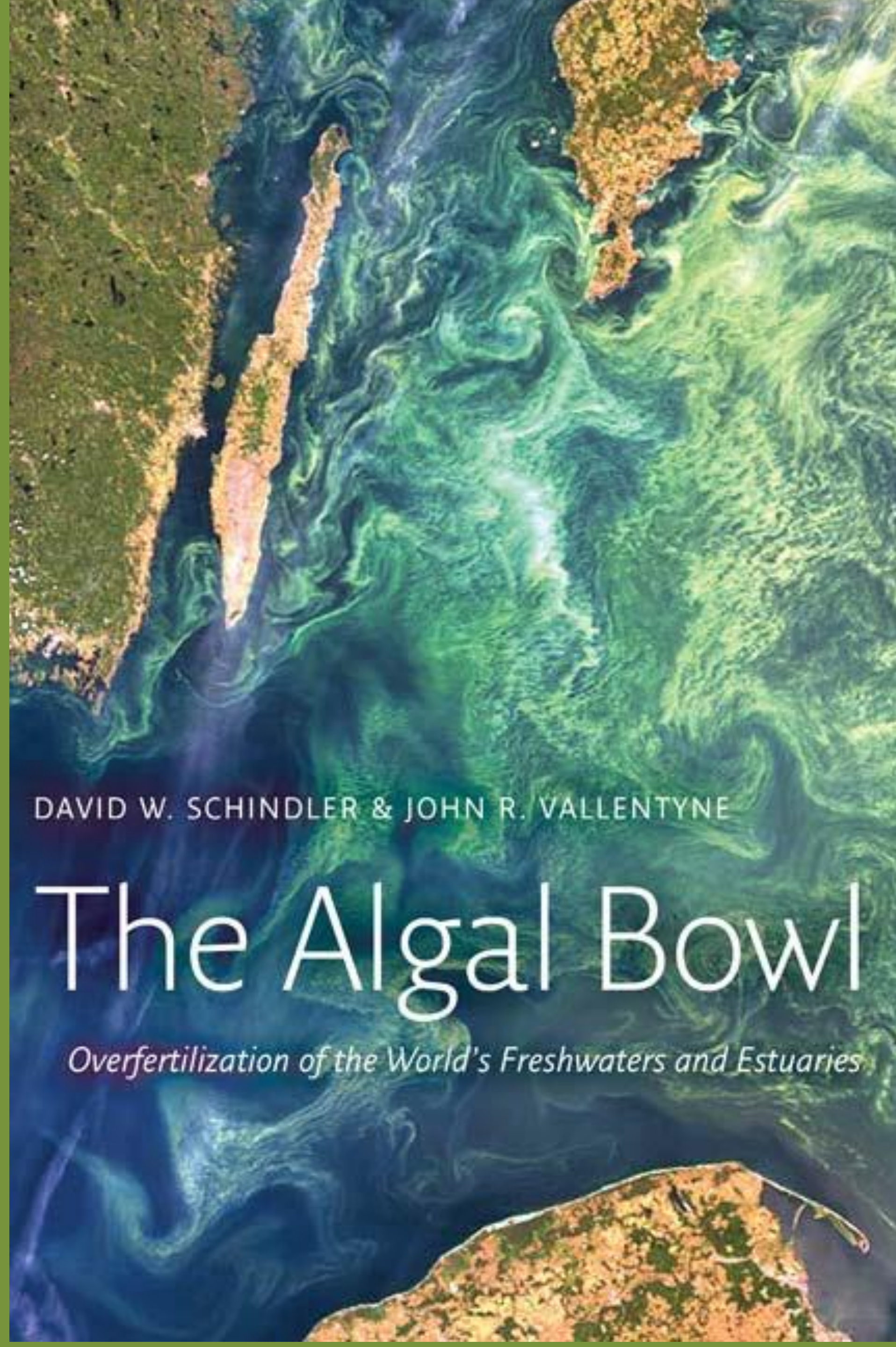
Lake Erie
Lake Ontario
Lake Michigan
Lake Huron
Lake Superior
Lake Onondaga, NY
Lake Geneva, Switzerland
Lake Lucerne, Switzerland
Lake Zurich, Switzerland
Lake Constance, Switzerland
Lake Norrviken, Sweden
Lake Malaren, Sweden
Lake Hjalmaren, Sweden
Lake Vattern, Sweden
Lake Vanern, Sweden
Lake Mjosa, Sweden
Gravenhurst Bay, Muskoka
Kootenay Lake, BC
Moses Lake, Washington
Several ELA lakes

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

Stockholm Archipelago

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

U of Alberta
Press 2008



ASLO 2015 Redfield Prize Lecture

Pee N

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

D. W. Schindler

Redfield Ratio

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

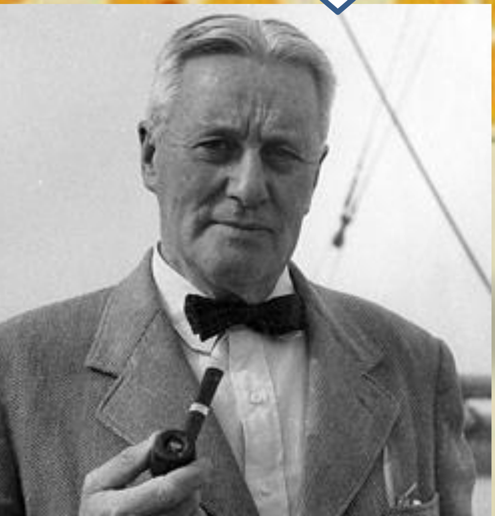
Redfield, A.C., The biological control of chemical factors in the environment, *American Scientist*, 1958

Emperor Nitrogen is very scantily clad!

On close inspection, Phoenix turns out To be Icarus.

N

You are living in a House of Cards, Boys!



Reducing Phosphorus to Curb Lake Eutrophication is a Success

David W. Schindler, Stephen R. Carpenter, Steven C. Chapra, Robert E. Hecky and Diane M. Orihel. Environ. Sci. Technol. 2016

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) biogeochemical 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 are too short to estimate slow biogeochemical processes and successional changes that require years.

Limnology is plagued by flawed logic

Lake 227 is *nitrogen limited* for most of the summer according to bottle bioassays and mesocosms.

But **there are no anthropogenic sources of N to control.**

Proximate nitrogen limitation does not indicate that N must be reduced, as commonly interpreted.

Instead, N limitation means that a lake is receiving *too much phosphorus*, ie the very opposite of the traditional interpretation.

Eutrophication requires controlling the *ultimate* rather than the *proximate* limiting nutrient, ie phosphorus.

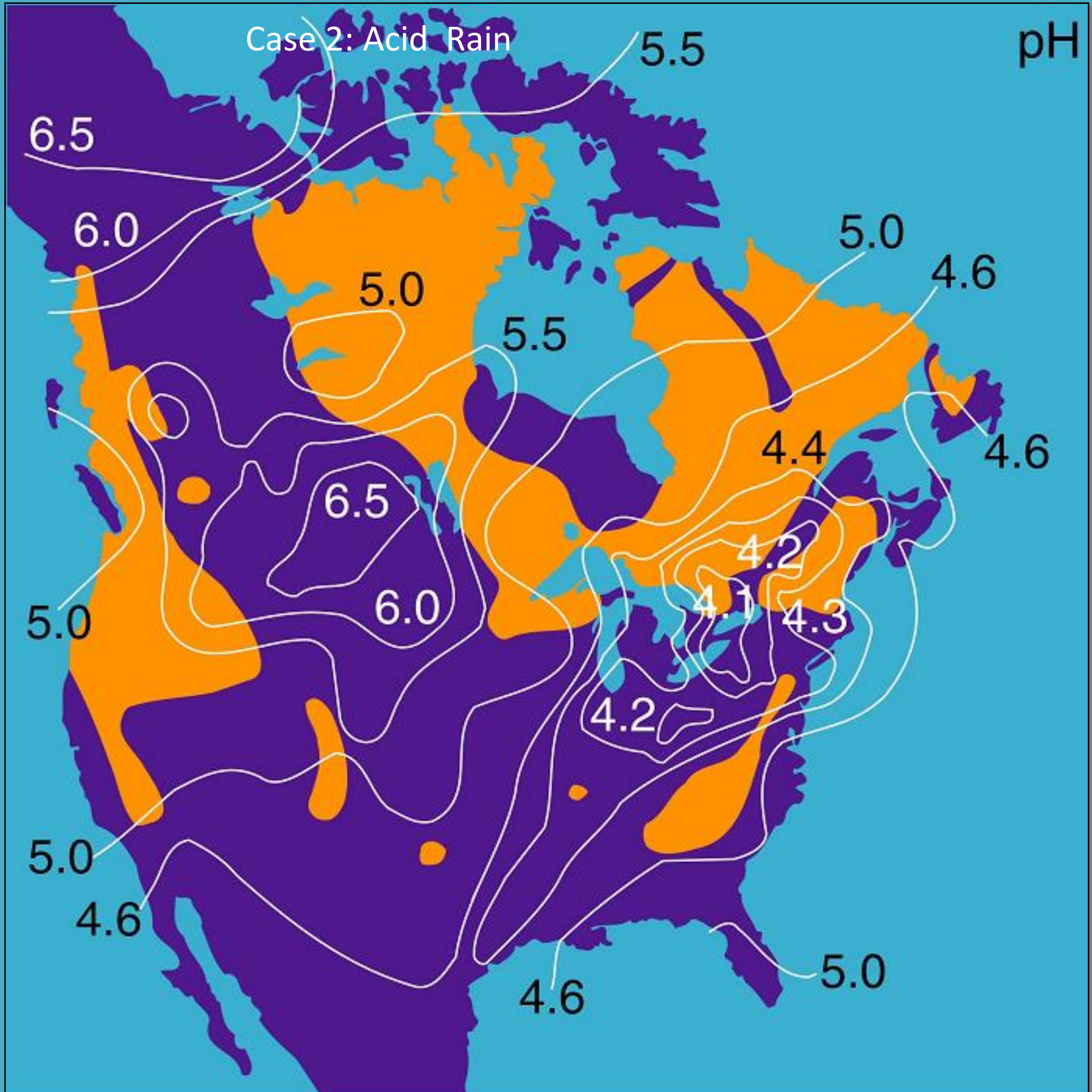
.

The Costs of a Mistake are Huge

Ex: 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.

Case 2: Acid Rain




Lake 223

pH in L223 & L302S

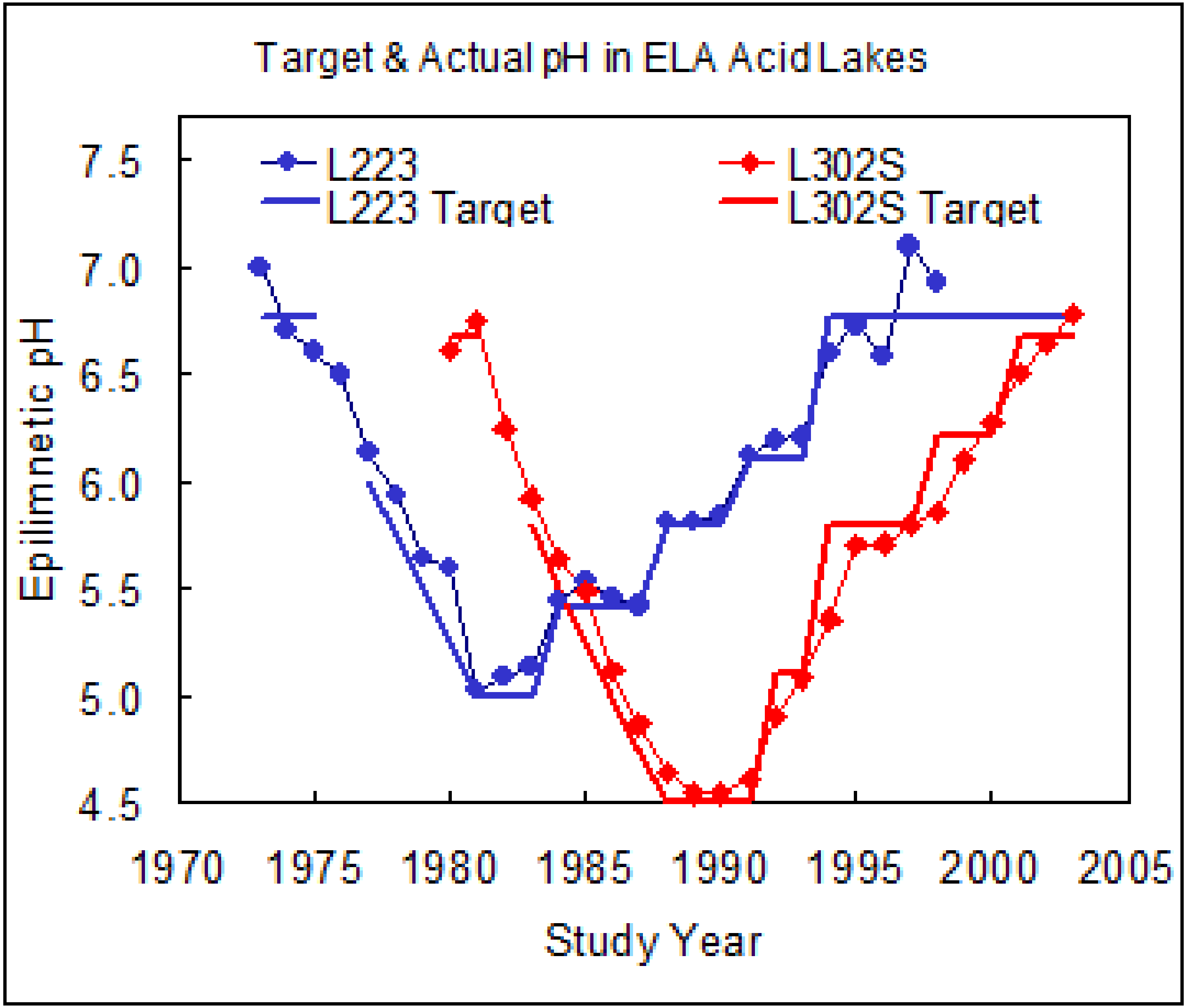


Figure 3. One of the key food species of lake trout eliminated at pH 6 *Pimephales promelas* (Fathead minnow). **Photo by Ken Mills**

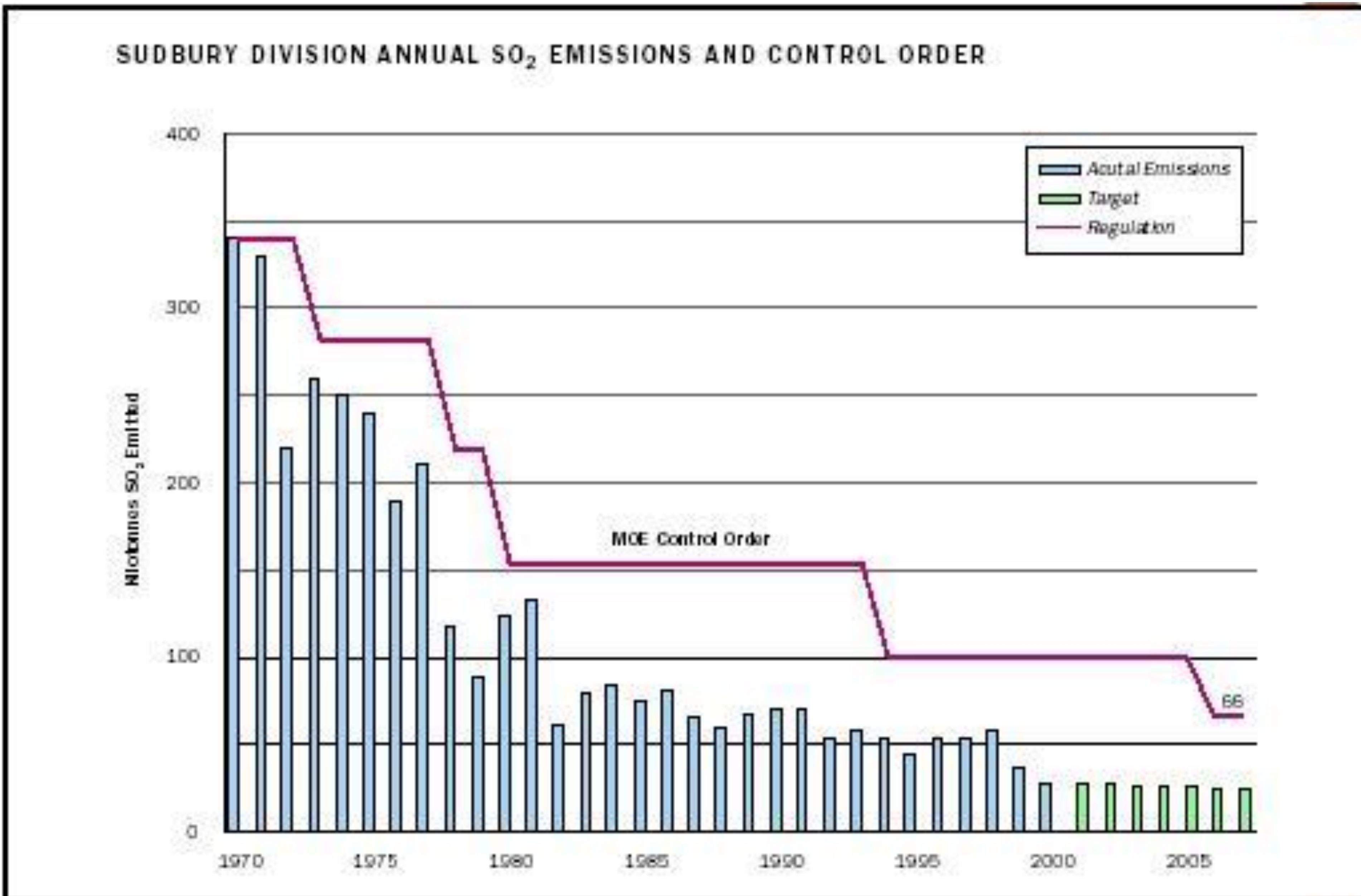
Mysis relicta

Figure 2. Lake trout before and after acidification extirpated key food species in Lake 223, leaving the trout too starved to reproduce.
Schindler et al. 1985. Science 228: 1395-1401. Photos by Ken Mills

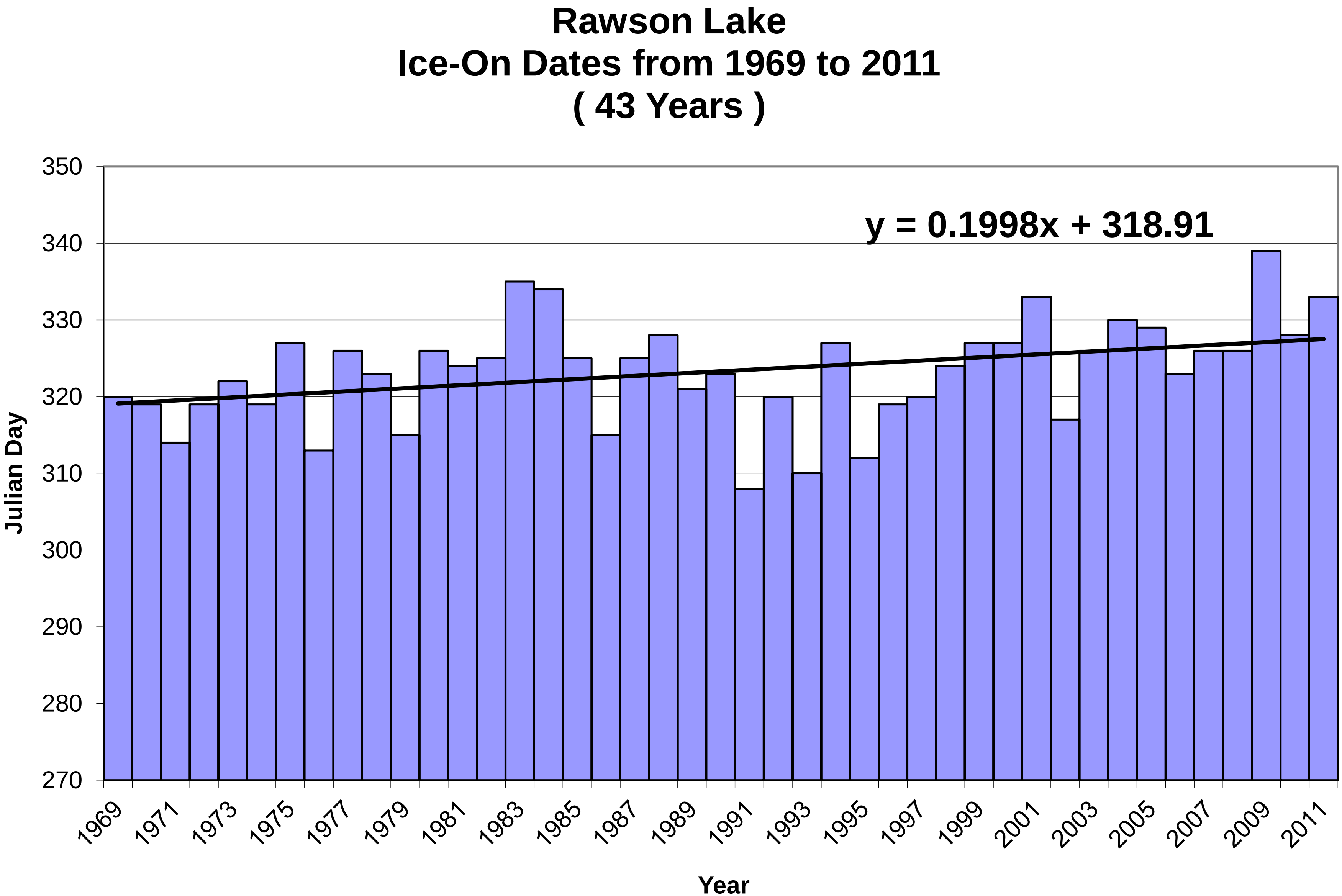
Changes in the number of species in various taxonomic groups in Lake 223 during experimental acidification

Taxonomic Group	1974-75 pH > 6.5	1981-83 pH 5.0-5.1	% Lost
Planktonic algae	78	73	6
Benthic algae	30	16	47
Zooplankton	31	19	39
Dipteran insects	70	36	51
Benthic crustaceans	3	0	100
Fish	6	3	50-100
Total species	218	144-147	33-34

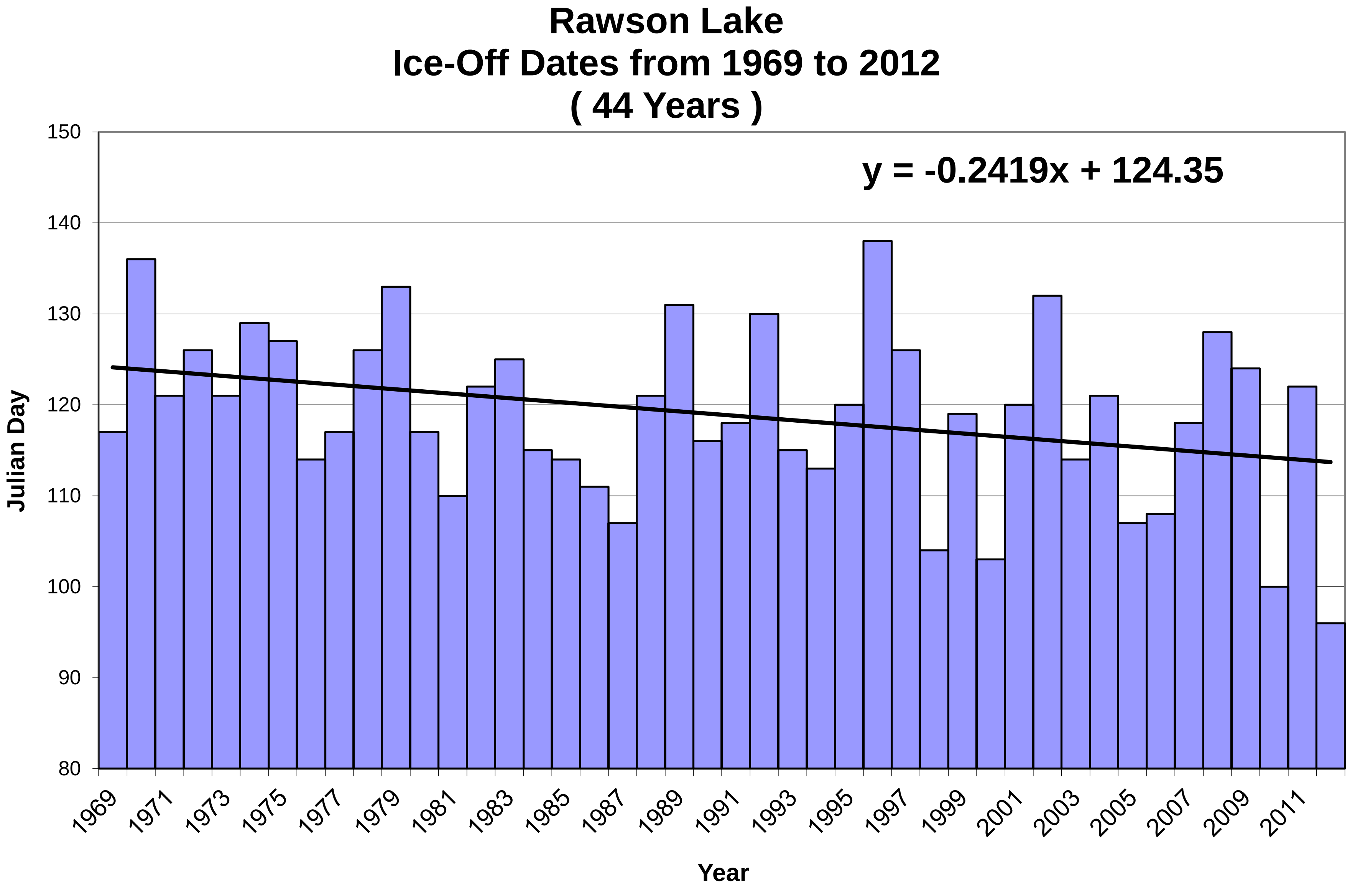
Figure 5. Biodiversity in Lake 223, ELA, under pristine conditions and after acidification to pH 5.

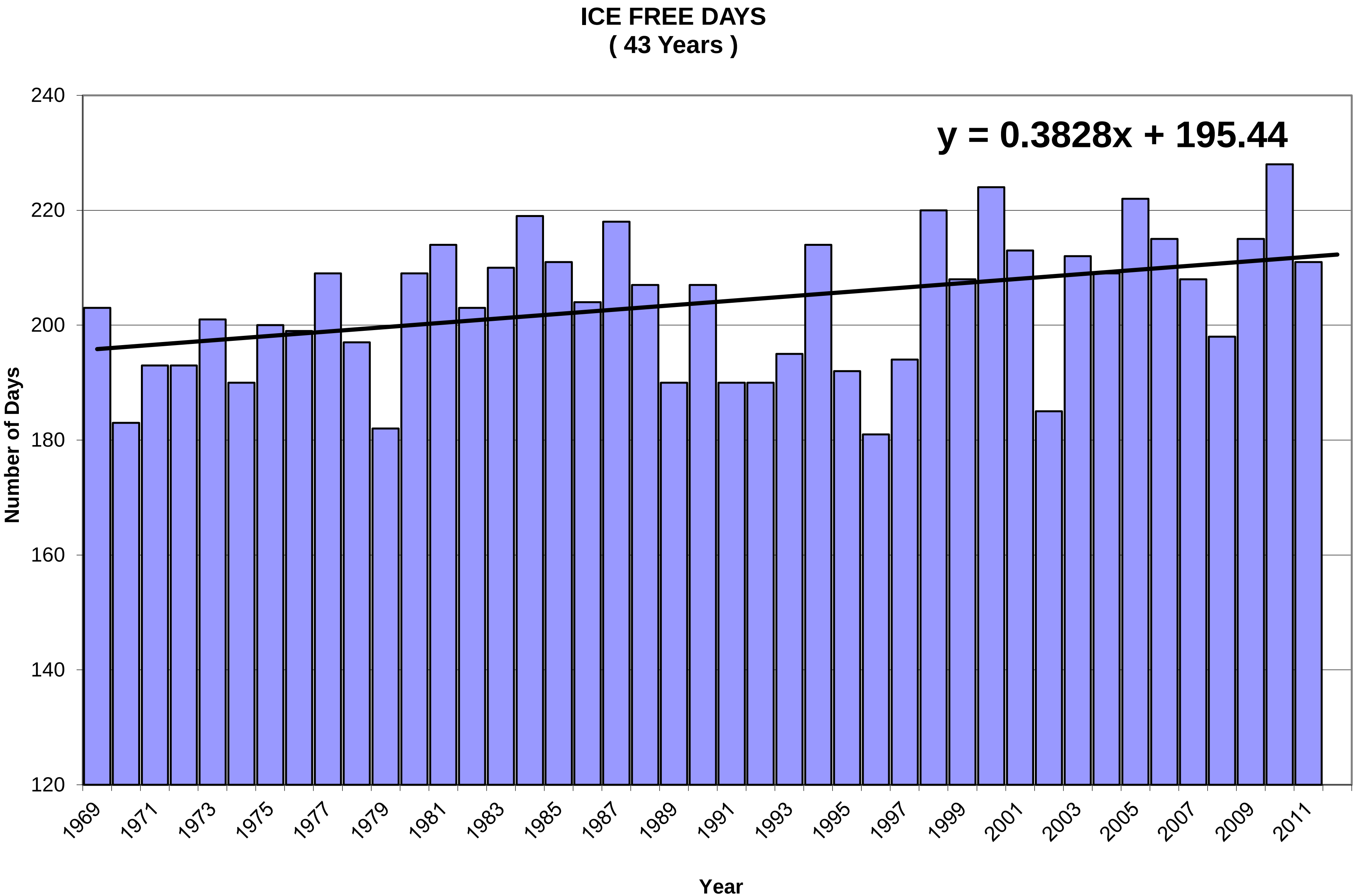

SUDBURY DIVISION ANNUAL SO2 EMISSIONS AND CONTROL ORDER
Acutal Emissions
Target
Regulation
MOE Control Order
66
Kilotonnes SO2 Emitted
0
100
200
300
400
1970
1975
1980
1985
1990
1995
2000
2005


A. Hamilton 1971


Rawson Lake
Ice-On Dates from 1969 to 2011
(43 Years)
y = 0.1998x + 318.91
Julian Day
350
340
330
320
310
300
290
280
270
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year

K. Beaty


Rawson Lake
Ice-Off Dates from 1969 to 2012
(44 Years)
y = -0.2419x + 124.35
Julian Day
150
140
130
120
110
100
90
80
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year


ICE FREE DAYS
(43 Years)
y = 0.3828x + 195.44
Number of Days
240
220
200
180
160
140
120
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year

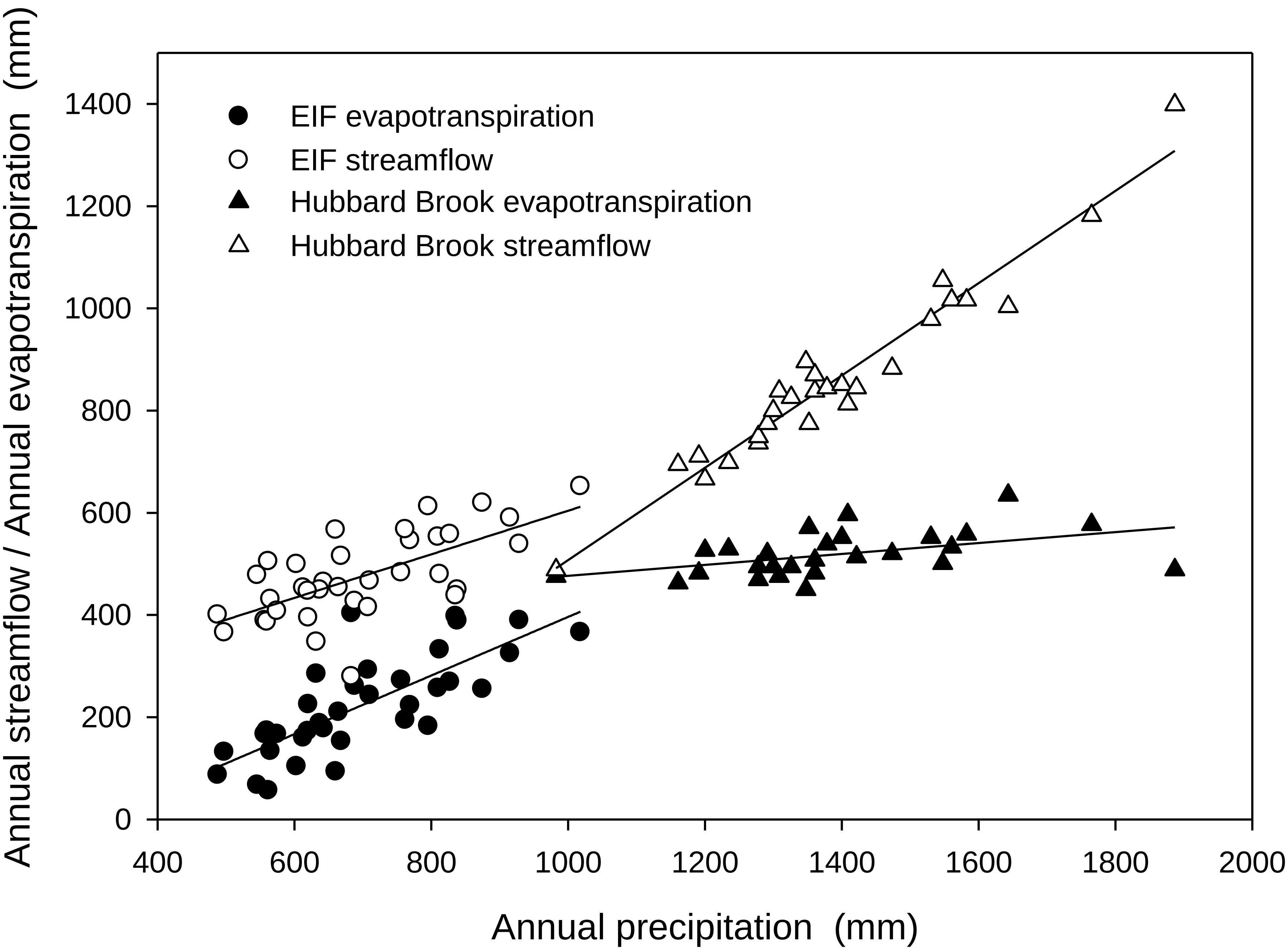
Significant ELA Temp and Precipitation Trends 1969-2005

Annual Average temp. 0.045 C/y $p<0.005$
Winter (DJF) temp. 0.105/y $p=0.013$
Summer (Apr-Sept) ppt. 0.3%/y $p=0$

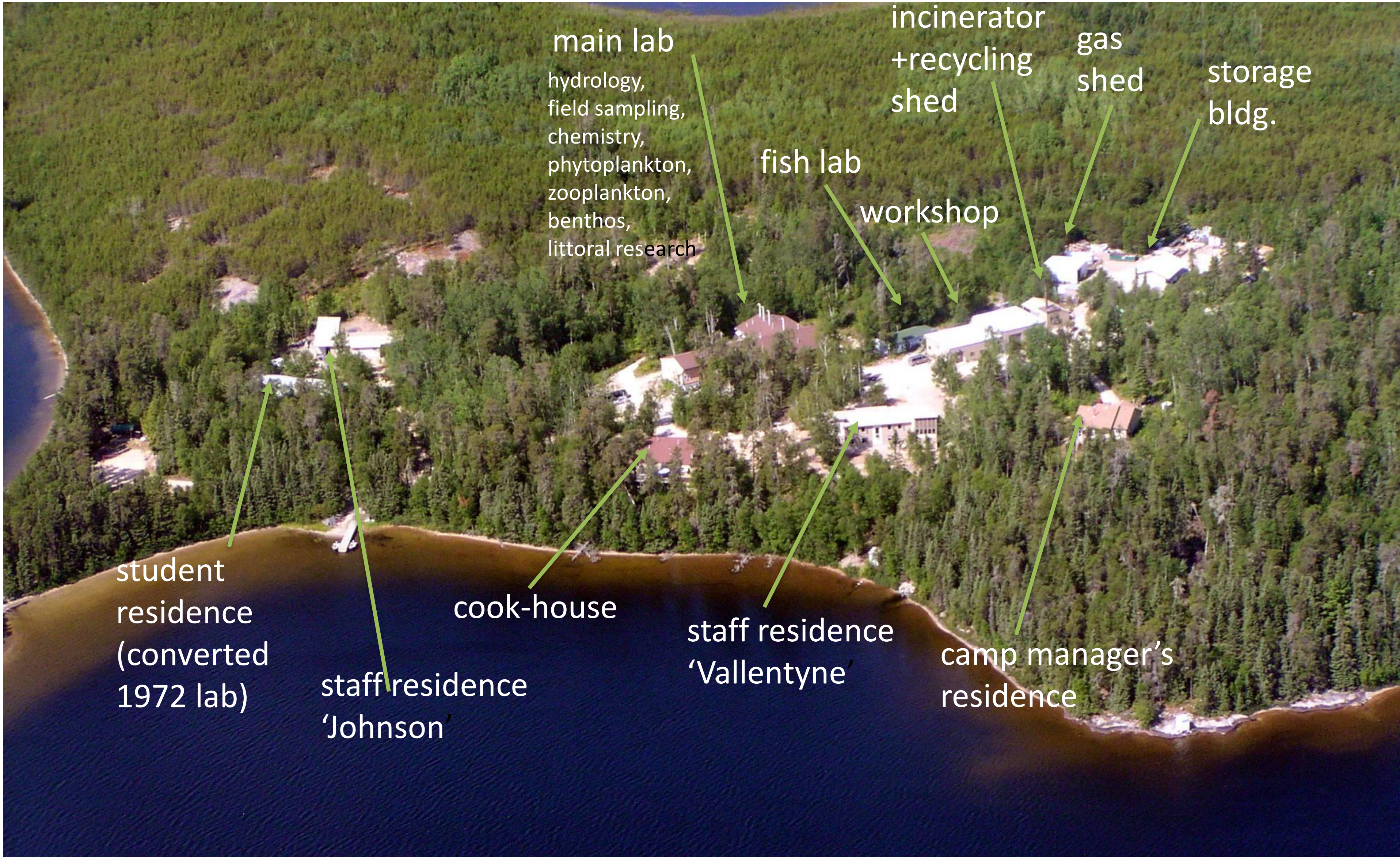
H^+ -2.2%/y
NH_4- N +1.4%/y
DOC +2.9%/
Si -3.1%/y
Ca -1.4%/y
Mg -1.8%/y
Na -3.3%/y

SO_4 -1.4%/y
Cl -6.4%/y

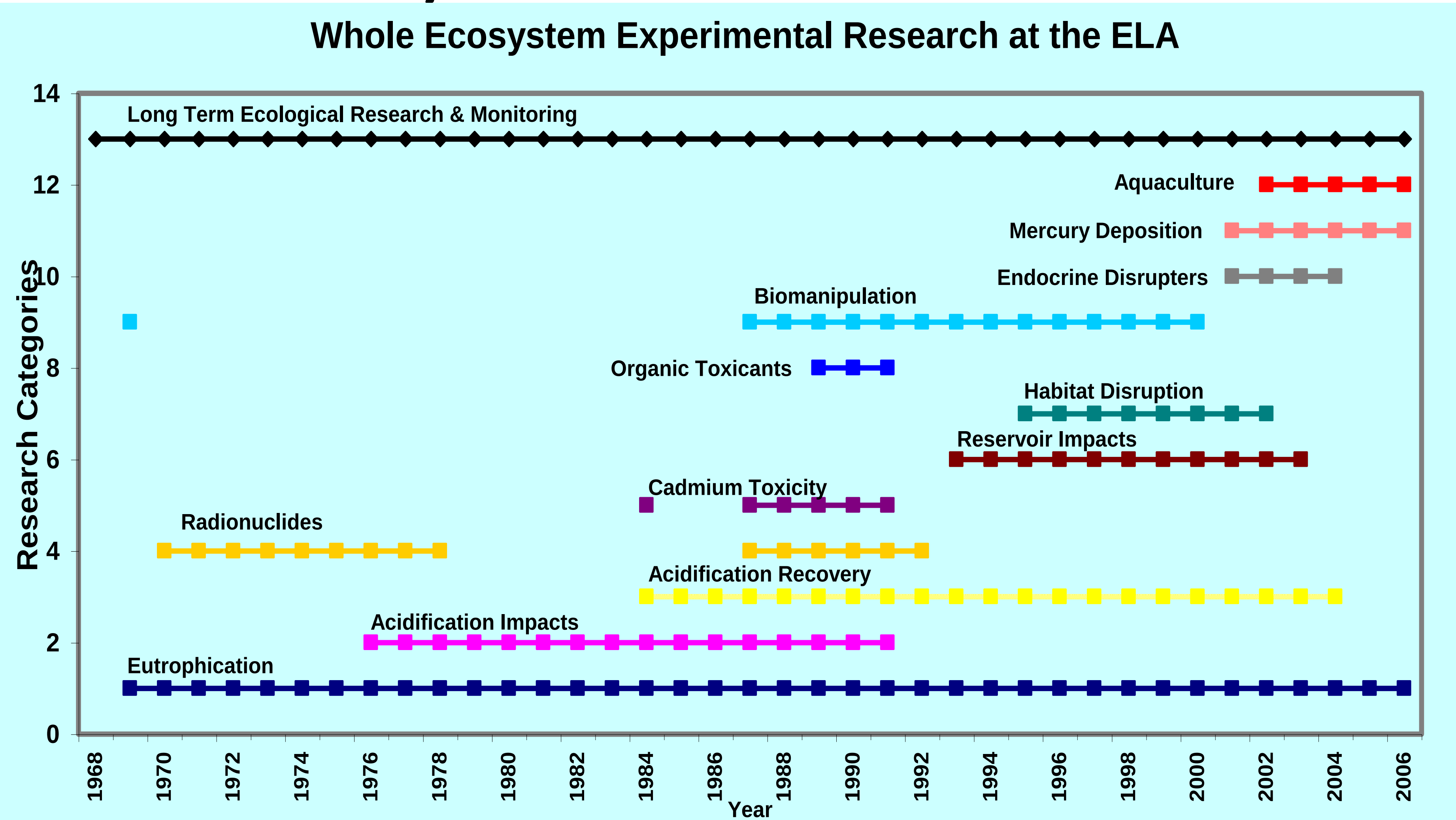
Parker et al. 2009 CJFAS and ELA unpubl.



Parker et al. 2009


main lab
hydrology,
field sampling,
chemistry,
phytoplankton,
zooplankton,
benthos,
littoral research
incinerator
+recycling
shed
gas
shed
storage
bldg.
fish lab
workshop
student
residence
(converted
1972 lab)
staff residence
'Johnson'
cook-house
staff residence
'Vallentyne'
camp manager's
residence

Ecosystem Research at ELA



- "Whole-ecosystem" research
- Multidisciplinary, multi-year duration

D.W. Schindler

J.R. Vallentyne

Deck of the Bradbury
June 1969