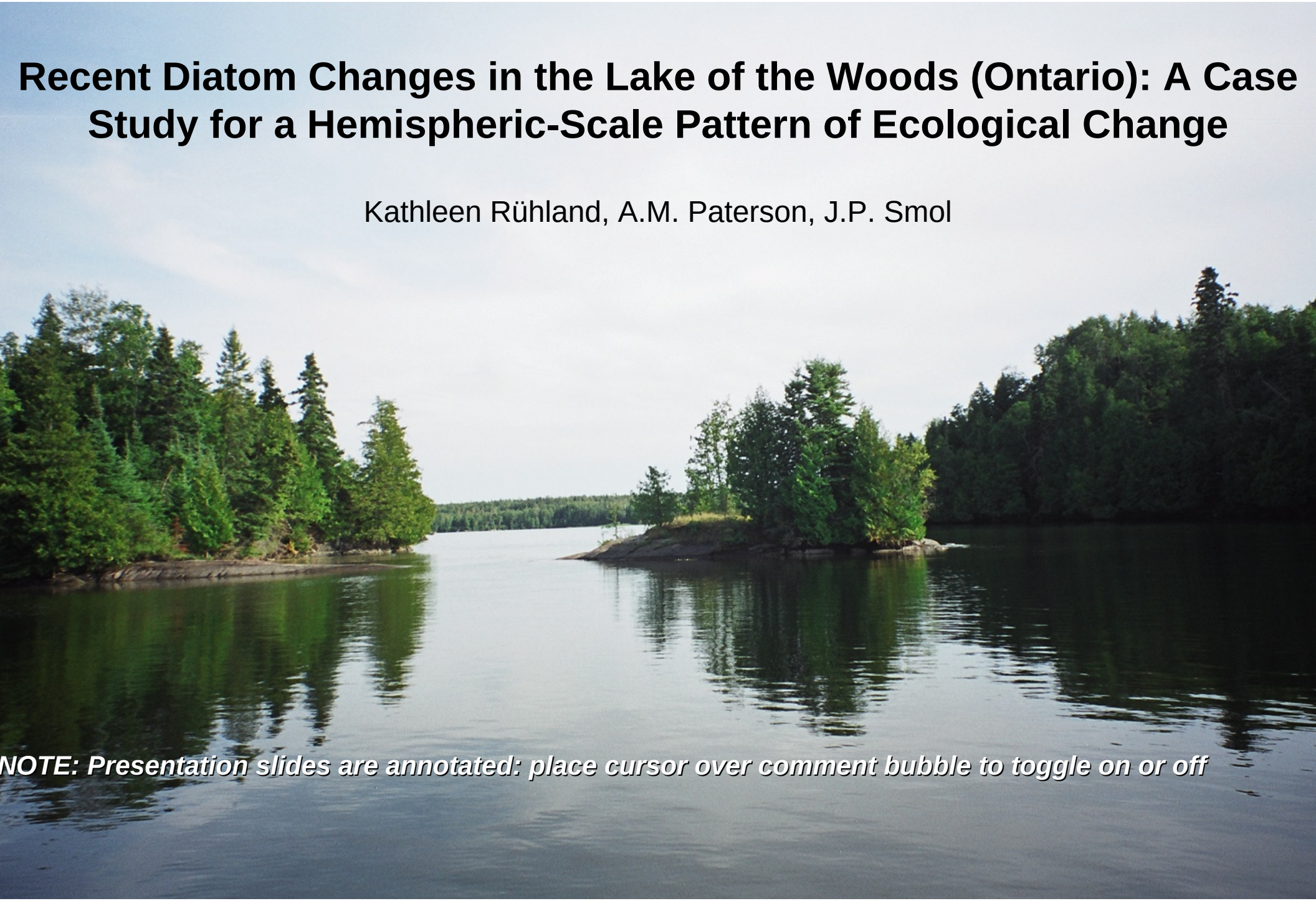
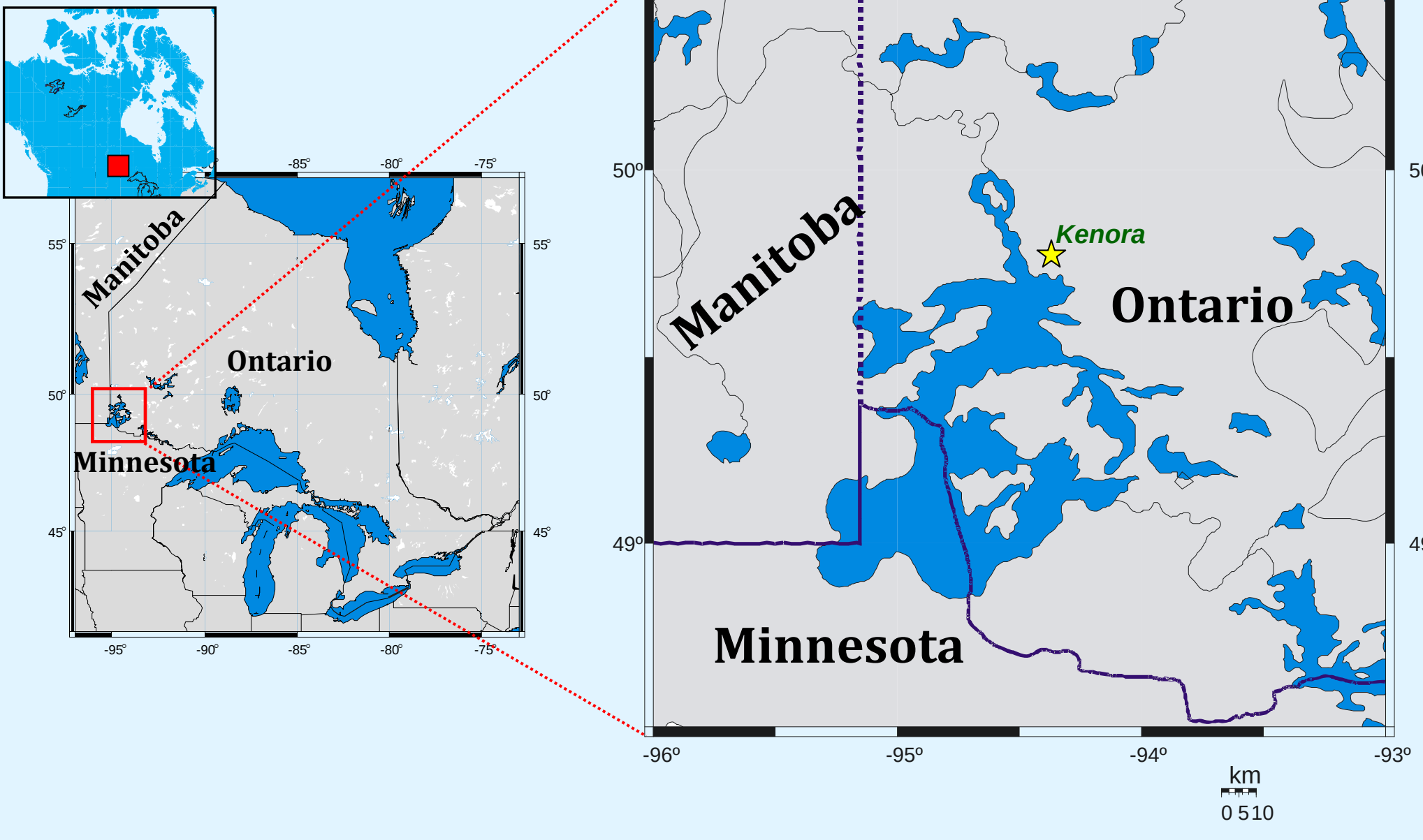
Recent Diatom Changes in the Lake of the Woods (Ontario): A Case Study for a Hemispheric-Scale Pattern of Ecological Change

Kathleen Rühland, A.M. Paterson, J.P. Smol



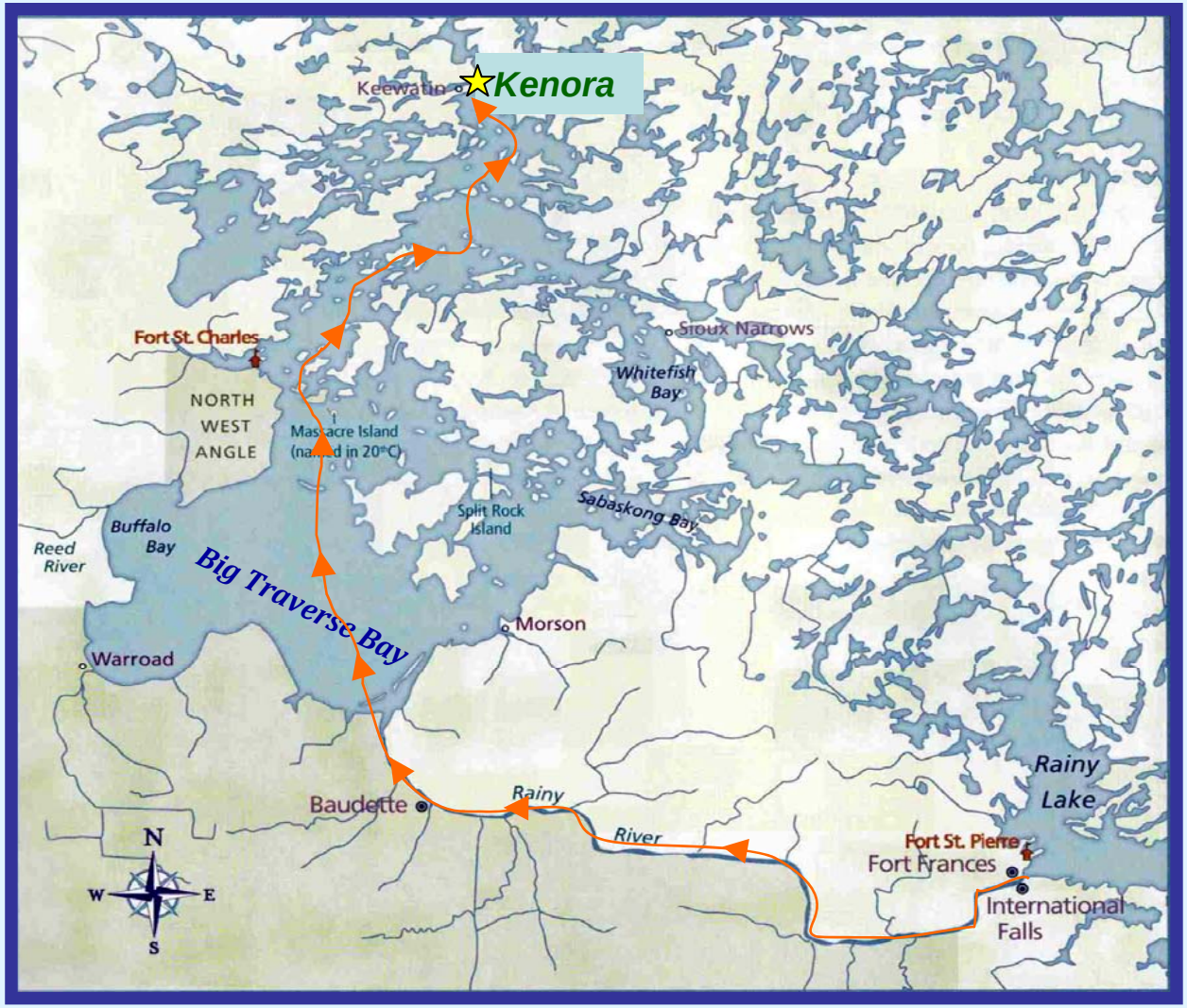
NOTE: Presentation slides are annotated: place cursor over comment bubble to toggle on or off

Lake of the Woods, Ontario, Canada



Lake of the Woods, Ontario, Canada

- Main direction of flow is south from the Rainy River to the northern outlet, the Winnipeg River
- Steep gradient in total phosphorus generally follows this direction of flow



Modified from Robertson & McCracken 2003

Development of an Algal Bloom - 2003

(Terra MODIS images – G. McCullough, U. of Winnipeg)

“The islands were numerous and crowded, the water shoal and foul, frequently with a green scum of vegetable matter”

- Major Joseph Delafield, July 30th, 1823

“…the water became tinged with green, derived from a minute vegetable growth”

- S. J. Dawson, Summer 1857

“…deposits of green vegetable matter” in the lake’s bays during the summer.

- objection to a proposal to use LOW to supply clean water to Winnipeg 1883

Some Important Lake Management Questions:

1) What is the ‘natural’ or baseline condition of the lake?

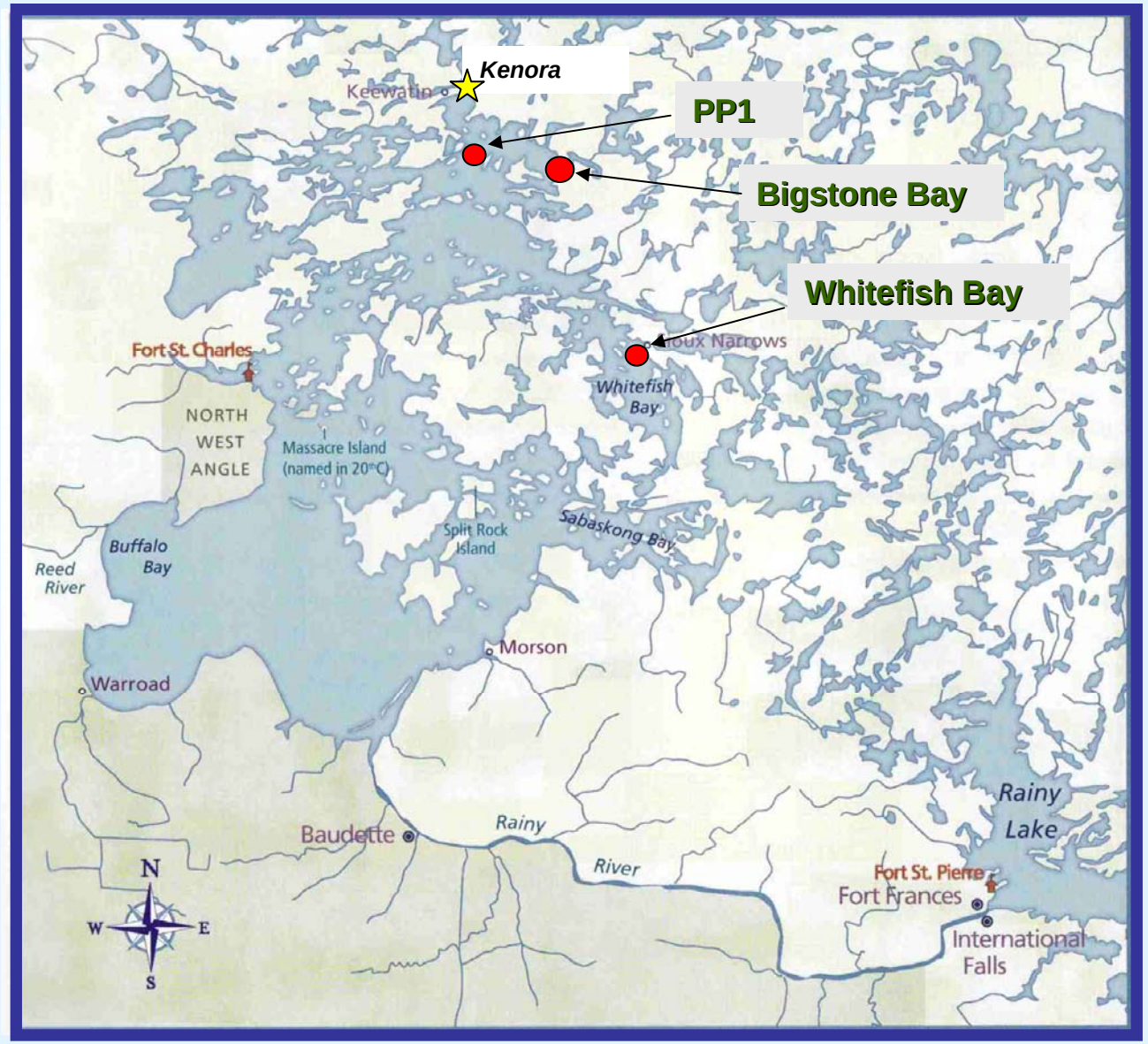
2) Has the water quality changed since pre-development (or pre-industrial) times?

3) If so, when did these changes occur?

4) What is the direction and magnitude of this change?

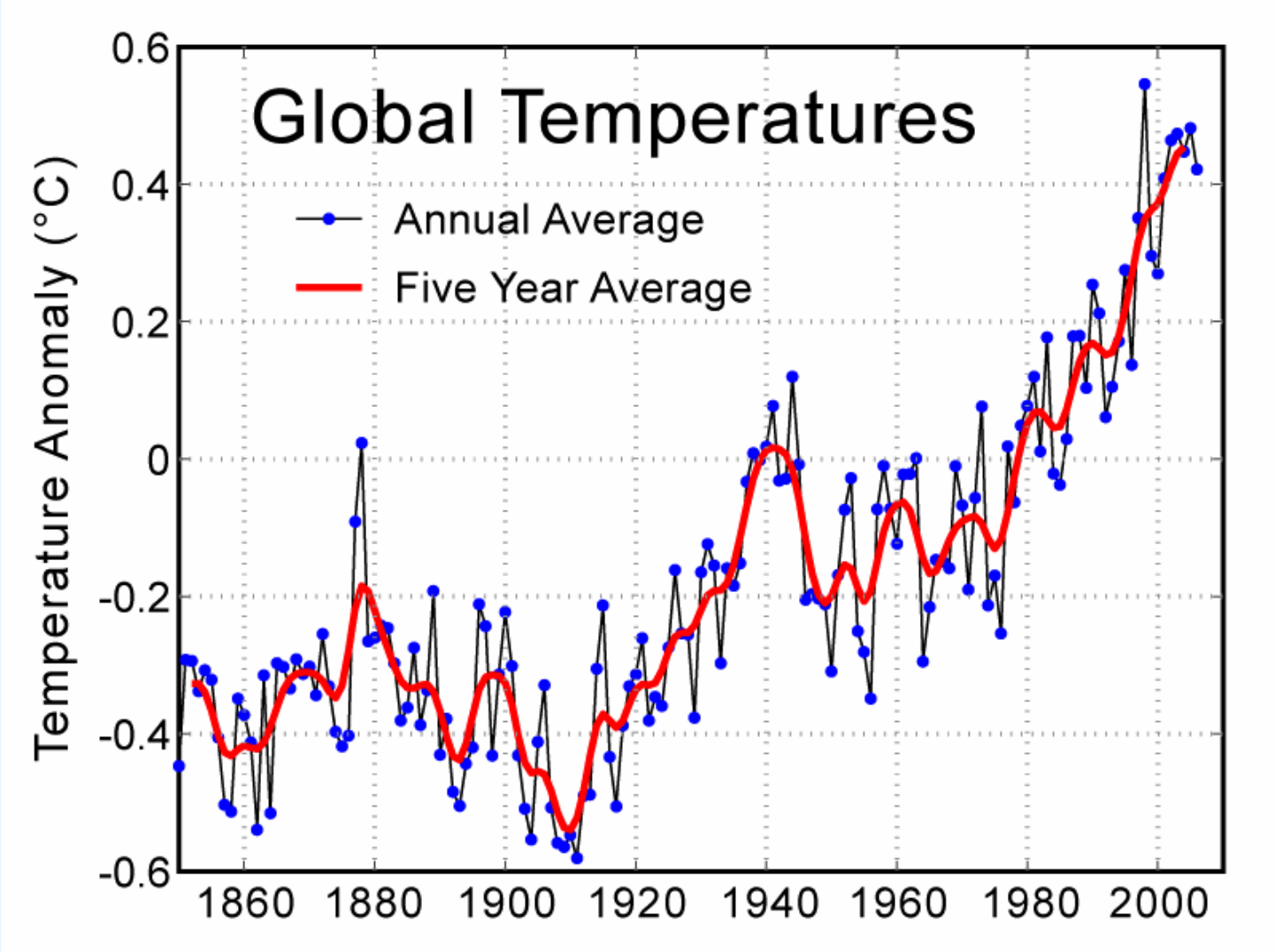
5) What are the possible reasons for this change?

Location of sampling sites for sediment cores

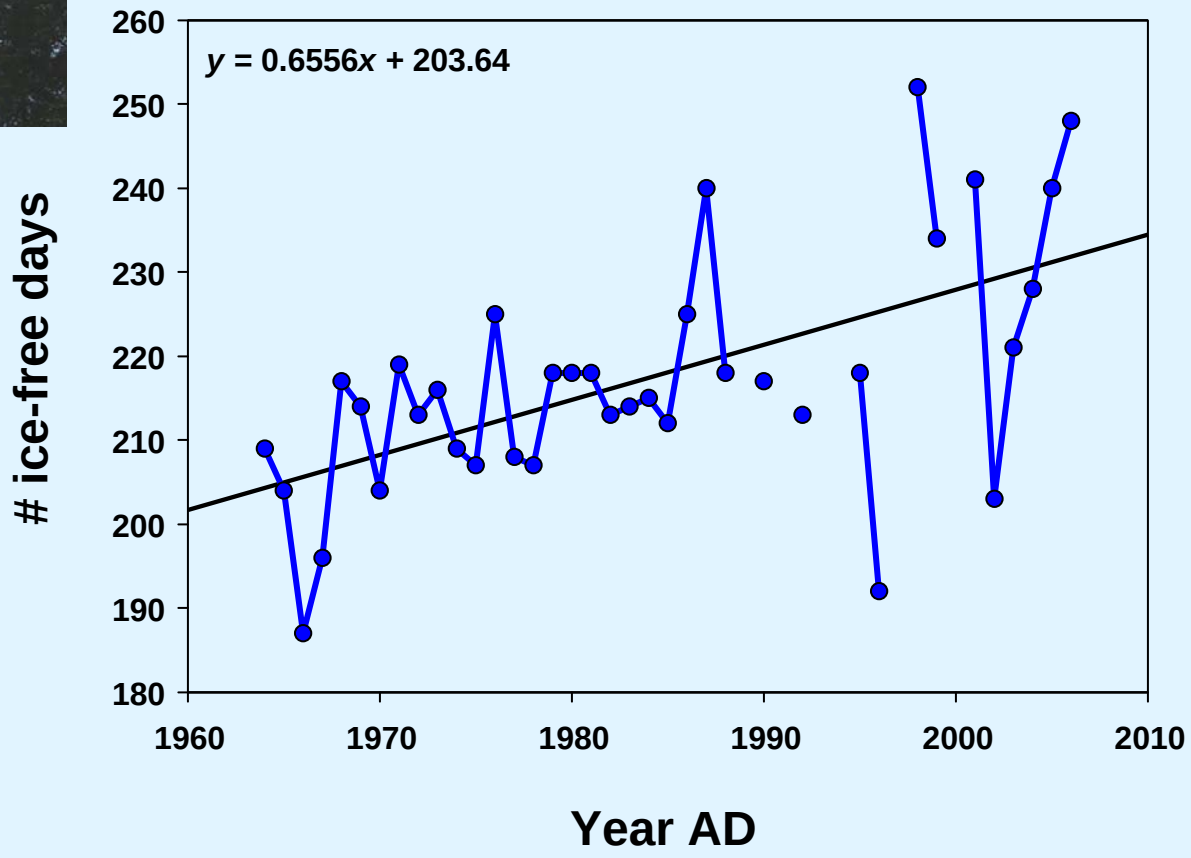


Modified from Robertson & McCracken 2003

The Instrumental Record



Historical Lake Ice Records

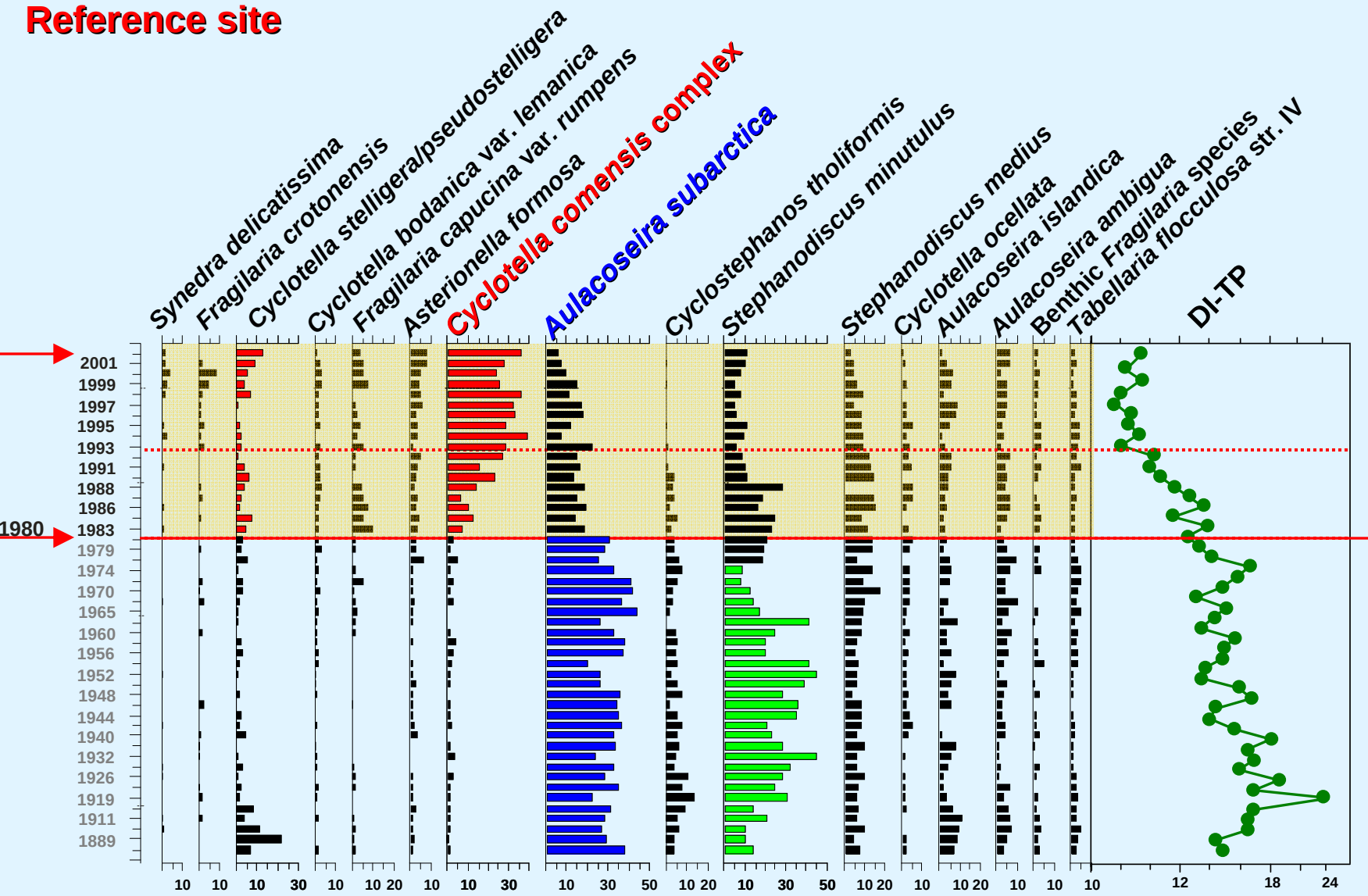


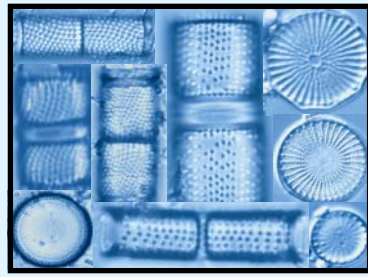
Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Whitefish Bay Diatom Profile

1980 – present

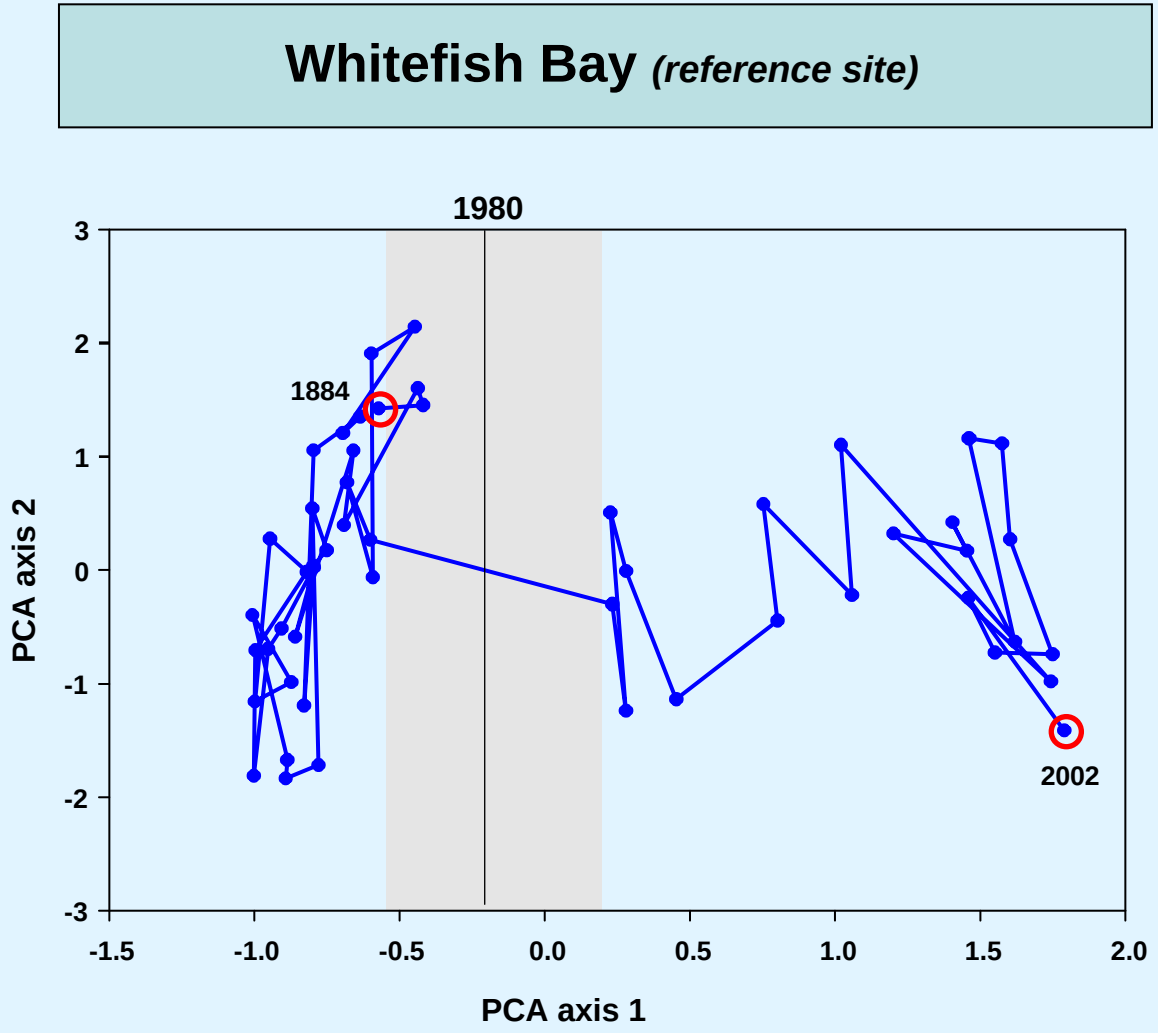
Reference site





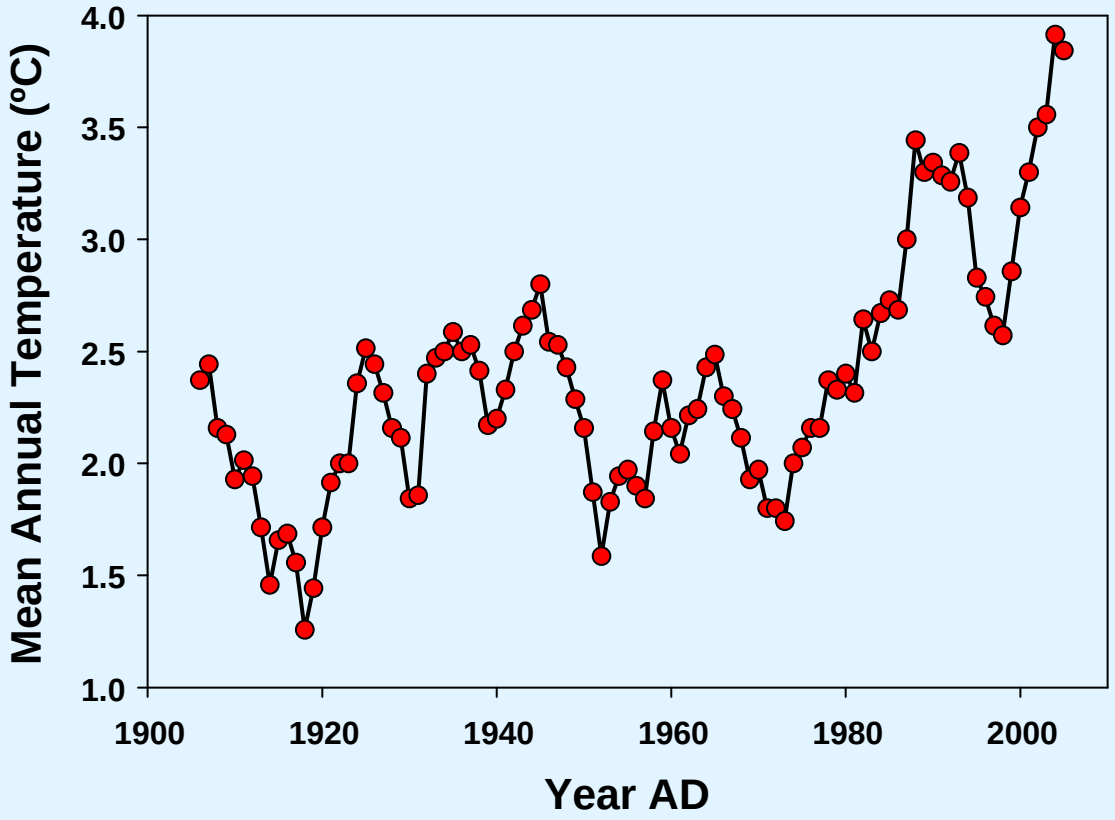
Rühland et al. in prep

Summary of Diatom Trends: principal components analysis (PCA)

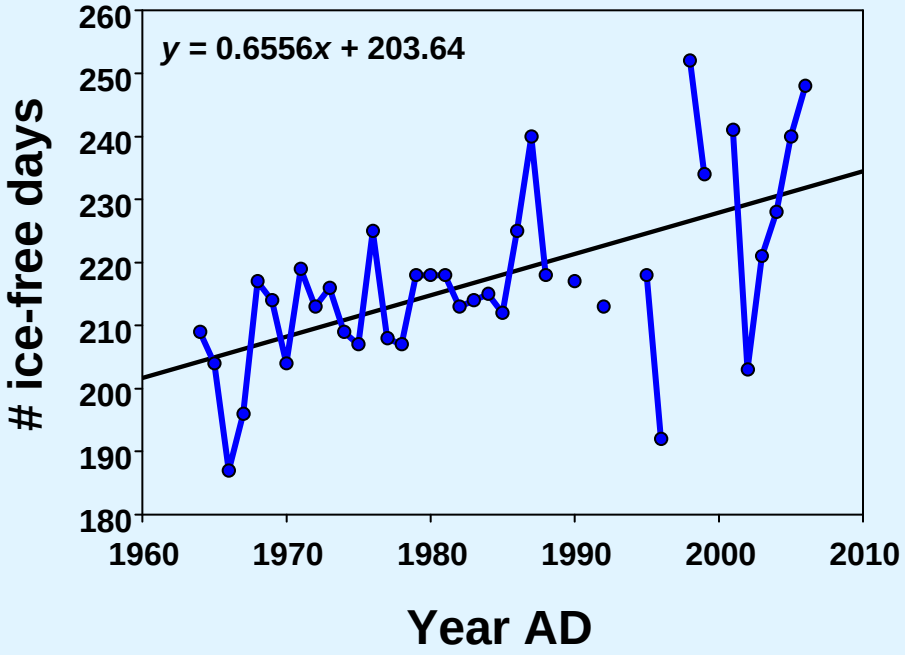


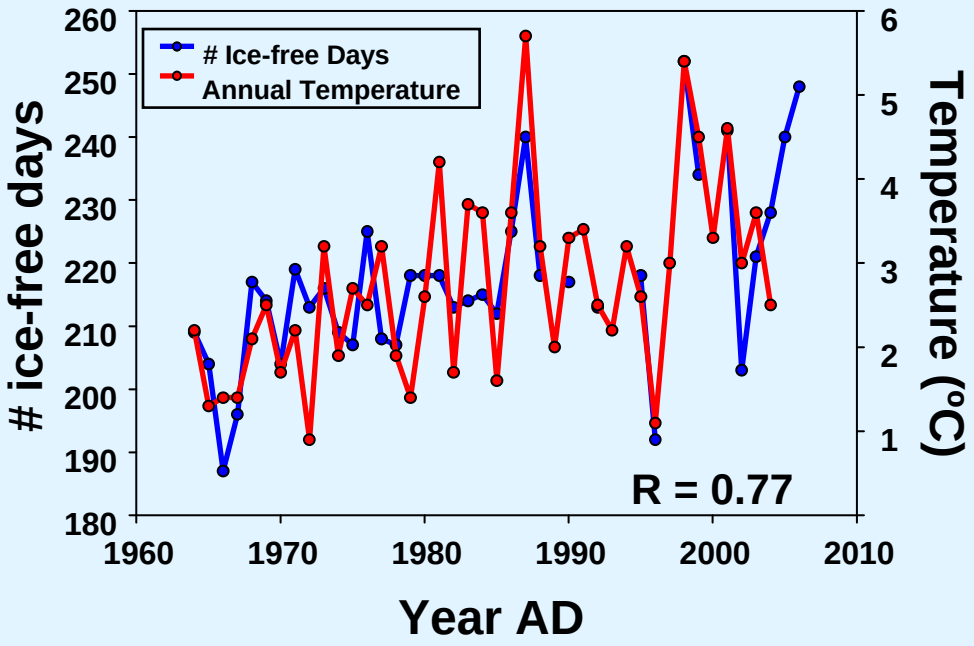
Rühland et al. in prep

Kenora 100-year Temperature Record



Whitefish Bay Ice Cover Record



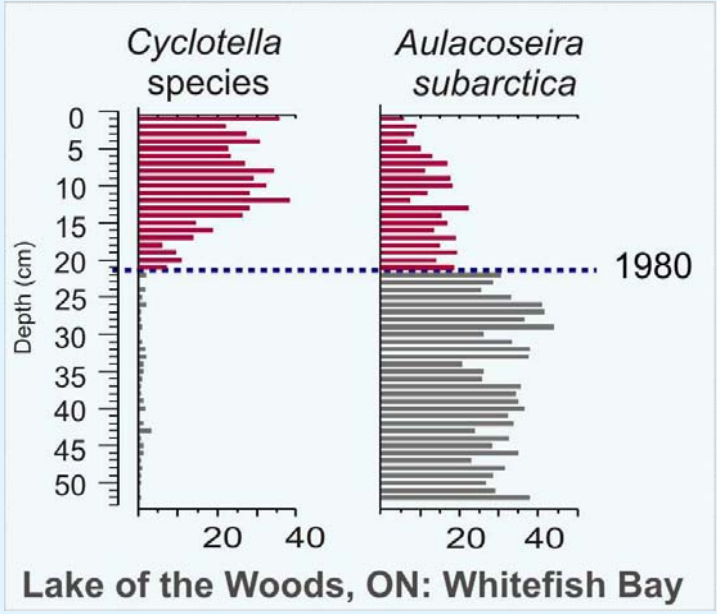


- Ice-free period increased by **27.7** days since 1964
- Corresponds to increased temperatures

Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Taxon-specific shifts: a closer look at Whitefish Bay

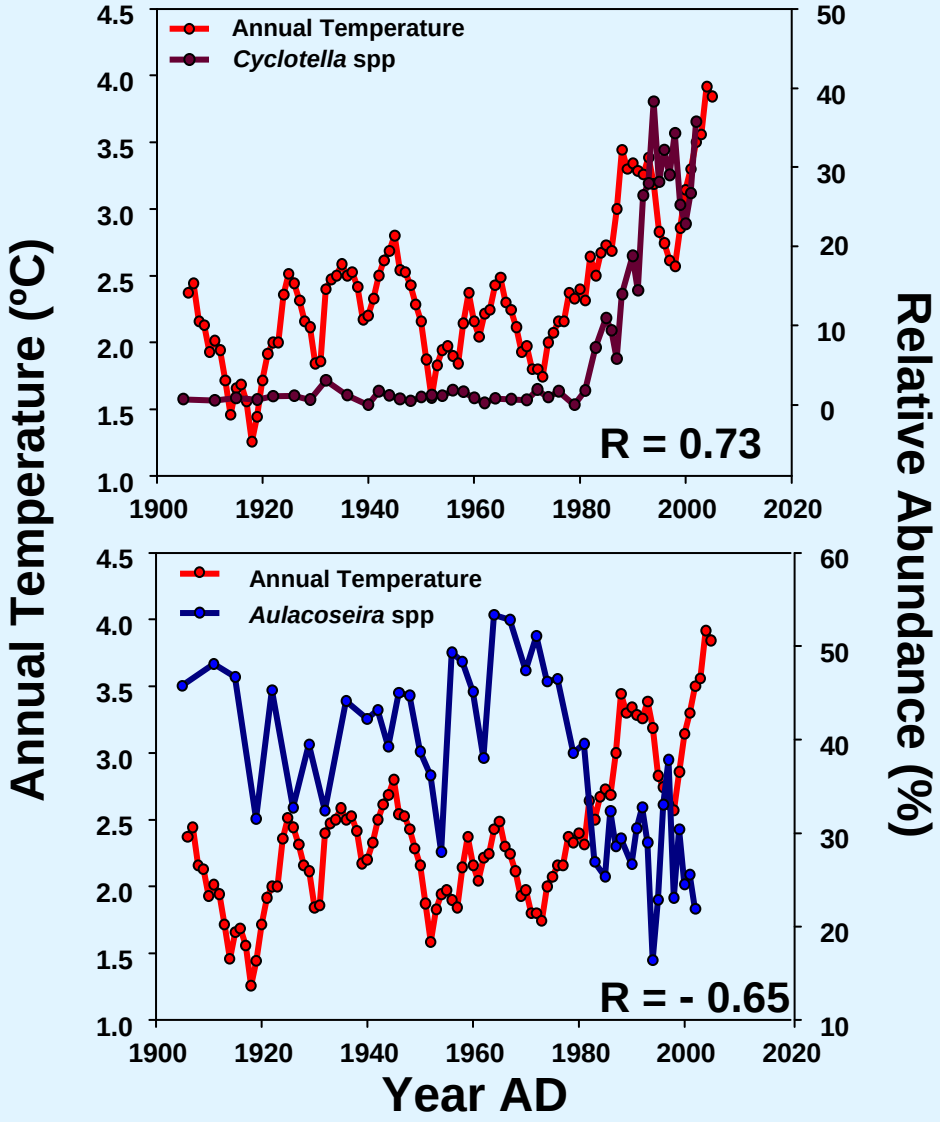
Whitefish Bay ***(reference site)***

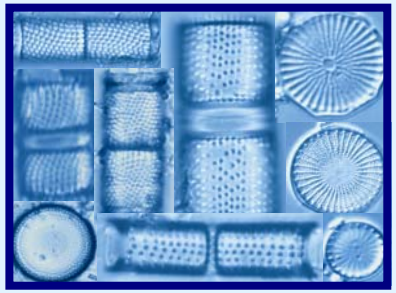


Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Whitefish Bay: Taxon-Specific Relationships

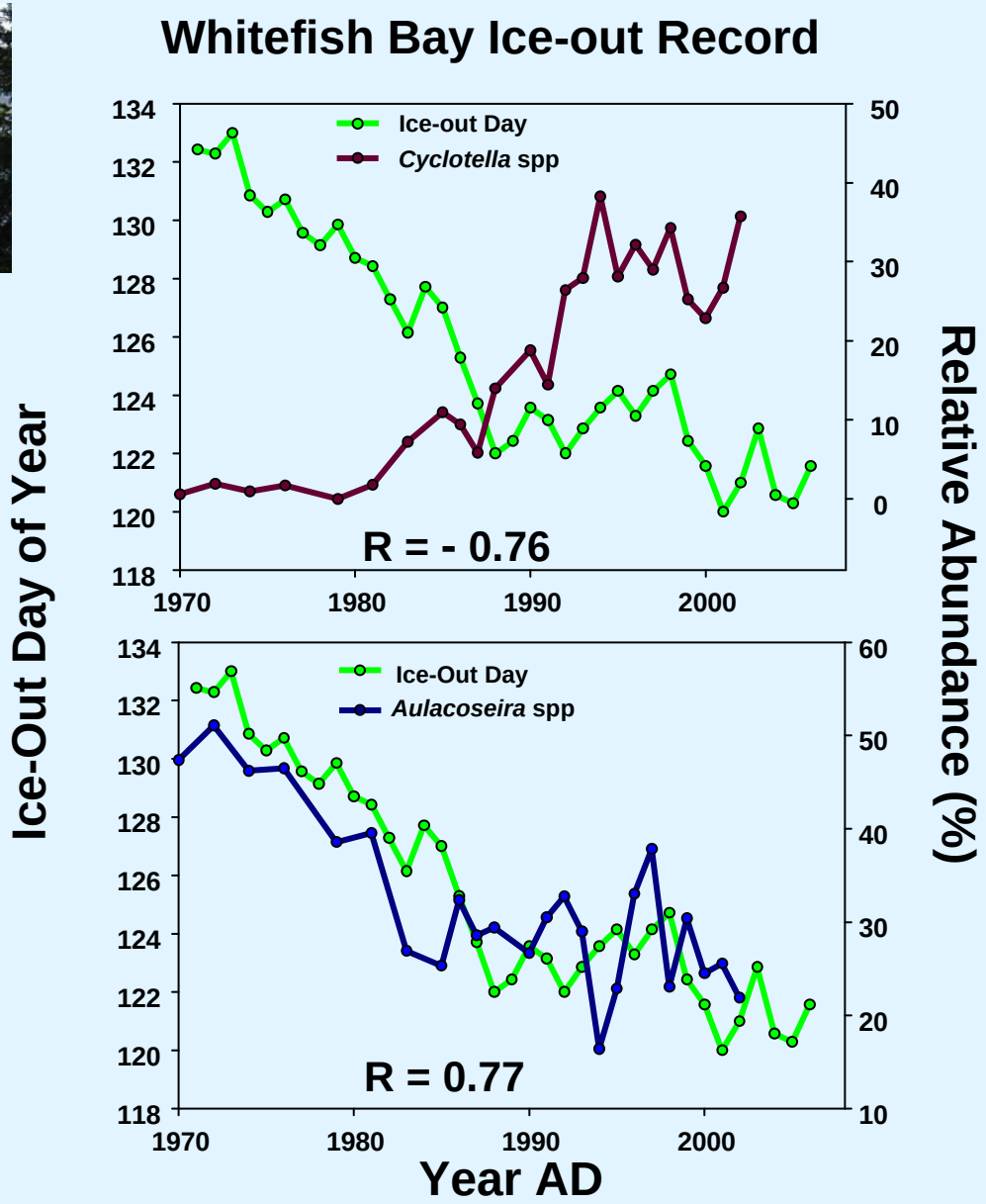
Kenora Temperature Record

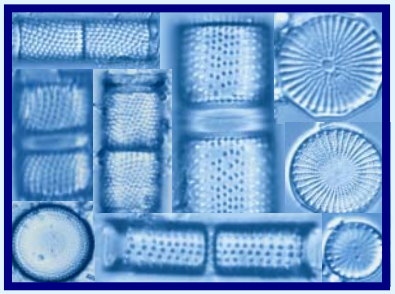




Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Whitefish Bay: Taxon-Specific Relationships

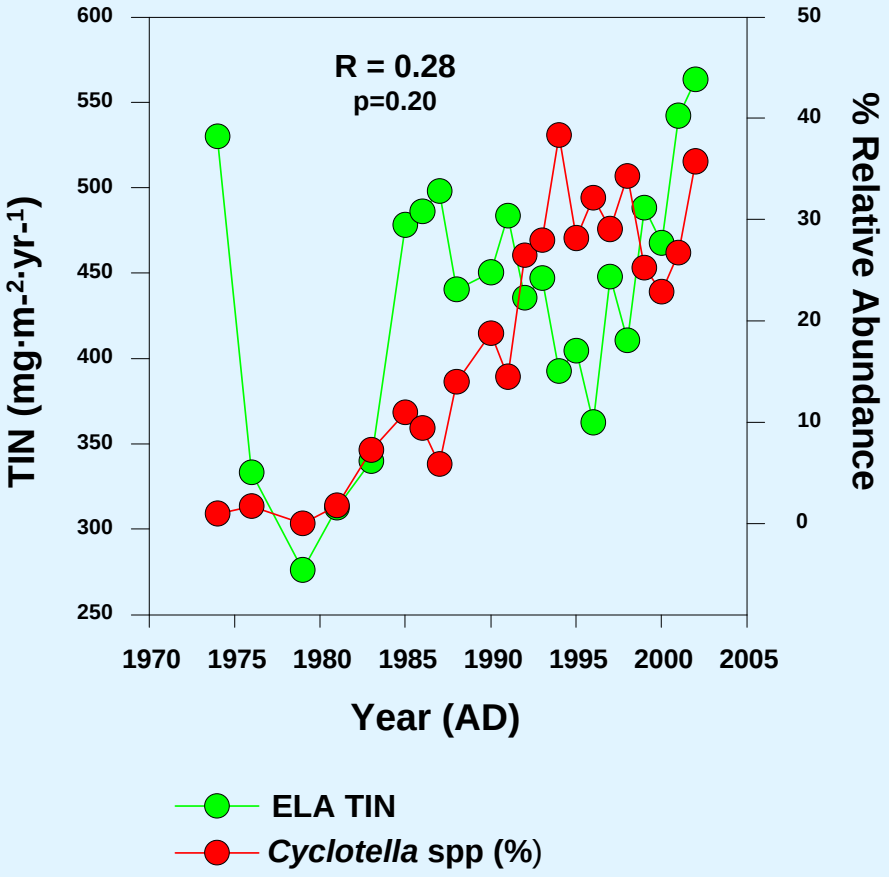


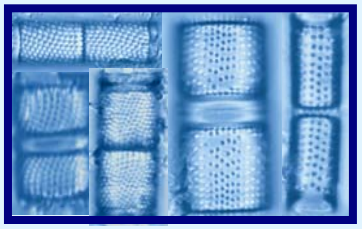


Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

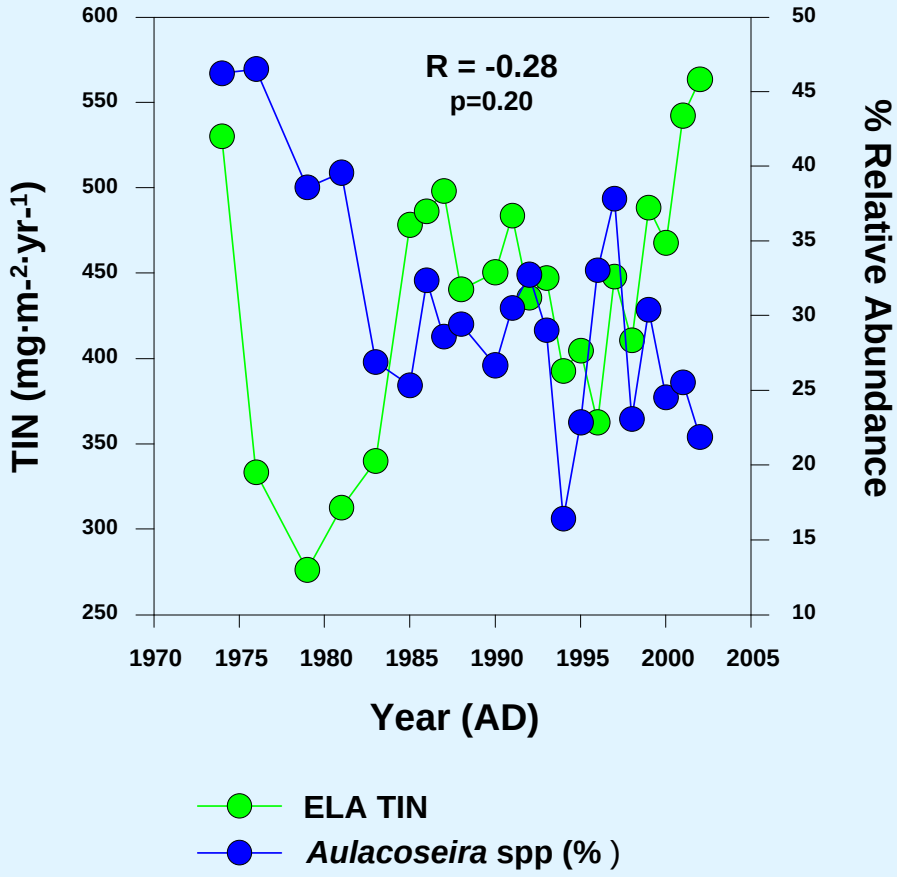
Taxon-Specific Shifts: ELA Nitrogen Data

% *Cyclotella* spp. vs TIN (3 year mean) from 1974-2004





% *Aulacoseira* spp. vs TIN (3 year mean) from 1974-2004



Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Diatom trends in the Lake of the Woods

- **Substantial change in last few decades**
  - Timing of changes consistent between sites
    - *Impact site: PP-1*
    - *Reference site: Whitefish Bay*
  - PCA trajectories - ecological threshold passed?

Diatom trends in the Lake of the Woods

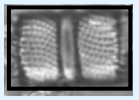
- **Possible mechanisms** (*Whitefish Bay*)
  - Strong relationship to increased temperature
  - Strong relationship to decreased ice cover

Taxon-specific trends in the Lake of the Woods

- **Temperature**
  - strong +ve correlation to increased % *Cyclotella* spp
  - strong -ve correlation to decreased % *Aulacoseira* spp.
- **Ice-out day of year**
  - strongly correlated to increase % *Cyclotella* species
  - strongly correlated to decrease % *Aulacoseira* species
- **Inorganic nitrogen deposition (ELA)**
  - Weak correlation to *Cyclotella* trends
  - Weak correlation to *Aulacoseira* trends

Warming and diatom changes

- **Physical, chemical & biological changes**
  - Decrease in ice cover duration
  - Longer growing season
  - Decrease in DI-TP
- **Thermal stratification**
  - Light properties – more stable
  - Deeper subsurface habitats - nutrients
  - Reduction in water column mixing (turbulence)
- **Species-specific shifts**
  - Planktonic ***Cyclotella*** species increase
  - Heavier ***Aulacoseira*** species decrease

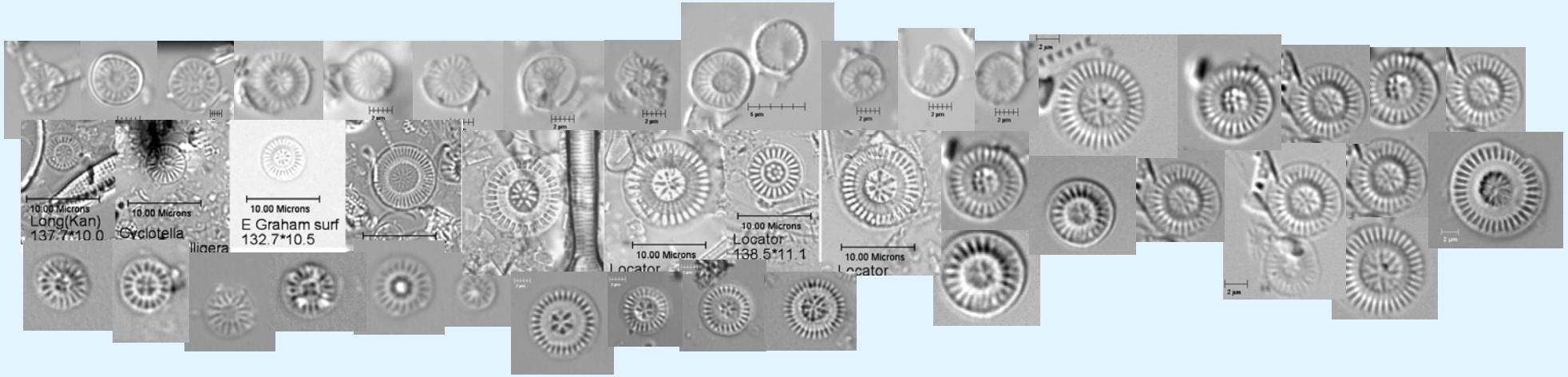


Further reading : Raubitschek et al. 1999 JOPL: Forsström et al. 2005 Polar Biol; Fahnenstiel & Glime 1983 Int Rev Hydrobiol

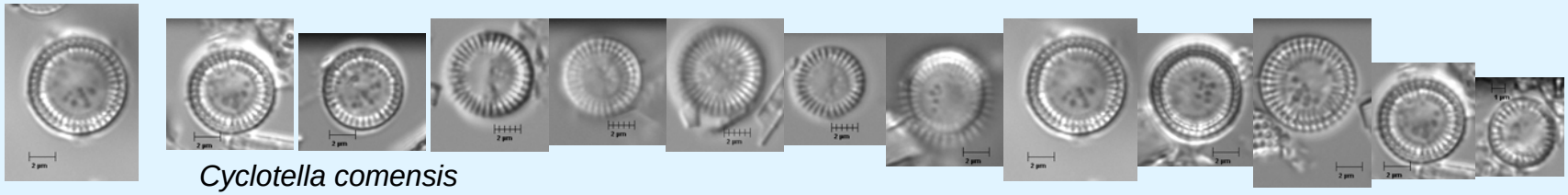
★ ***Hemispheric-scale trend***

Planktonic Cyclotella stelligera & C. comensis

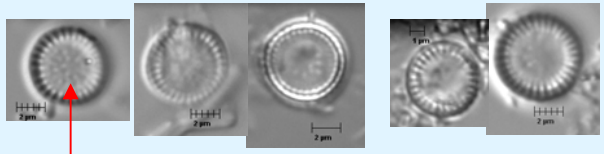
Cyclotella stelligera/pseudostelligera



Cyclotella comensis/gordonensis



Cyclotella comensis



Cyclotella gordonensis

From the Lake of the Woods Diatom Taxonomy Workshop: View a pdf of this booklet on our website under Research and Diatoms

Synthesis of *Cyclotella/Aulacoseira/Fragilaria* trend

1) How many profiles contain *Cyclotella* species?
2) How many record an increase? A decrease?
3) What do these lakes have in common?
4) Do these profiles show concurrent decreases in *Aulacoseira* species and/or *Fragilaria* species?
5) What is the geographic extent of this trend?
6) What are the most plausible mechanisms
    - Whitefish Bay = case study

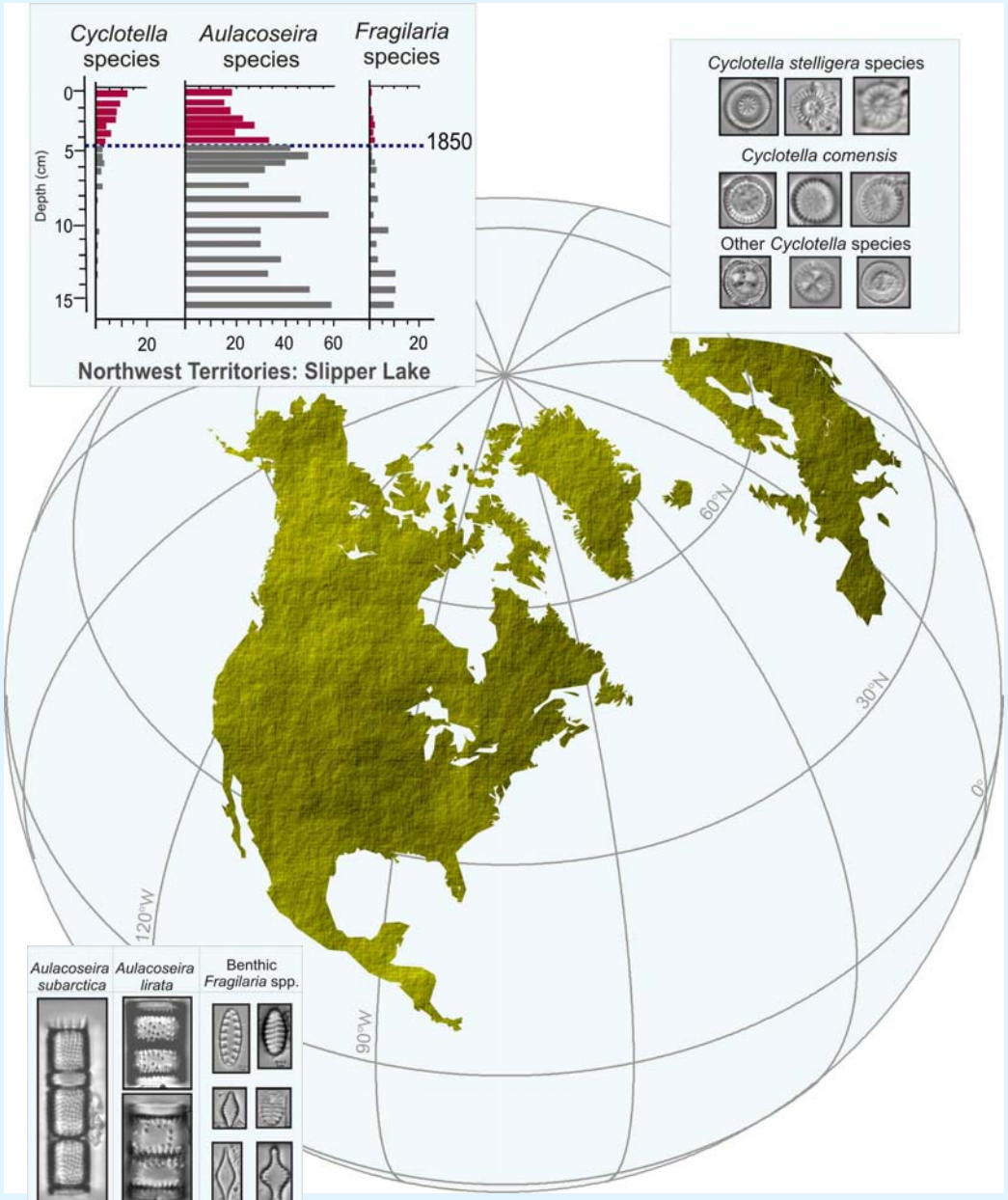
Criteria for *Cyclotella* compilation

1) Established chronology for last ca. 200 years (i.e. ^{210}Pb dating)
2) At least 2% relative abundance of *Cyclotella* in at least one interval
3) Increase in *Cyclotella* = 5% or greater compared to background levels

Results of *Cyclotella* compilation

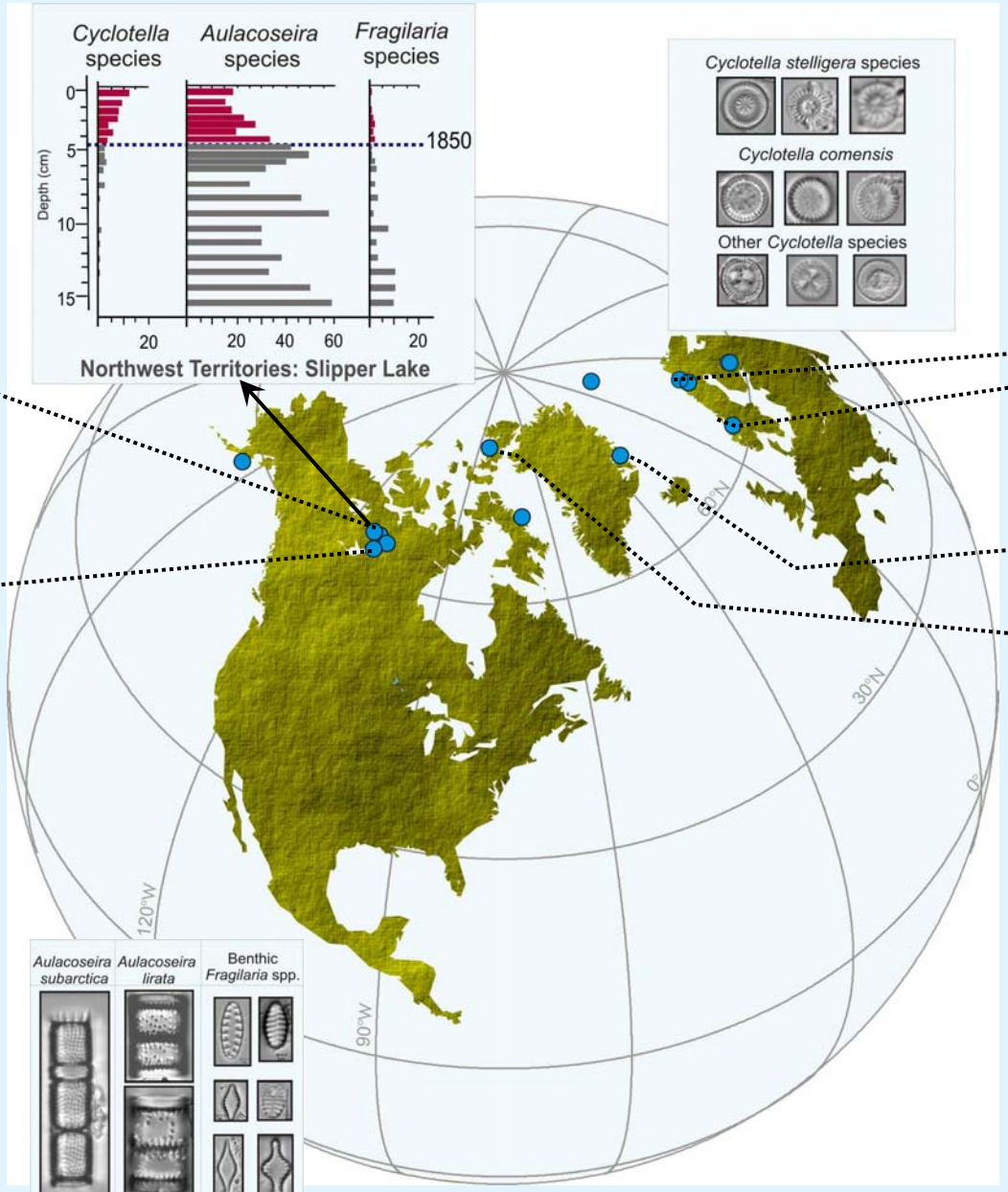
- **Detailed Cores**:
  - 170 lakes contained *Cyclotella* deposited within last ca. 200 years
  - 14% of these did not have established chronology
  - Remaining 147 lakes met first two criteria
    - **89** lakes (61%) of these showed an increase >5%
      - Unimpacted sites
    - 29% showed a decrease
      - 98% of these from eutrophic/acidic lakes
    - 10% showed no change
- **Top-Bottom:**
  - 146 lakes
    - **120** recorded increases in *Cyclotella* from pre-industrial times

Geographic extent of *Cyclotella* species increases



Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Geographic extent of *Cyclotella* species increases



Subarctic Canada
Rühland et al. 2003

Great Slave L. N.W.T
Stoermer et al. 1990

Subarctic Finland
Sorvari et al. 2002

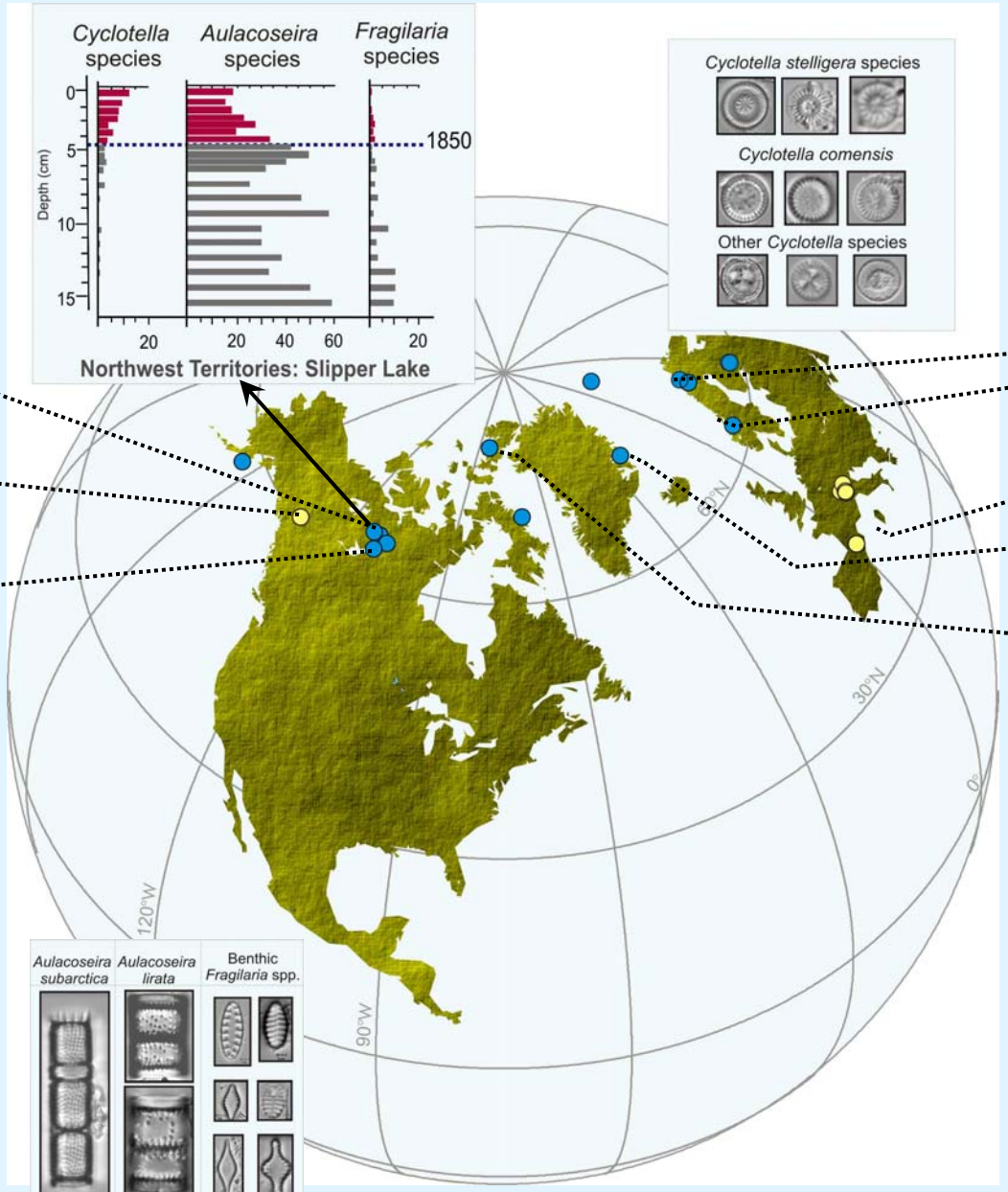
Sweden
Bigler & Hall 2003

Eastern Greenland
Cremer et al. 2001

High Arctic Canada
Perren et al. 2003

Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Geographic extent of *Cyclotella* species increases



Subarctic Canada
Rühland et al. 2003

Yukon Canada
Karst-Riddoch et al. 2002

Great Slave L. N.W.T
Stoermer et al. 1990

Subarctic Finland
Sorvari et al. 2002

Sweden
Bigler & Hall 2003

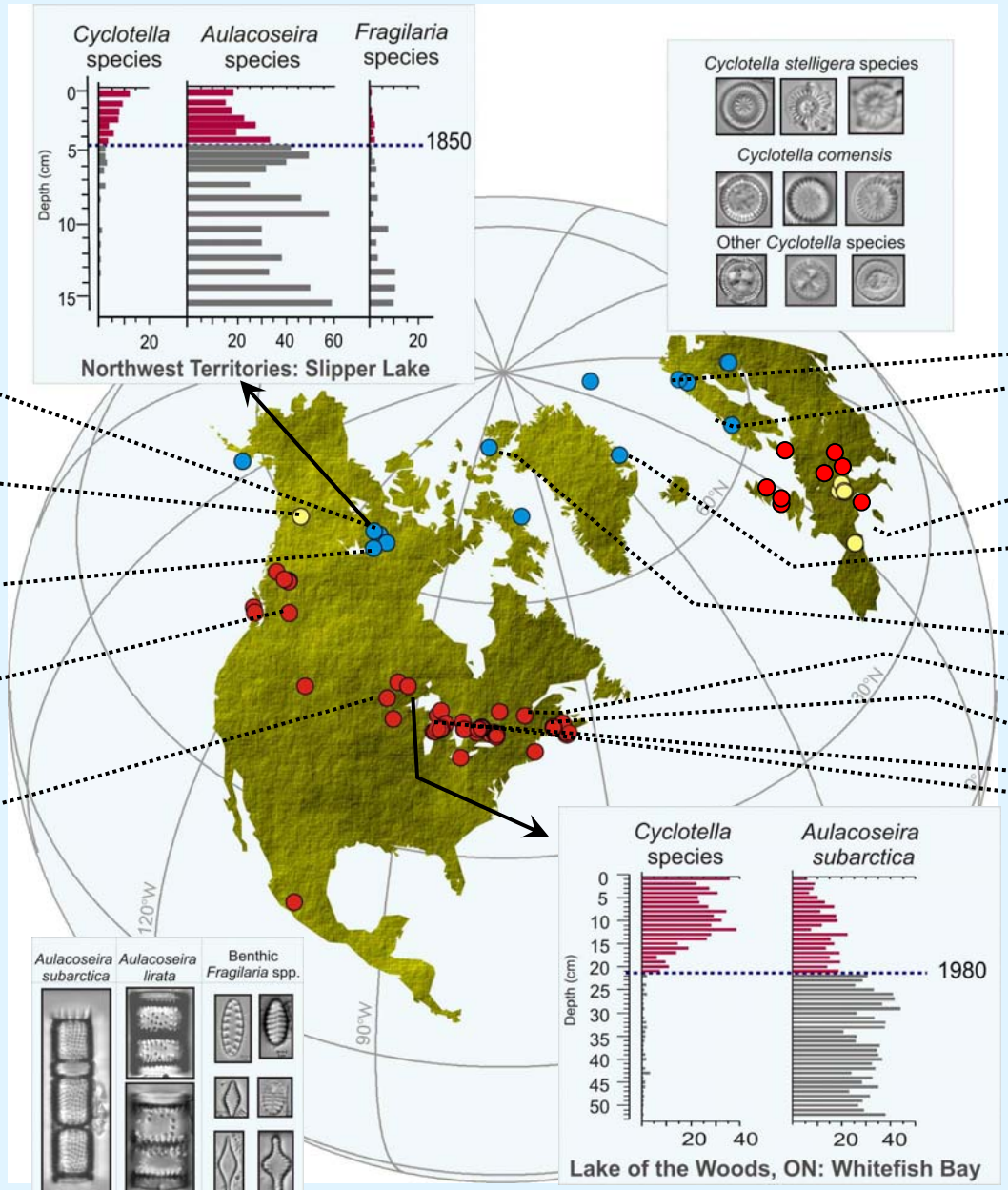
Spanish Pyrenees
Catalan et al. 2002

Eastern Greenland
Cremer et al. 2001

High Arctic Canada
Perren et al. 2003

Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Geographic extent of *Cyclotella* species increases



Subarctic Canada
Rühland et al. 2003

Yukon Canada
Karst-Riddoch et al. 2002

Great Slave L. N.W.T
Stoermer et al. 1990

BC Canada
Reavie et al. 2005, 2006; Laird et al. 2001

ELA NW ON
Enache et al. unpubl.

Subarctic Finland
Sorvari et al. 2002

Sweden
Bigler & Hall 2003

Spanish Pyrenees
Catalan et al. 2002

Eastern Greenland
Cremer et al. 2001

High Arctic Canada
Perren et al. 2003

NB Canada
Harris et al. 2006

NS Canada
Ginn et al. in press

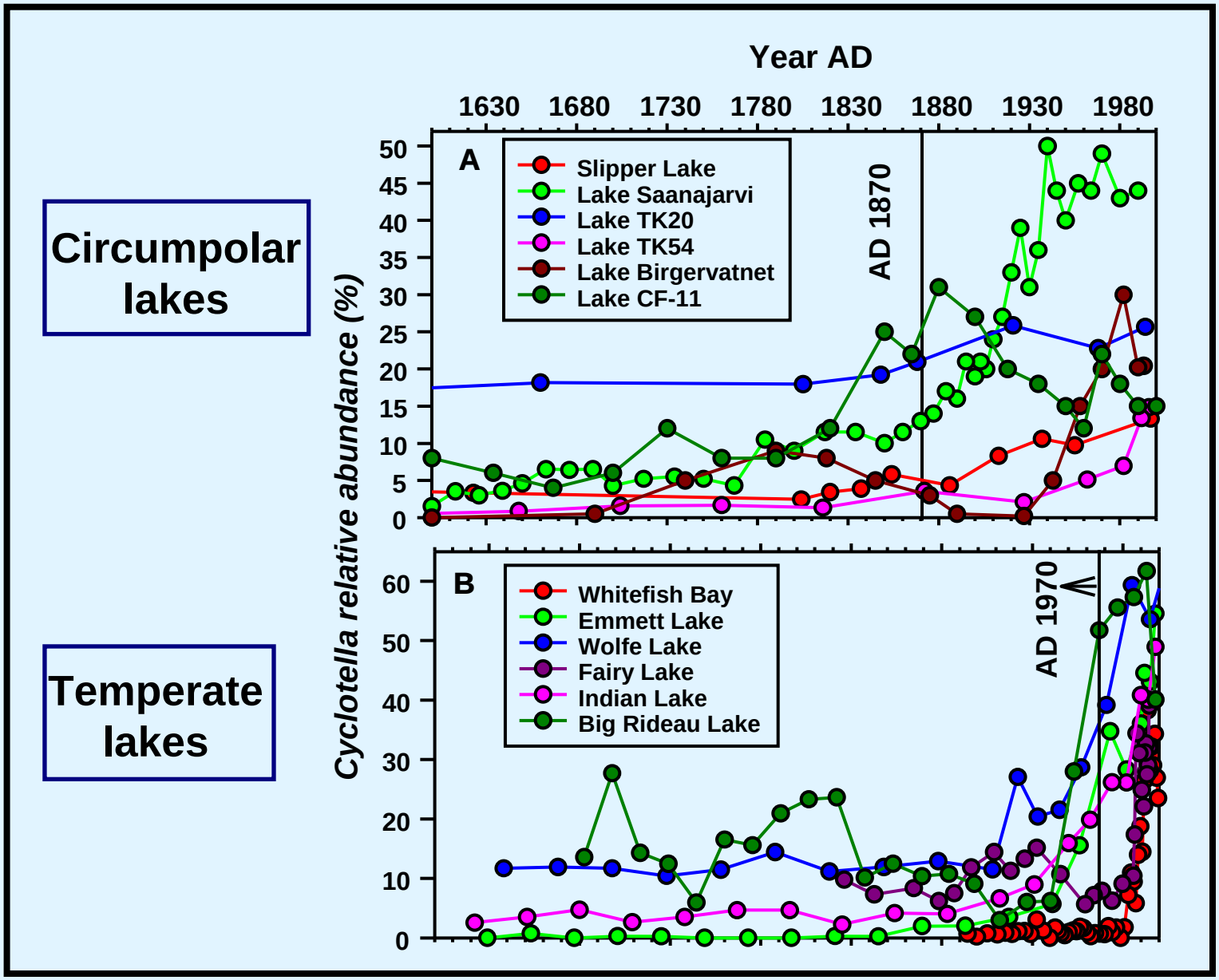
SE ON
Forrest et al. 2002

SW ON
Werner et al. 2005

Northern Hemisphere-Scale Trend

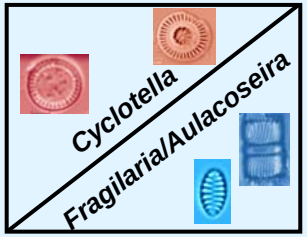
Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Comparison in the timing of *Cyclotella* increases



Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Climatic Warming and Taxon-specific Shifts



1. NWT-Nunavut (n=40)

Rühland et al. 2003 AAAR

2. New Brunswick (n=16)

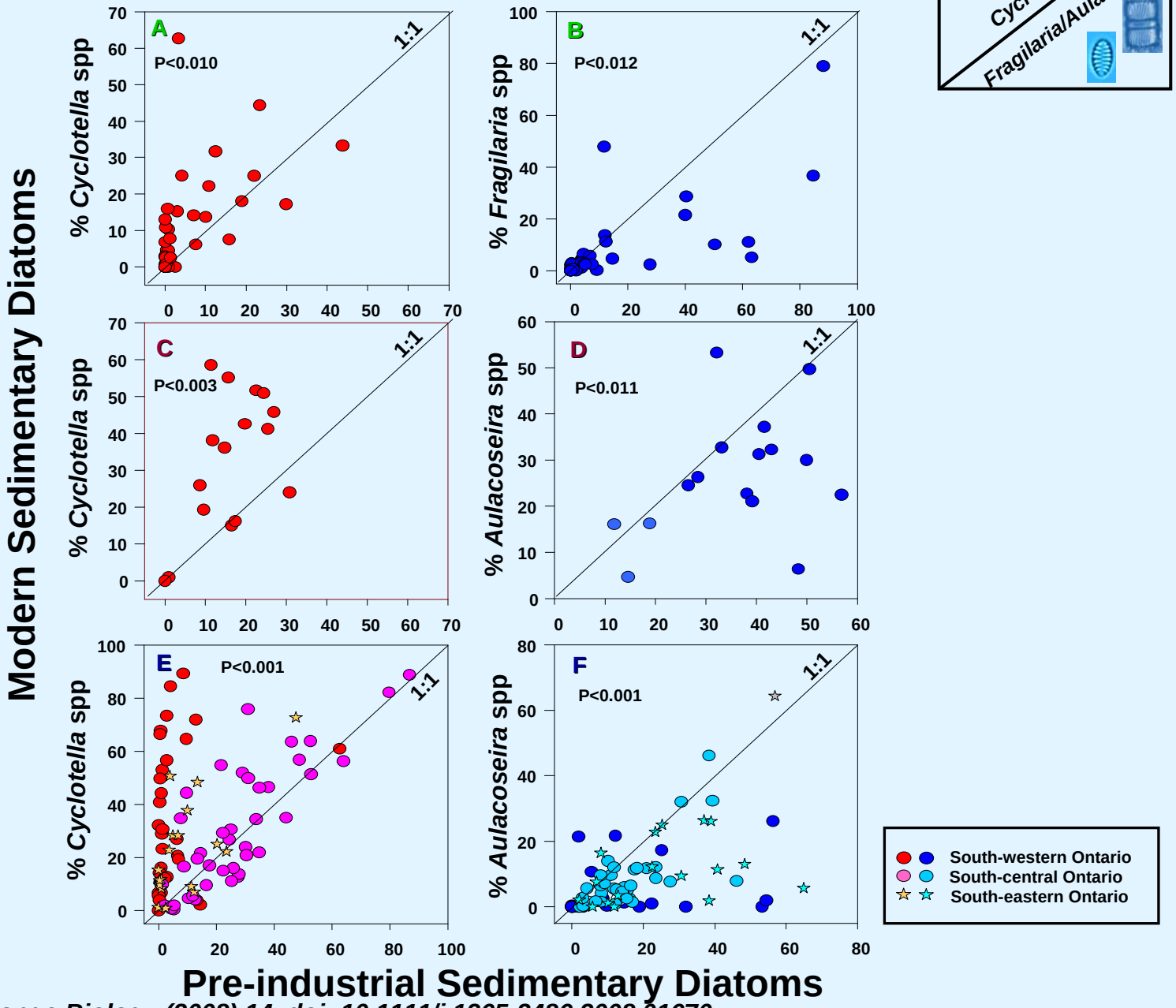
Harris et al. 2006 CanJBot

3. Ontario Combined (n=91)

Hall & Smol 1996 CanJFishAquat Sci

Reavie et al. 2002 Hydrobiol

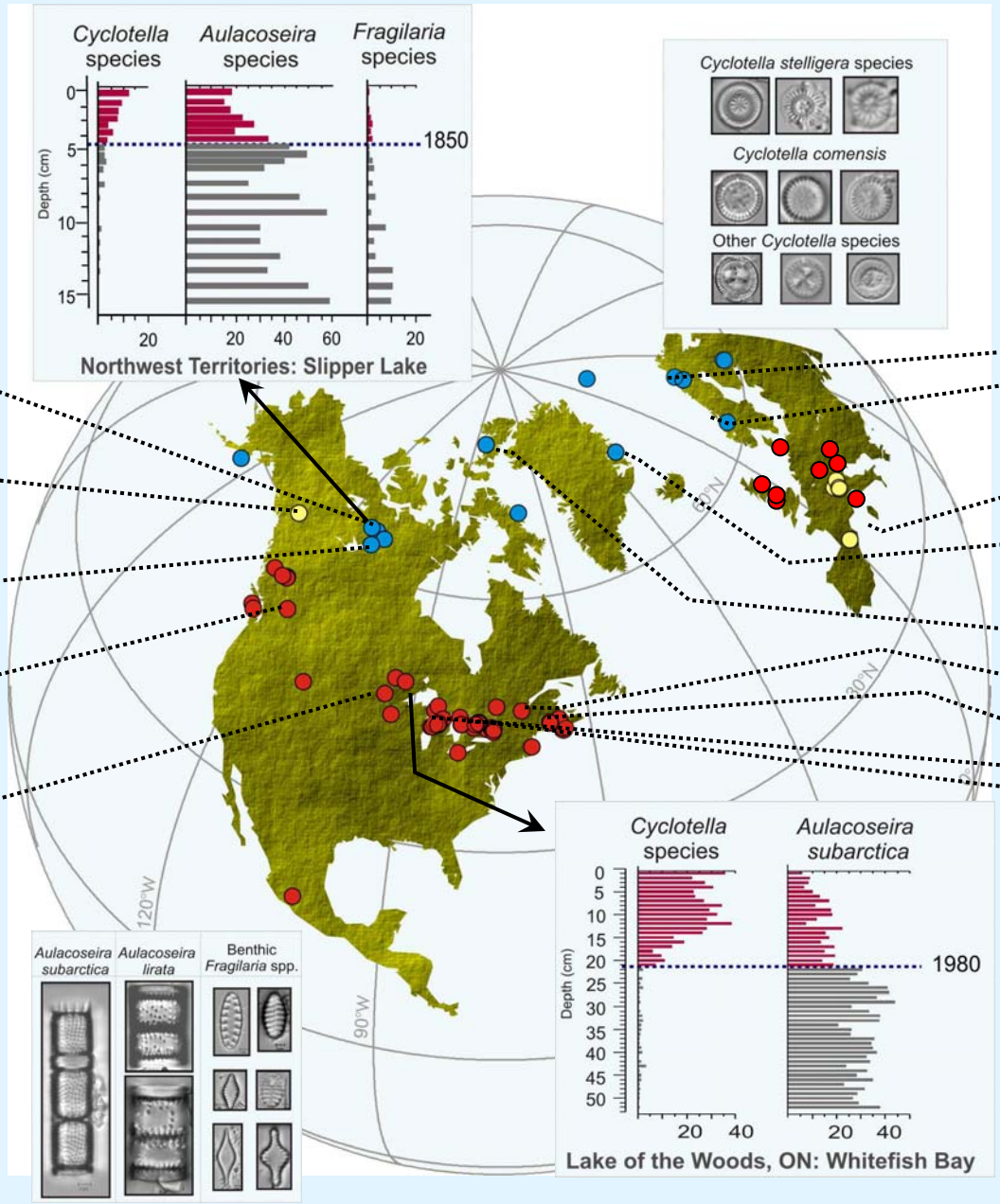
Werner 2003 PhD thesis



Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Climatic Warming and increases in *Cyclotella* species

Northern Hemisphere-Scale Trend



Subarctic Canada
Rühland et al. 2003

Yukon Canada
Karst-Riddoch et al. 2002

Great Slave L. N.W.T
Stoermer et al. 1990

BC Canada
Reavie et al. 2005, 2006; Laird et al. 2001

ELA NW ON
Enache et al. unpubl.

Subarctic Finland
Sorvari et al. 2002

Sweden
Bigler & Hall 2003

Spanish Pyrenees
Catalan et al. 2002

Eastern Greenland
Cremer et al. 2001

High Arctic Canada
Perren et al. 2003

NB Canada
Harris et al. 2006

NS Canada
Ginn et al. in press

SE ON
Forrest et al. 2002

SW ON
Werner et al. 2005

Rühland, Paterson & Smol: Global Change Biology (2008) 14, doi: 10.1111/j.1365-2486.2008.01670.x

Summary of Results: Lake of the Woods

- Greatest change in diatom composition over last ca. 20-30 yrs
- Changes consistent with climate records
- Taxon-specific shifts correlated to increase in temperature
- Taxon-specific shifts correlated to decrease in length of ice cover
- Taxon-specific shifts not related to nitrogen deposition
- Climatically-induced limnological changes = 1º mechanism
- Climate must be included in lake management strategies
- LOW fits into global pattern of recent taxon-specific diatom shifts

Acknowledgements

- Bev Clark (MOE, Dorset)
- Mike Stainton (DFO, MB)
- Sergi Pla (formerly at PEARL)
- Tom Mosindy & Gavin Olson (MNR Kenora)
- Ron Ingram (MOE, Dorset)
- Joy Ramstack (St. Croix Watershed Research Station, MN)
- Mark Edlund (St. Croix Watershed Research Station, MN)
- Euan Reavie (Natural Resources Research Institute, Ely MN)
- Nolan Baratono (Minnesota Pollution Control Agency)