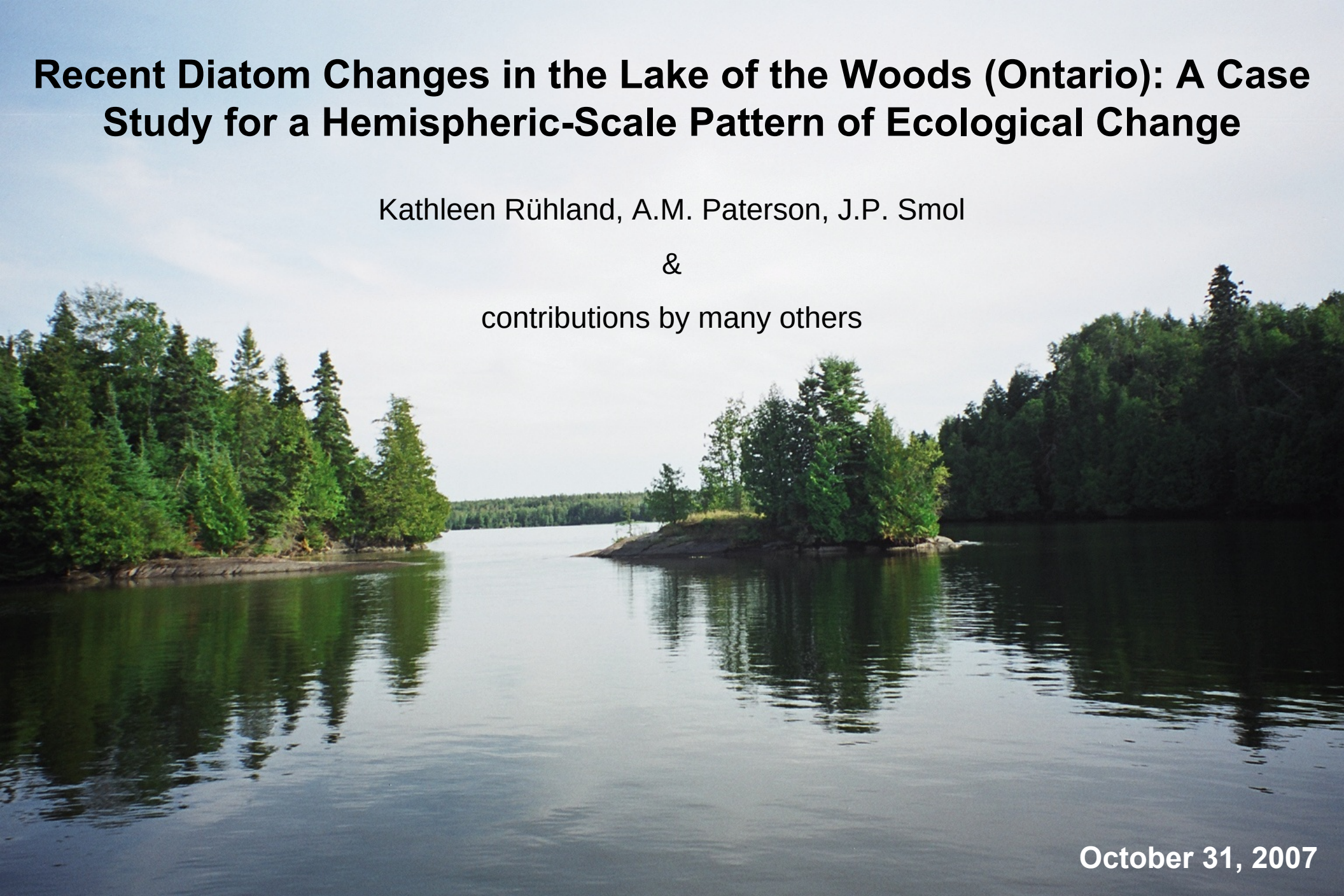
Recent Diatom Changes in the Lake of the Woods (Ontario): A Case Study for a Hemispheric-Scale Pattern of Ecological Change

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

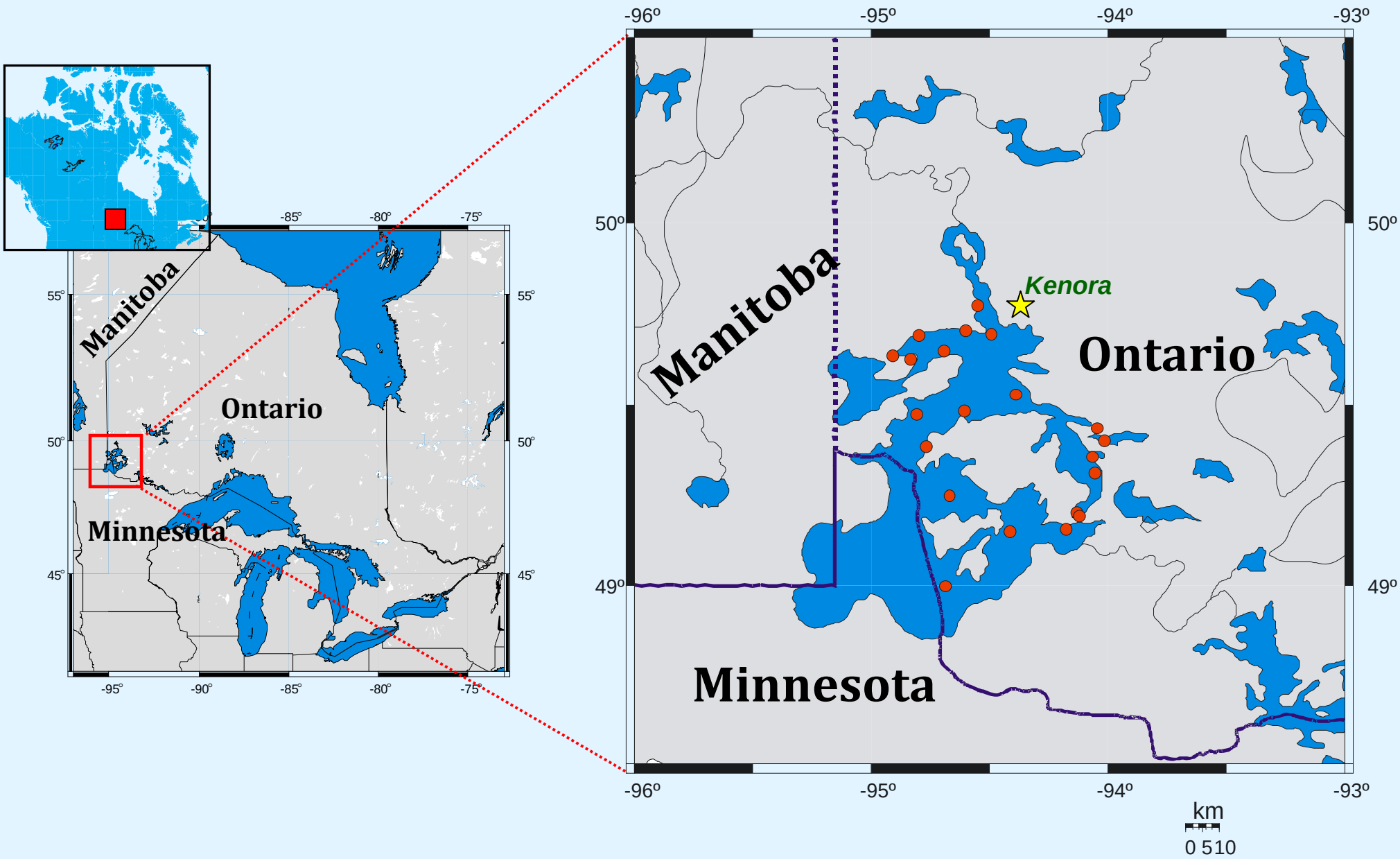
&

contributions by many others

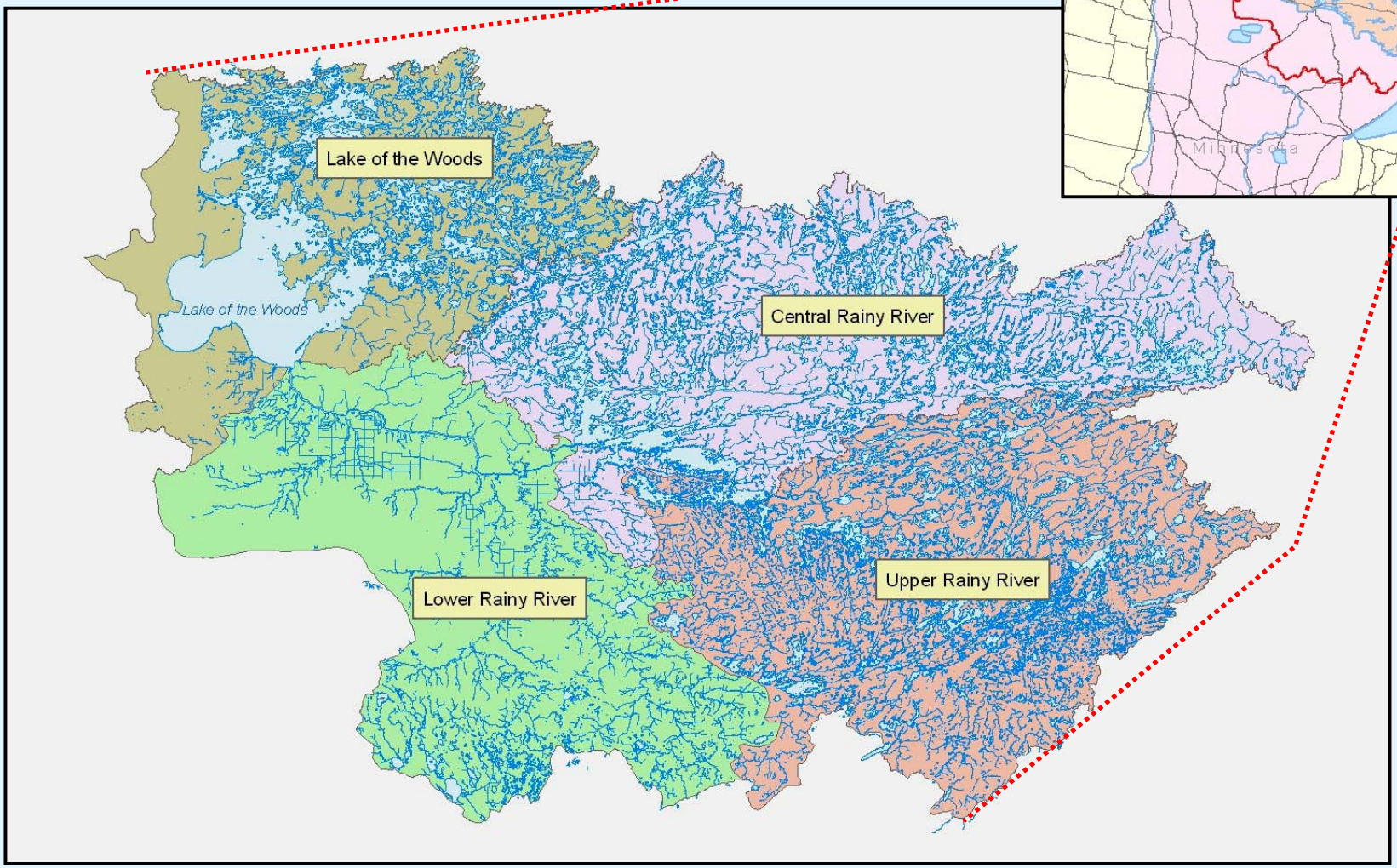


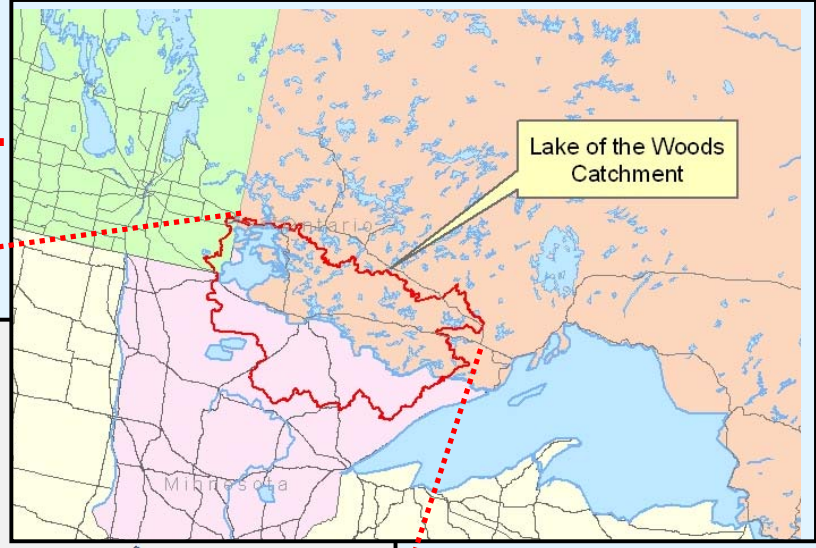
October 31, 2007

The Lake of the Woods



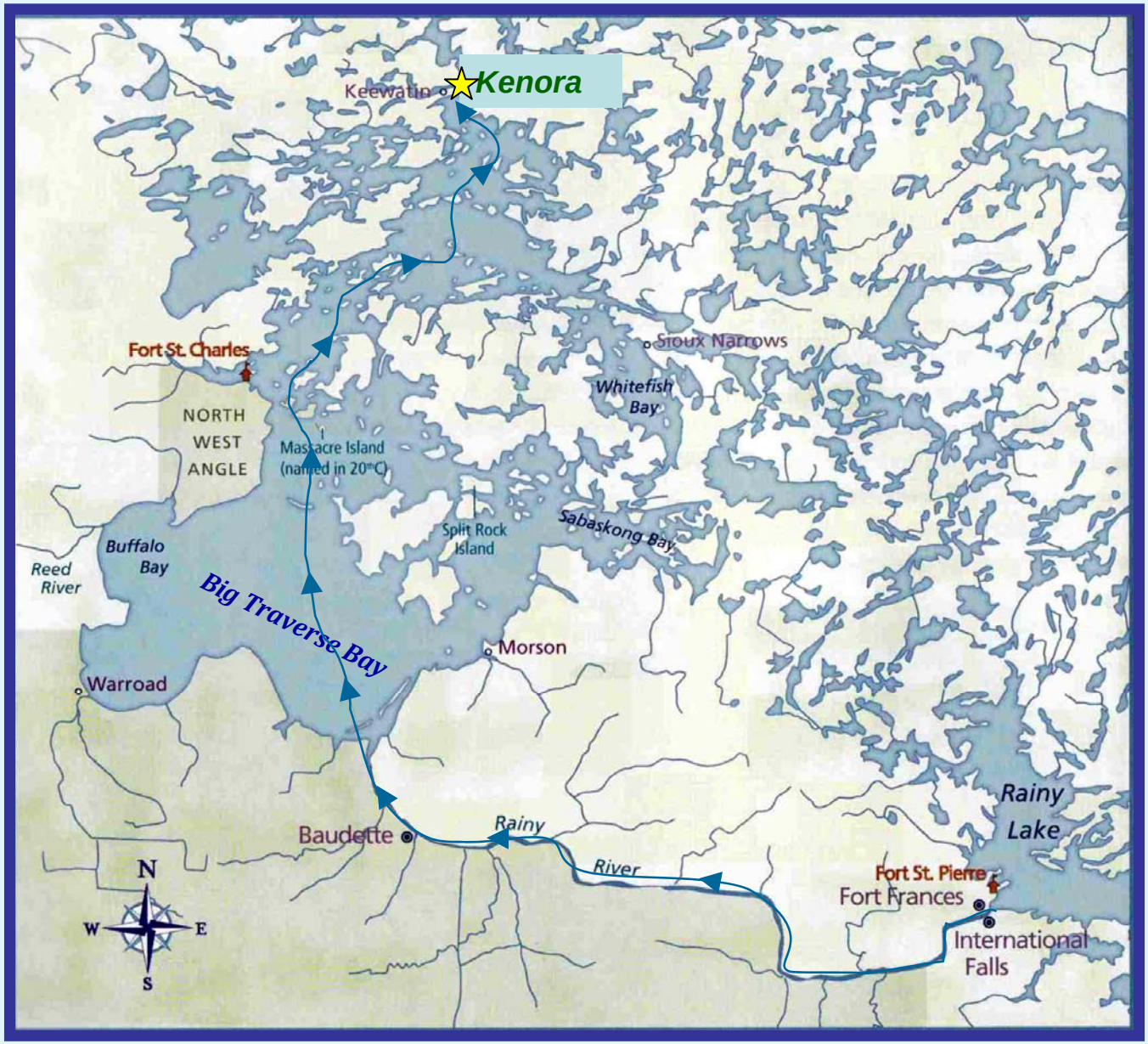
The Lake of the Woods: A complex system





LOW has a a low Lake:Drainage basin area of 5.5 (Chen et al. 2007: Lake Res Management)

Maps by Gartner Lee Ltd.



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?

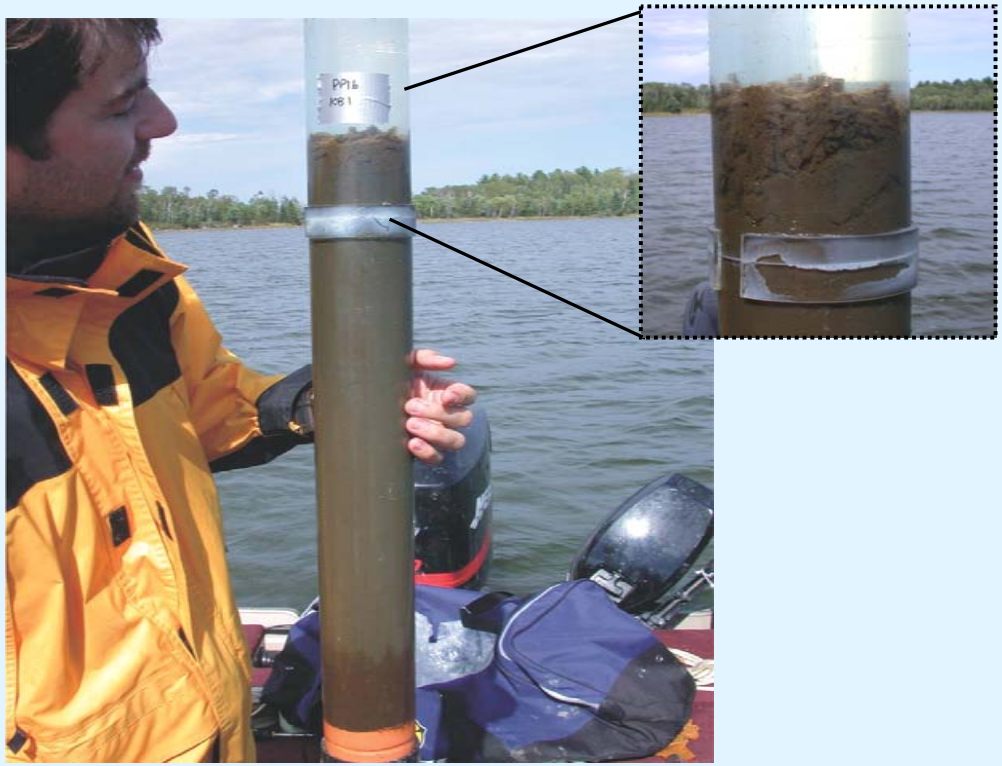
4) What is the direction and magnitude of this change?

5) What are the possible reasons for this change?

Location of sampling sites for sediment cores

Modified from Robertson & McCracken 2003

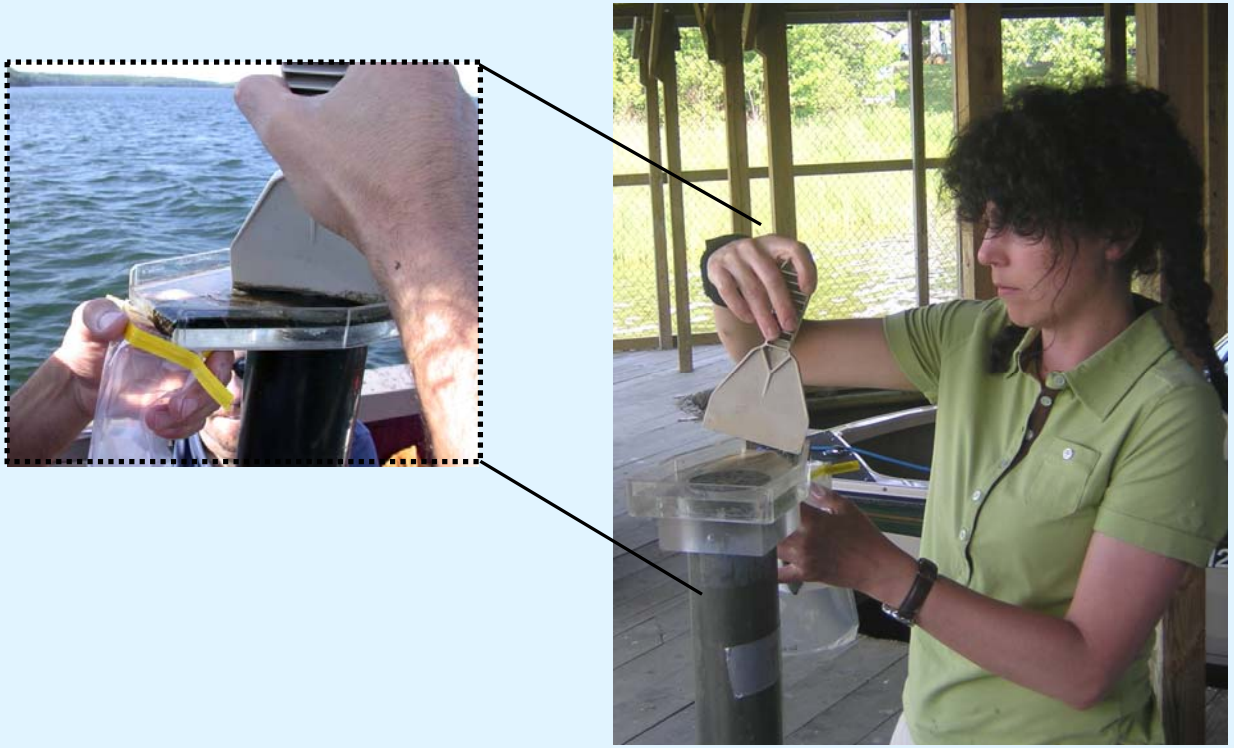
Sampling Lake of the Woods



Core retrieval

- gravity cores retrieved from deep, quiet locations
- undisturbed water-sediment interface = most recent deposits retrieved

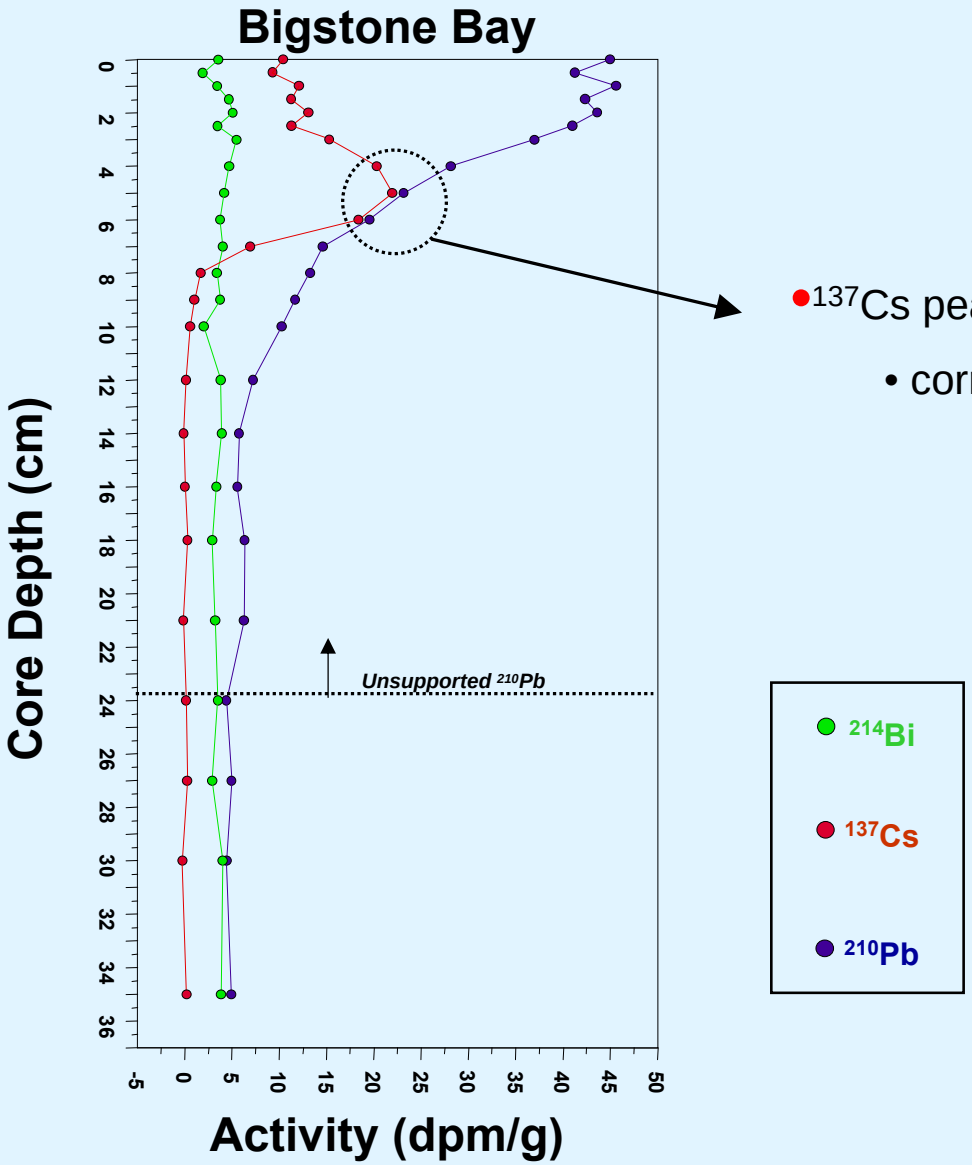
Sampling Lake of the Woods



Core sectioning

- sediment is sectioned into intervals (Glew 1988 extruder)
- each 0.5 cm interval extruded into plastic sample bags

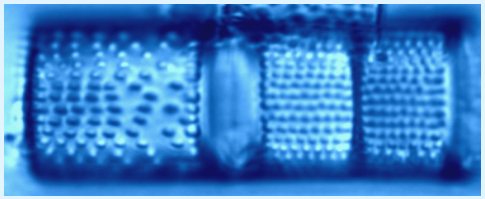
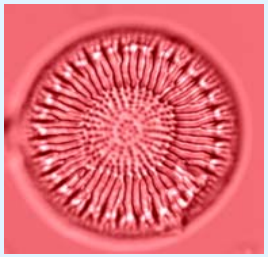
Dating the sedimentary sequences

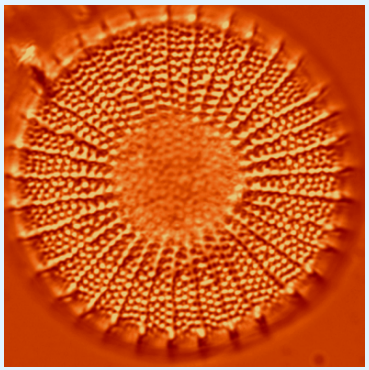
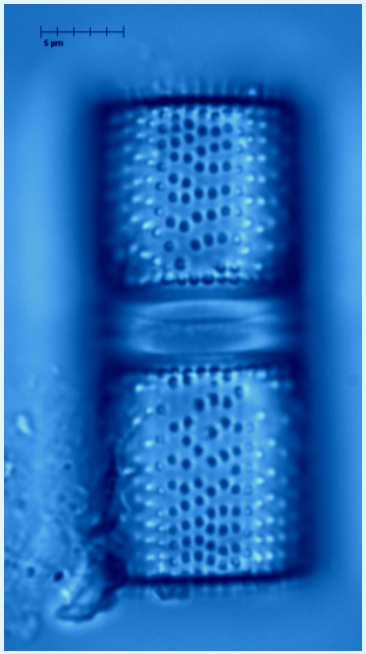


- ^{137}Cs peak ca. 1963
  - corresponds to nuclear test ban treaty

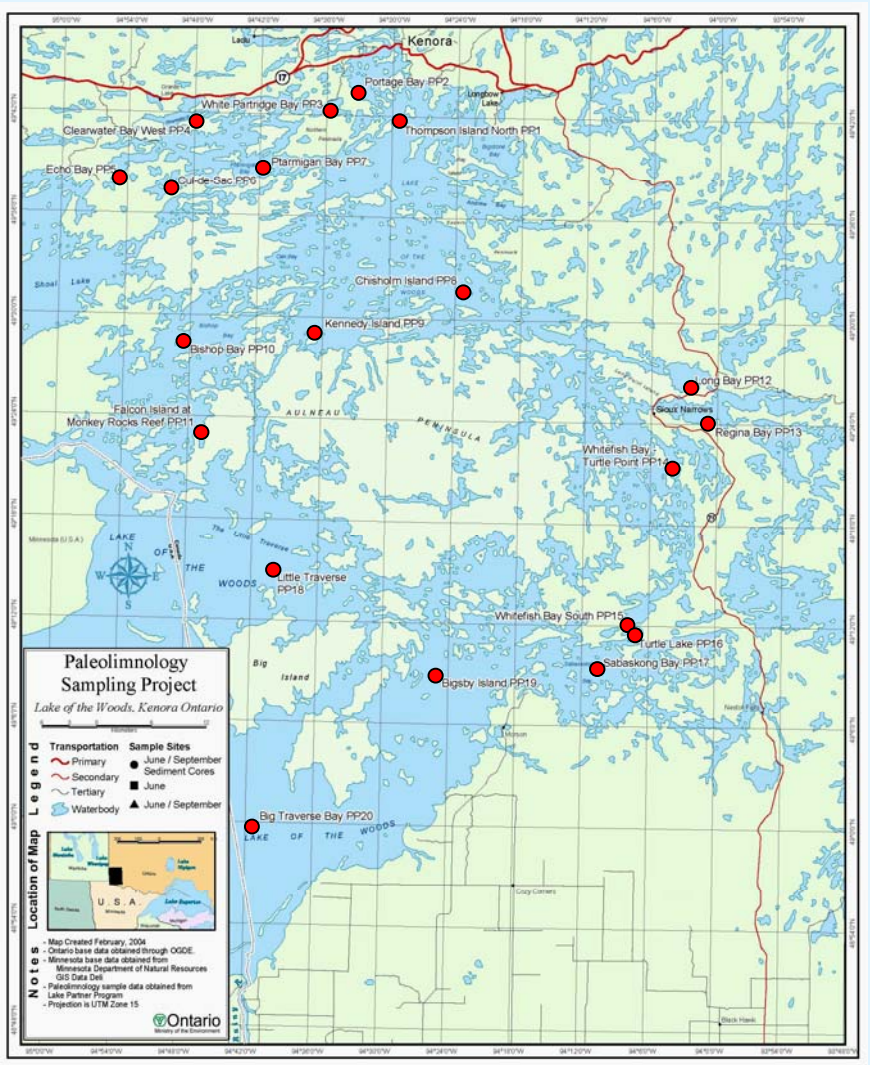
Diatoms as Indicators of Environmental Change

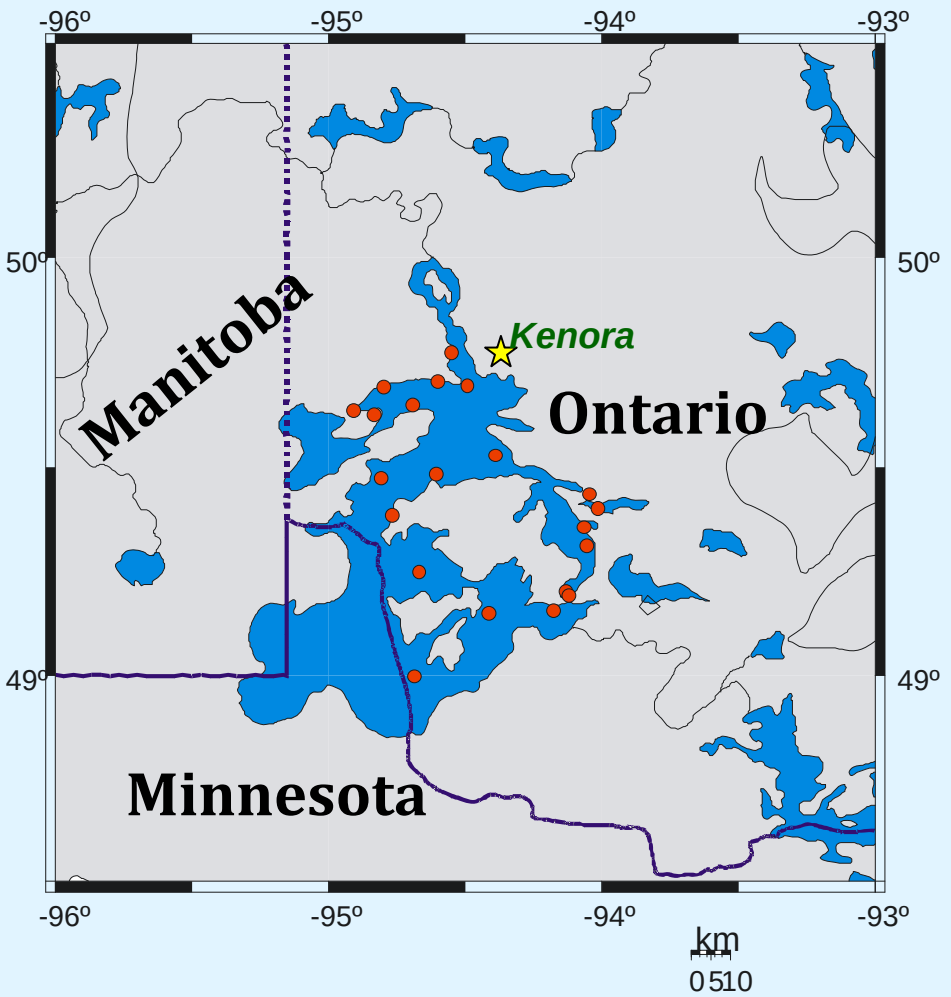
- well preserved in lake sediments
- remain stable in sedimentary sequences
- taxonomically specific ornamentation
- many have narrow optima and tolerances
- respond rapidly to environmental change

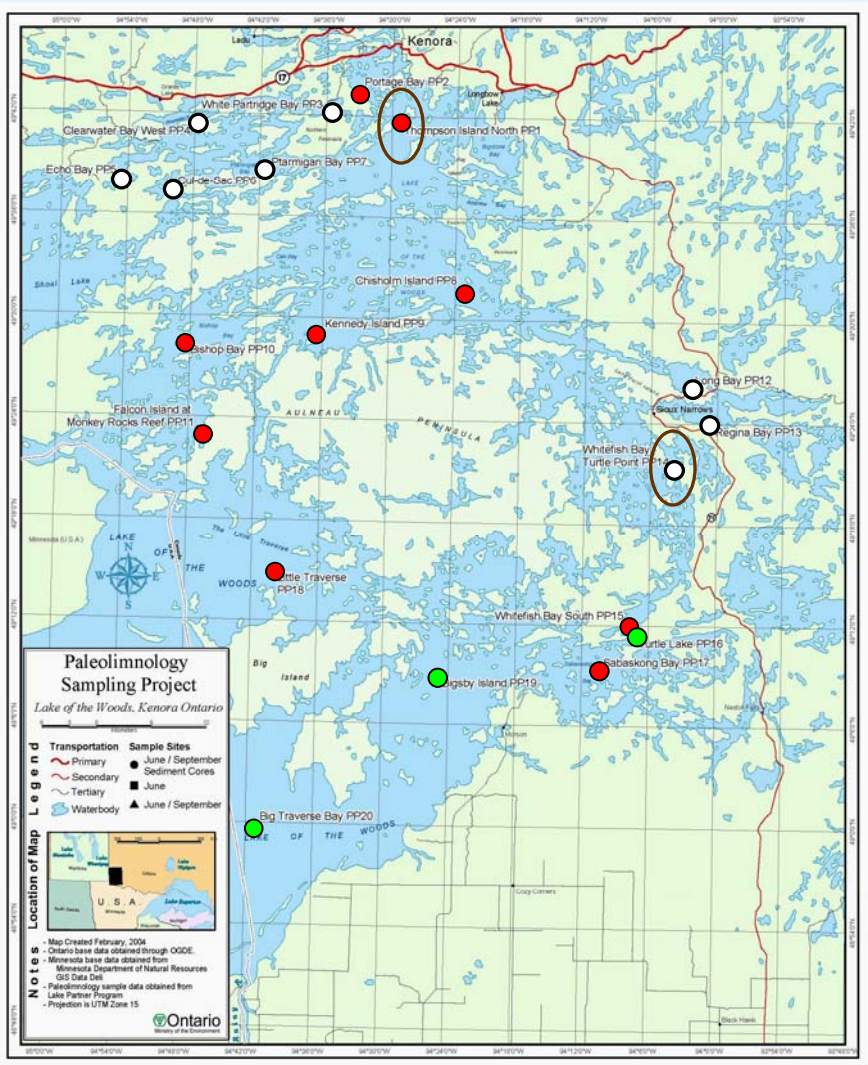
Developing Models for Total Phosphorus

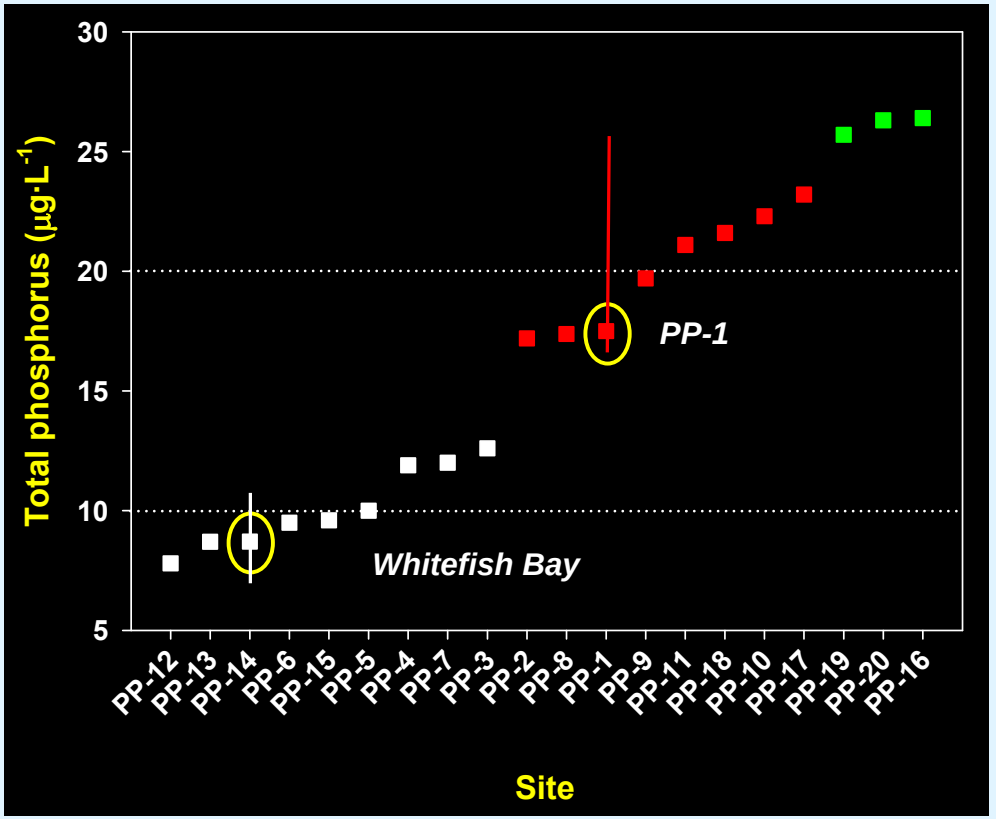




Lake of the Woods training set

Developing Models for Total Phosphorus





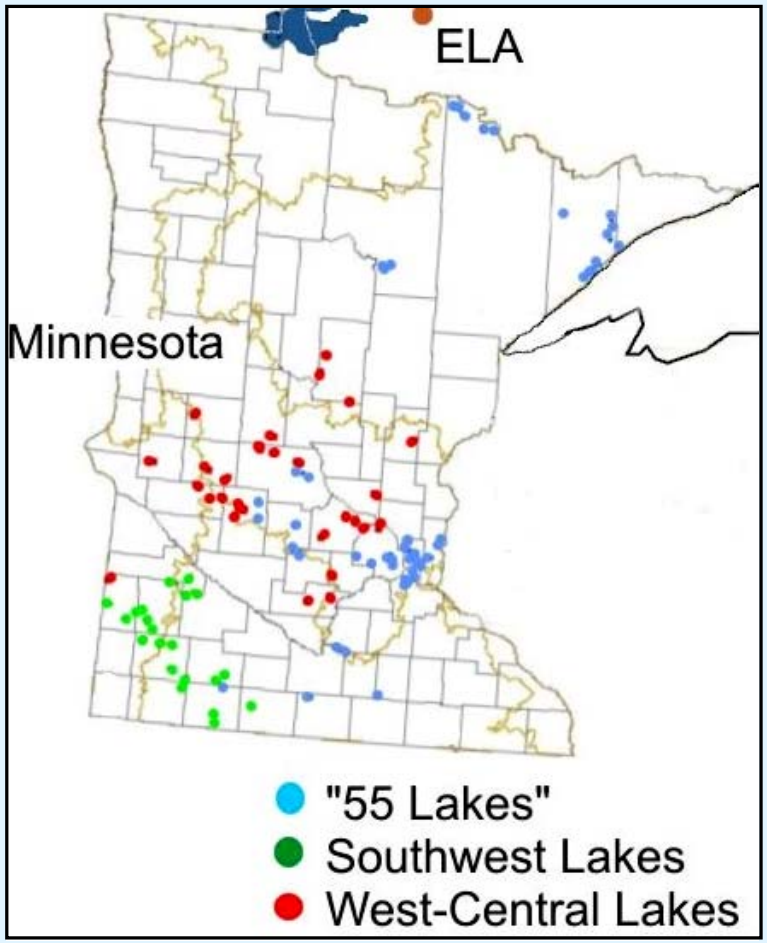
Summer measurements

Lake of the Woods training set

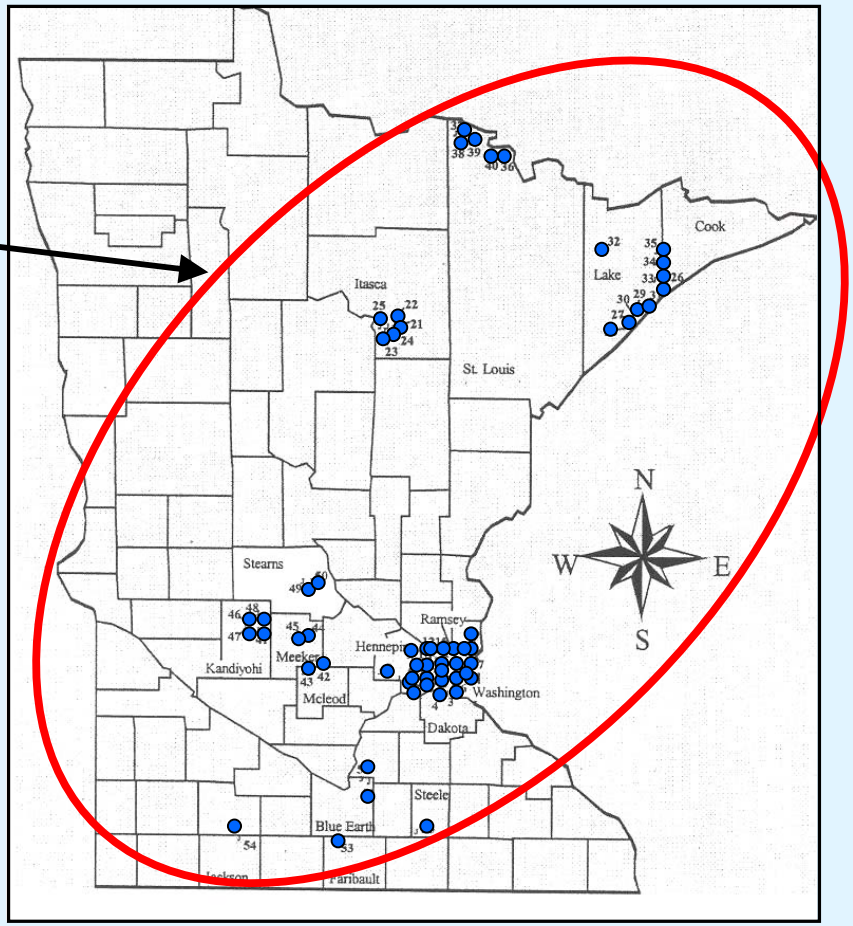
Developing Models for Total Phosphorus

Minneosta training set

developed by St. Croix Research Stn, Natural Resources Res. Stn Duluth



Full lake set

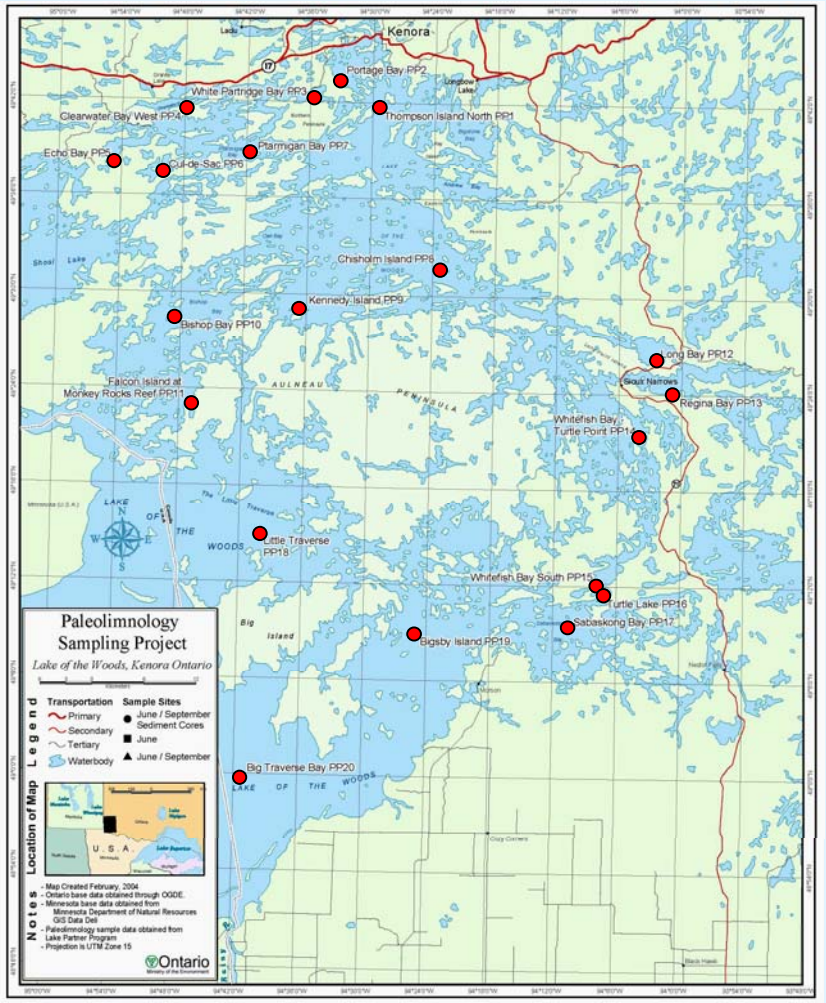


Northern Lakes and Forests (NLF) sites

From Ramstack et al. 2003 (JOPL)

Developing Models for Total Phosphorus

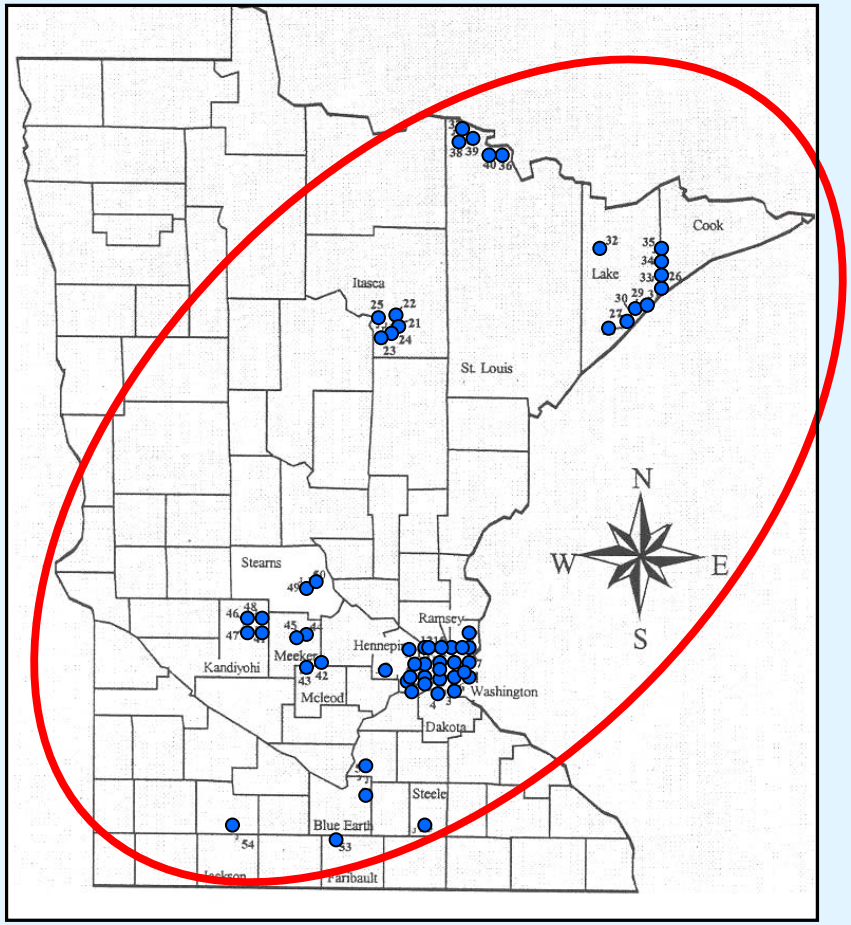
16 sites in LOW



Lake of the Woods training set

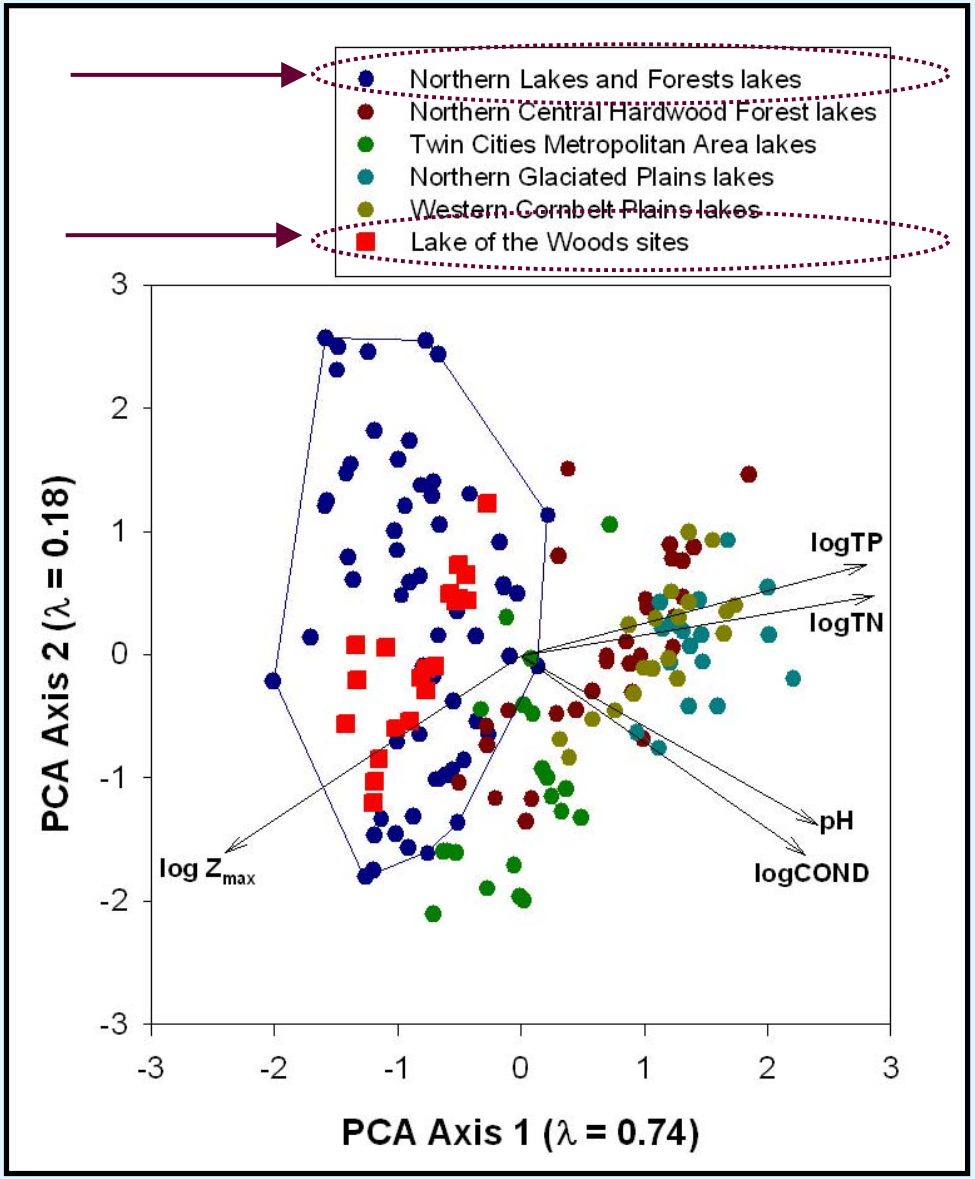
+

55 Minnesota lakes



Northern Lakes and Forests (NLF) sites

Developing Models for Total Phosphorus



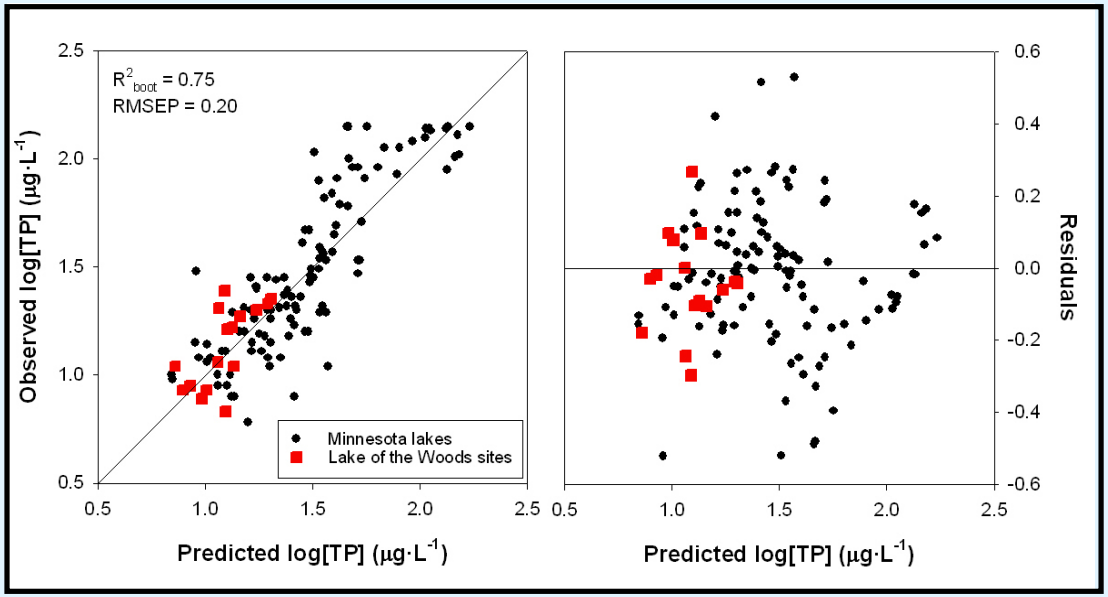
Developing Models for Total Phosphorus

Full model: 112 Minnesota lakes

R^2_{boot} = 0.75

RMSEP = 0.20

n = 128 sites



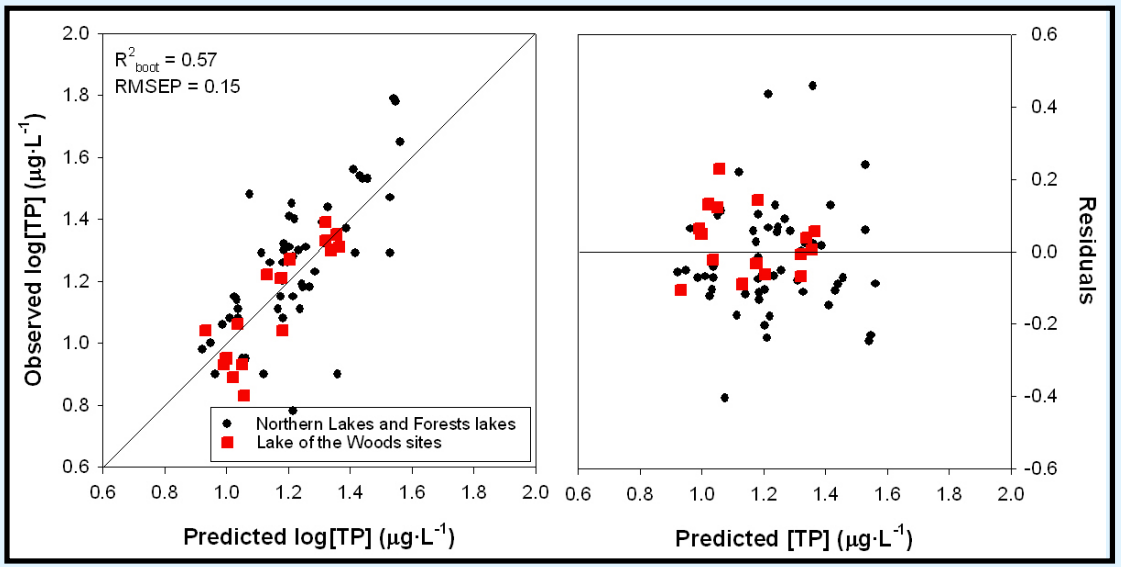
Reduced model: 55 Minnesota lakes (NLF lakes)

WAPLS- 2components

R^2_{boot} = 0.57

RMSEP = 0.15 (~1.41 ug/L)

n = 71 sites



Developing Models for Total Phosphorus

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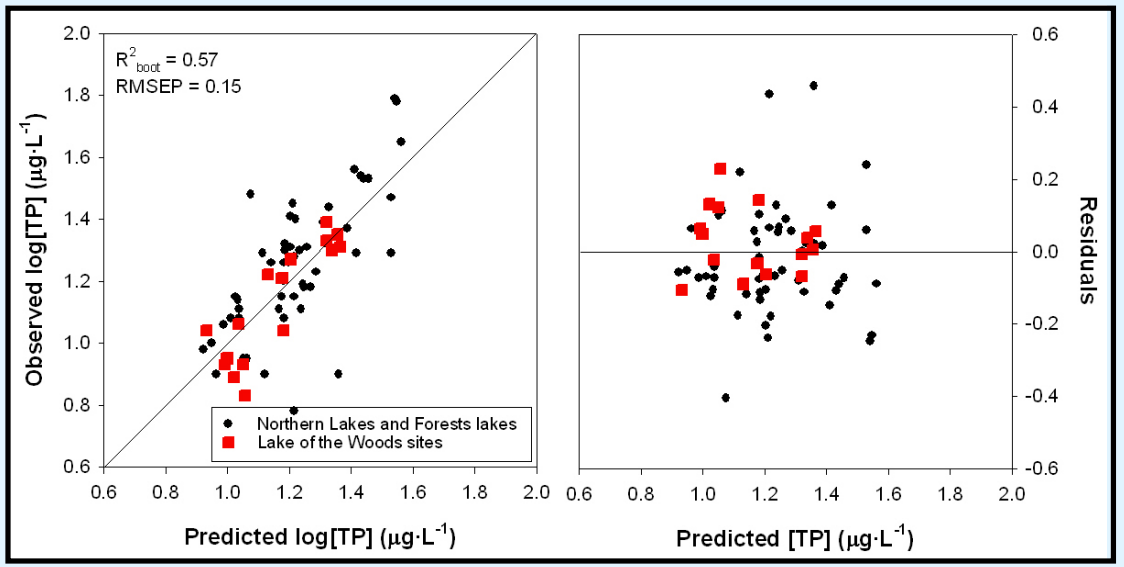
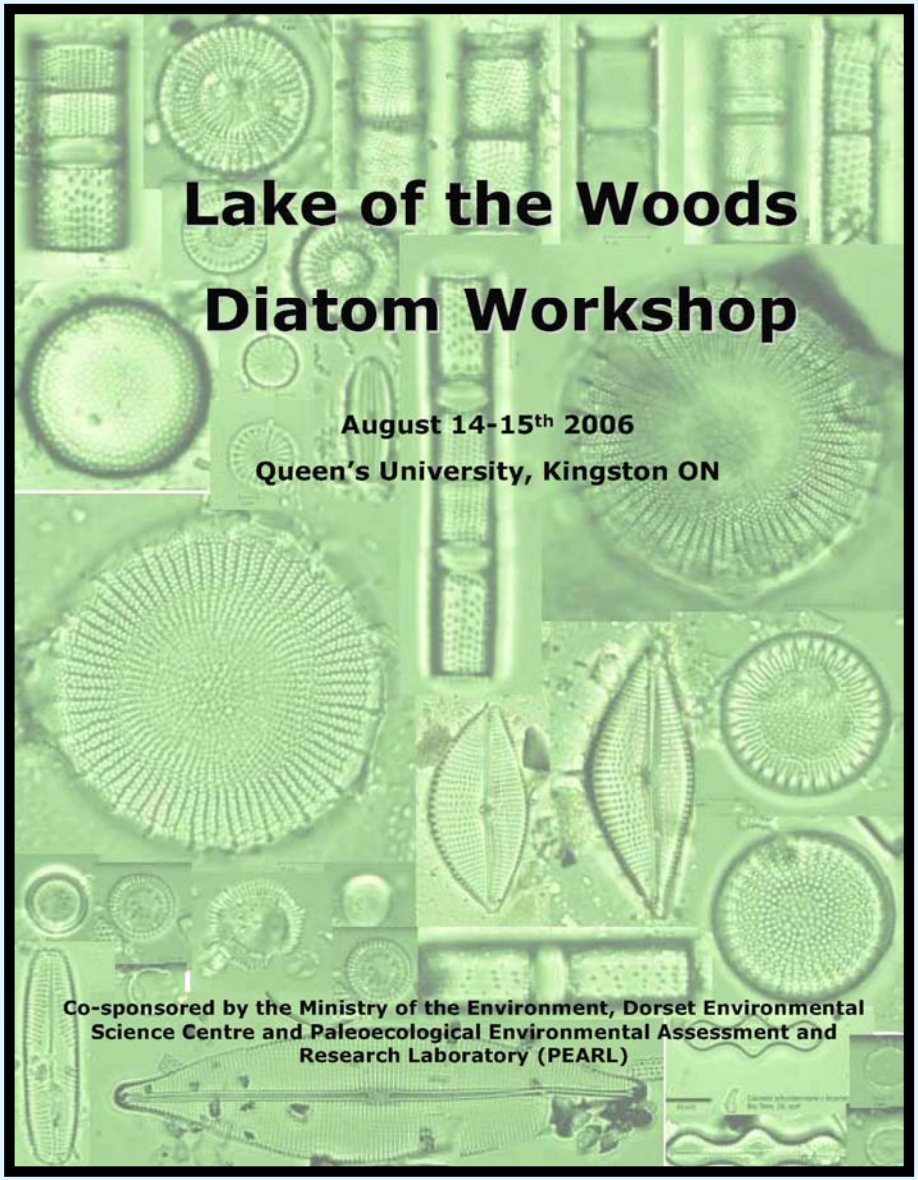


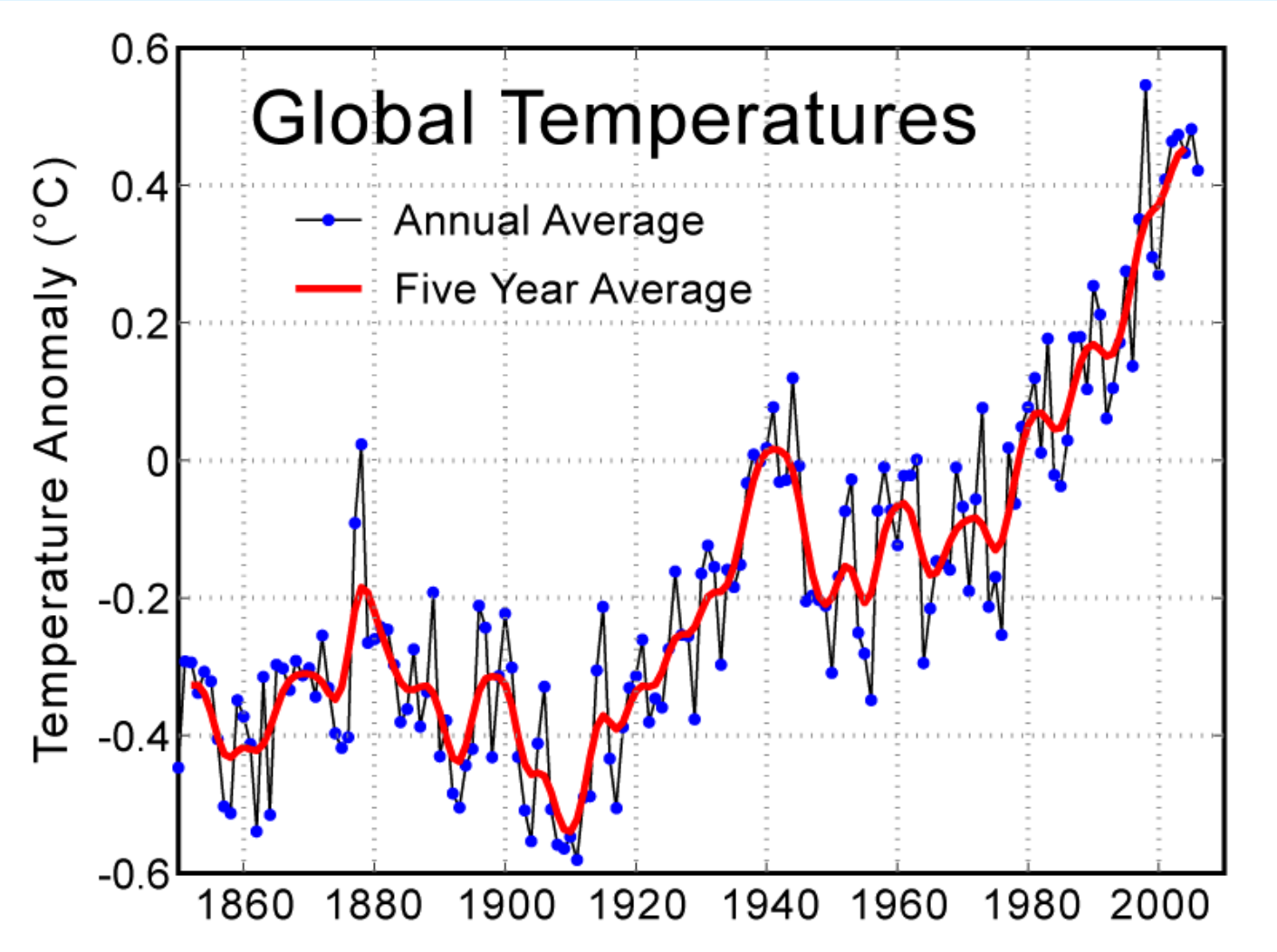
Taxonomic Consistency



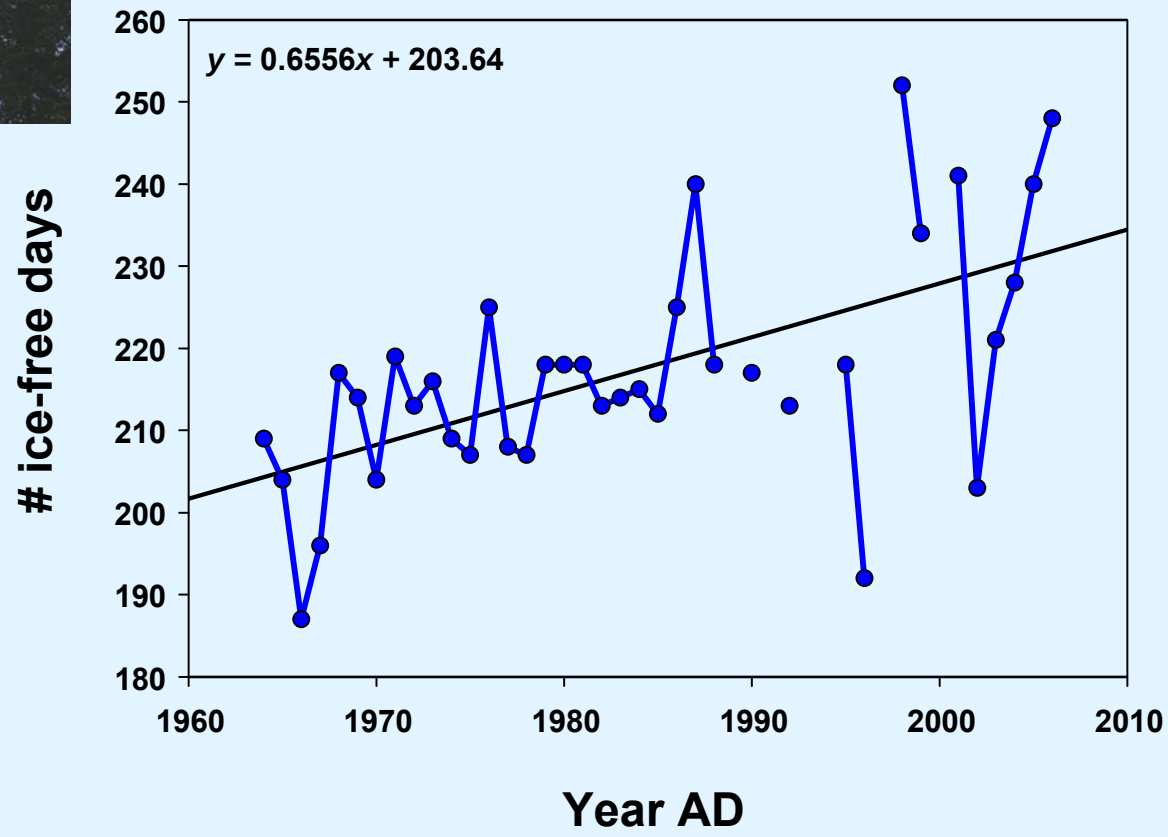
- Exchange of diatom datasets requires taxonomic consistency

- Diatom workshop, August 2006

The Instrumental Record

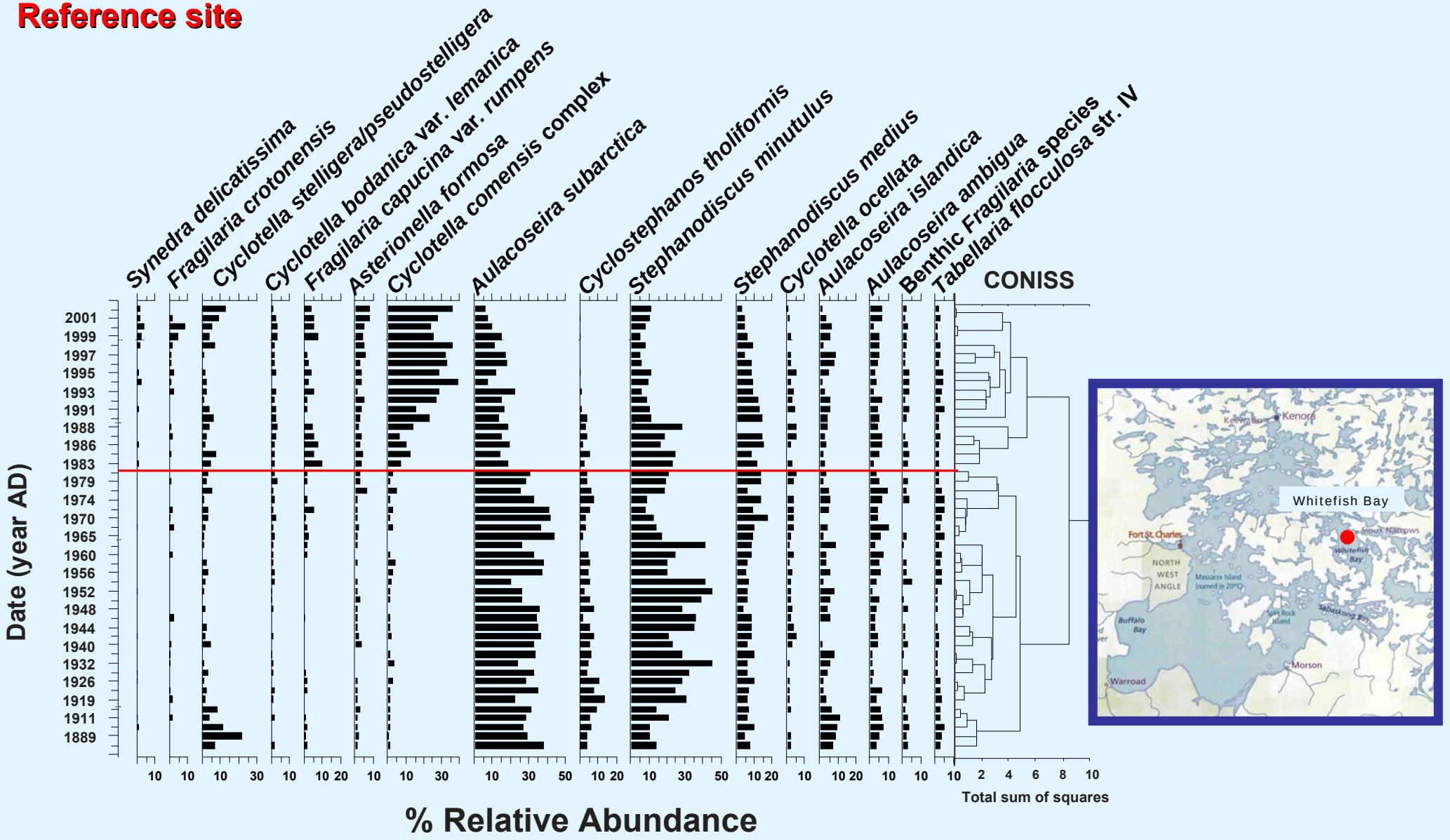


Historical Lake Ice Records



Whitefish Bay Diatom Profile

Reference site



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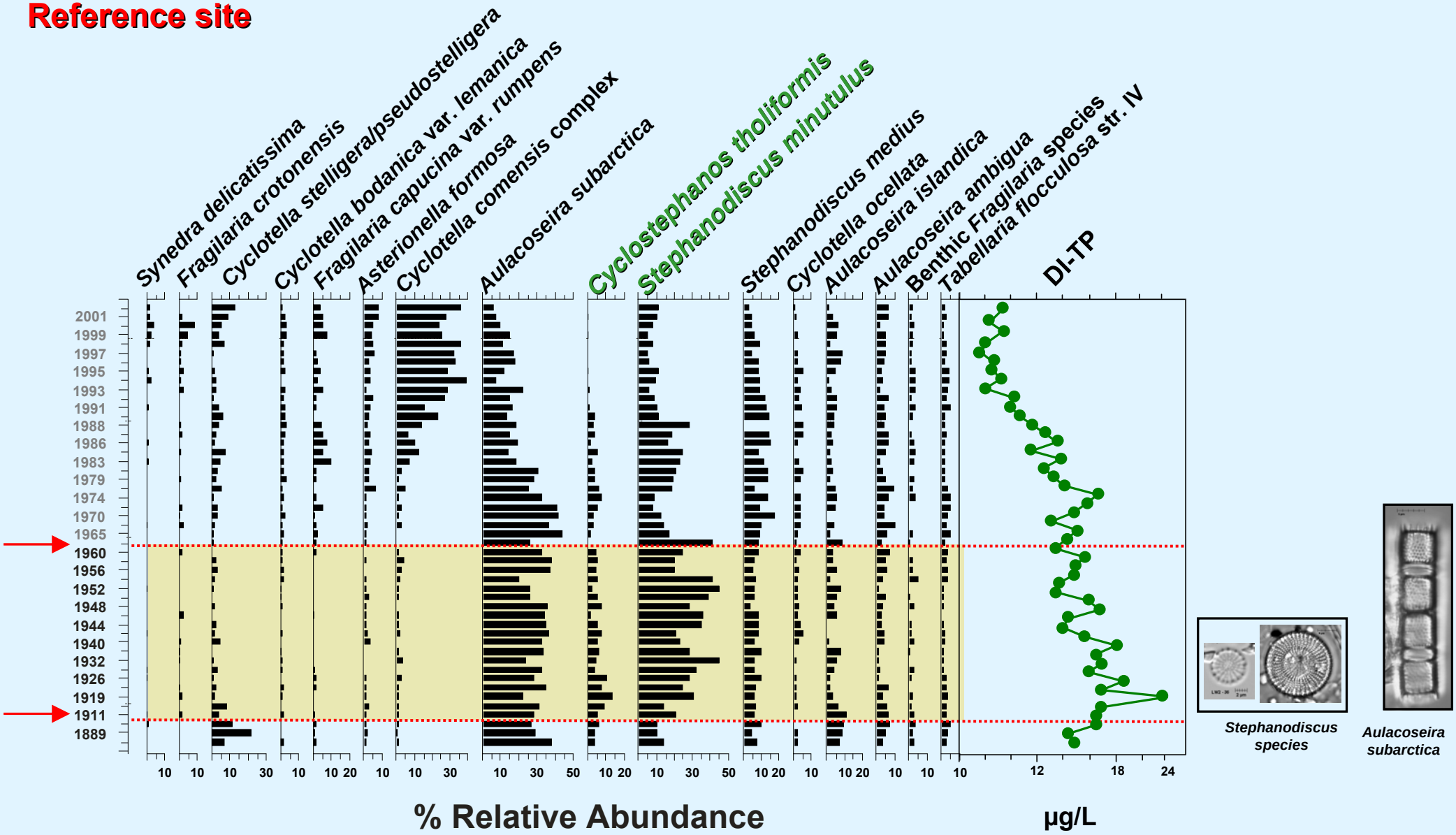
Whitefish Bay Diatom Profile

Reference site

ca. 1905 Rise in water level



Stephanodiscus species

Aulacoseira subarctica

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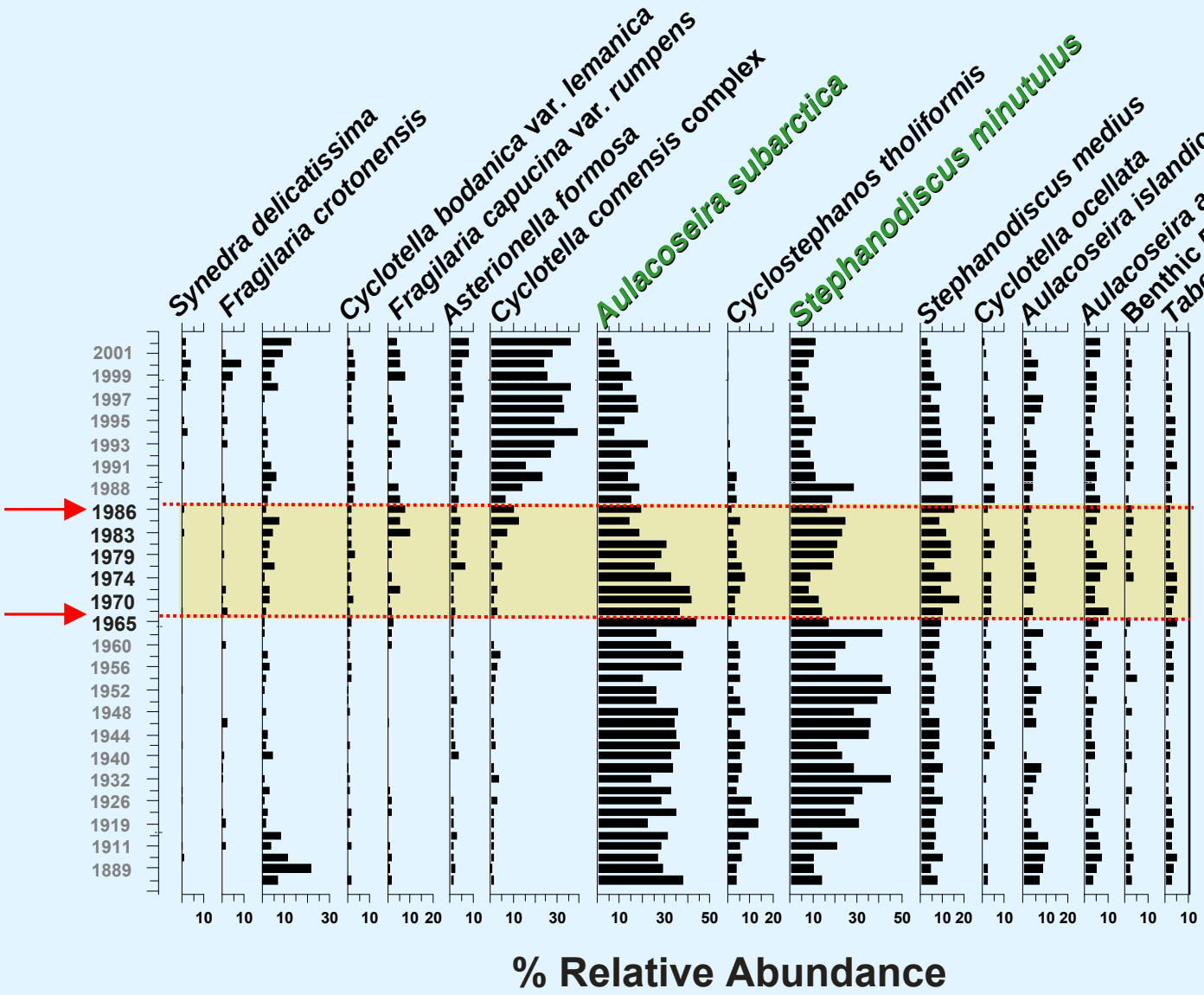
Whitefish Bay Diatom Profile

ca. 1966-1986 Canal

Reference site



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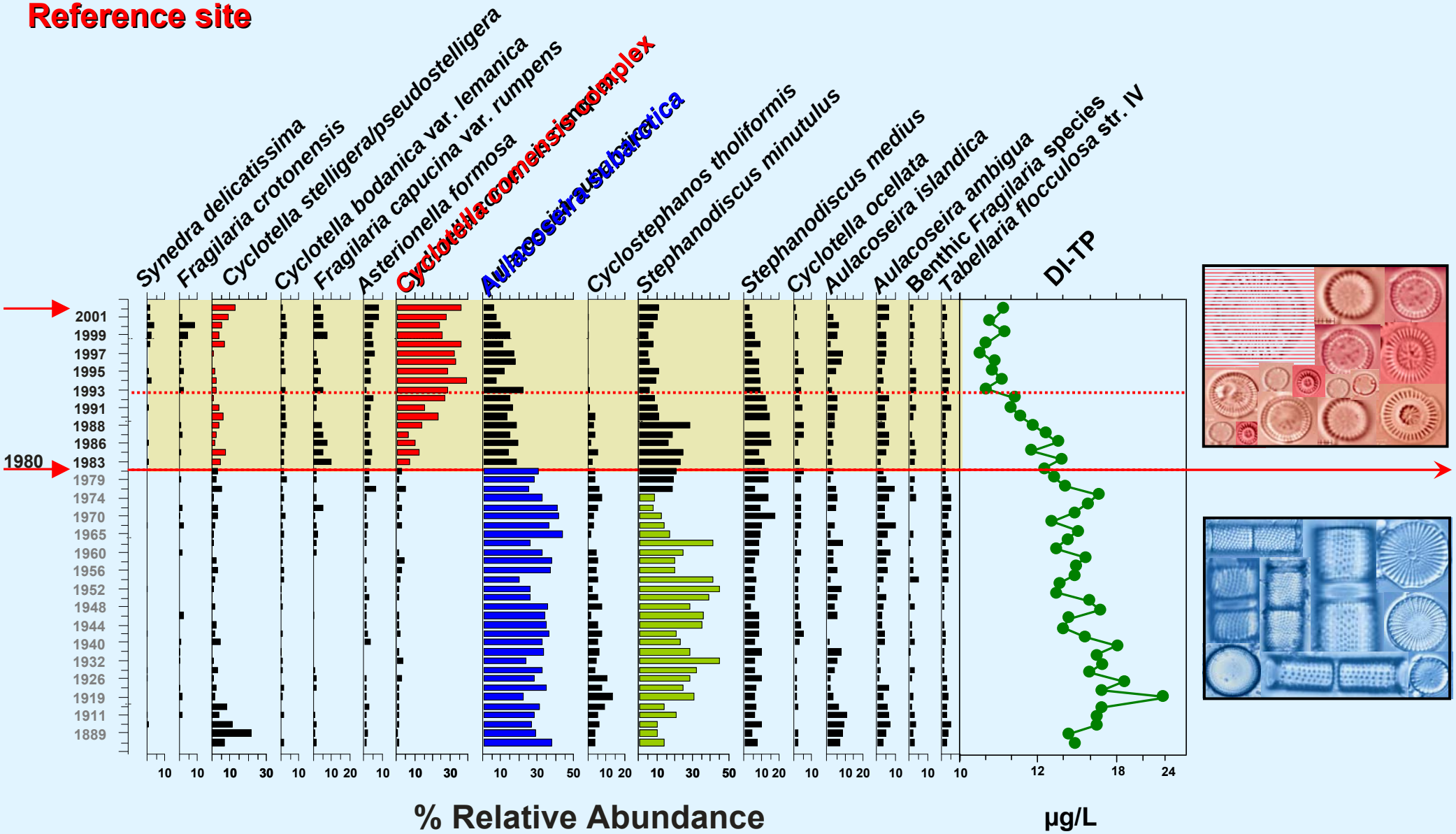
Whitefish Bay Diatom Profile

1980 – present

Reference site



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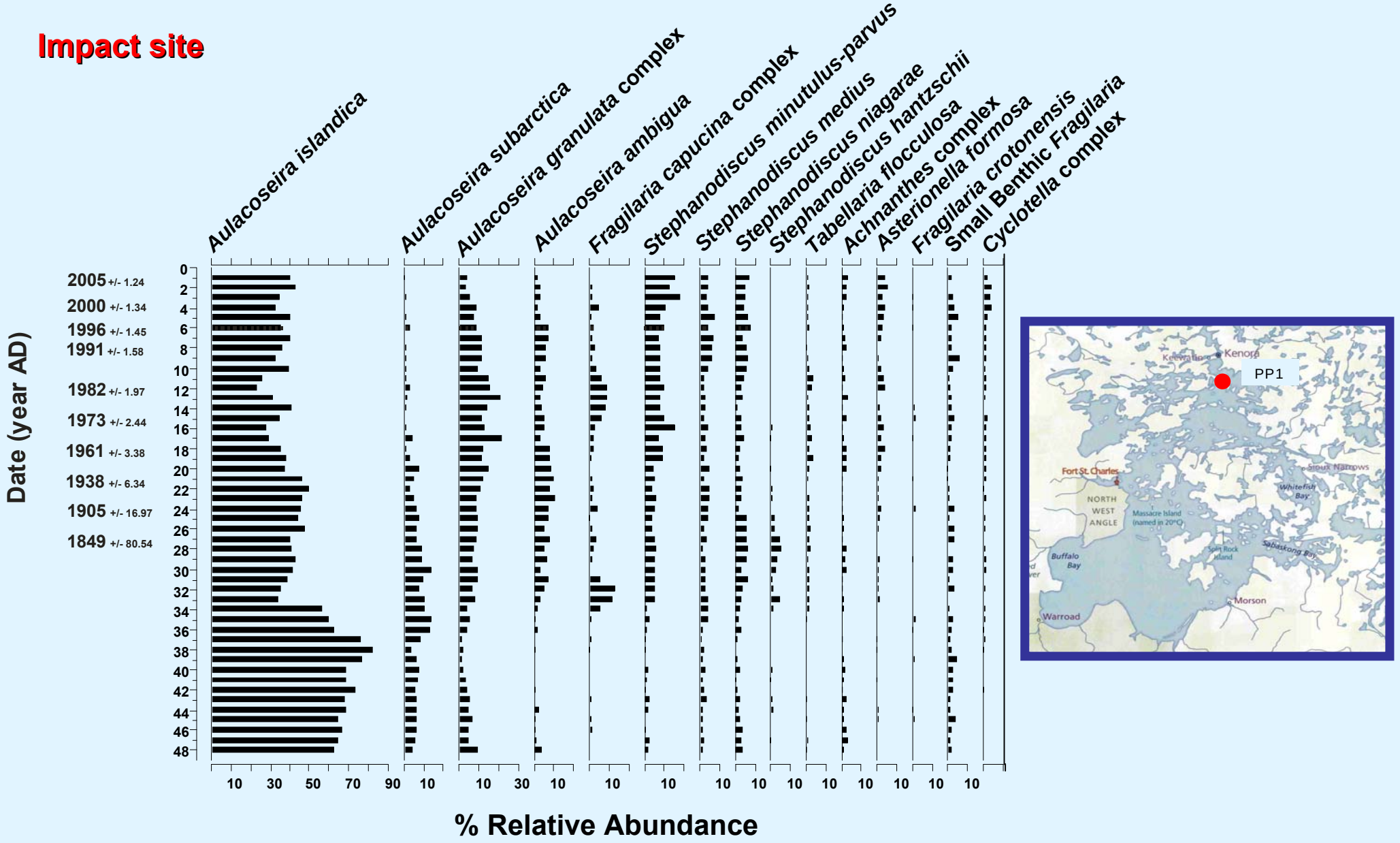
PP1 Diatom Profile

Impact site



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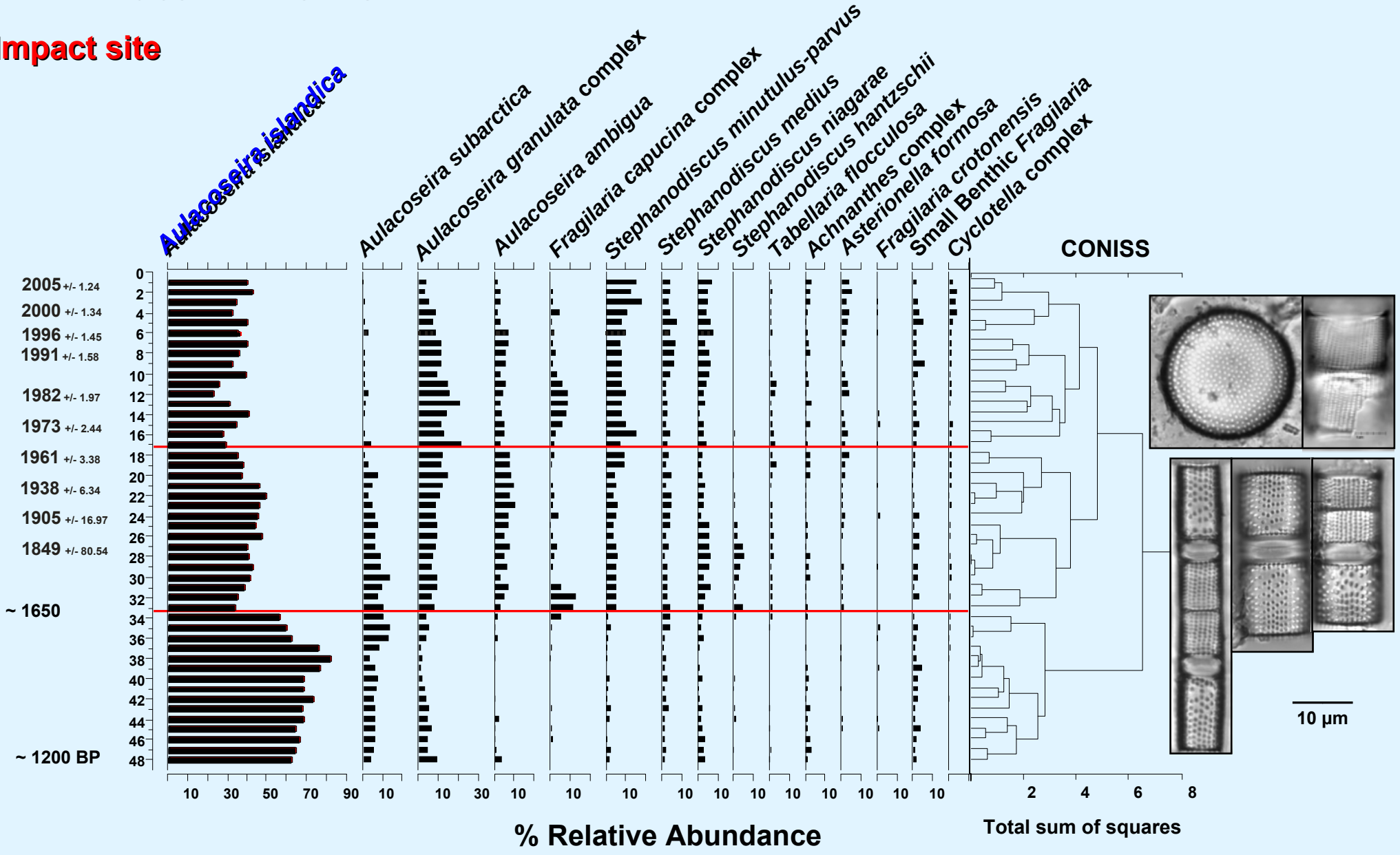

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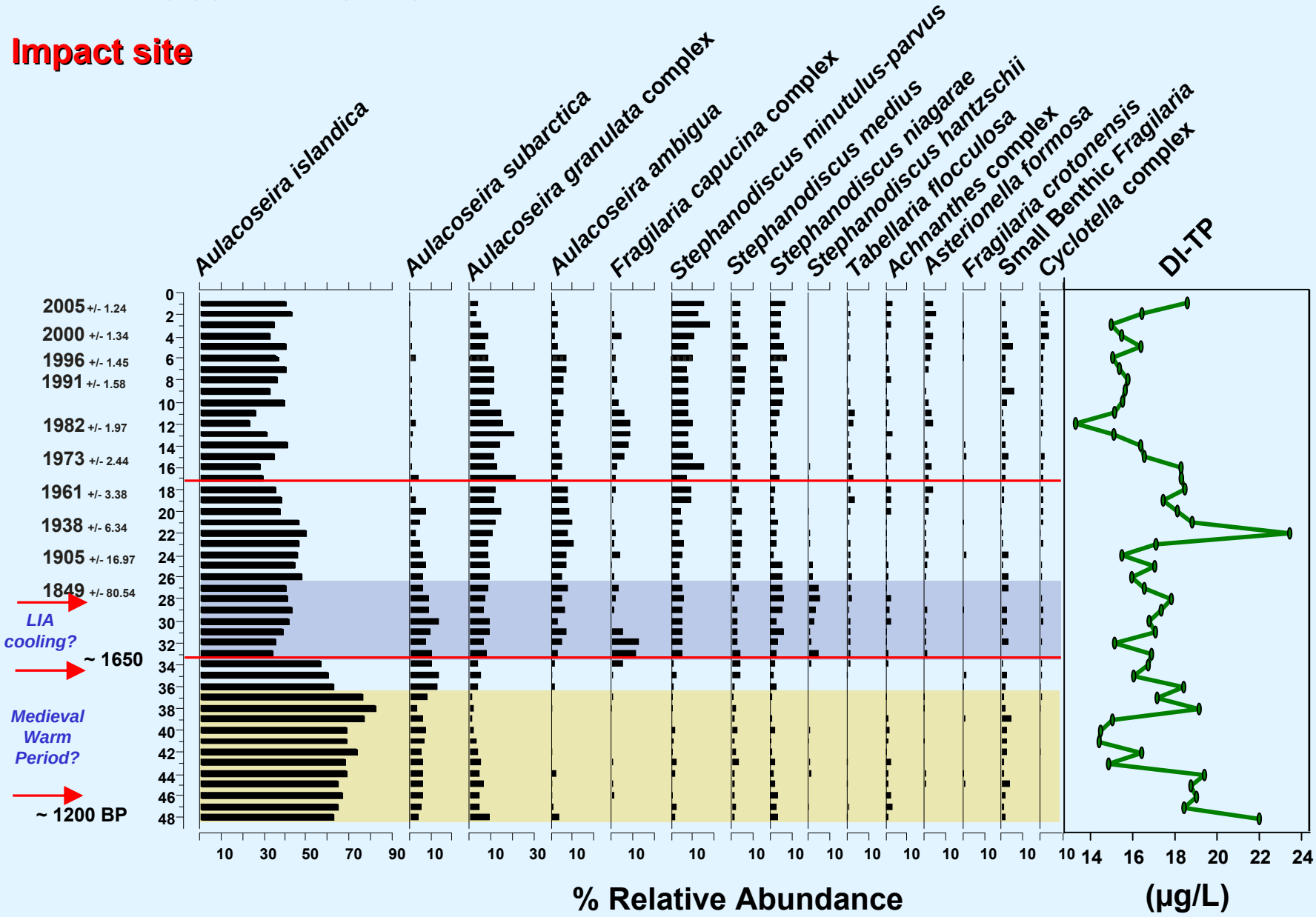
PP1 Diatom Profile

~ AD 1100 – AD 1850

Impact site



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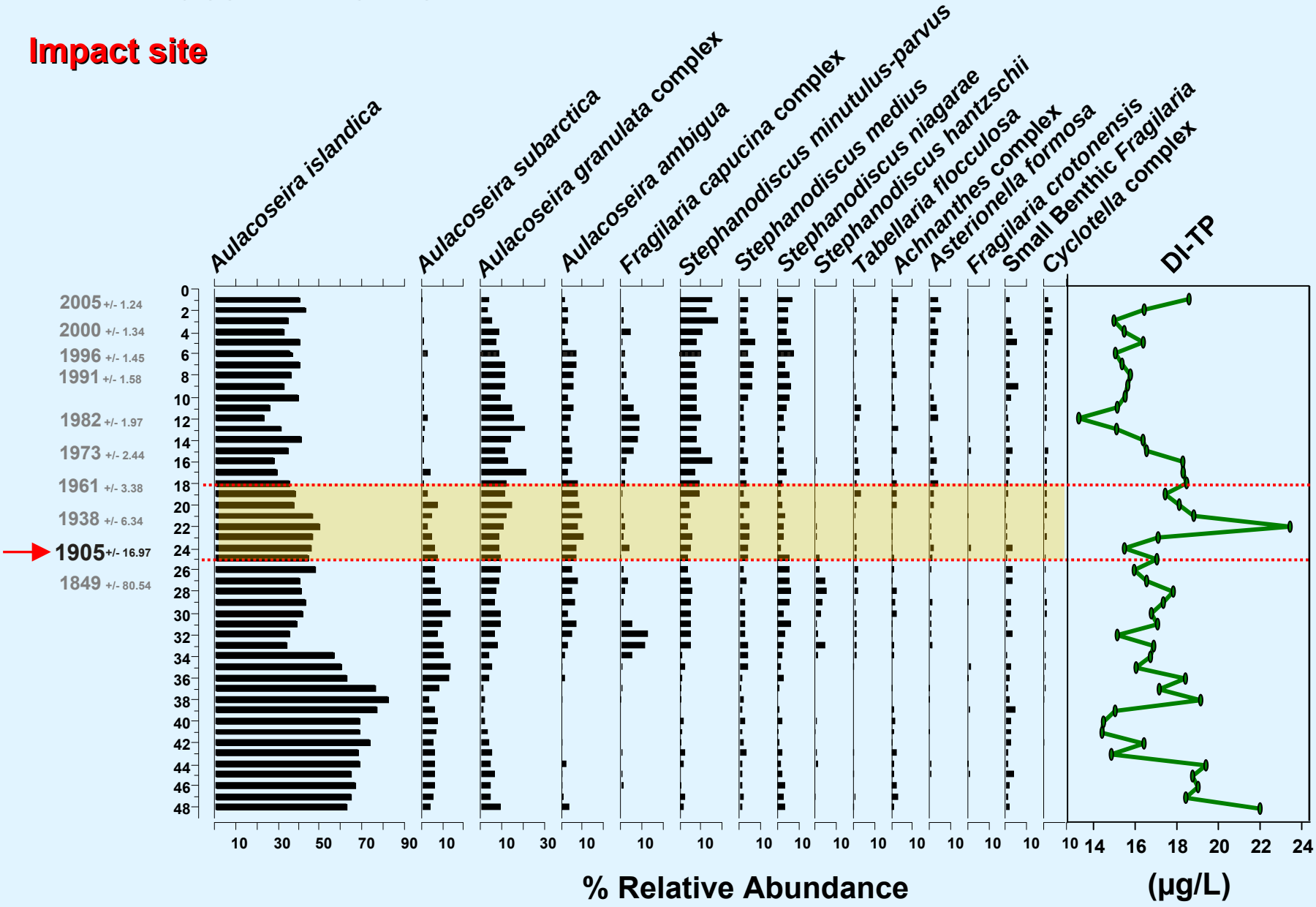
PP1 Diatom Profile

Impact site

ca. 1905 Rise in water level



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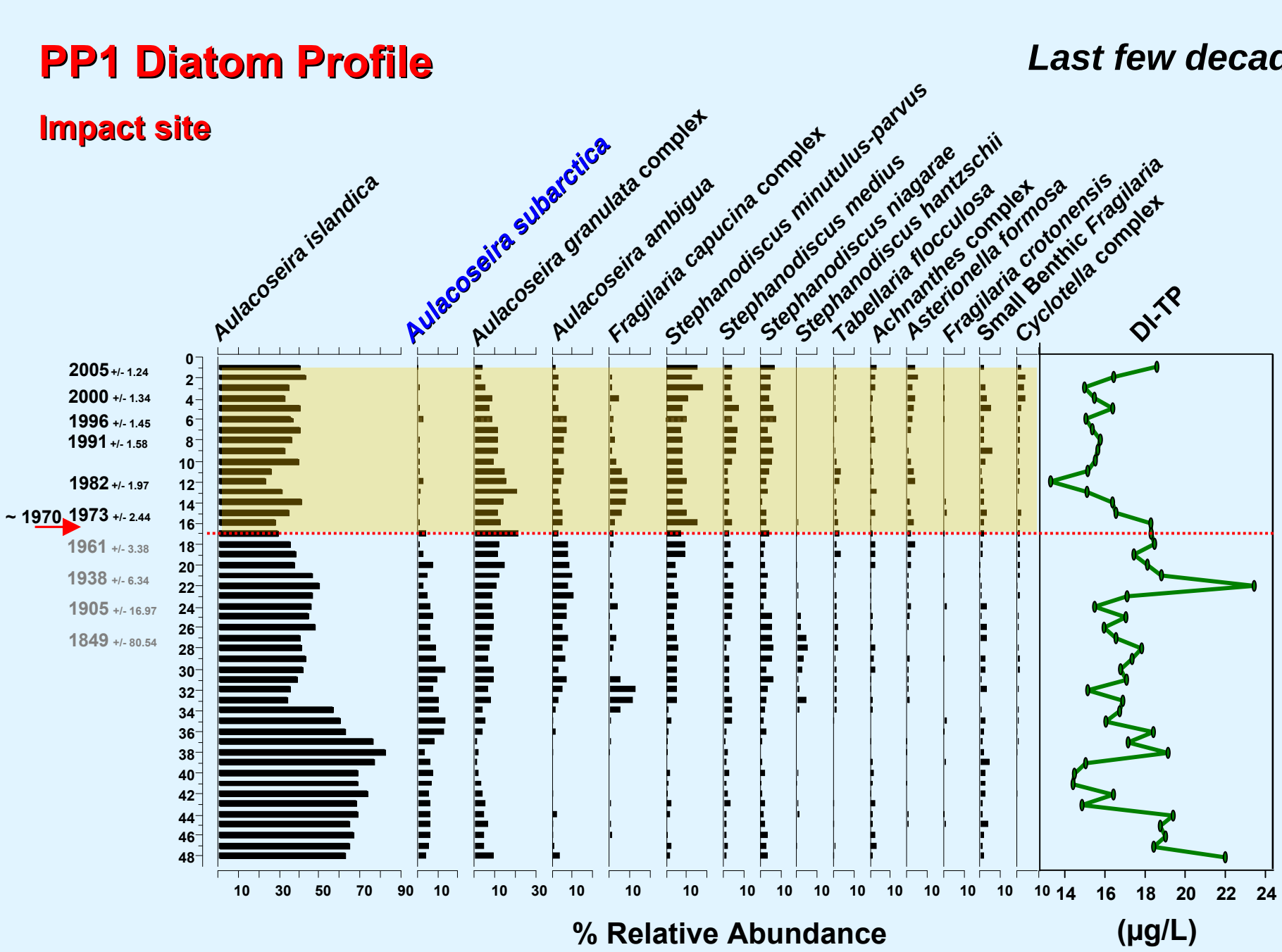
PP1 Diatom Profile

Last few decades

Impact site



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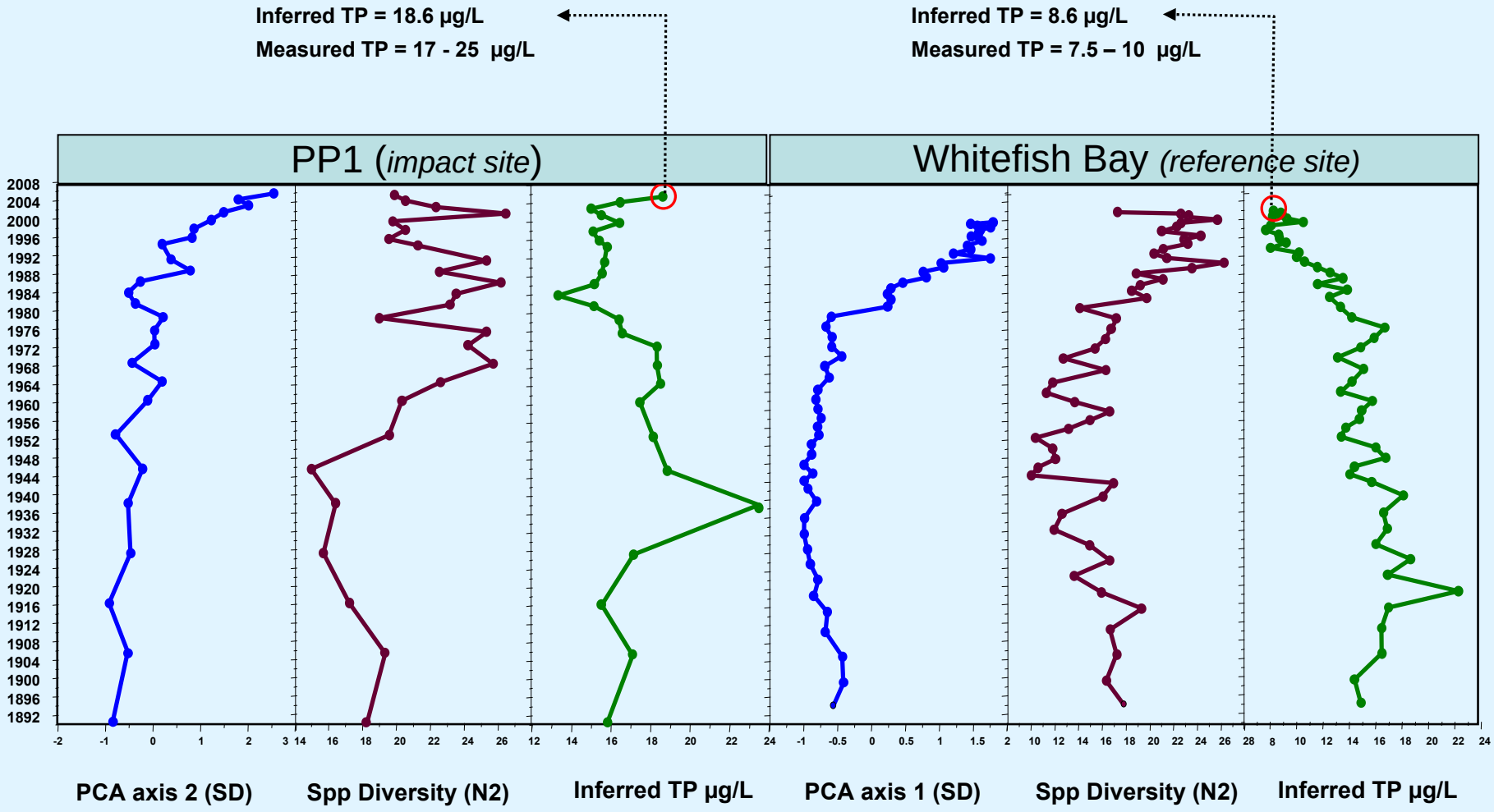
Summary of Diatom Trends



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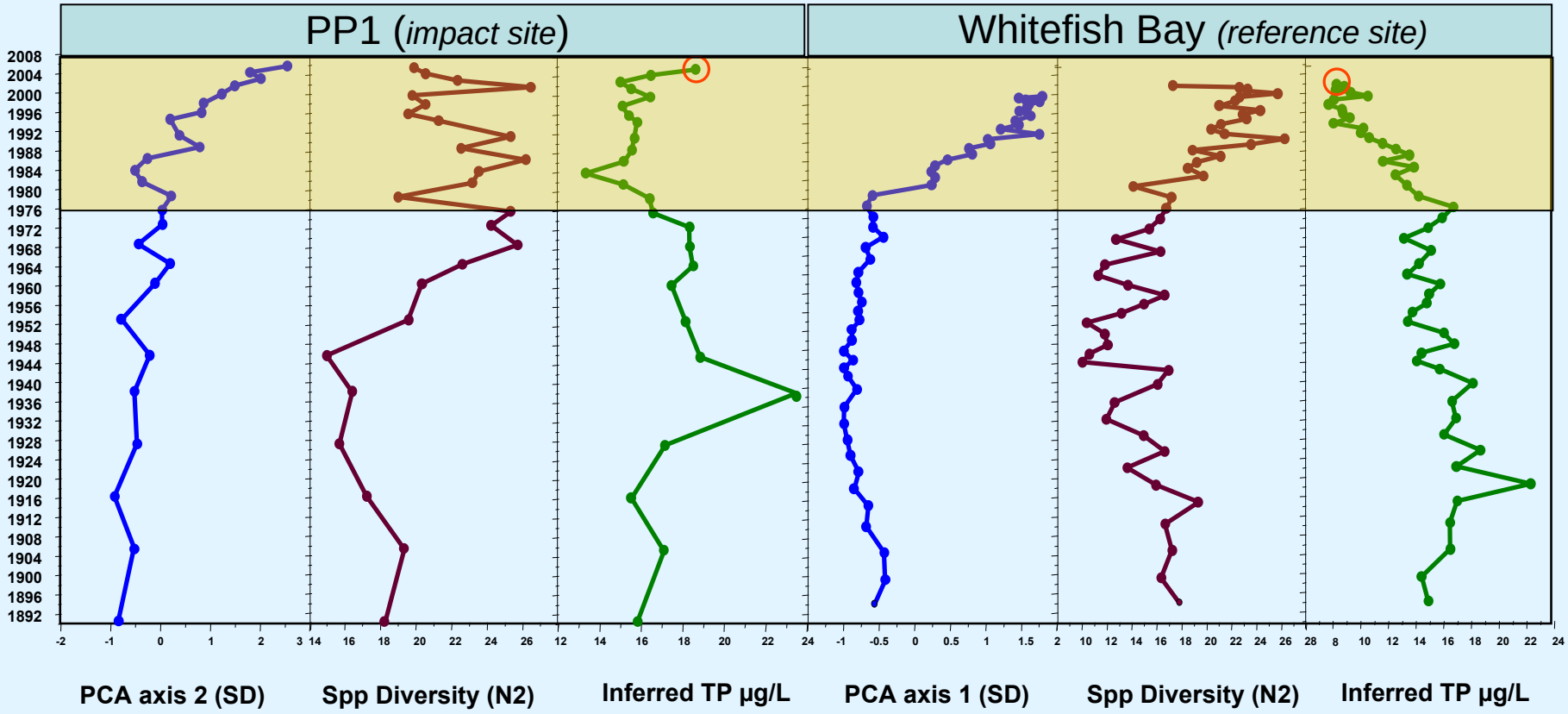

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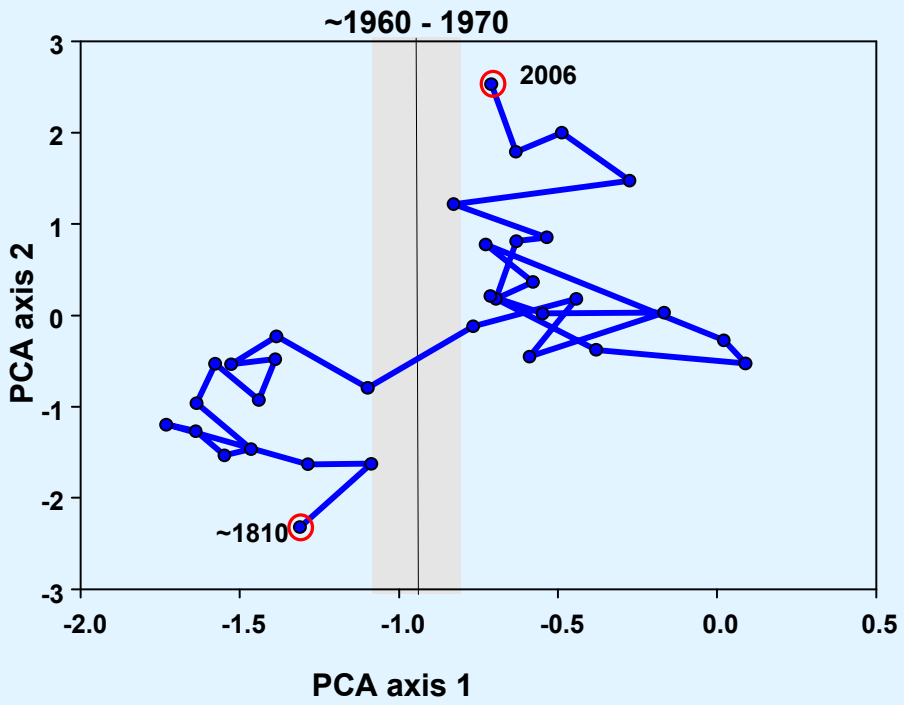
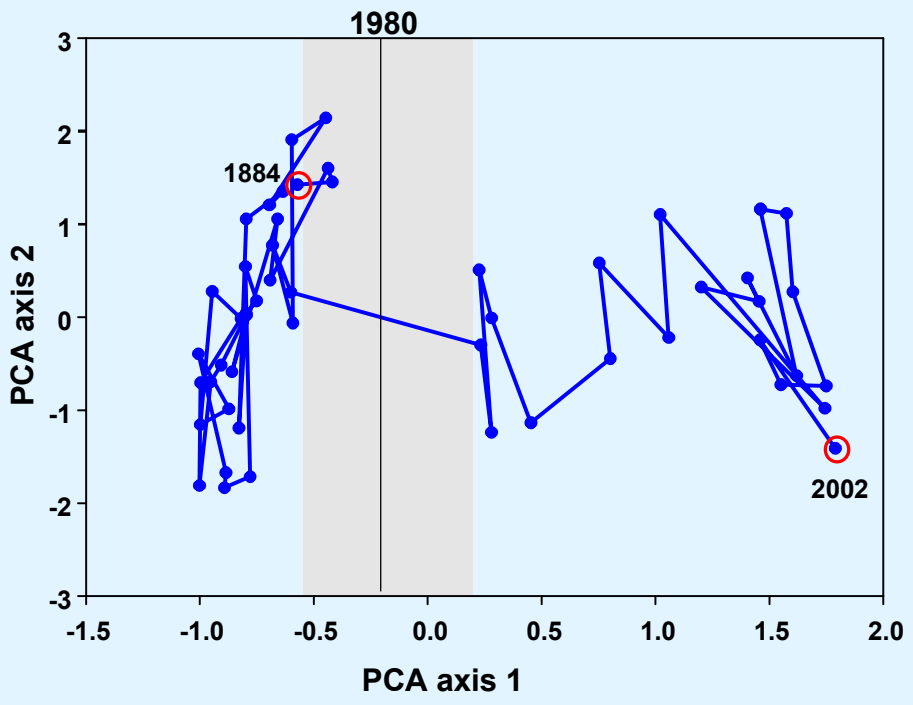
Summary of Diatom Trends

PP-1 *(impact site)*



Whitefish Bay *(reference site)*



Trajectory of change over time

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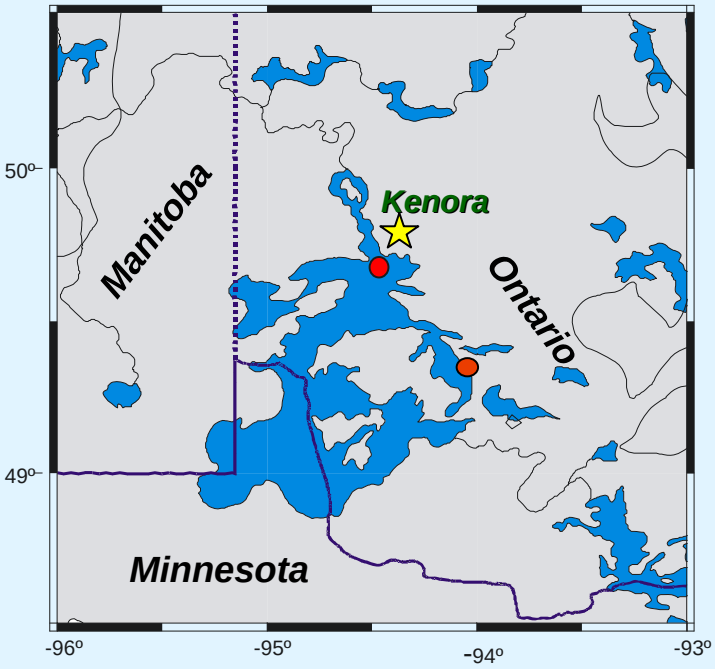
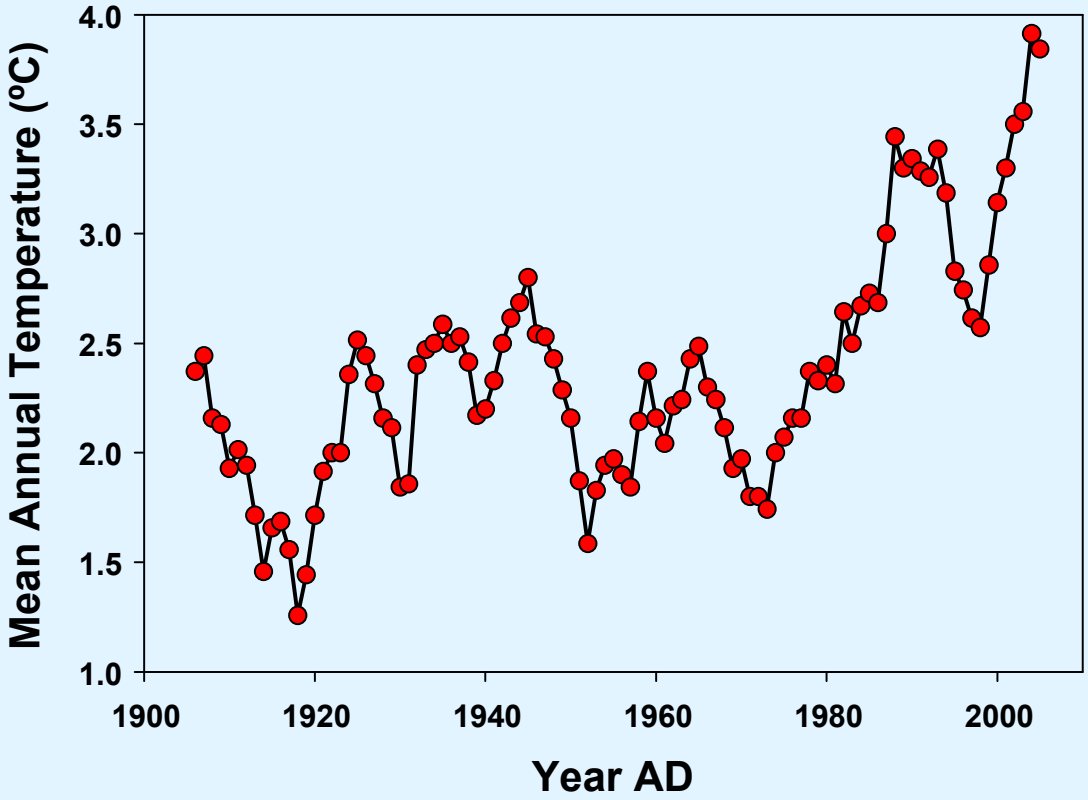
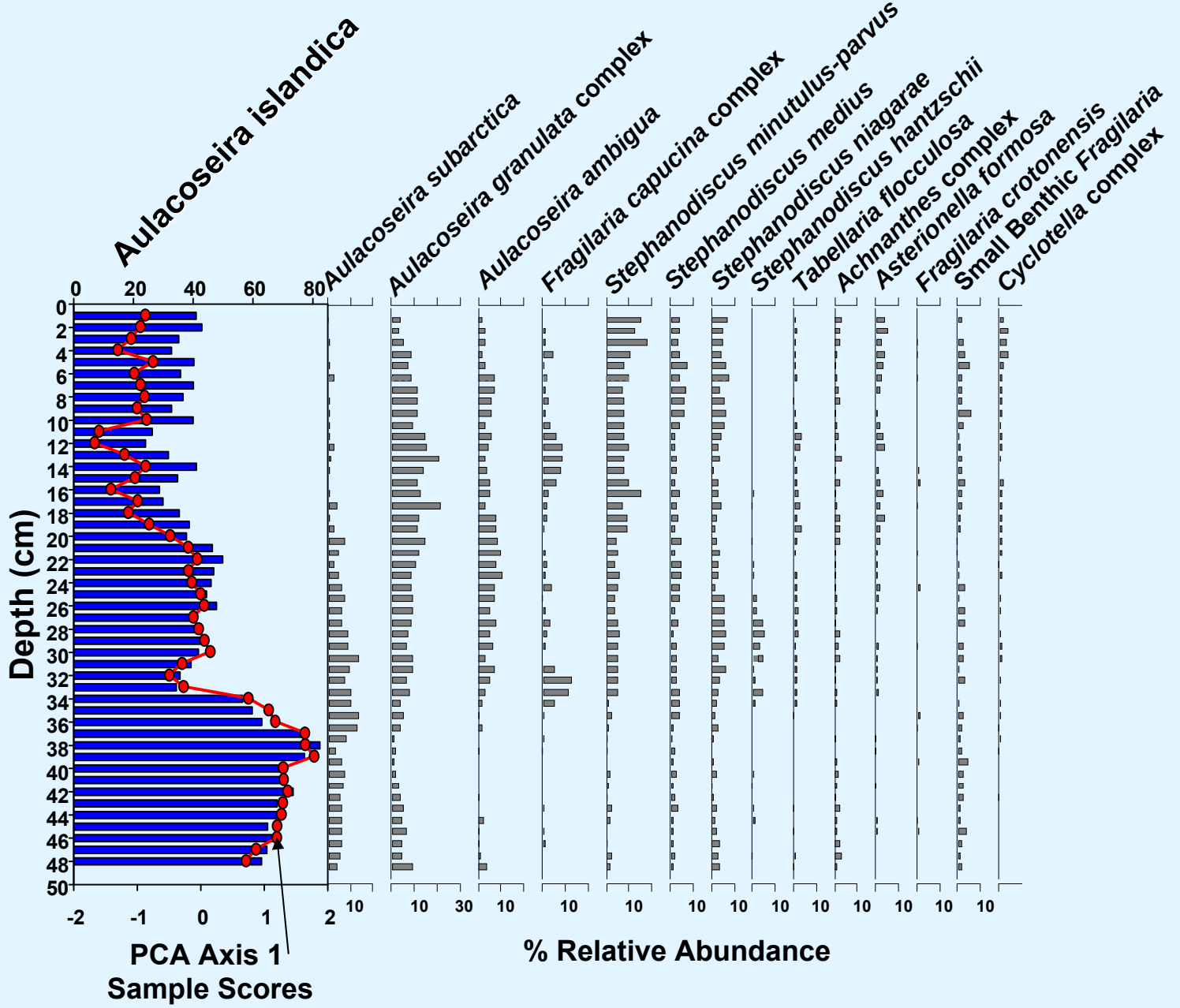
Kenora 100-year Climate Records



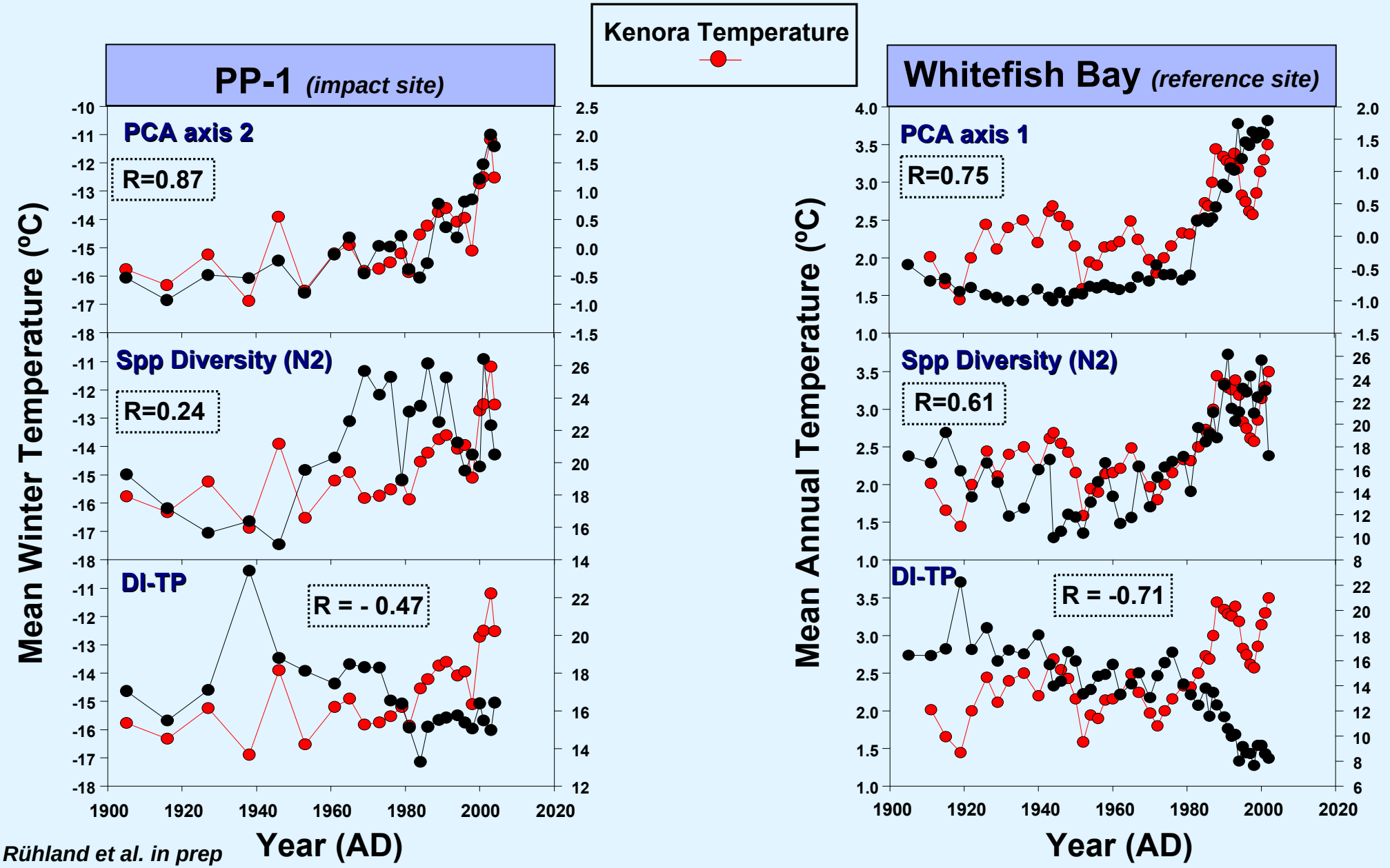


PP1 Diatom Profile

Impact site



Diatom – Temperature Relationships



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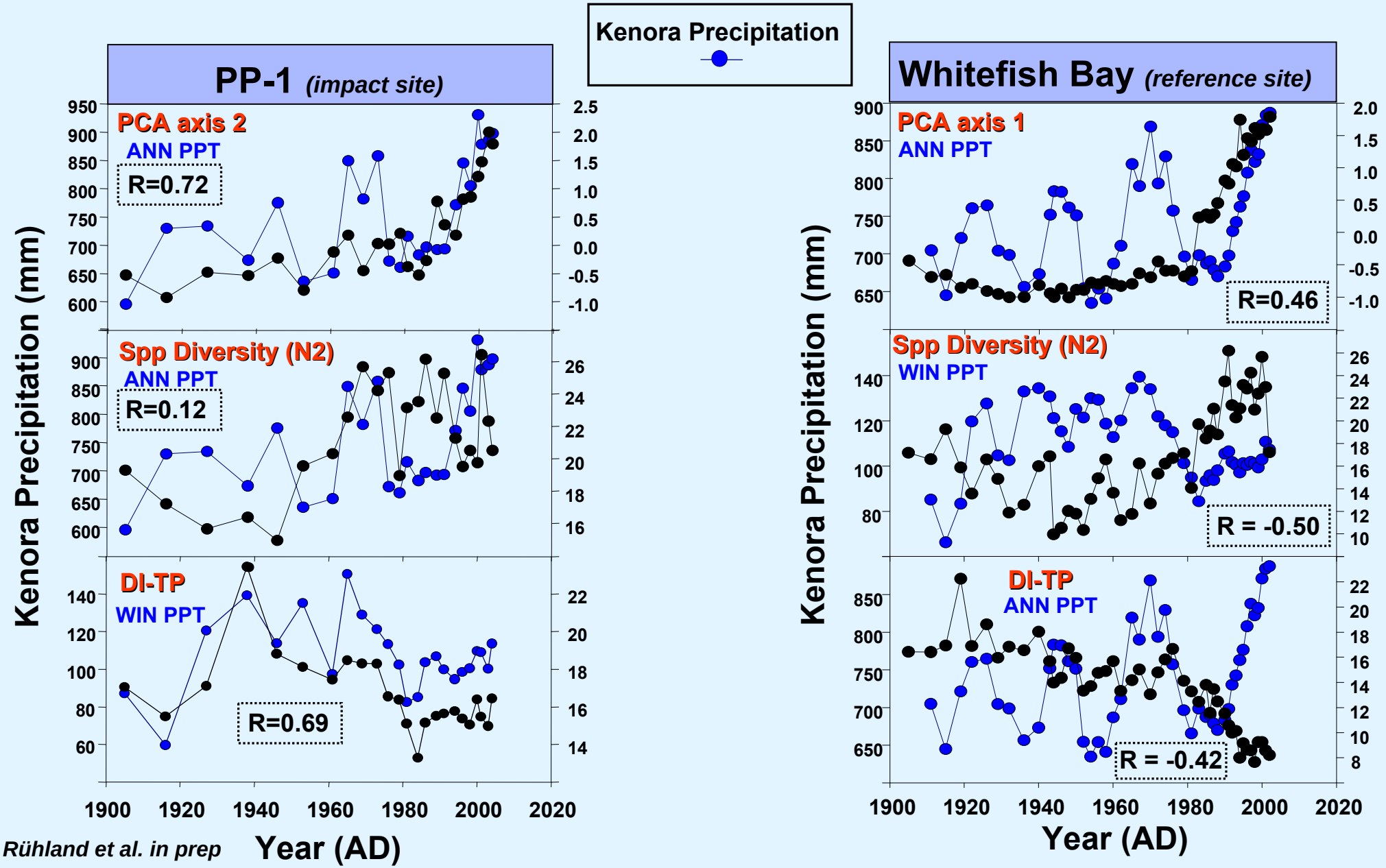
Diatom – Precipitation Relationships



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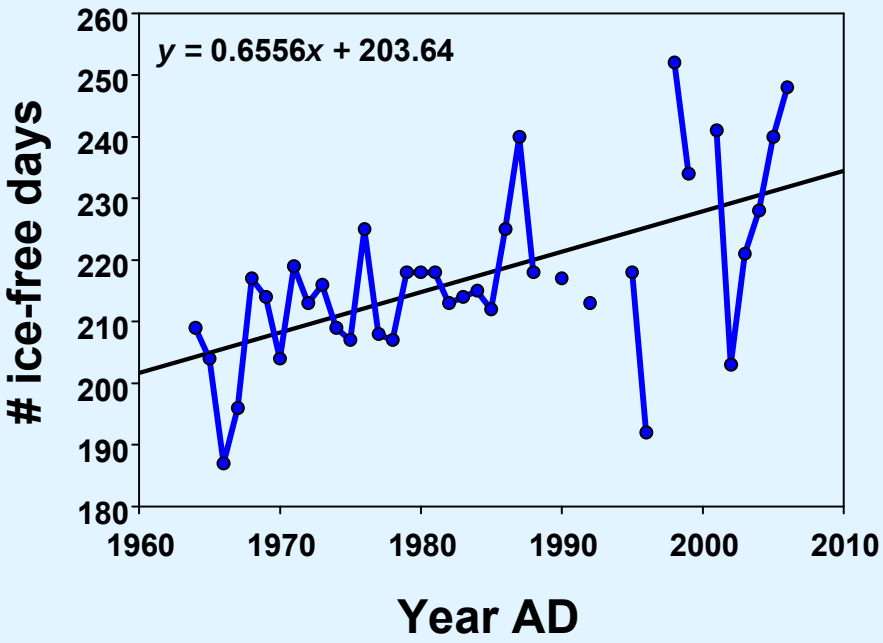
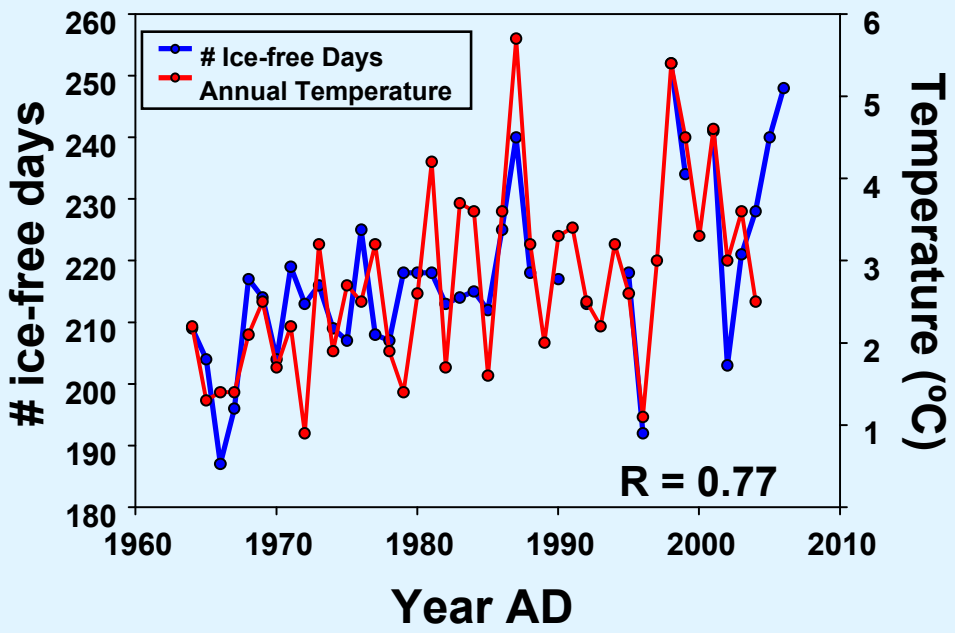
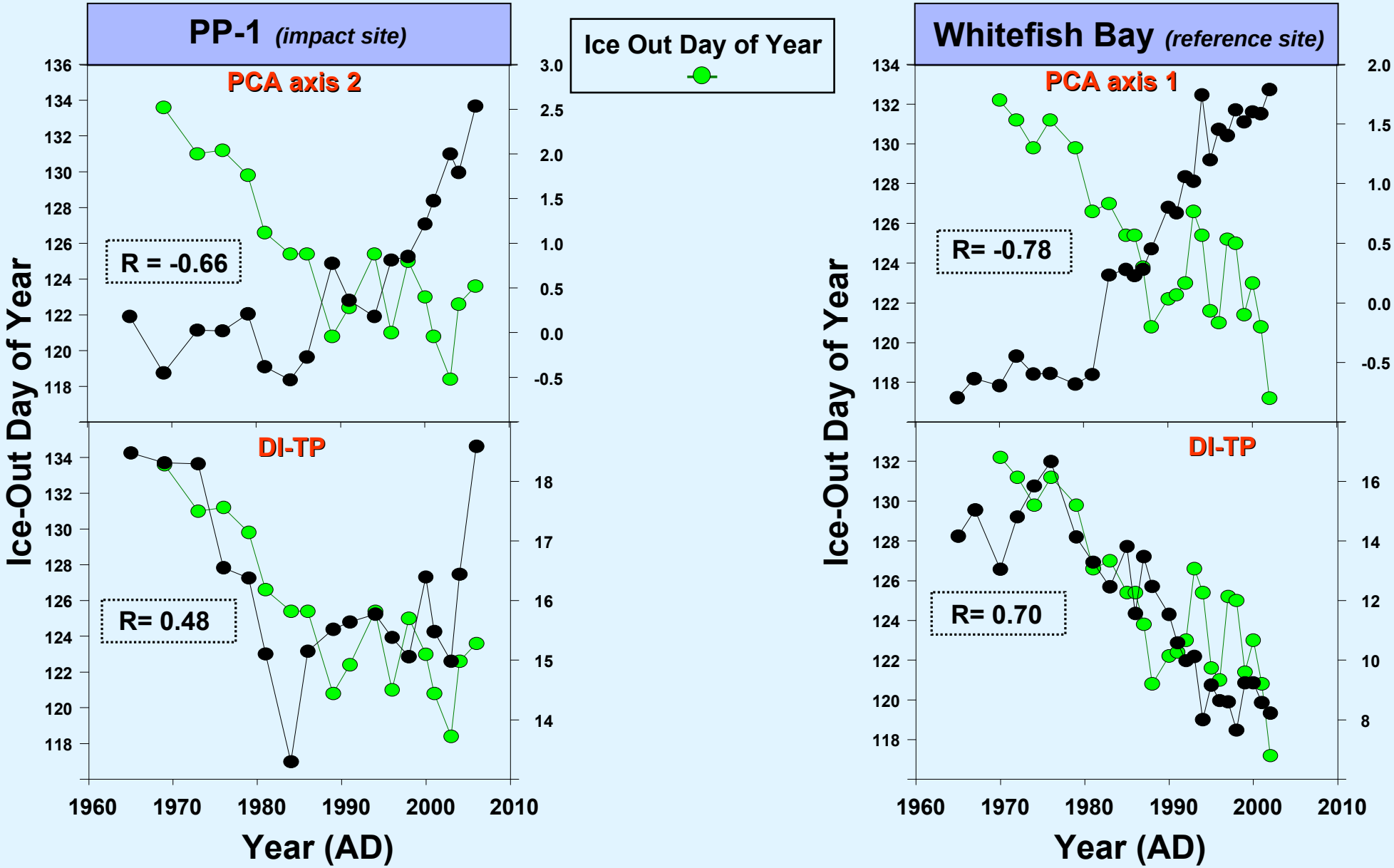
Whitefish Bay Ice Cover Record





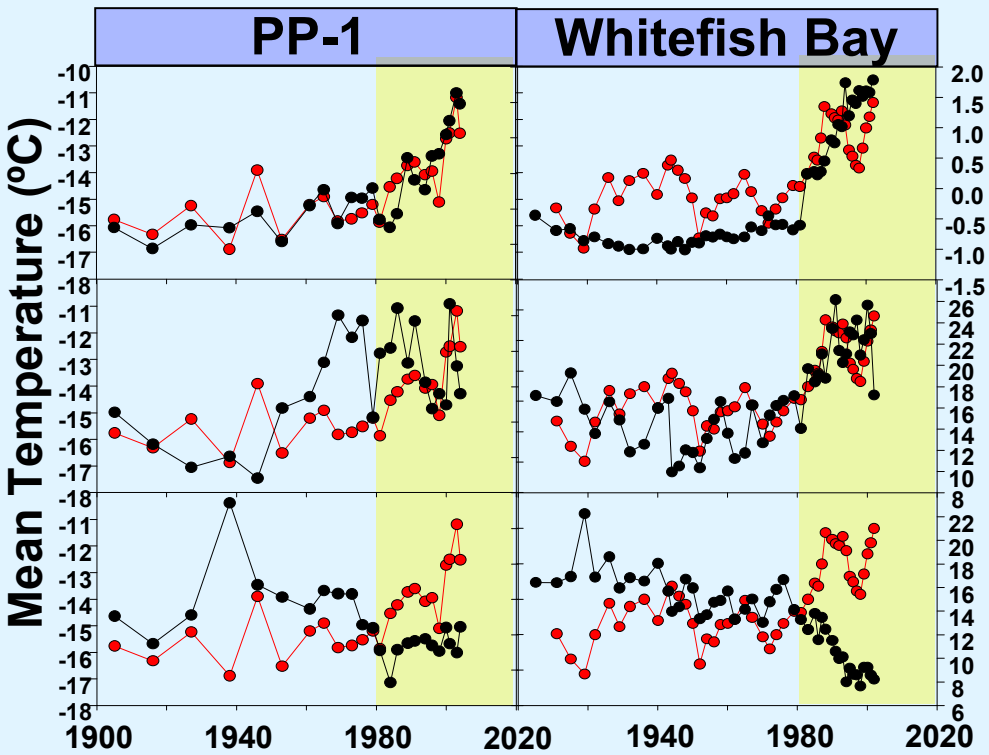
- Ice-free period increased by **27.7** days since 1964
- Corresponds to increased temperatures

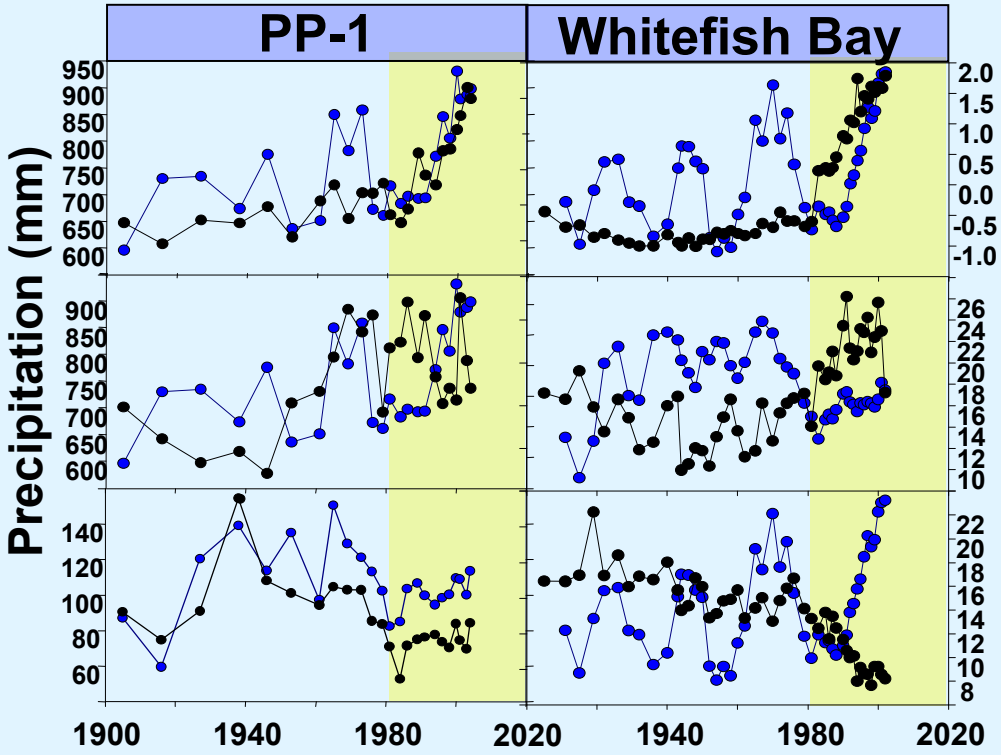
Lake Ice Record & Diatom Relationships



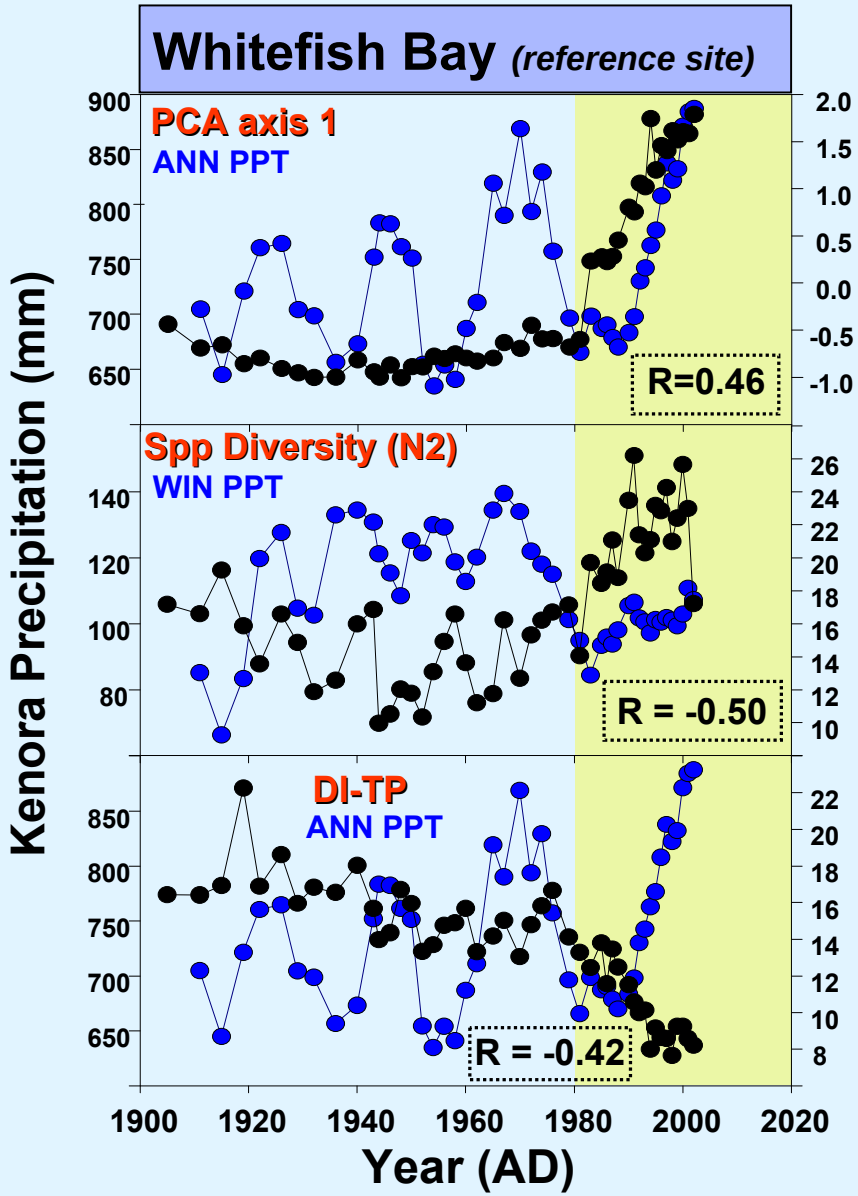
Rühland et al. in prep

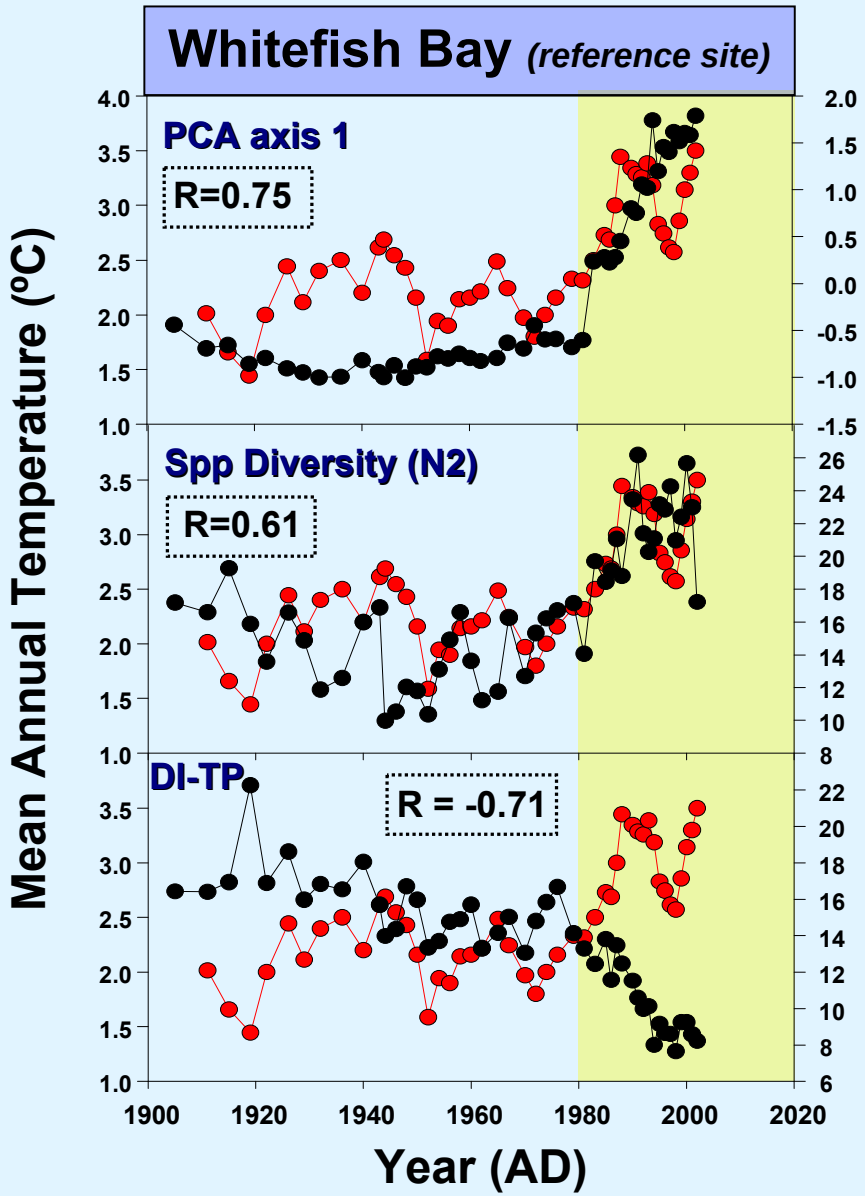
Diatom – Climate Relationships – last 20-30 years



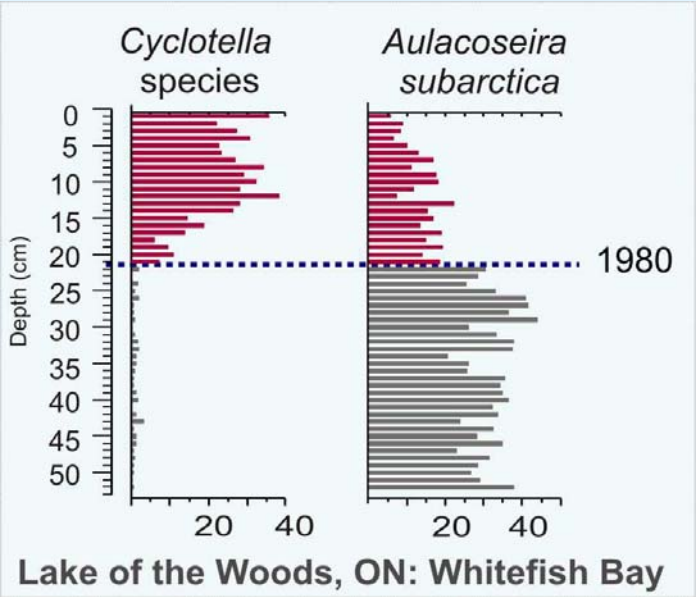


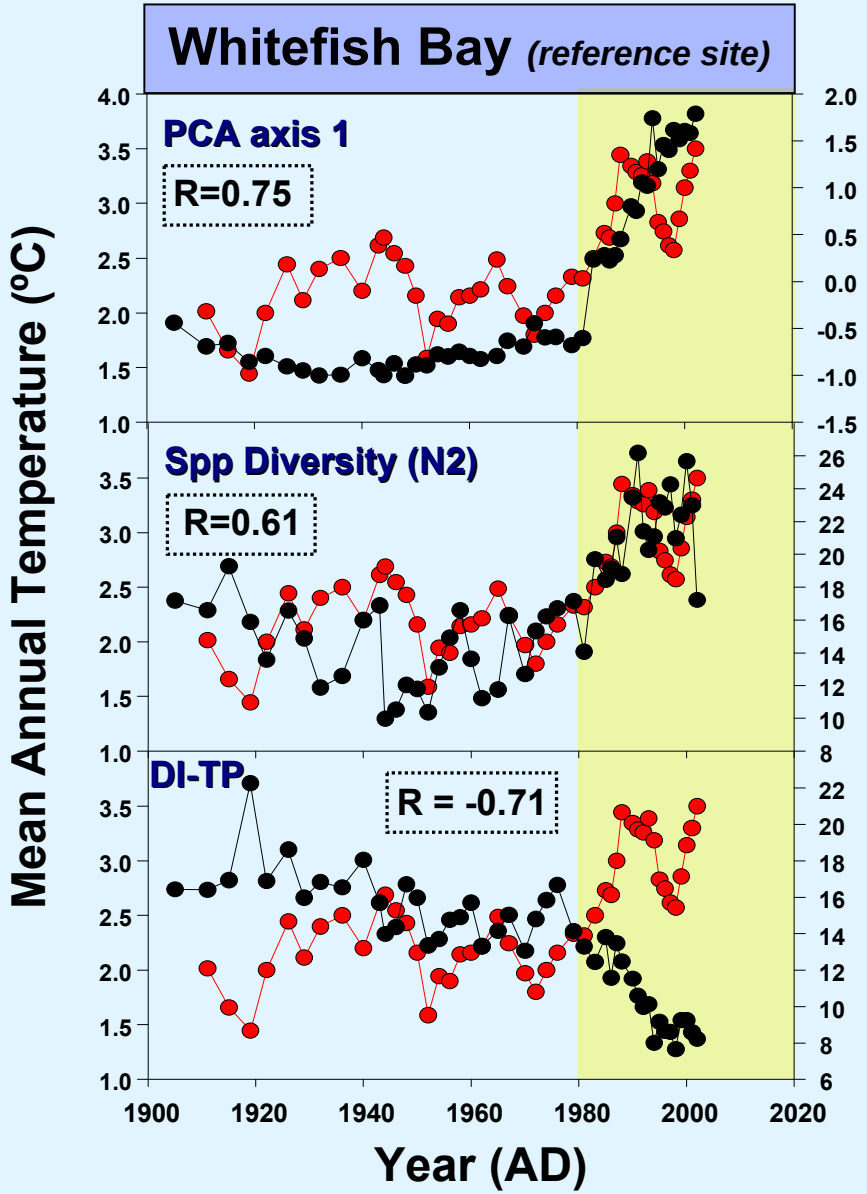
Diatom – Climate Relationships – Whitefish Bay





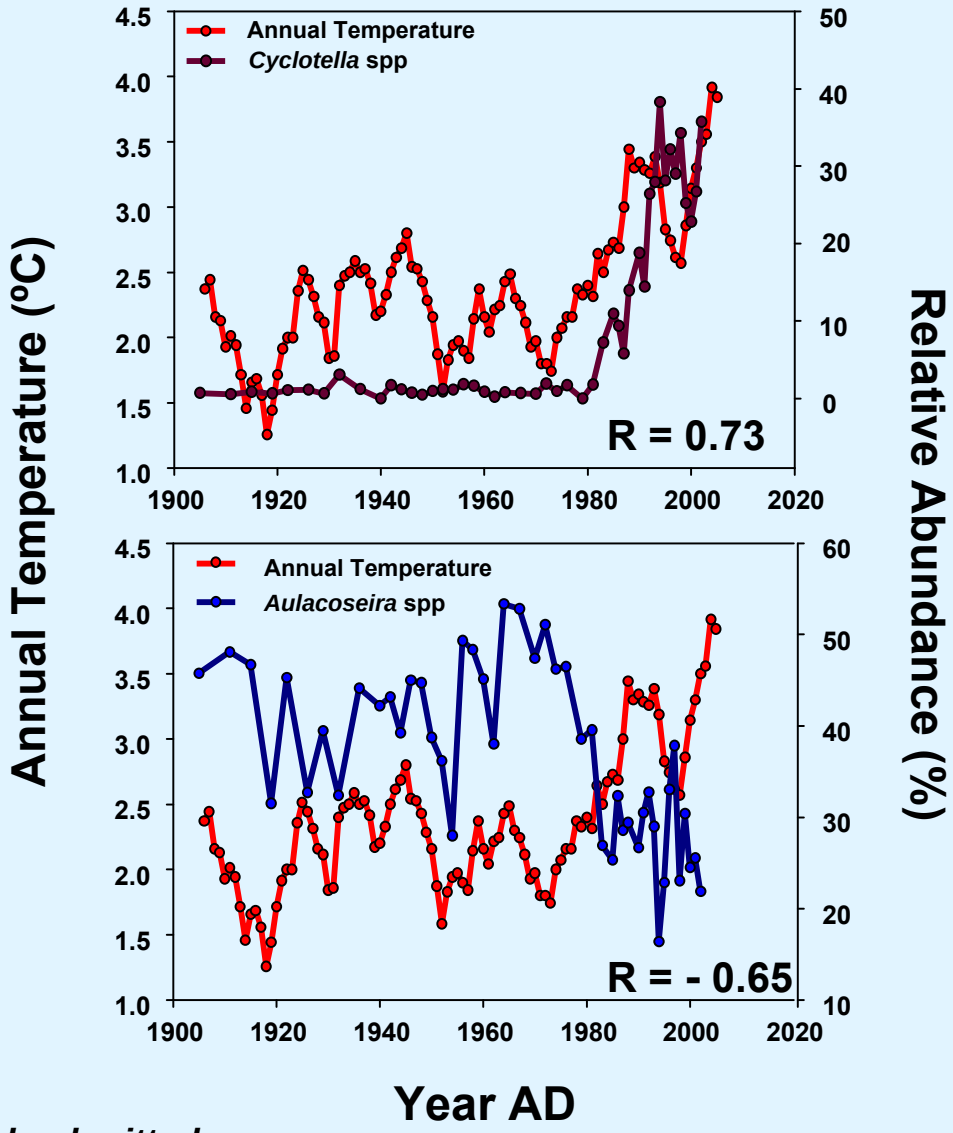
Taxon-specific Relationships: Whitefish Bay

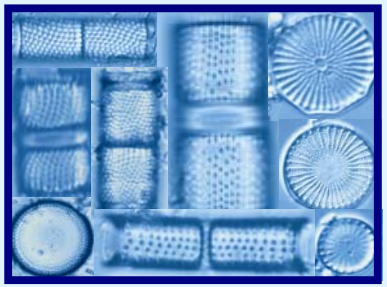




Whitefish Bay: Taxon-Specific Relationships

Kenora Temperature Record





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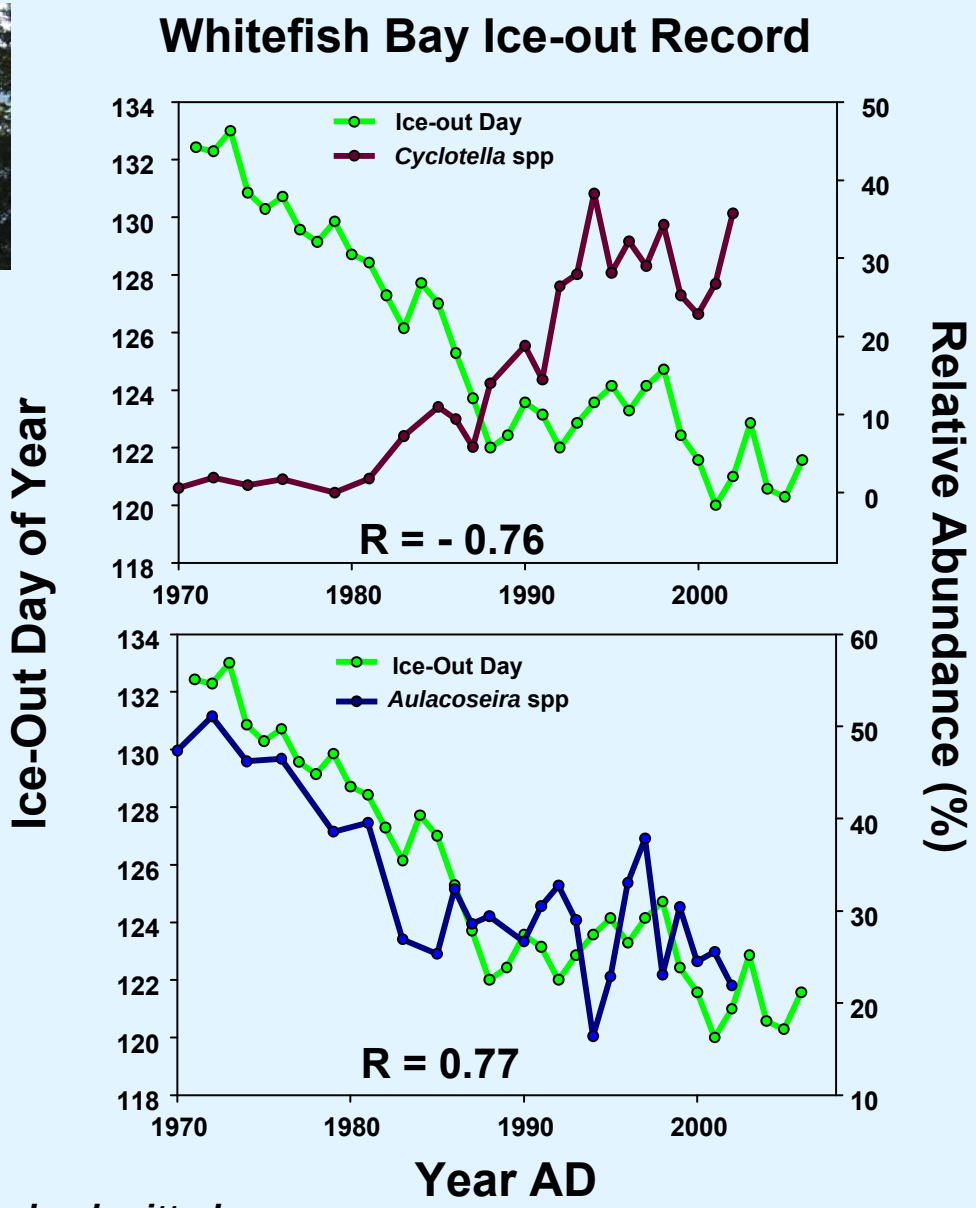
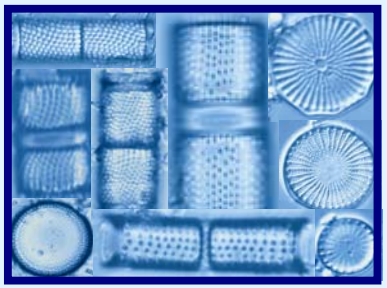
Whitefish Bay: Taxon-Specific Relationships





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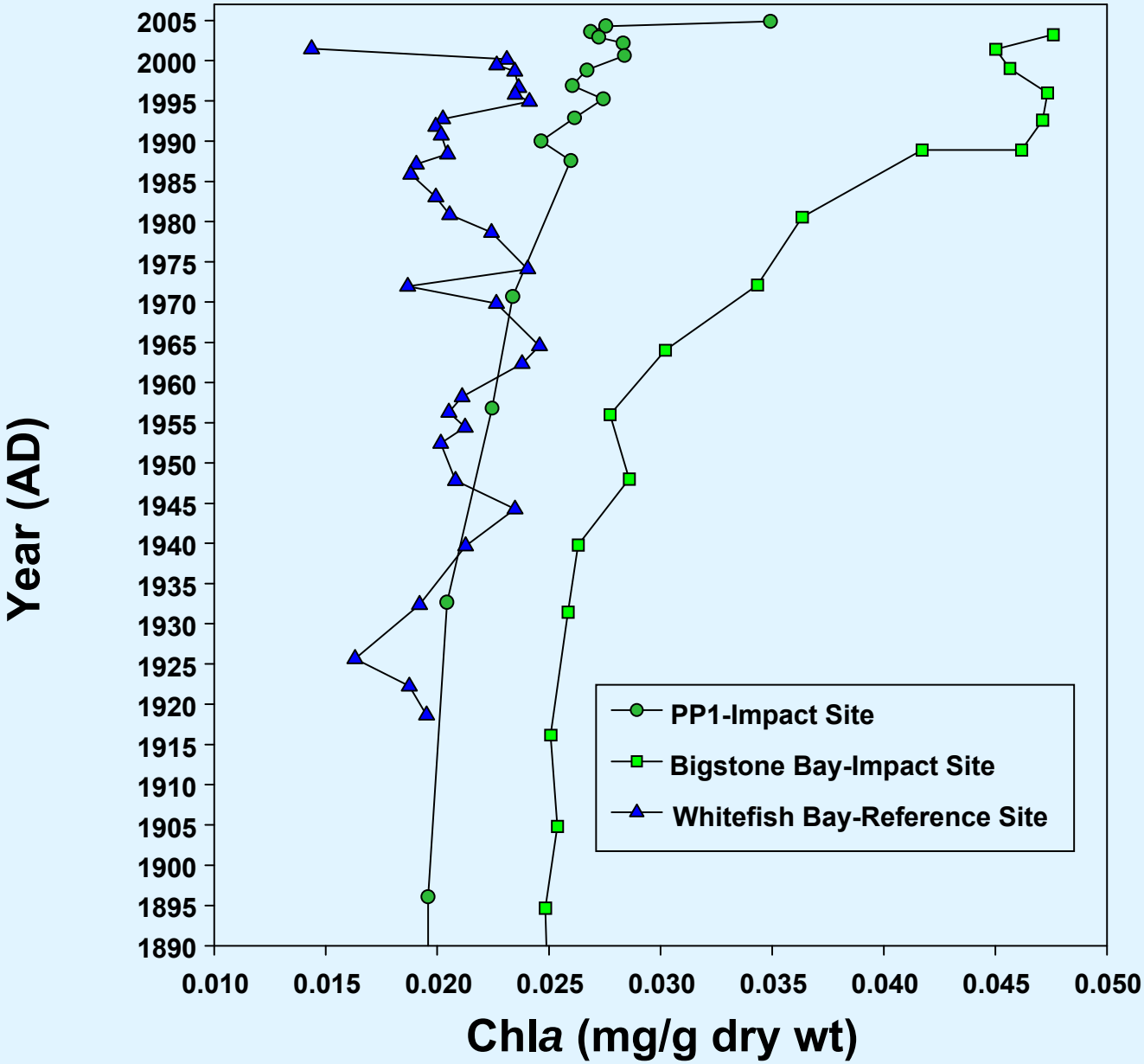
Spectrally-inferred Chl*a* trends from 3 sites in LOW



Algal blooms , TP & Chl*a* in the Lake of the Woods

IMPACT SITES:

PP1 & Bigstone Bay

- Elevated TP concentrations
- Cyanobacterial algal blooms
- DI-TP historically elevated
- Algal blooms in the past
- Recently, DI-TP ↓
- Recently, inferred Chla ↑

REFERENCE SITE:

Whitefish Bay

- TP concentrations lower
- No algal blooms
- DI-TP historically low-ish
- Algal blooms in past- unlikely
- Recently, DI-TP ↓
- Inferred Chla – no clear trend

↑ **Chl*a* at both impact sites likely tracking increases in blue-green algae**

What is triggering increases in 1° production (Chl*a*)?

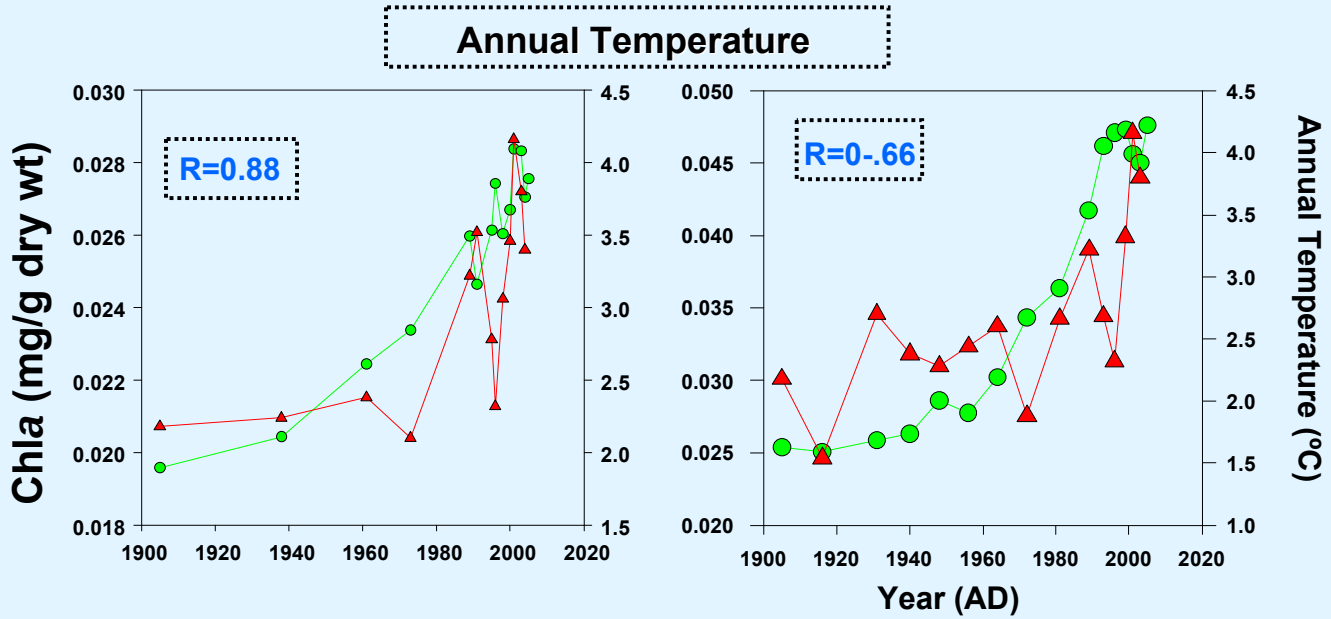
TP has long been a factor for algal blooms at both impact sites (elevated TP)

However, TP cannot explain perceived recent increases in algal blooms

Climate Trends vs. Spectrally-inferred Chl*a*

Impact sites:

algal blooms



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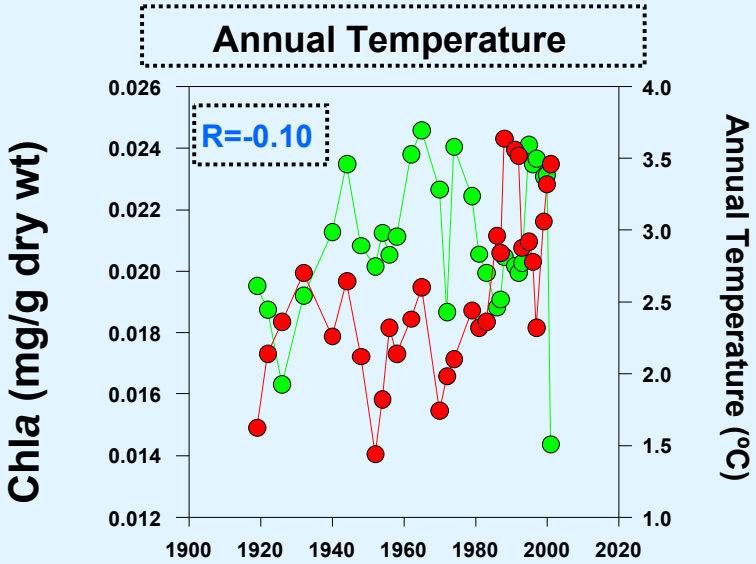
Climate Trends vs. Spectrally-inferred Chl*a*

Reference site:

No algal blooms



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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

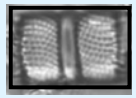
- **Possible mechanisms** (*PP-1 & Whitefish Bay*)
  - Phosphorus – DI-TP decreased
  - Strong relationship to increased temperature
  - Strong relationship to precipitation- esp. winter
  - Strong relationship to decreased ice cover

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

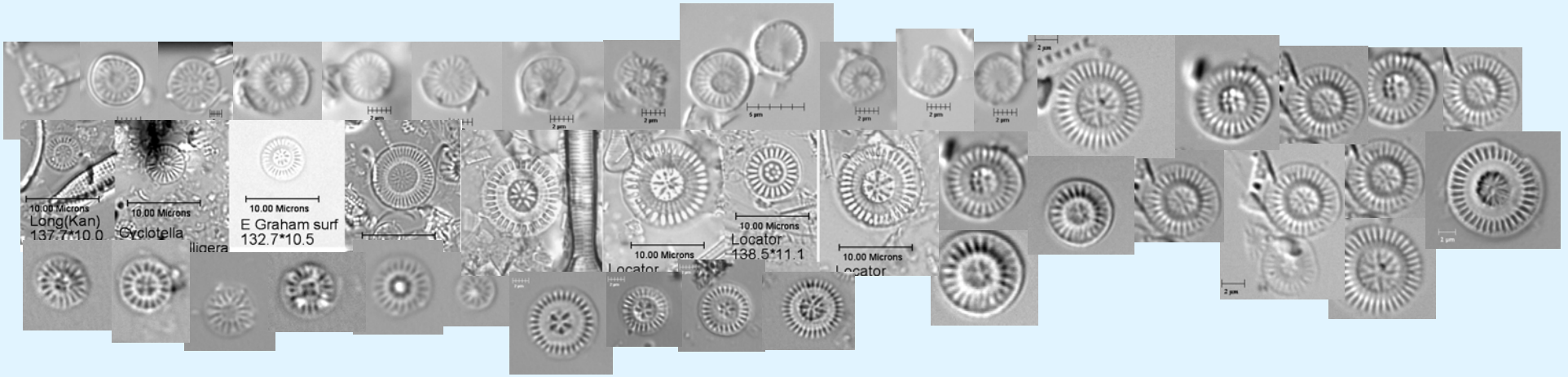


Further reading : Raubitschek et al. 1999 JOPL: Forsström et al. 2005 Polar Biol; Fahnenstiel & Glime 1983 Int Rev Hydrobiol; Gibson et al. 2003 Eur J Phycol

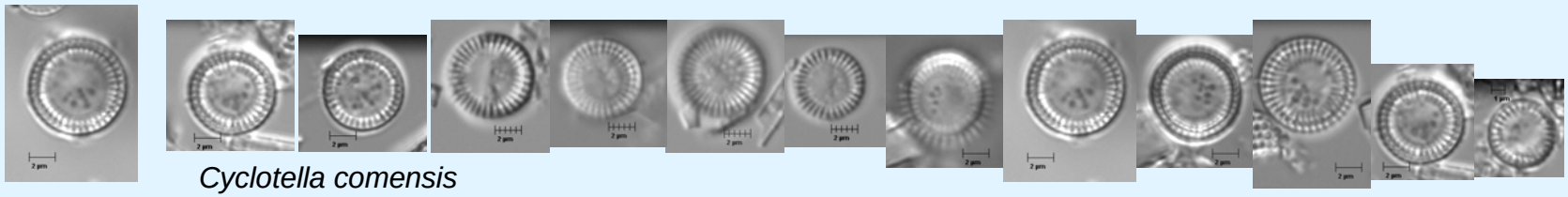
★ ***Hemispheric-scale trend***

Planktonic Cyclotella stelligera & C. comensis

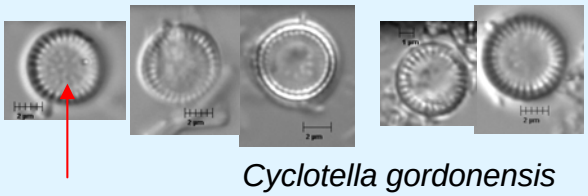
Cyclotella stelligera/pseudostelligera



Cyclotella comensis/gordonensis



Cyclotella comensis



Cyclotella gordonensis

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

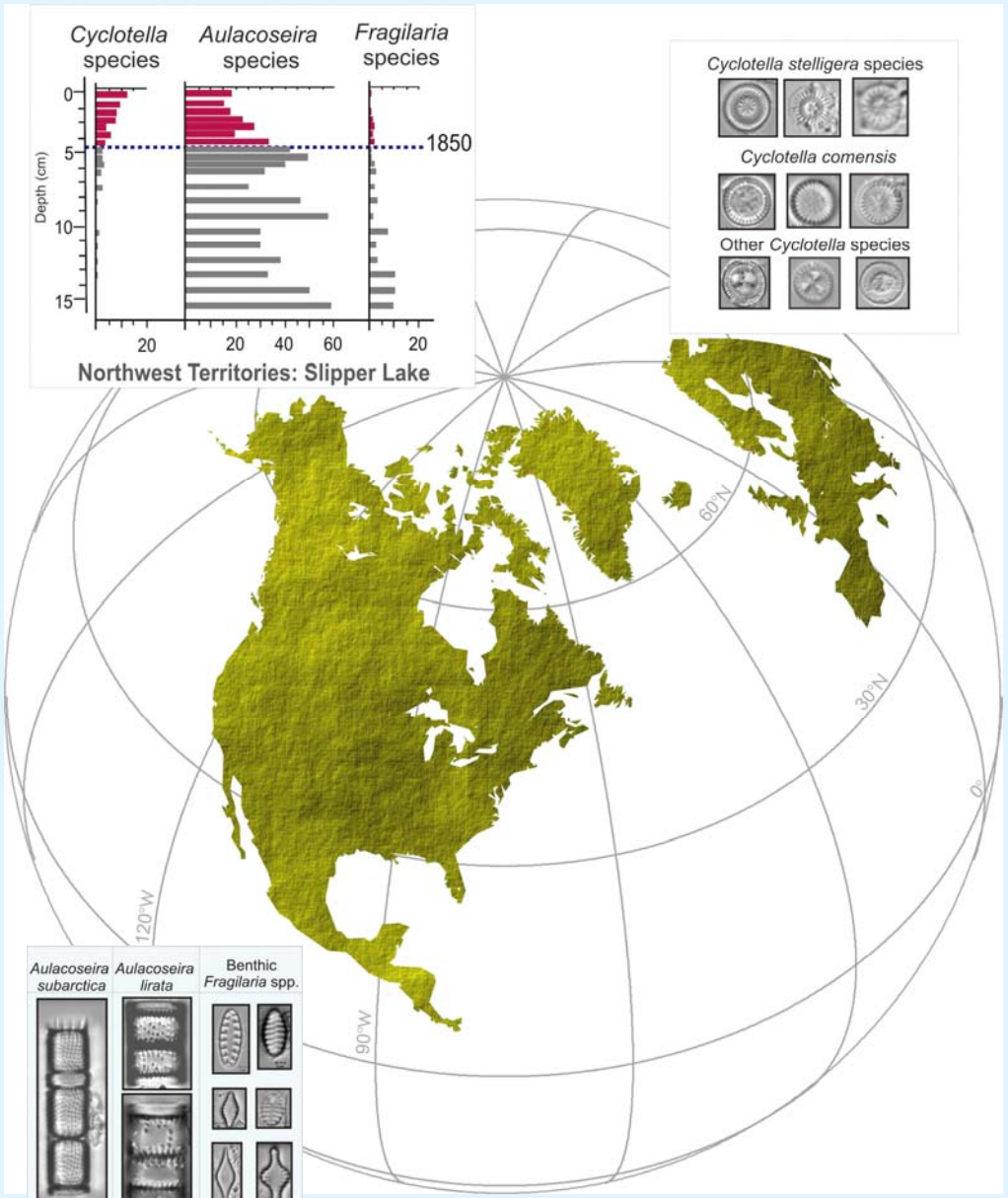
1) Established chronology for last ca. 200 years (i.e. ^{210}Pb dating)
2) At least 2% relative abundance of *Cyclotella* in at least one interval
3) Increase in *Cyclotella* = 5% or greater compared to background levels

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



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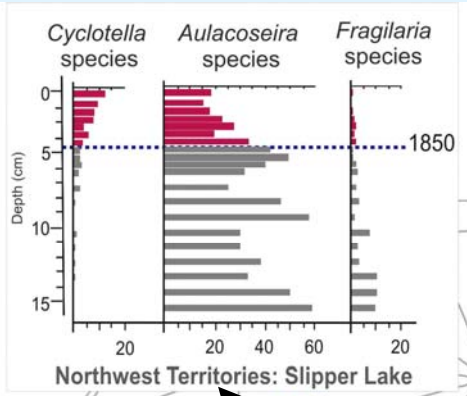
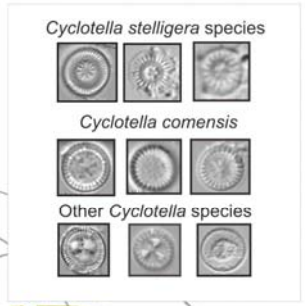
Geographic extent of *Cyclotella* species increases





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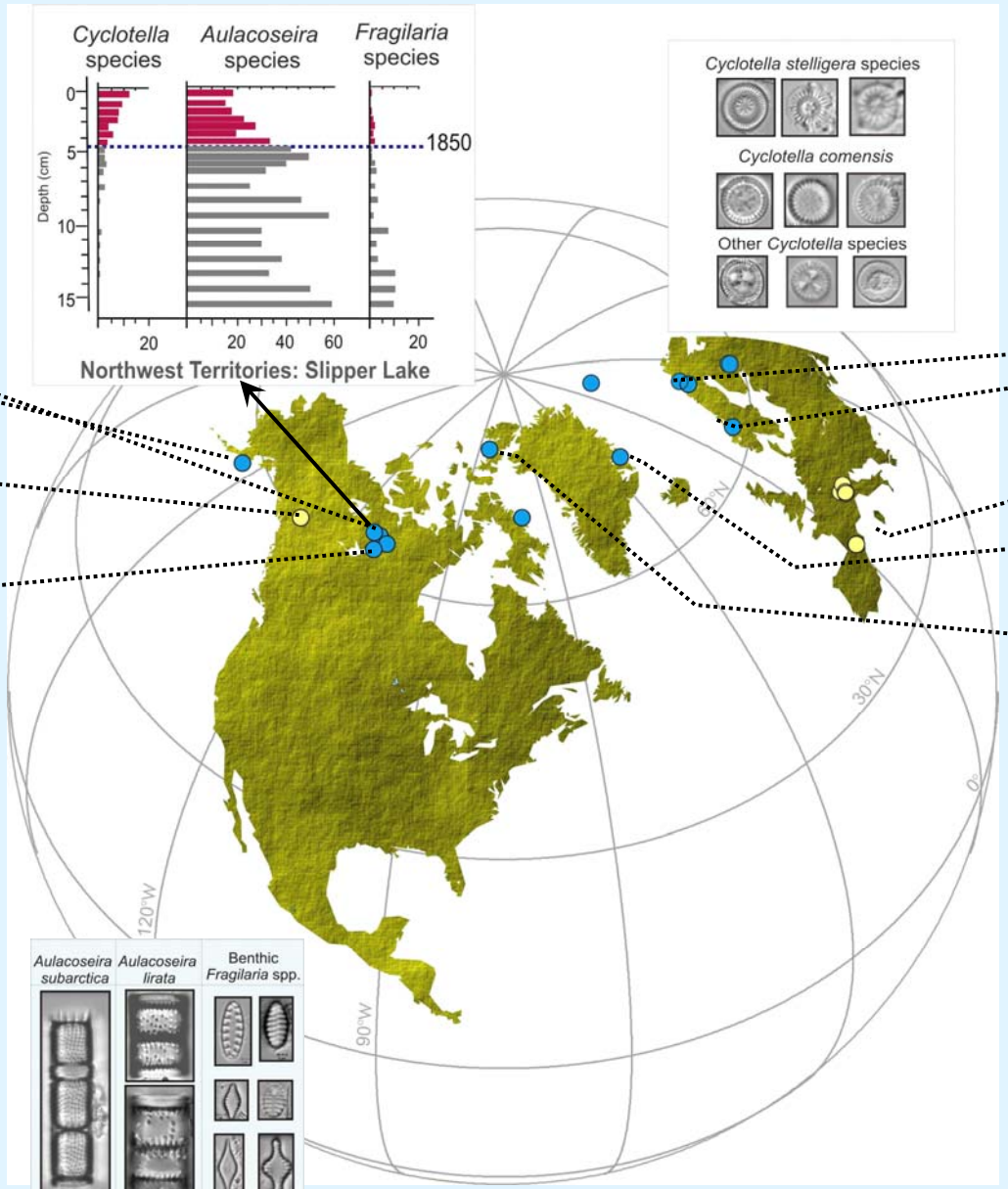

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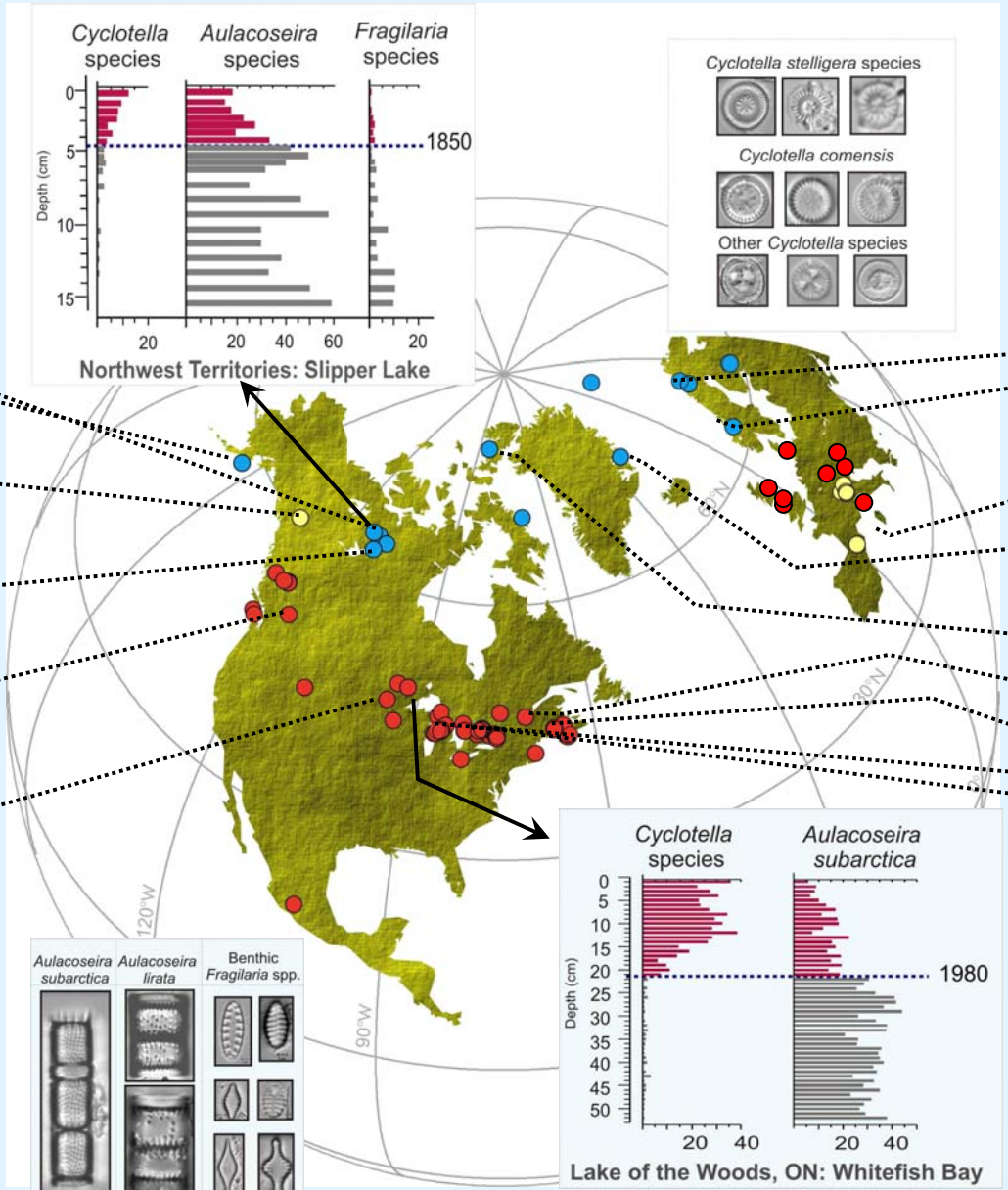

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Enache et al. unpubl.

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NS Canada
Ginn et al. in press

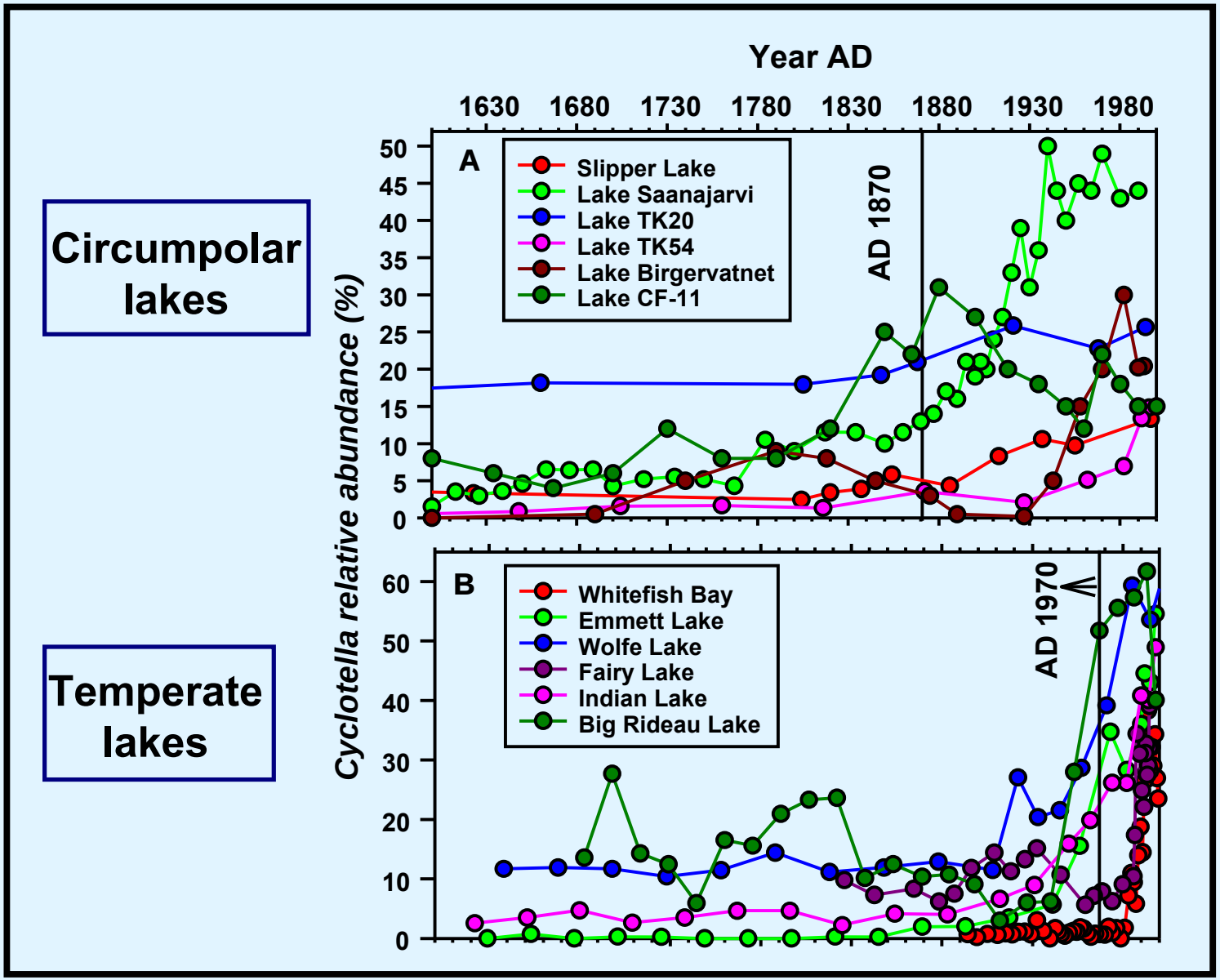
SE ON
Forrest et al. 2002

SW ON
Werner et al. 2005

Northern Hemisphere-Scale Trend

Rühland, Paterson & Smol submitted

Comparison in the timing of *Cyclotella* increases



Rühland, Paterson & Smol submitted

Climatic Warming and Taxon-specific Shifts

1. NWT-Nunavut (n=40)

Rühland et al. 2003 AAAR

2. New Brunswick (n=16)

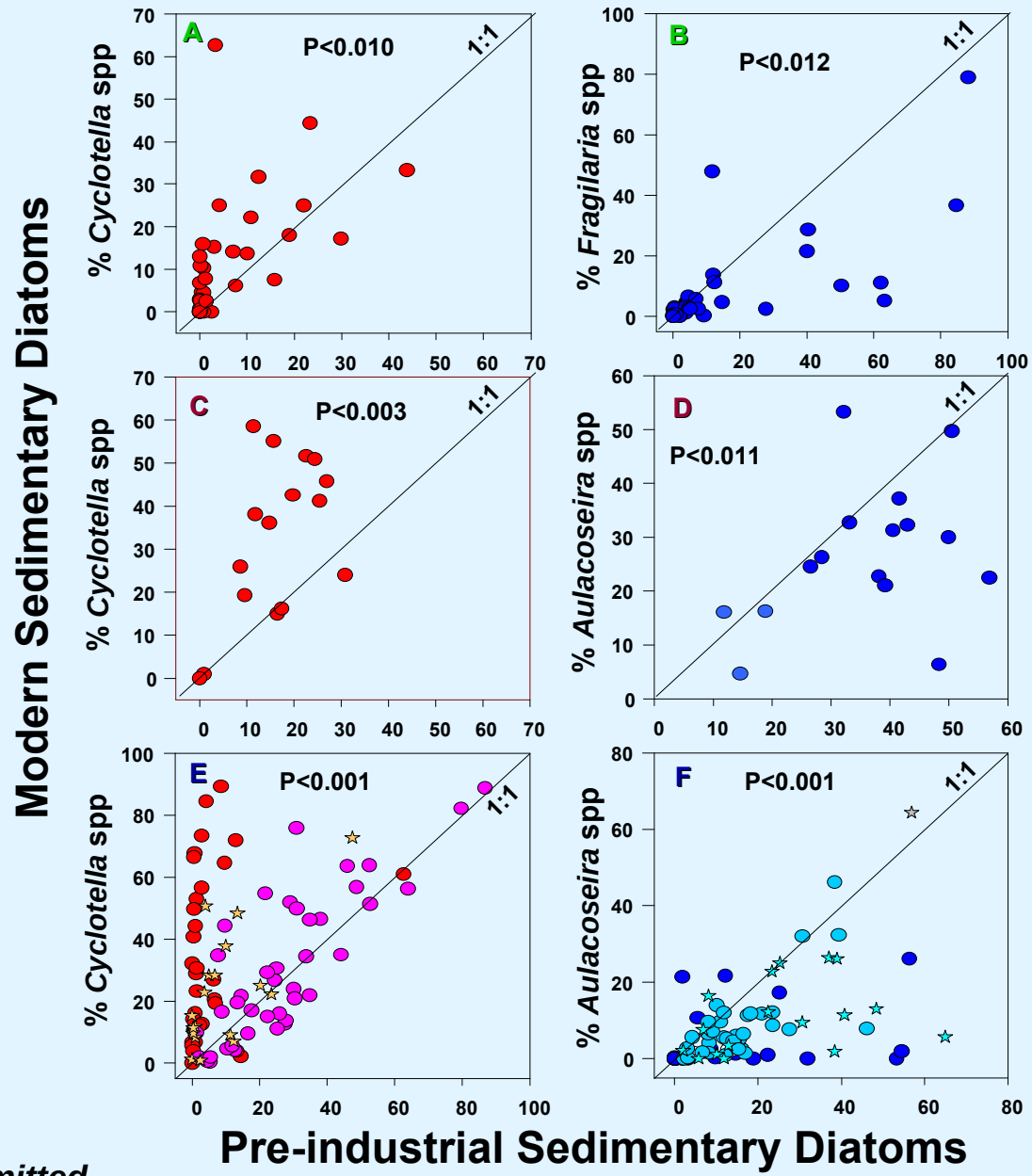
Harris et al. 2006 CanJBot

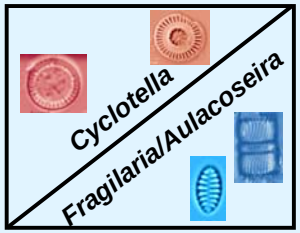
3. Ontario Combined (n=91)

Hall & Smol 1996 CanJFishAquat Sci

Reavie et al. 2002 Hydrobiol

Werner 2003 PhD thesis





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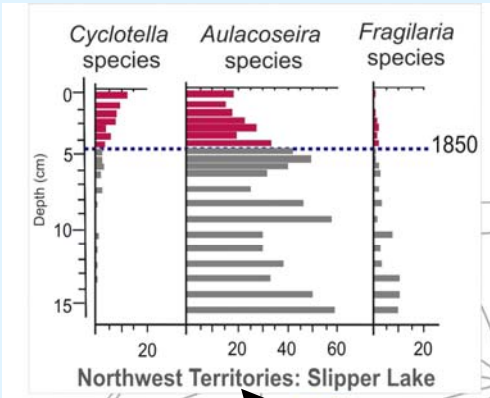
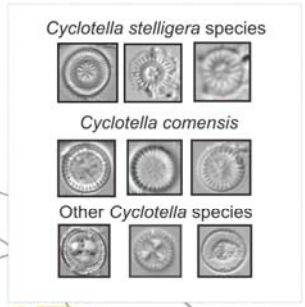
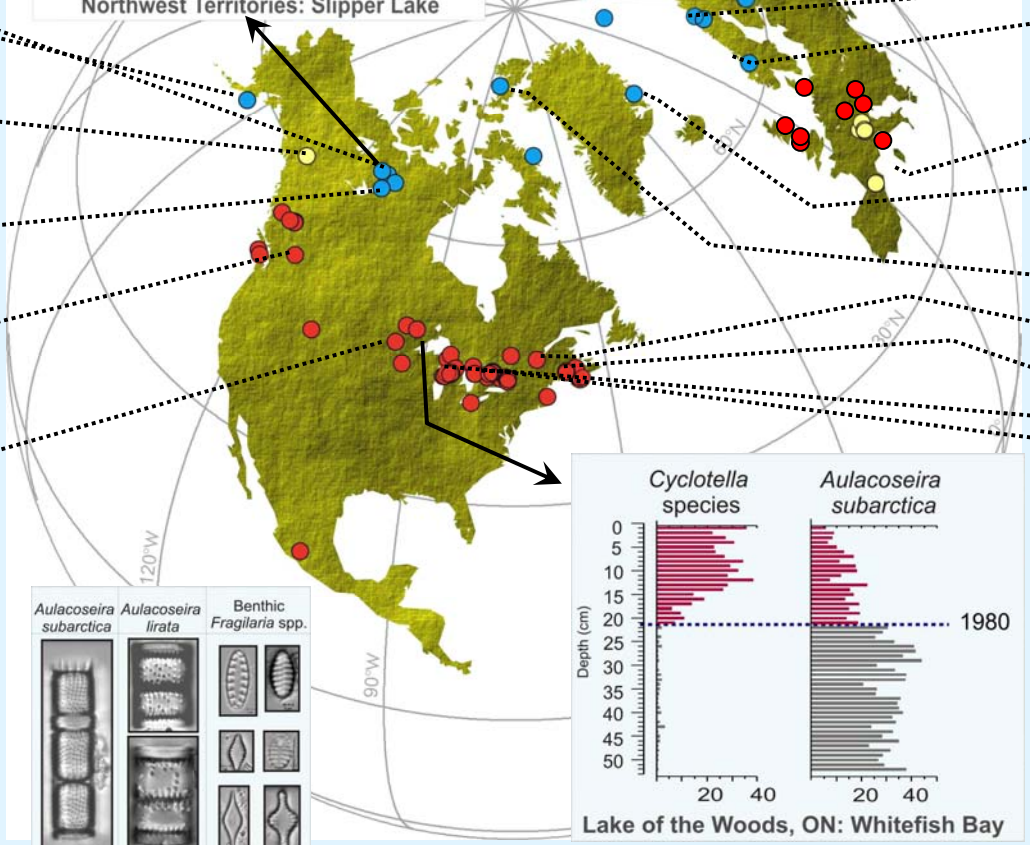
Climatic Warming and increases in *Cyclotella* species







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Northern Hemisphere-Scale Trend

Rühland, Paterson & Smol submitted

Summary of Results: Lake of the Woods

- Greatest change in diatom composition over last ca. 20-30 yrs
- Decrease in DI-TP starting ca. 1980
- Timing of changes consistent between sites
- 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
- Chl*a* trends highly correlated to increase in temperature – algal blooms

Concluding Remarks:

- Phosphorus has long been an important component of the LOW
- 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

Based on these LOW data and the timing, magnitude & nature of diatom changes –

climatically-induced change in lake-ice cover and associated limnological changes is the most plausible explanation for increases in planktonic diatoms over the last ca. 200 years

Acknowledgements

- Bev Clark (MOE, Dorset)
- Mike Stainton (DFO, MB)
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- Mark Edlund (St. Croix Watershed Research Station, MN)
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