Diatom-based Paleolimnological Assessment of Long Term Water Quality Trends, near Forrest Island, Lake of the Woods, Ontario

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Background

An important requirement for understanding environmental change is determining the 'natural' or baseline condition for a given aquatic system.

Determining a lake's **water quality** history can provide important insights into key lake management questions including whether the ecosystem today is different than in the past, how much conditions have changed and when these changes occurred.

Given the lack of long-term monitoring data, **paleolimnology** can be used to reconstruct a lake's environmental history by examining changes in biological communities preserved in lake sediment.[1]

Diatoms are single-celled siliceous algae of the class Bacillariophyceae that are reliable indicators in paleoecological studies for several reasons:

- Well preserved in sediments
- Rapid reproduction rates & rapid response to environmental change
- Narrow environmental optima
- Found in almost all aquatic environments[2]

Objectives

- Do diatoms track changes in water quality at a disturbed site (e.g. more shoreline development) in the **Lake of the Woods** (LoW)?
- What is the magnitude and timing of these changes?
- Possible mechanisms for these changes will be explored including:
  - Changes in total phosphorus [TP]
  - Changes related to historical events (e.g. dam construction and flooding)
  - Recent warming (temperature and lake ice records)
- How do diatom changes at this site compare to a relatively undisturbed (reference) site?

Study Region

- **LoW** is large and complex, sharing borders with Ontario, Manitoba, and Minnesota (**Figure 1**)
- LoW water quality varies greatly throughout its extent
- Anecdotal evidence suggests that the northern parts of the LoW have recently experienced increasingly severe cyanobacterial blooms[5]
- This has raised concerns as to whether water quality has deteriorated as a result of recent increases in nutrients
- LoW shows a distinct south to north gradient in [TP][5]
- Dams constructed between 1890 – 1905 in the northern outlets near the city of Kenora increased the average water level by ~2m[6]

Study Site

Forrest Island: (**Figure 1**) main study location (**impact site**):

- Elevated [TP]: varies seasonally between **16 to 20 µg/L**[7]
- **Algal blooms** occur in the late summer to early autumn
- **Polymictic** (does not thermally stratify)
- Located close to Winnipeg River outlet
- Most northerly site of previously studied sediment cores collected by PEARL

Methods

- 24.5 cm sediment core collected using a Glew gravity corer & subsampled at 0.5 cm intervals using a Glew extruder[3]
- Chronology established using ^{210}Pb dating
- Minimum of 600 diatom valves enumerated per slide for 34 sediment intervals
- Diatom data expressed as % relative abundances
- Cluster analysis (CONISS) used to establish zones of change in diatom profile
- Changes in water quality over the last ca. 200 years assessed through diatom-inferred model for total phosphorus (DI-TP)
- Sedimentary chlorophyll *a* analysis used to track historical trends in primary production[4]
- Trends in diatom assemblage composition summarized using Principal Components Analysis (PCA)
- PCA axis 1 (PC1), DI-TP and Chl *a* were compared to Kenora temperature and Whitefish Bay lake-ice records

Figure 1. Location of study sites at Lake of the Woods

Whitefish Bay: (**Figure 1**) previously studied site for comparison (**reference site**)

- Minimal human disturbance & is isolated from the main channel
- Lower [TP]: **~7.5 – 10.0 µg/L**[7]
- **No algal blooms**
- **Dimictic** (thermally stratifies)

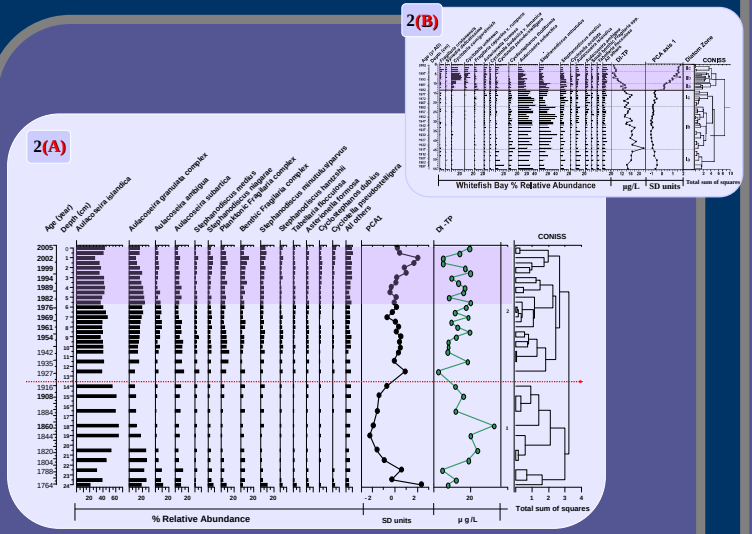

Figure 2. Stratigraphic profile of the most common diatom taxa (occurring at >5% relative abundance) encountered in the **(A)** Forrest Island (impact site) sediment core and in the **(B)** Whitefish Bay (reference site) sediment core. Principal Components Analysis for axis 1 (PCA 1) as well as diatom-inferred inference model for total phosphorus (DI-TP) are included in the figures. Cluster analysis using Constrained Incremental Sum of Squares (CONISS) defined stratigraphic zones.

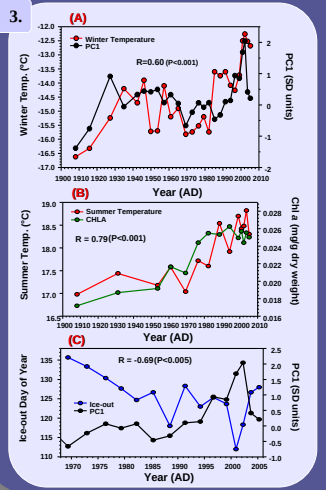

Figure 3. Relationships of mean seasonal temperature (Kenora, Ontario), chlorophyll *a*, and Principal Components axis 1 scores (PC1) for the **Forrest Island** core **(A)** Mean winter temperature versus PC1 **(B)** Mean summer temperature versus chlorophyll *a* **(C)** Ice out day of the year versus PC1.

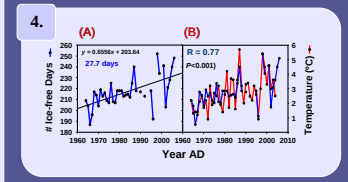

Figure 4. **(A)** Change in the number of ice-free days since 1964 from lake ice data recorded at **Whitefish Bay** (reference site). The number of ice-free days has increased by ~28 days in last ca. 40 years **(B)** High correlation between ice-free days and warming trend recorded at Kenora climate station.

Results and Discussion

General Diatom Trends

- Distinct diatom changes observed over the last ~250 years (**Figure 2A**)
- Diatoms indicative of elevated nutrient levels common throughout core
- Earliest intervals (~pre-1900) have the highest abundances of *Aulacoseira islandica*

Construction of dams (1887-1906): Rise in water level

- Notable change in diatom assemblages (Zone 1 and Zone 2)
- Diatom changes consistent with modest increase in nutrients following dams/flooding
  - Increase in planktonic *Fragilaria* complex, *Aulacoseira ambigua*, *A. granulata*
  - Decrease in relative abundances of *Aulacoseira islandica*
- DI-TP (~23 µg/L) highest during this period of damming
- Whitefish Bay (reference site) shows increase in DI-TP (~22 µg/L) (**Figure 2B-inset figure**)

Recent trends (ca. 1980-present)

- Increase in diatom taxa indicative of lower TP optima
  - *Cyclotella* taxa appear in modest abundances
  - Decreases in *A. ambigua* and *A. subarctica*
- Greatest diatom change occurs at this time in Whitefish Bay (reference site)
  - Pronounced increase in *Cyclotella* taxa and decrease in *Aulacoseira* taxa

Comparing diatom trends (Forrest Island) to temperature, lake-ice and Chl a

- Strong positive relationship between PCA axis 1 scores and winter temperature trends (R=0.60; P<0.001) (**Figure 3A**)
- Strong positive relationship between Chl *a* and summer temperature (R=0.79; P<0.001) (**Figure 3B**)
- Strong negative relationship between PCA axis 1 scores and Ice-out day of year (R=-0.69; P<0.005) (**Figure 3C**)
  - Relationships suggest that warmer temperatures (~2.3°C warmer since 1900) and longer ice-free periods (~28 days longer since 1964) have played an important role in recent diatom changes (**Figure 4A + B**)
- High correlations also found between diatom trends and temperature and ice-out data at reference site (data not shown)
- No relationship found between Chl *a* trends from reference site and temperature (data not shown)
  - Differences in Chl *a* trends between impact & reference sites suggest tracking algal blooms
  - High correlation between Chl *a* and temperature at impact site suggests recent warming may play an important role in algal bloom frequency and intensity

Conclusions

- DI-TP trends suggest that the Forrest Island site was naturally somewhat nutrient-rich over the last ca. 200 years, with a pronounced increase in DI-TP in the earlier part of the record (~1800s) and then variable post-~1900
- Diatom assemblage changes and DI-TP are not indicative of recent increases in [TP] at both the Forrest Island impact site and at the Whitefish Bay reference site
- Strong relationships between diatom trends and temperature and lake-ice records suggest that substantially warmer temperatures and longer ice-free periods (particularly over the last ~40 years) has played an important role in diatom changes
- Whitefish Bay likewise showed strong relationships to recent warming and, as expected, diatom changes here were more pronounced
- Primary production (Chl *a*) increased at impact site
  - Highly correlated to recent warming
  - Likely tracking algal blooms
  - Warmer temperatures together with already elevated [TP] may exacerbate algal blooms
- Collectively these data suggest that **warming** over the last few decades has been the **main driver** of the diatom changes

References

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