BROADENING THE SPECTRA

LOOKING BEYOND CHLOROPHYLL-α TO IDENTIFY CHANGES IN WHOLE-LAKE PRIMARY PRODUCTION

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A project submitted in partial fulfillment of the requirements for the course of BIOL 812

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1 THE PROBLEM

Lack of water quality information to establish reference conditions increases **uncertainty** in management targets.

Monitoring is typically reactive and begins **after an impact** has already occurred

e.g. large cyanobacterial blooms are detected so studies examine nutrient sources and modern lake water chemistry.

2 PALEOLIMNOLOGY

Reconstructing past environments to observe changes using **biological**, **physical**, & **chemical** indicators preserved in lake sediments.

Visible Range Spectroscopy (VRS) can be used to infer past whole-lake concentrations of **chlorophyll *a*** and its degradation products.

3 SIGNIFICANCE & QUESTIONS

We aim to explore the environmental histories of previously unmonitored lakes to inform local lake managers and present exploratory results from the application of machine learning to paleolimnological spectral data and chlorophyll *a* reconstructions.

❓ Does chlorophyll *a* change over time in each lake?

If so, are increases in chlorophyll *a* represented by a model using an ultimatum game simulation?

❓ Can we differentiate absorbance values from lakes grouped by trophic status or depth using machine learning?

If so, are the primary differences in the photosynthetically active radiation (PAR) range, or are they in other biologically-relevant spectra?

4 METHODS

Lake sediment cores were collected and analyzed to produce absorbance values for study lakes (Figures 1 and 2) and chlorophyll was inferred using standard methods .

- In addition, support vector machines (SVM) classified absorbance values (400-800nm) from sediment cores of 4 ages (10, 30, 50, and 70 years) from Lac-des-Iles and Stoco Lake (classification was 9-fold cross-validated with data re-shuffling).

Each of the 4 sediment absorbances was tested independently with the highest accuracy retained and subsequent iterations using the first variable plus each remaining variable until depleted.

Simulated data was generated according to individual-based modelling (IBM), a variation on Agent-based modelling (ABM).

- Using a modified game theoretical model, the parameter of resource division was used to simulate the evolution of an algae population in a lake according to individual behavior.

5 RESULTS & INTERPRETATIONS

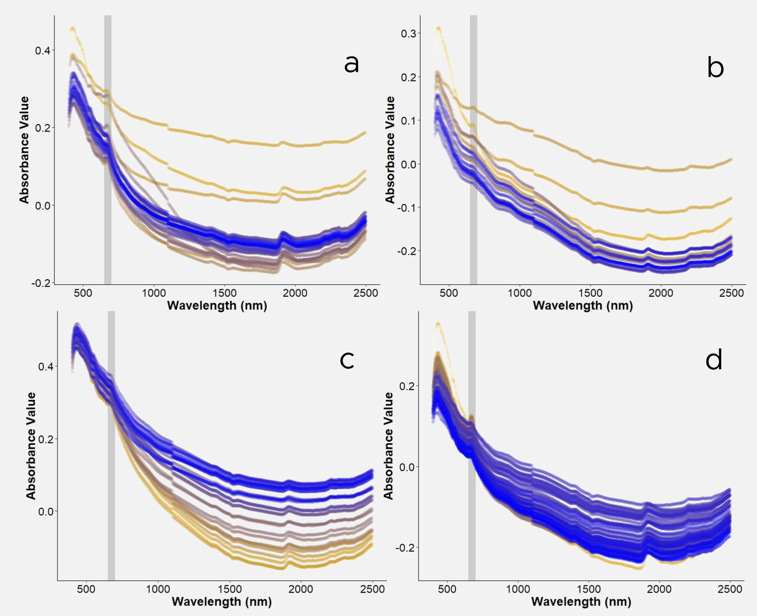

Figure 1. Absorbance values for the 400-2500nm wavelengths obtained from a Near-Infrared Spectrophotometer (NIRS) for (a) Duhamel, (b) des-Iles, (c) Stoco, and (d) Muskrat Lakes. Older samples are displayed in blue, with most recent sediments in yellow.

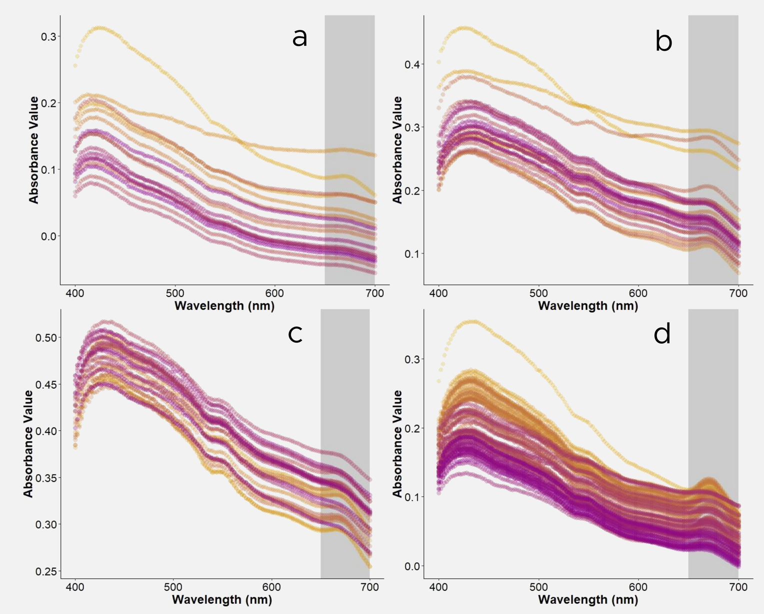

Figure 2. Absorbance values for the Photosynthetically Active Range (wavelengths 650-700nm) obtained from a Near-Infrared Spectrophotometer (NIRS) for (a) Duhamel, (b) des-Iles, (c) Stoco, and (d) Muskrat Lakes. Older samples are displayed in purple, with most recent sediments in yellow.

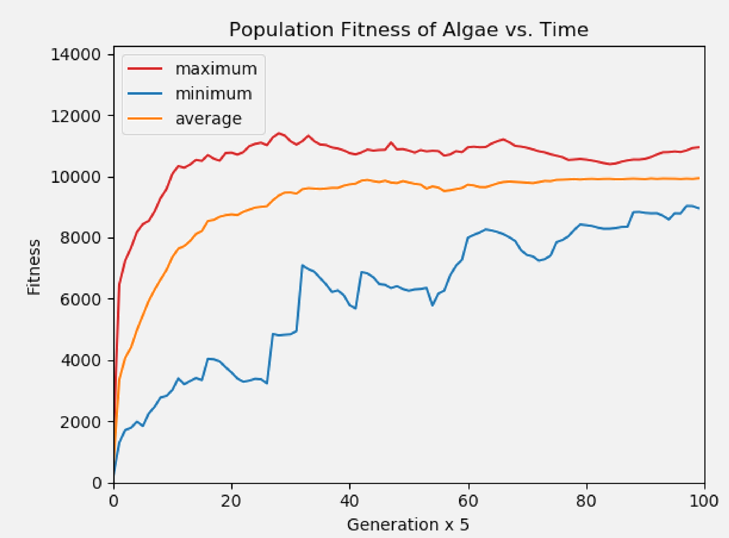

Figure 3. Data obtained from an ultimatum game simulation with initial population = 500, epoch = 5 generations, and non-zero mutation rates. The fitness score of an algae correlates to its production of chlorophyll *a* .

The simulation predicts that the algae population will tend towards a population that produces more chlorophyll *a* through increased population size (Figure 3), which is primarily what was observed in the focal lakes. From the sediment cores, the most drastic changes in VRS-inferred chlorophyll are in the two eutrophic lakes, **Muskrat** and **Stoco**.

Recent concentrations are more than double conditions found earlier in the sedimentary record (Figure 4)

- This is likely related to cultural eutrophication, the addition of nutrients from human development, combined with regional climate warming

Lac-des-Iles is relatively stable through time, which is to be expected in an oligo-mesotrophic lake, but shows an increase in chlorophyll *a* in the most recent sediments (Figure 4b)

- This may be related to regional climate warming or very recent anthropogenic watershed development.

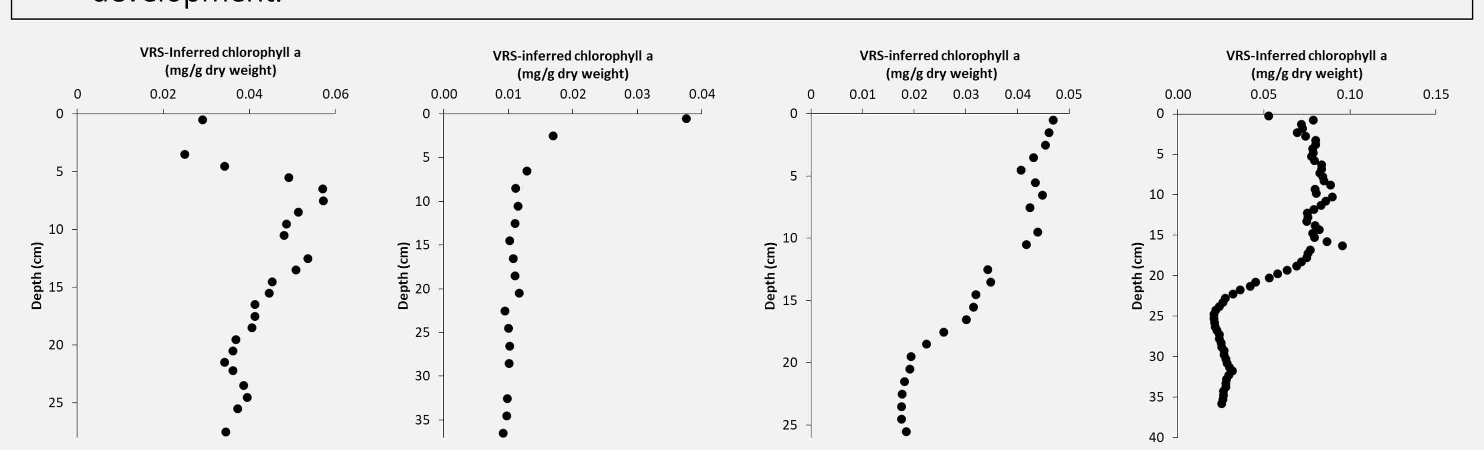

Figure 4. VRS-inferred chlorophyll *a* (x-axis) through the depth of the core (y-axis) for (a) Duhamel, (b) des-Iles, (c) Stoco, and (d) Muskrat Lakes. The most recently deposited sediment is at 0cm. Inferred-chlorophyll *a* is expressed in mg/g freeze-dried sediment weight.

Interestingly, chlorophyll *a* at **Duhamel** does not increase through time and therefore does not necessarily follow the ultimatum game prediction.

- Instead, chlorophyll *a* decreases at ~6cm (corresponding to the late-1800s)
- this may be related to increased zooplankton grazing pressure or a large erosional event diluting chlorophyll *a* in the sediments and/or clouding the water to preclude primary production, but further paleolimnological studies are required to determine the cause of the drastic decline

We also examined whether the raw absorbance data can be used to distinguish a deep, oligotrophic lake (Lac-des-Iles) from a shallow, eutrophic lake (Stoco Lake), which would be ecologically distinct from each other

- We trained SVM models using absorbance data from sediment at 4 ages (10, 30, 50, and 70 years since deposition)
- We found a peak classification accuracy between these lakes of 62%, with a range of 45% to 62% (Figure 5).

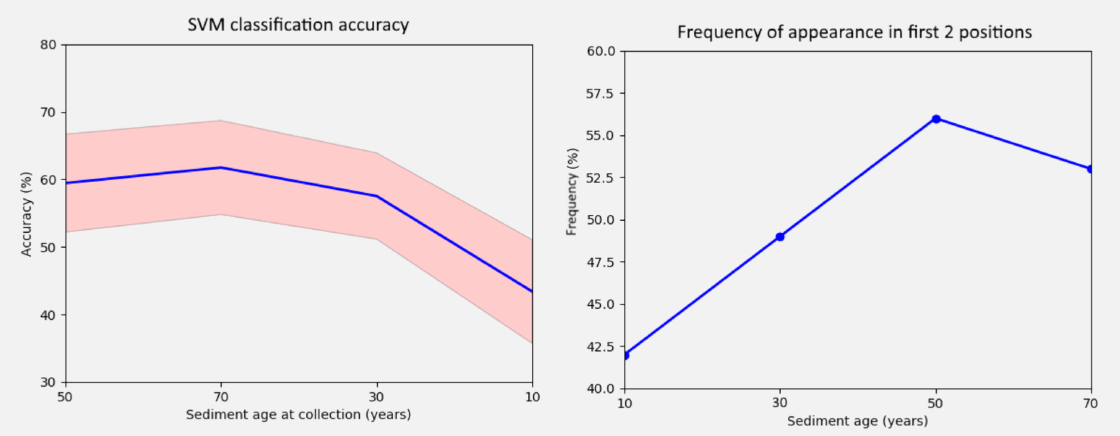

Figure 5. Average accuracy for the SVM classifier for each of the sediment samples (absorbance range: 400-800nm). Accuracies are for models incorporating all sediment samples moving rightward, e.g. '70' includes both 50- and 70-year old sample absorbances, but not 30 or 10. Shaded patch is ±1SD.

- Accuracy typically increased when absorbances from 50- and 70-year old sediments were included in the models, and then decreased again when sediments of other ages were included
- Absorbances derived from sediments 50 years old were most frequently chosen for one of the first 2 positions in the model (as it was iteratively built)

These results indicate that absorbance values from specific sediment intervals provided more information regarding the identity of each lake than others, which is likely related to differing organic content as VRS-inferred chlorophyll *a* increases through time

The peak classification accuracy was relatively low in this experiment, although this could be because of a relatively small number of sediment ages to draw from. The use of other software implementations could provide different results as well.

6 SAMPLING SITES

Lake	Core Depth	Trophic Status	Bedrock Geology
Stoco Lake	12m	Eutrophic	Canadian Shield Limestone
Muskrat Lake	33m	Eutrophic	Canadian Shield Limestone
Lac Duhamel	26m	Oligotrophic	Canadian Shield
Lac-des-Iles	37m	Oligo-mesotrophic	Canadian Shield

7 CONCLUSIONS

For the majority of our focus lakes, VRS-inferred chlorophyll *a* is **increasing** as is expected in temperate Boreal Shield lakes influenced by climate change and eutrophication since European colonization.

- **Lac-des-Iles is an exception** that have other factors decreasing recent chlorophyll *a* concentrations.

In addition, SVM models could not consistently differentiate absorbance values from two ecologically distinct lakes (accuracy maximum of 62%), though this is likely related to a small sample size. Further, simulated data from an ultimatum game model shows that algal populations will likely increase in size, and therefore be represented by higher VRS-inferred chlorophyll *a* concentrations in the sedimentary record, as time progresses.

This information may be useful to guide future lake management decisions regarding the control of algal blooms and eutrophication. It is likely that increased algal biomass will propagate or perpetuate water quality degradation in Boreal Shield lakes as human watershed development places multiple stressors on freshwater systems.

REFERENCES

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