7 LAKES
BELGRADE LAKES
MAINE

7 Lakes-Colby Water Quality Initiative

+ Wake Boats, Loons, and Data Modeling

Dr. Danielle Wain, Matt Farragher, Miles Hagedorn (7 Lakes Alliance)

Dr. Casey O'Connor, Dr. Whitney King (Colby)

Colby Summer Research Students:

King Lab: Cogan Lawler, Elisa Arteaga, Ella Novion, Sam Bunge, Soomin Lee, Maddy Tran
Bates Lab: Ayseli Karabekmez
Bevier Lab: Makena Logan, Ariana Raschid Farrokhi
Chowdhury Lab: Rishit Chatterjee
Ortiz Lab: Mahali Mabesa

Colby

Water Quality Monitoring Program

Year-round monitoring

- 15+ lake visits, 1200+ lake water samples
- 300+ stream samples, autosamplers continuously deployed

Over 10 years of Colby collaboration

- 60+ students in King lab
- Currently working with 4 additional labs at Colby:
- Bates, Buck, Chowdhury, Ortiz

Funding sources

- Klingenstein Philanthropies
- Harold Alfond Foundation
- Private donors
- Colby College
- Grants from USGS, NSF, Horizon Foundation

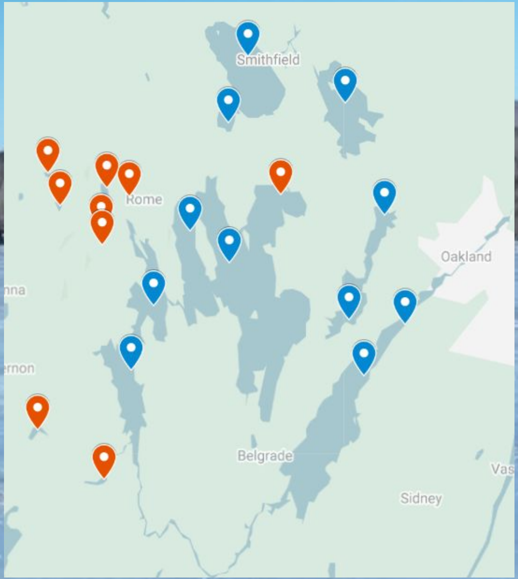
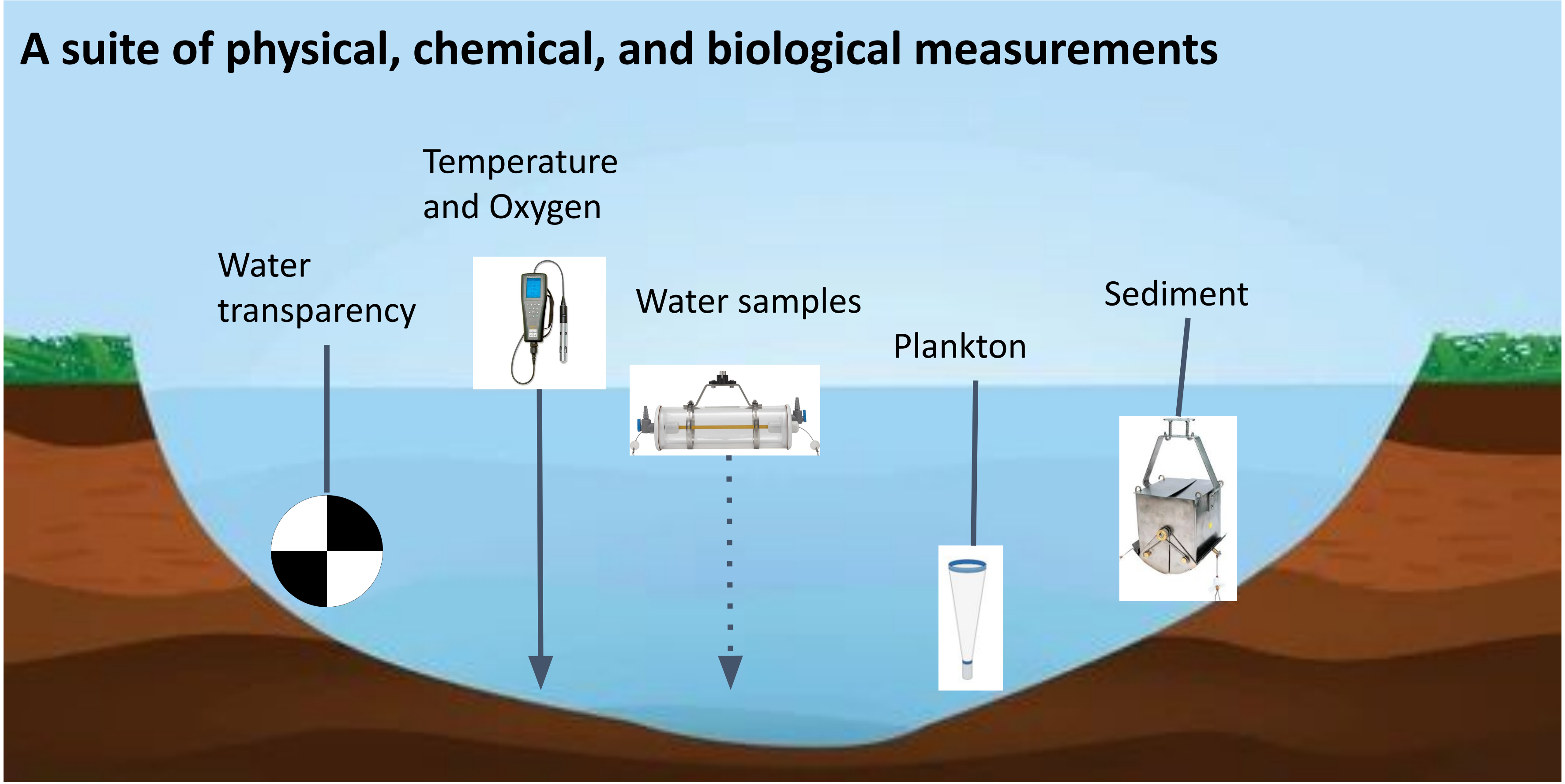
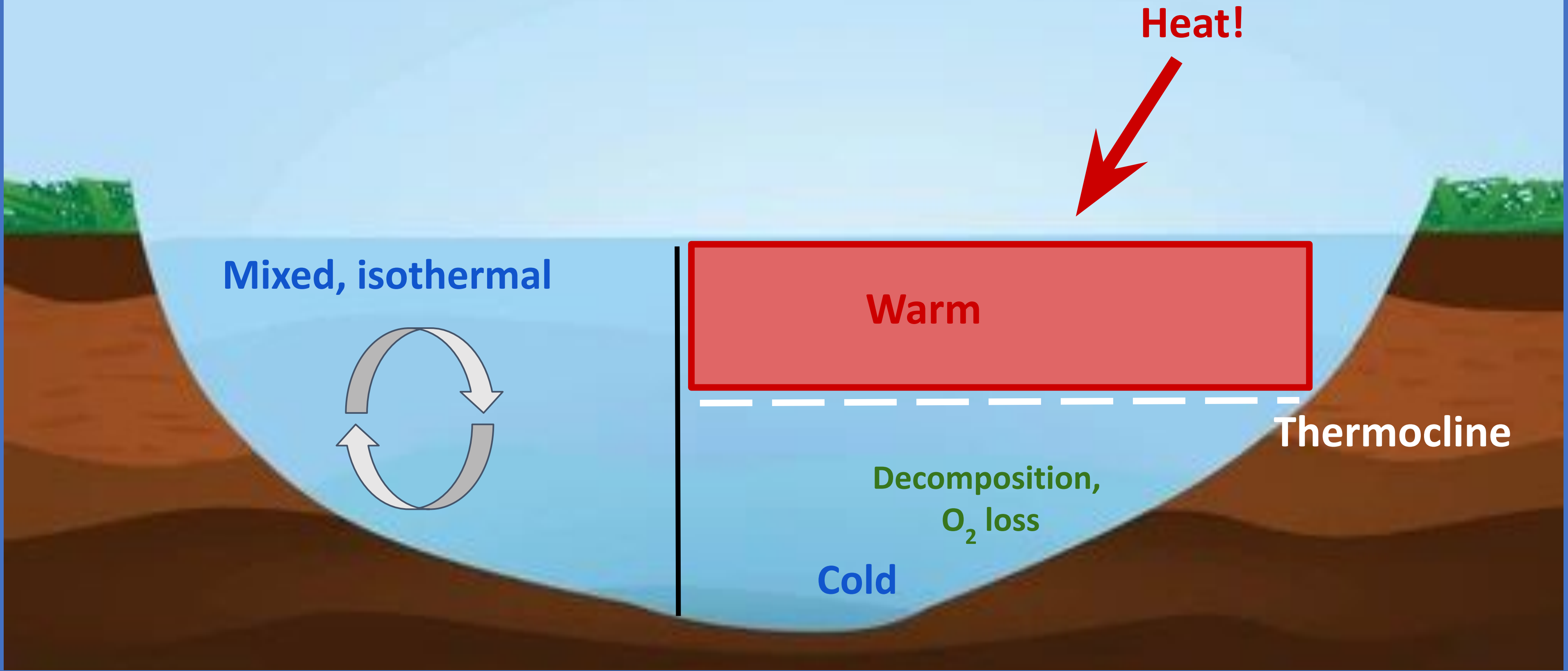


Photo: Alex Wall

Water Quality Monitoring Program

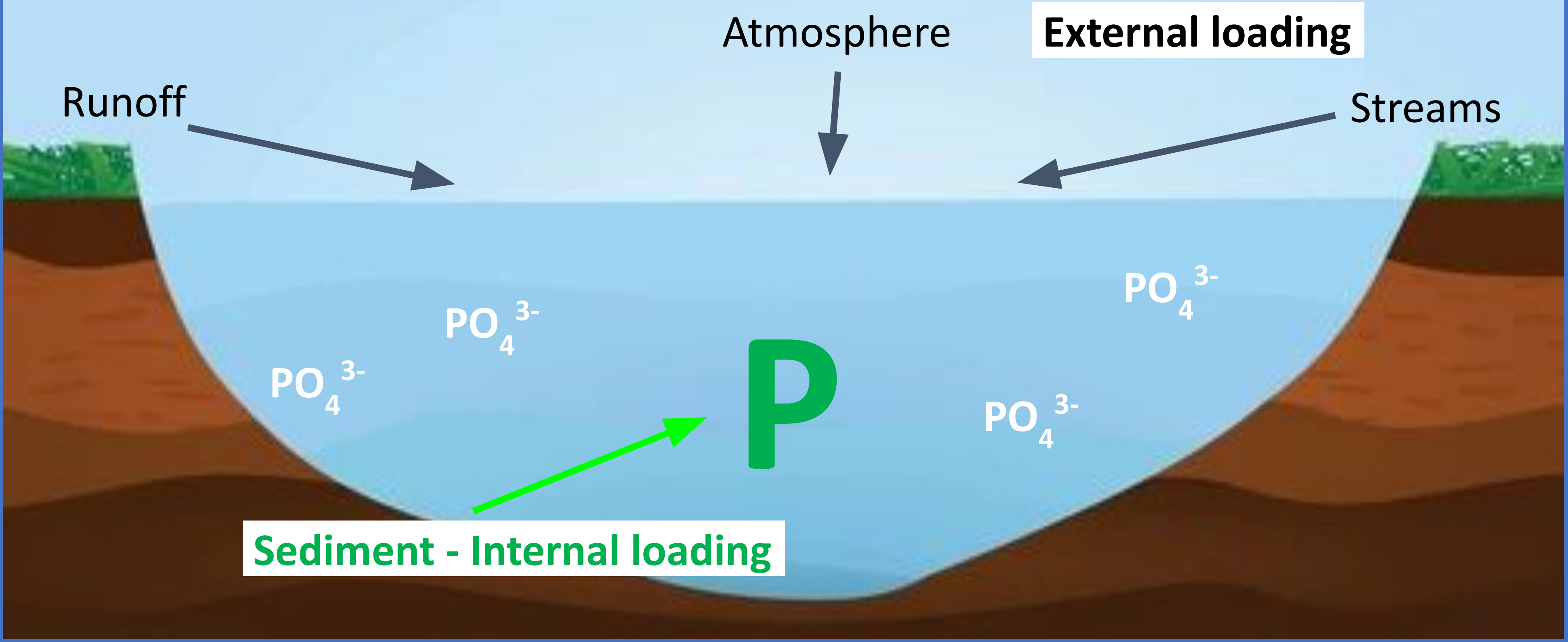


Stratification = the separation of warm surface water and colder deep water



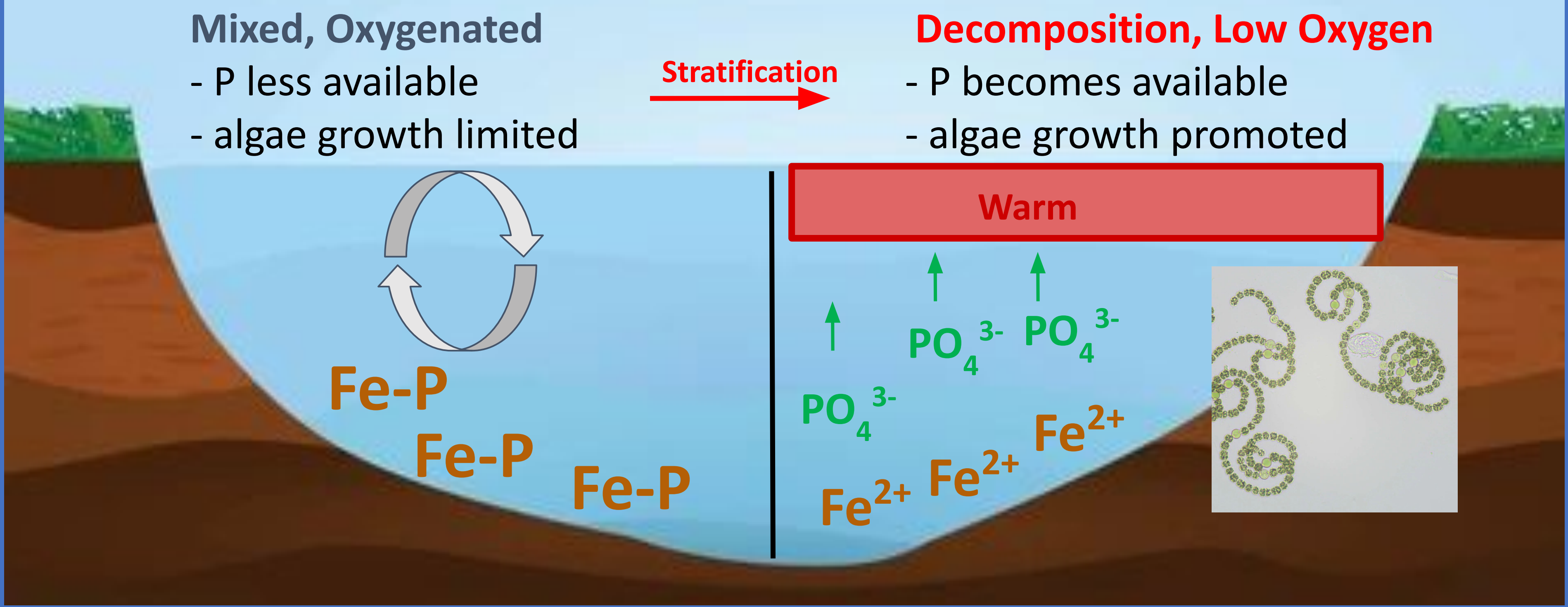
Phosphorus = limiting nutrient for algae in our lakes

Decades of deposition from watershed increases sediment P



Internal Loading = cycling of phosphorus between lake sediment and water column

Internal loading contributes 50% of North Pond's phosphorus annually, but 80-90% of P while blooming
(North Pond WBMP 2023)



Colby Summer Student Research Presentations

Madilyn G. Tran ‘28 Analyzing Effects of Lakebed Topography on the Propagation of Boat-Wake Waves Generated by Wakesurfing

Ayseli Karabekmez ‘27, Anne Johnson ‘25 Bridging Science, Stakeholders, and Policy: A Qualitative Study of Boating Impacts on Maine Lakes

Rishit Chatterjee ’28 Forecasting Lake Water Quality with Missing Data

Soomin Lee ’27 Balance in the Belgrade Lakes: Monitoring Phosphorus and Nitrogen to Mitigate Algal Blooms

Ella A. Novion ’28 Phosphorus Sequestration in North Pond Sediment Pre- vs. Post-Algal Bloom

Elisa M. Arteaga ’26 Phosphorus Speciation in Lake Sediment Extracts of North Pond

Cogan Lawler ’26 Creating a Mass Balance for North Pond: A Comprehensive Analysis of Stream Water and Lake Sediment

Sam Bunge ’27 Classifying Zooplankton of the Belgrade Lakes

Makena Logan ‘27, Ariana Raschid Farrokhi ‘27 Monitoring Common Loons on Great Pond and Long Pond in the Belgrade Lakes Region

Time for one question in between talks!
Additional questions at the end

Madilyn G. Tran ‘28, Dr. Danielle Wain, Dr. Alison Bates, Dr. Alejandra C. Ortiz

Analyzing Effects of Lakebed Topography on the Propagation of Boat-Wake Waves Generated by Wakesurfing

Impacts of Recreational Boating in East Pond, Maine

What is Wakesurfing, Wakeboarding, and Waterskiing?

- Wake Boats
  - Specifically engineered to create bigger waves with higher energy in their wakes (boat-wake generated waves)
- Appeal to a growing popularity in wakesurfing activities on the lakes
- Regulatory minimum depth and distance from shoreline
  - Maine laws already in place (most recent update: Aug. 9th, 2024)



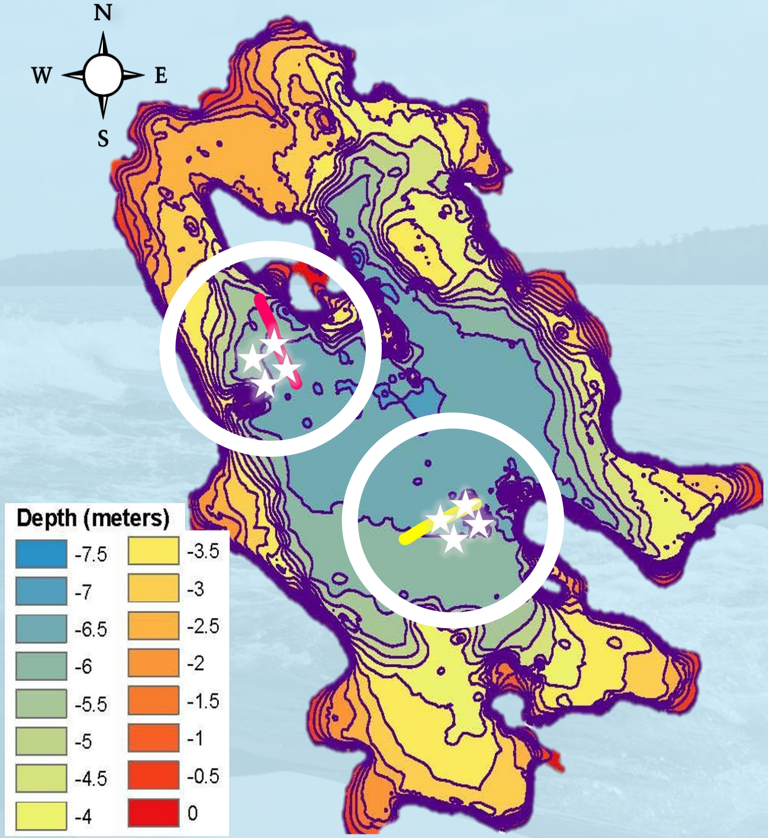
Left to Right: Wakesurfing, Wakeboarding, and Waterskiing

East Pond Site Overview and Procedures

- East Pond, Belgrade Lakes, Maine
  - Flat Site & Sloped Site

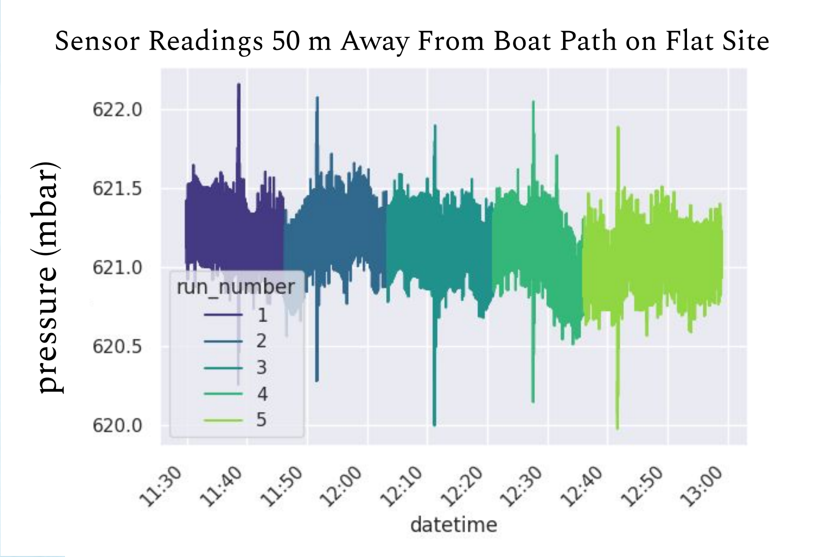
- Pressure sensors placed on the path and orthogonally outward

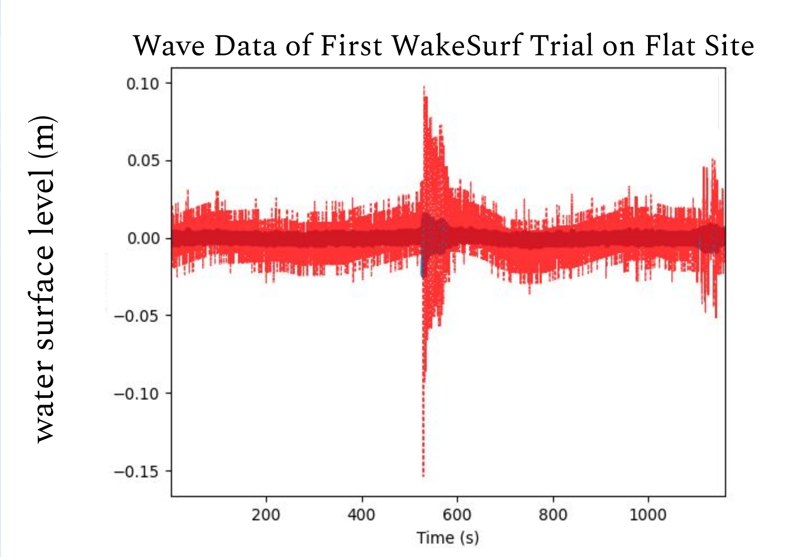
- Boat trials of three types of wakesurfing modes



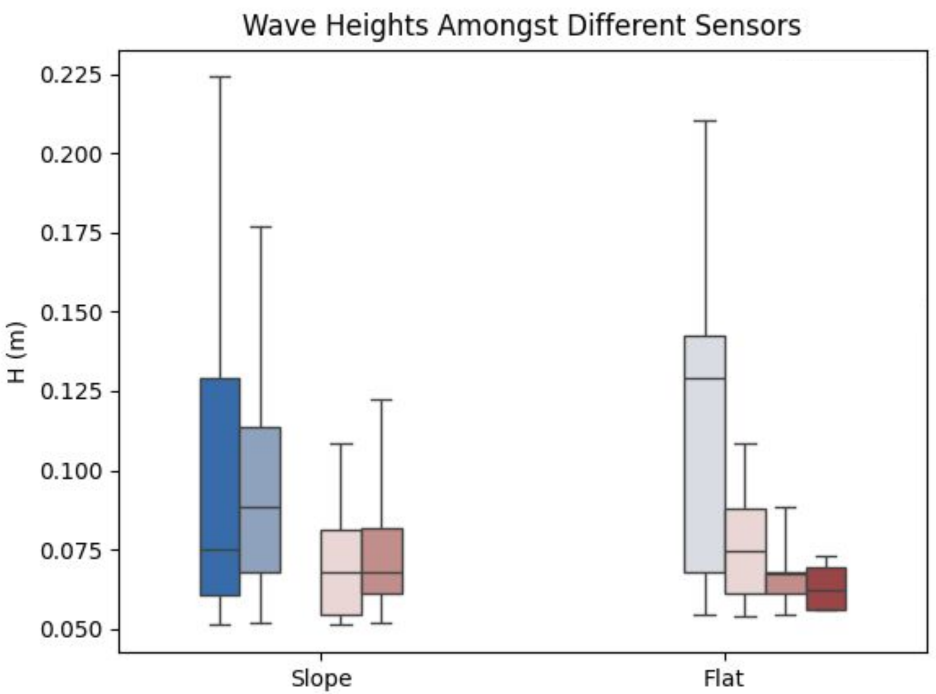
Data Collection and Processing

- Focusing on wakesurf trials
  - Average starting depths for both sites:
    - 6.6 m on Flat
    - 6.8 m on Slope



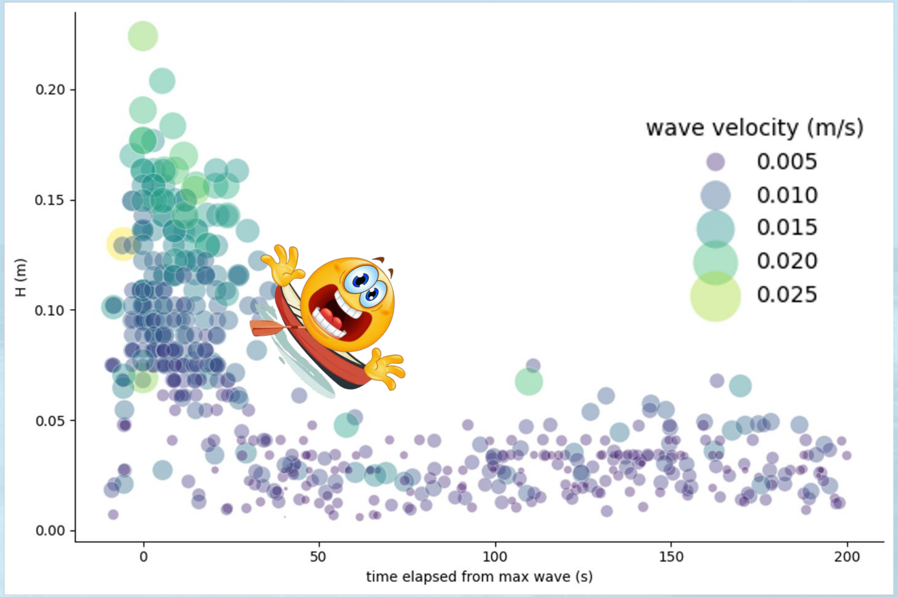


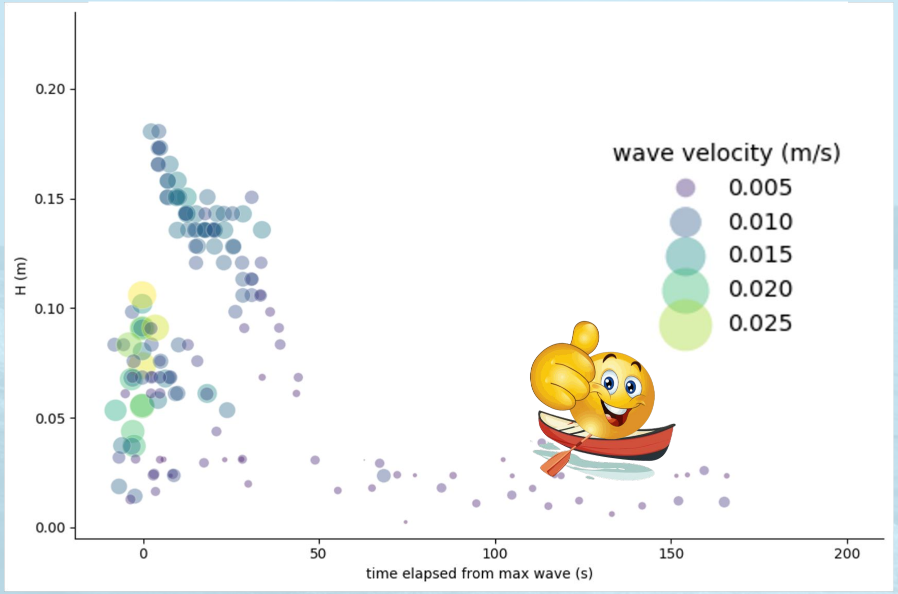
Results and Analysis



Sensor distances from boat path
(*Left to right:* 0 m, 10 m, 50 m, 50 m)

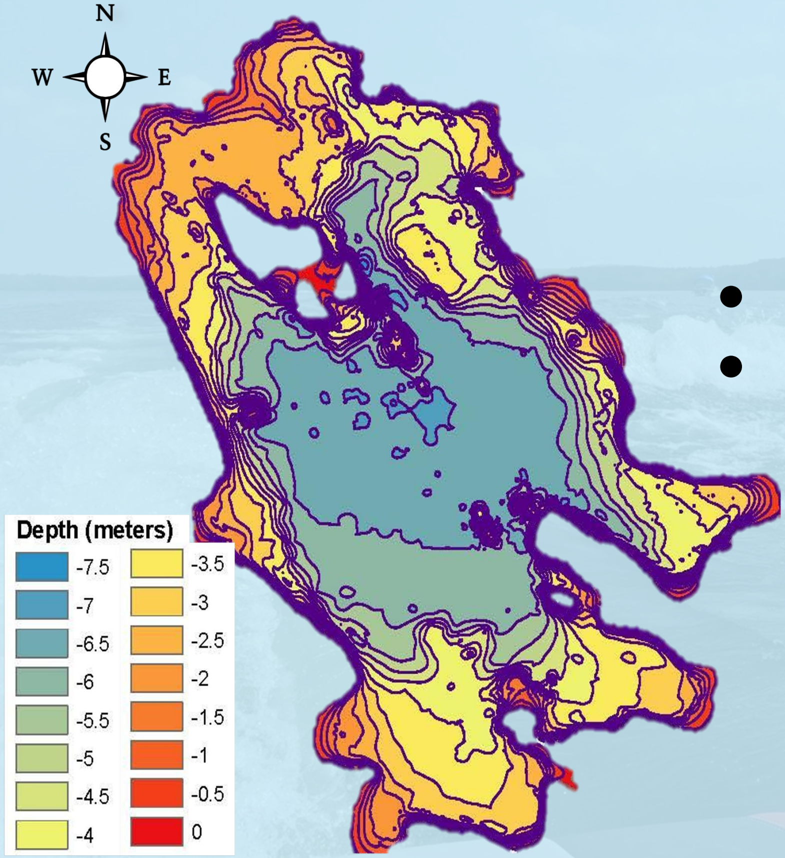
Results and Analysis





- Sloped Site reached **higher average *wave heights*** more often than Flat Site
  - Sloped Site also had **higher *wave velocities*** at the bed

Final Statements and Hopes for the Future



- Differences matter!
- No lake is perfectly uniform

Bridging Science, Stakeholders, and Policy: A Qualitative Study of Boating Impacts on Maine Lakes

Ayseli Karabekmez ’27, Anne Johnson ’25, Prof. Alison Bates,
Environmental Studies Department, Colby College


Wakesurfing


Waterskiing


Wakeboarding

Belgrade Great Pond Boat Launch


Mid-Maine Marine


Sydney Boat Ramp


Salmon/ McGrath Boat Launch

Forecasting Lake Water Quality with Missing Data

Rishit Chatterjee

Mentors: Prof. Tahiya Chowdhury, Prof. Whitney King, and Dr. Danielle Wain

Department of Computer Science and Chemistry

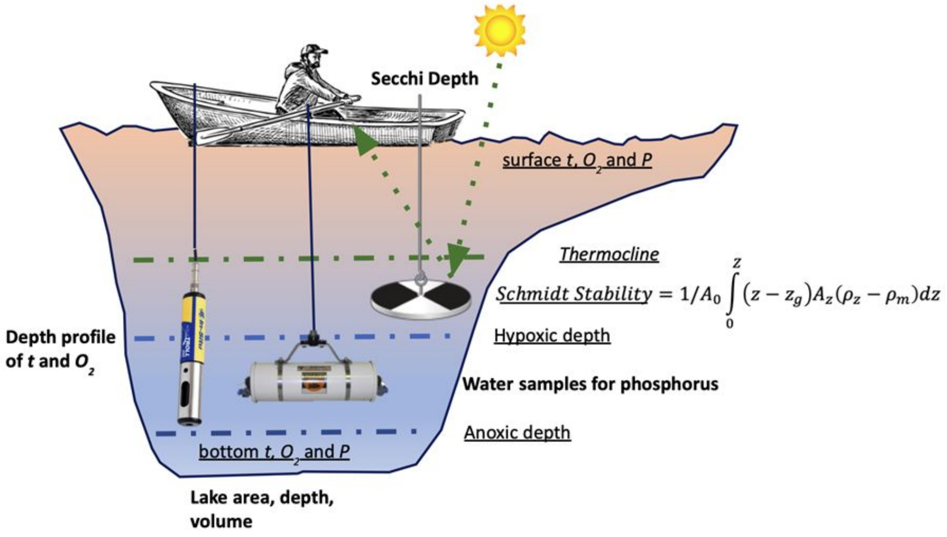
Why Monitor the Water Quality of Lakes?

Annabessacook Lake

North Pond

Data Landscape

- 40+ years of data for each lake
- 5000+ lakes measured statewide
- Collected by volunteers and quality-checked by Maine's DEP
- Properties Measured: Secchi Depth, Temperature profiles, Dissolved Oxygen, Chlorophyll, etc.
- ***Secchi Depth: The Target Variable for Prediction***
  - Measures how deeply light penetrates a lake



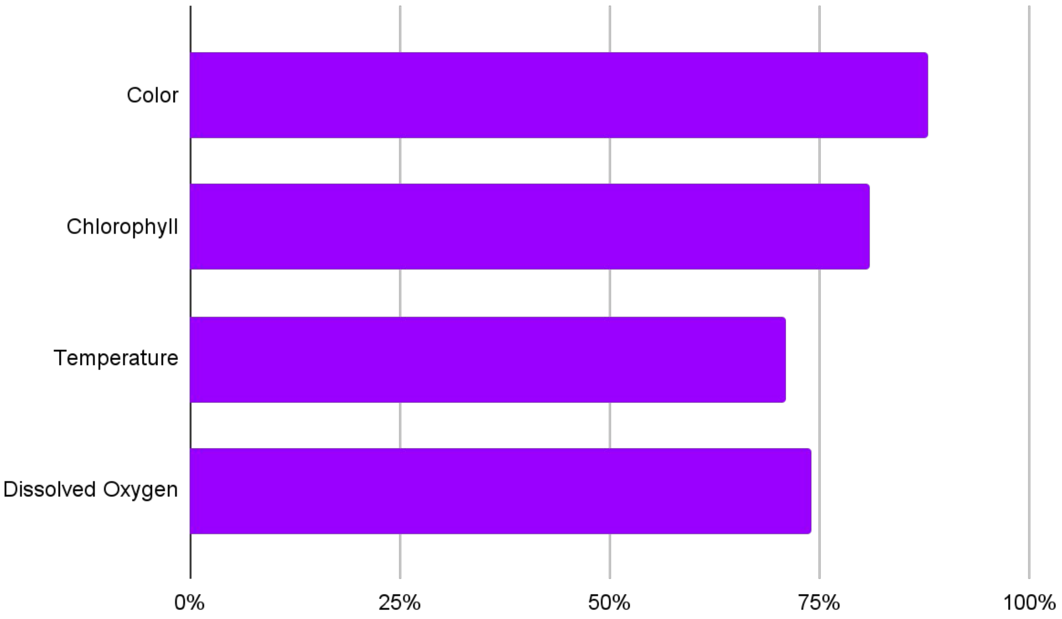
Challenges and Problems

However, to leverage this vast dataset, we need to address the “**missing**” data, caused by:

- Irregular sampling
- Seasonal Lake access
- Volunteer schedules

Variables	Missingness
Color	88%
Chlorophyll	81%
Temperature	71%
Oxygen	74%

How do we do it?
Imputation



Research Questions

- Can we accurately predict future Secchi depth with limited historical data? What's the minimal history needed for good performance?
- Can including lake-specific physical limits (e.g., max depth) improve imputation and forecasting accuracy?

Methods

Analyzing time series

Multiple Imputation by Chained Equations

Fills in missing values by statistically predicting each feature using the others

Machine Learning Model-Based Forecasting

Predicts future Secchi depth using historical water quality and lake features

(XGBoost, Random Forest, SVR, Ridge, KNN, Linear Regression)

Minimal Data by Years

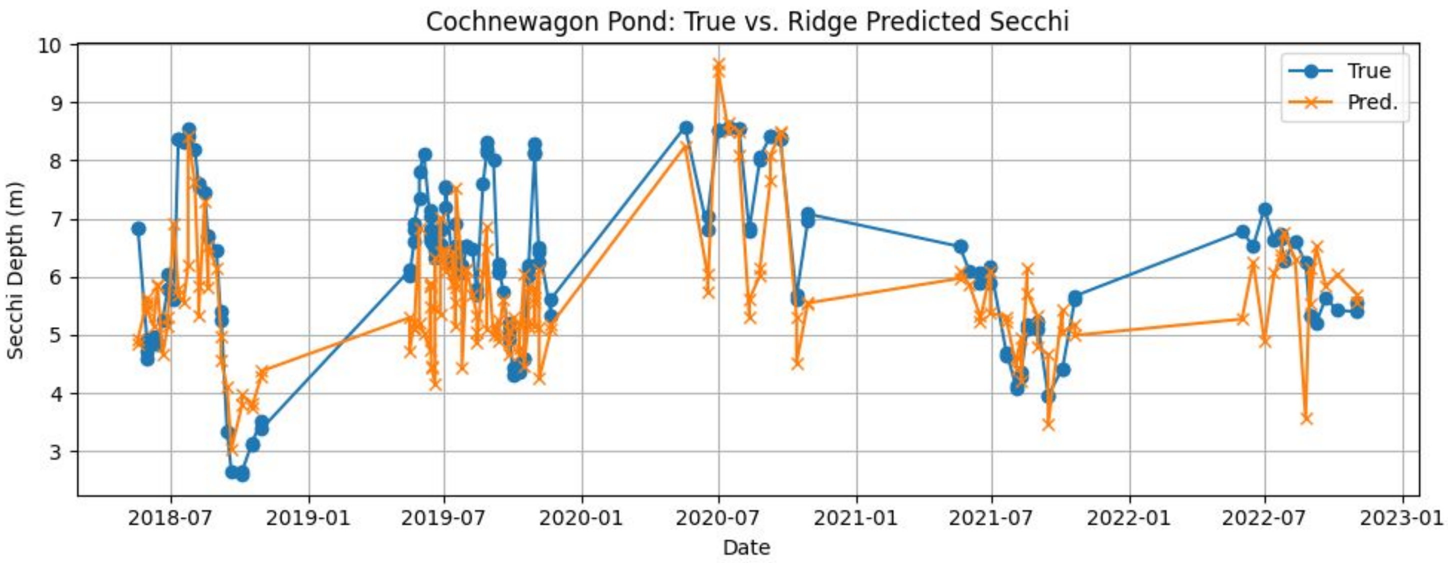
Find how much historical data is needed before prediction accuracy stops improving

Physics-Informed Loss Function

Penalized for Secchi predictions exceeding known depth

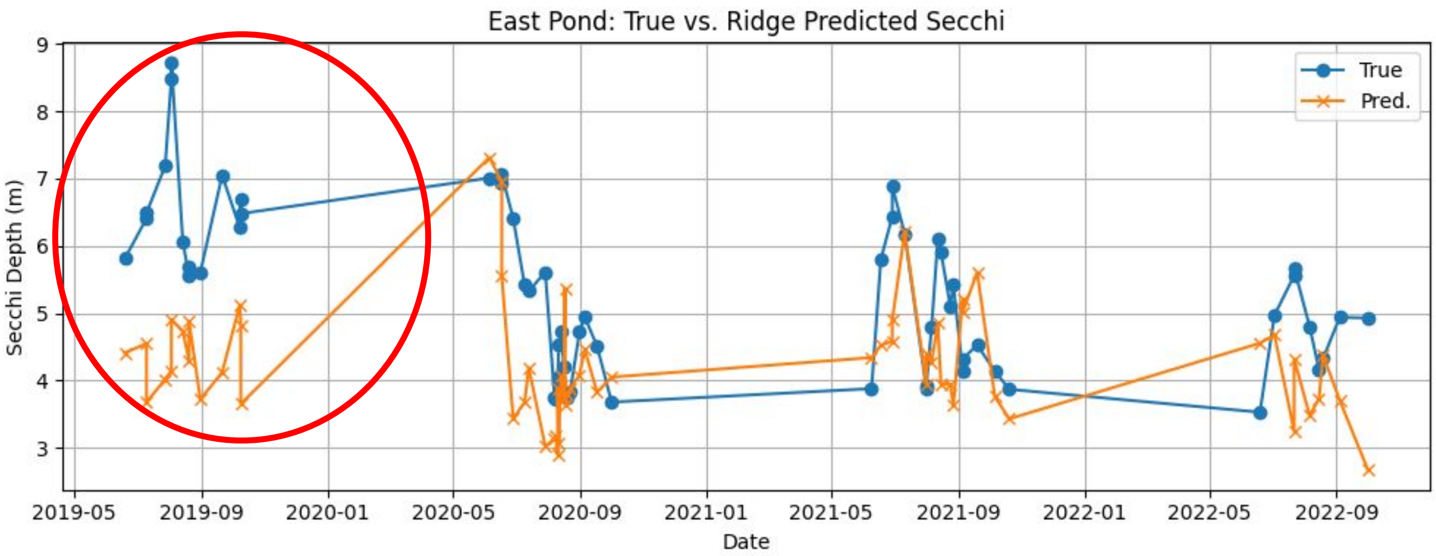
Predicted vs Original Secchi Values

The time-series plot for Cochnewagon Pond shows observed and predicted Secchi depths closely overlapping after imputation.



Predicted vs Original Secchi Values

The time-series plot for East Pond shows observed and predicted Secchi depths closely overlapping after imputation.



Metric: Mean Scaled Error (MSE)

Normalizes error **per lake** by average Secchi depth

→ accounts for lake-specific clarity ranges.

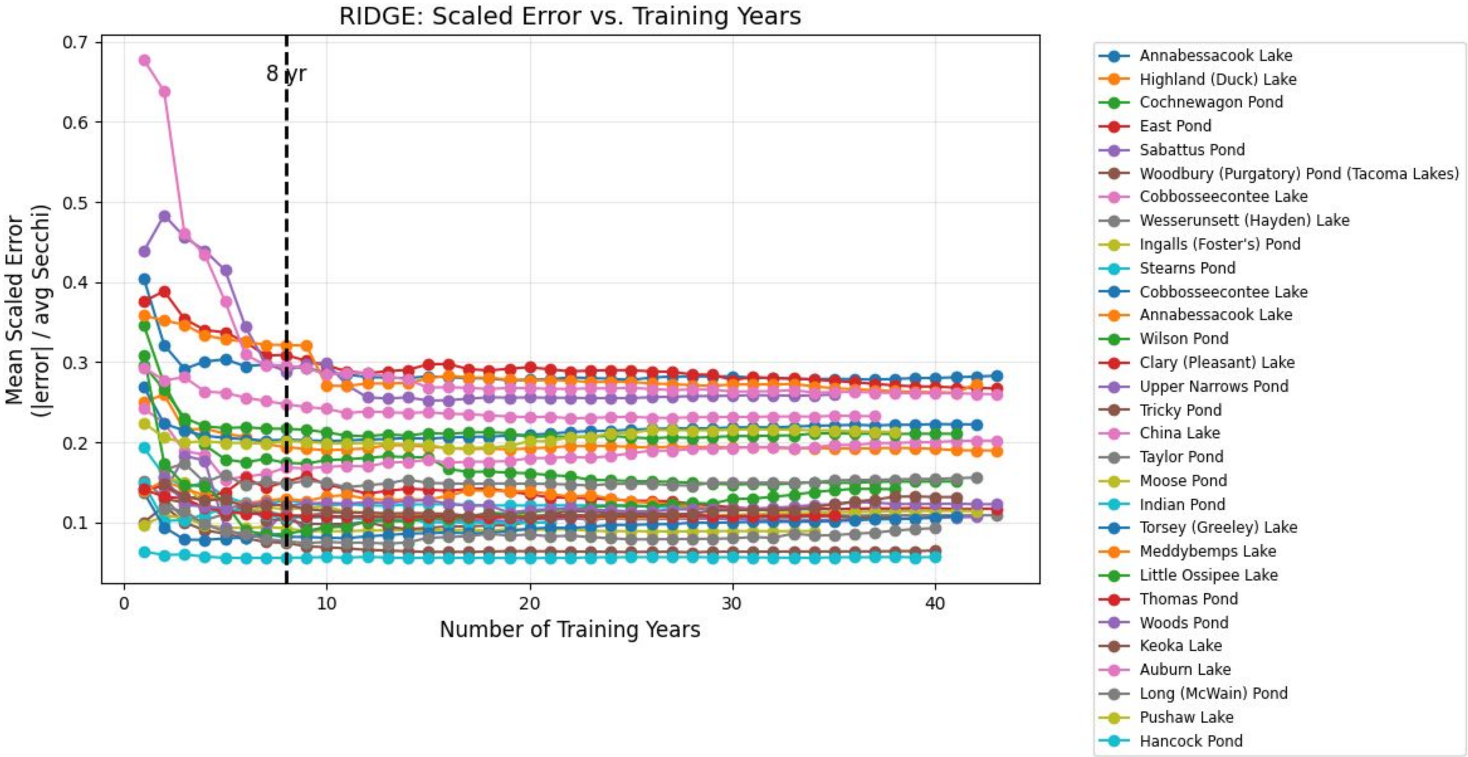
Why it's better than dividing by Sample Size (MAE):

- Dividing by sample size gives **mean absolute error**, but **ignores scale** differences across lakes.

$$\text{Scaled Error} = \frac{|\text{Prediction} - \text{Truth}|}{\text{Avg Secchi of lake}}$$

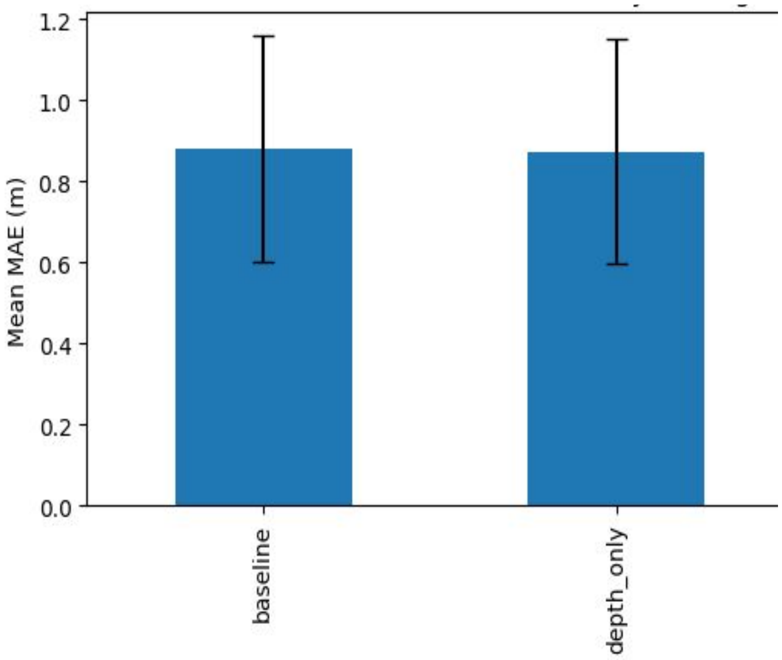
	Average Secchi	Prediction Error	MAE	MSE
Lake 1	1.0	0.5	0.5	0.5
Lake 2	5.0	0.5	0.5	0.1

Results: Data Sufficiency Findings



Prediction error shows diminishing returns (plateaus) after **~8 years**.

Results: Physics-Informed Forecasting



Constraint	Baseline MSE
Baseline (without constraints)	0.878656
Depth constraint	0.873268

Only slight improvement in baseline MSE.

Summary of Results

- *Prediction error levels off after ~6 – 8 years across all lakes and models.*

  Just **6–8 years** of past data is often sufficient — beyond that, accuracy gains are minimal. Helps prioritize efficient data collection and use.

- *Adding a depth-based constraint gave only slight improvements over the baseline.*

  While physically grounded models help enforce realism, such constraints offer limited gains alone. Even with more physical constraints like max temperature and Schmidt stability, the gains were minimal.

Limitations

Limited to 30 lakes with most data

Secchi-only focus limits ecological scope

No causal inference — only prediction

Environmental drivers (e.g., land use, precipitation) not included

Future Directions

- Explore **causal relationships** between variables
- Test **model transferability** across regions or lake types
- Refine **error metrics** for better ecological meaning

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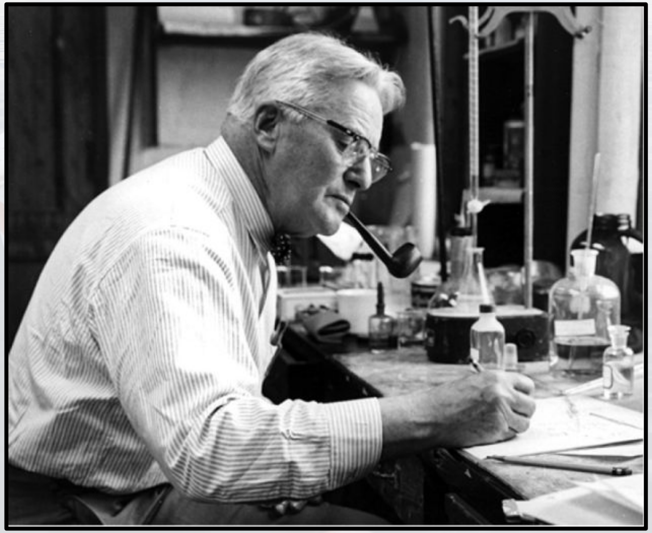
Comparing Redfield Ratios of the Belgrade Lakes

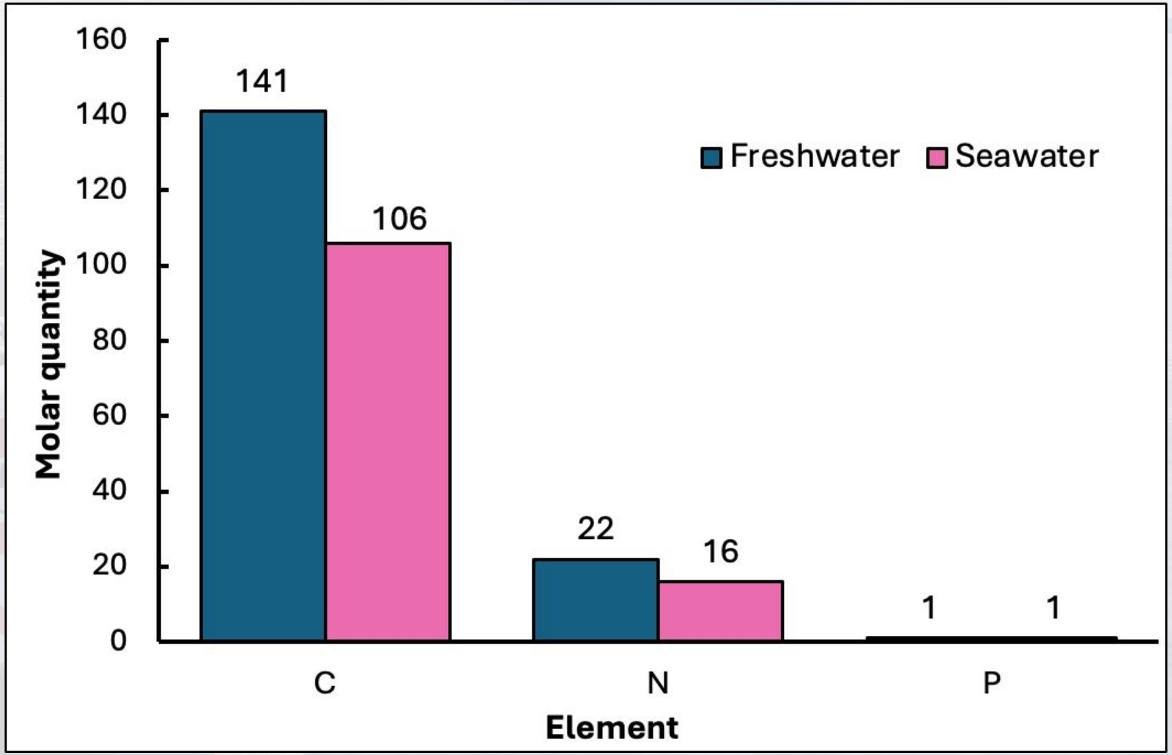
Soomin Lee ‘27

The Redfield Ratio

$$106\ CO_2 + 16\ NO_3^- + 1\ PO_4^{3-} + 122\ H_2O \ \rightarrow$$
$$1\ (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138\ O_2$$



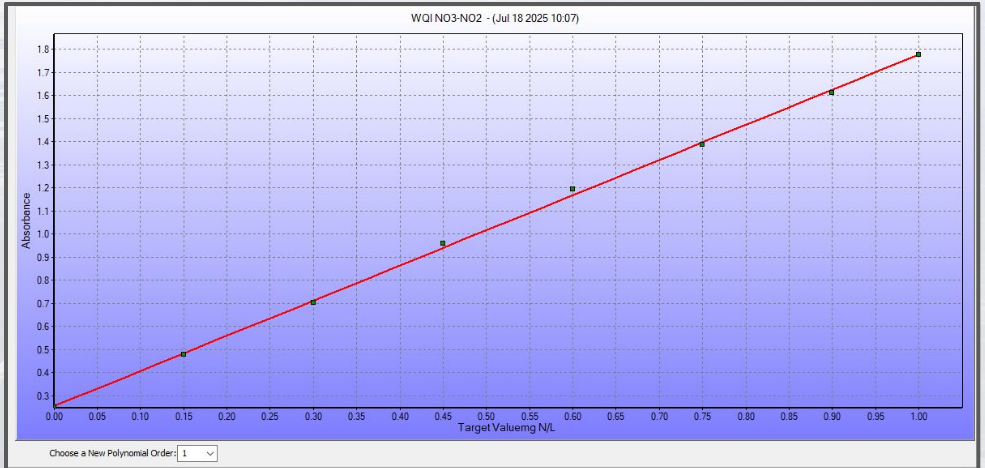
The Redfield Ratio



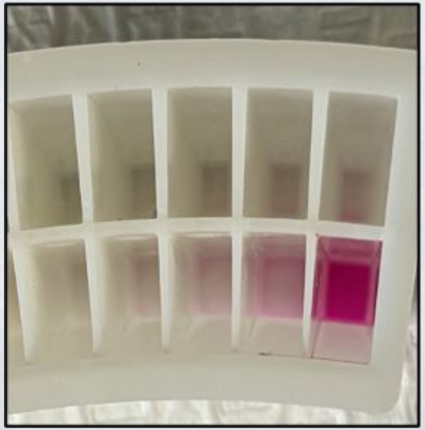
Method

$$A = -\log\left(\frac{I_T}{I_o}\right)$$

$$A = \epsilon L c$$



Calibration Status	
Date \ Time	2025-07-18 10:07:28
Status	Calibrated
Absorbance range	1.5280
Slope	0.657
Intercept	-0.167
Carryover (%)	1.3
Correlation coefficient	0.9997
Variance	0.013



Data Analysis

< 22:1

P

P

P

= 22:1

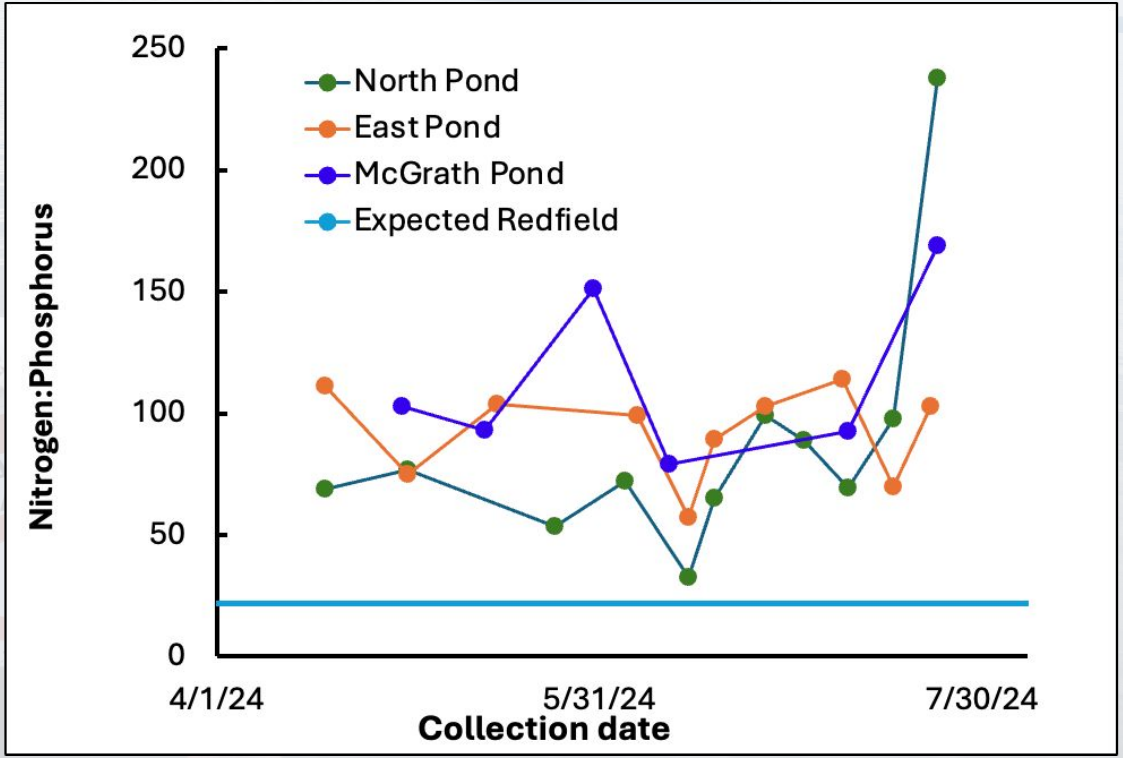
> 22:1

N

N

N

Data Analysis



Conclusions

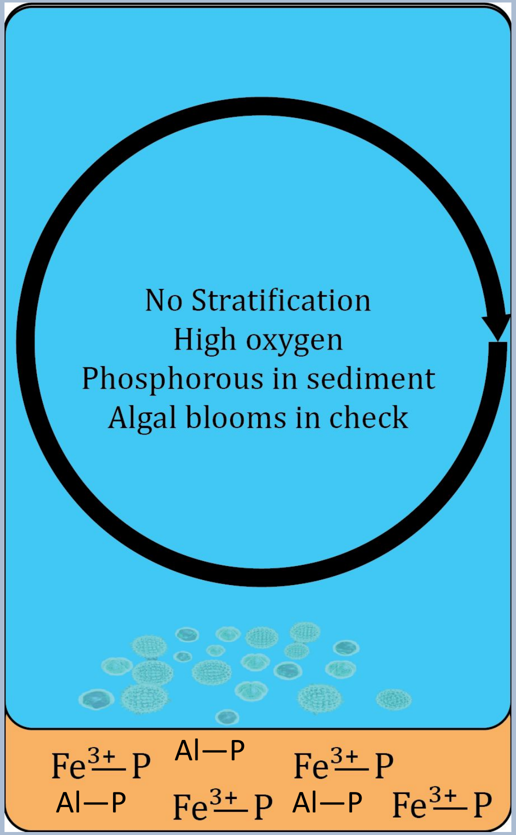
- Nitrogen is in abundance as a nutrient in the Belgrade Lakes—**phosphorus is the limiting nutrient for algal growth**
- Future work would include connecting chlorophyll-a data with nitrogen and phosphorus

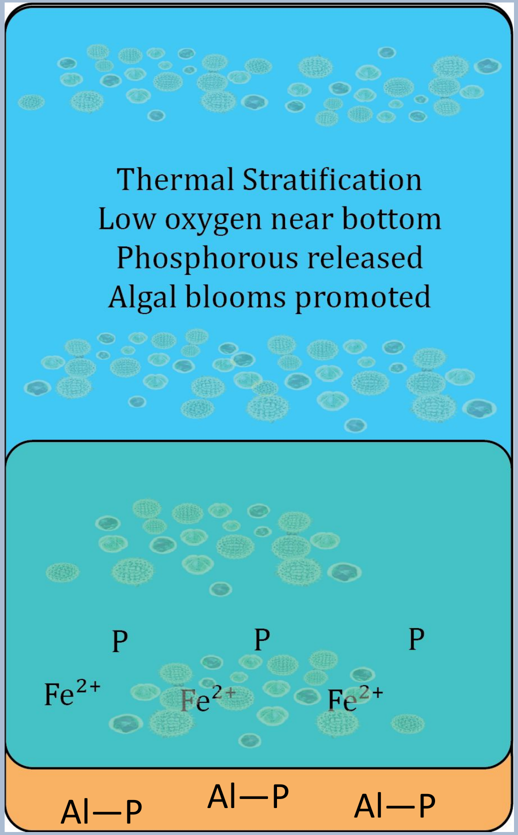
Phosphorus Sequestration in North Pond Sediment Pre- vs. Post-Algal Bloom

Ella Novion ‘28

Algal Blooming

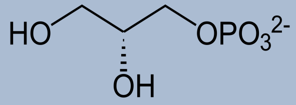
- Green film decreases water clarity due to over proliferation of algae
- Algae growth limited by the amount of phosphorus
- Internal loading



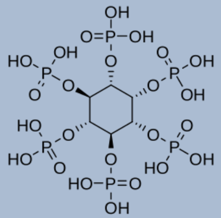


Research Question

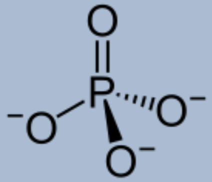
- Alum dose determined by post-bloom sediment
- Only partial sequestration from 2023 sediment samples
- Will timing of an alum treatment affect the amount of phosphorus sequestered?



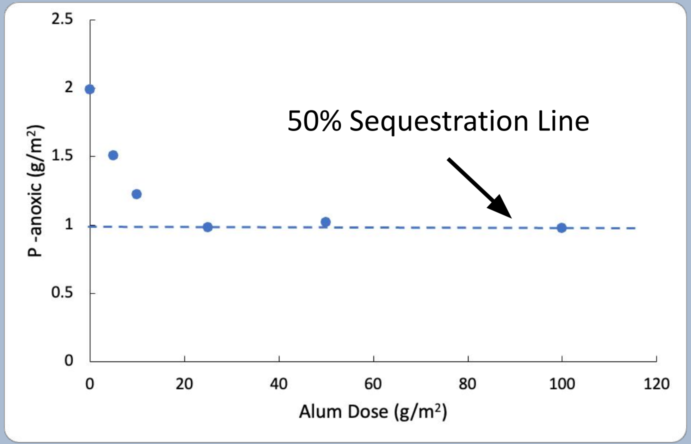
Glycerol 3-Phosphate



Phytic Acid

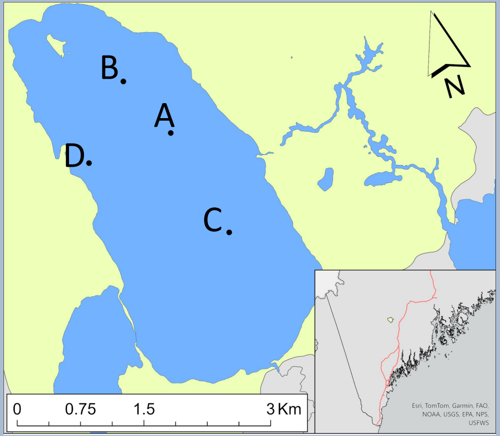


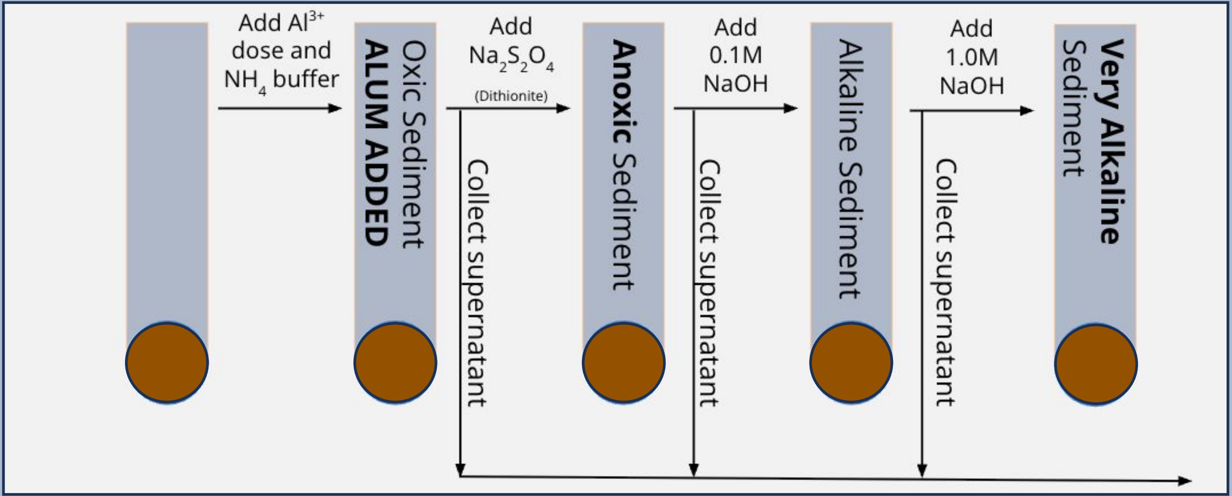
Inorganic Phosphate



2023 Post-Bloom Sediment “Jar Test”

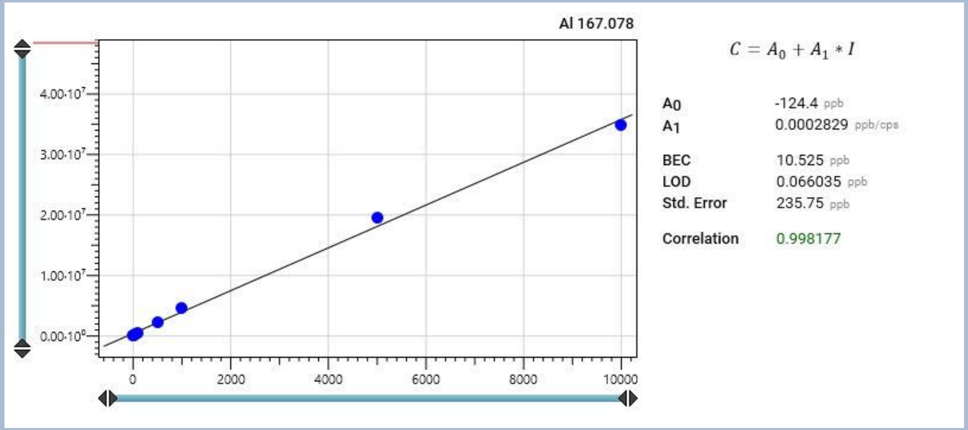
Locations and Jar Tests

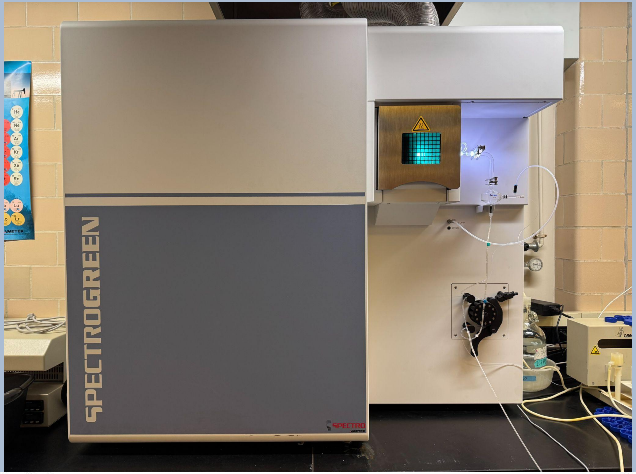


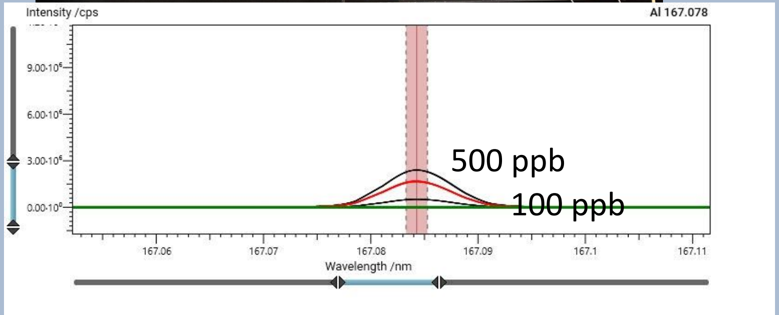


Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)

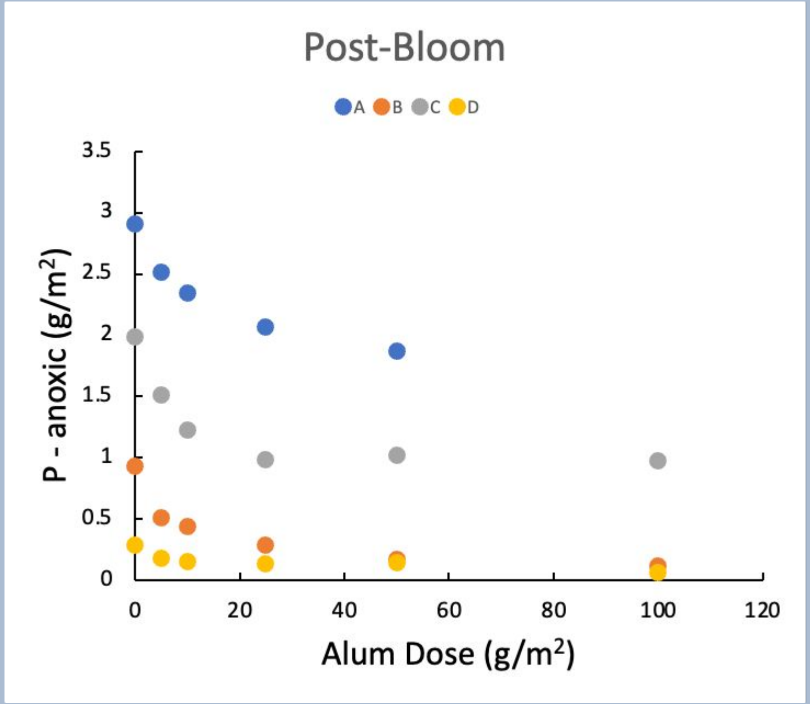
- Analyzes supernatants from the Jar Tests
- Determines concentrations of elements



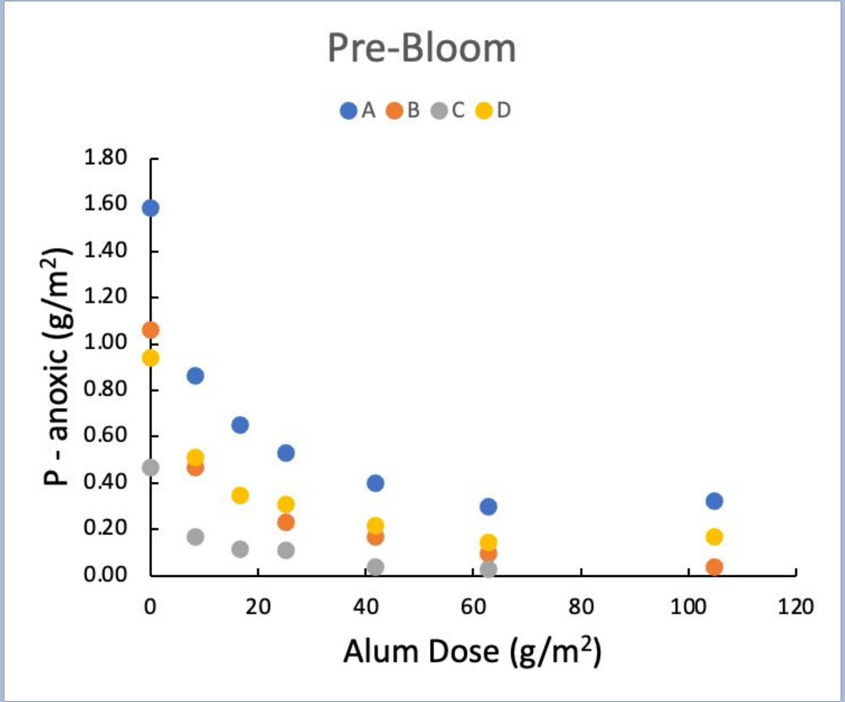




Pre- and Post-Bloom Phosphorus Sequestration



2023



2025

Conclusion

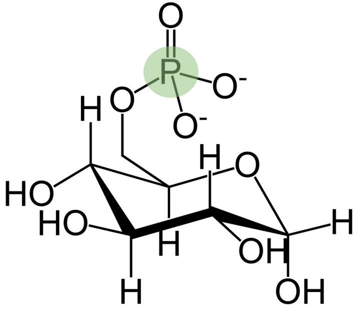
- Higher percent phosphorus sequestration pre-bloom

- Timing of alum treatment matters

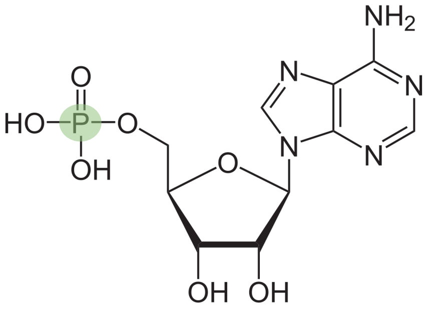
Phosphorus Speciation in Lake Sediment Extracts of North Pond

Elisa M. Arteaga ‘26, Casey O’Connor, D. Whitney King

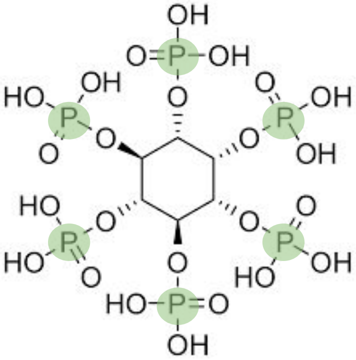
Common Phosphate-Containing Organic Molecules



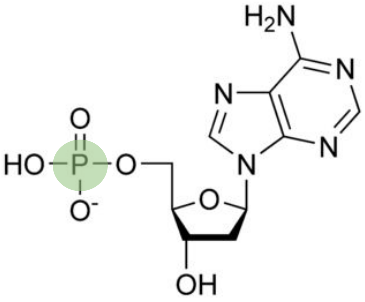
Glucose-6-phosphate



Adenosine monophosphate



Phytic acid



Nucleotide (DNA subunit)

^{31}P Nuclear Magnetic Resonance (NMR) Spectroscopy

- NMR spectrometer has a magnetic field strength hundreds of thousands times the Earth's
  - Aligns nuclei with its magnetic field
- Uses pulses to temporarily excite nuclei
  - Records resonance after excitation
- Provides unique chemical shifts (ppm) for nuclei of interest
  - Helps characterize molecular environments

Previous Methods

- Involved heating sediment
- Caused phosphate to change forms
- Resulted in artifacts in NMR spectra

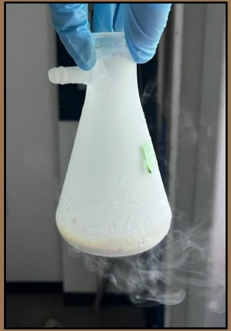
Updated Methods

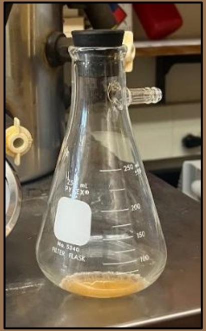
- Involved freeze drying
- Application of a sulfide treatment
- Aim to improve overall NMR spectra quality

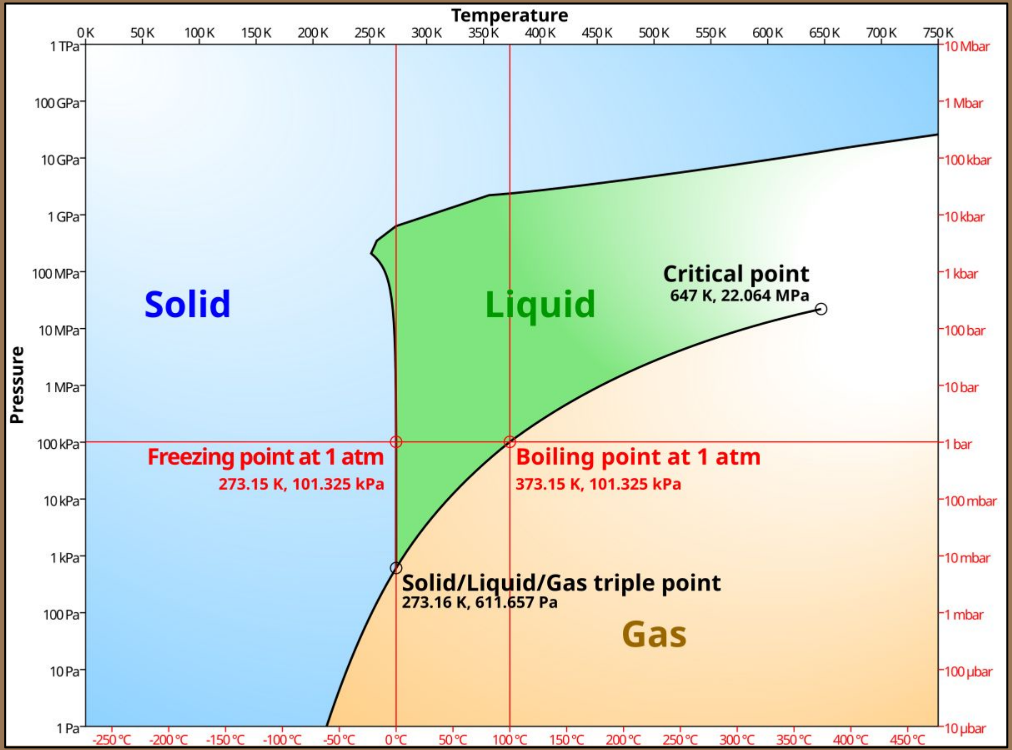
Research Question: How does sediment sample preparation affect the quantification of organic phosphates using ^{31}P NMR spectroscopy?

Lyophilization

- Freeze drying
- Removes water through sublimation (solid to gas)
- Ended up as assisted evaporation but still effective in drying



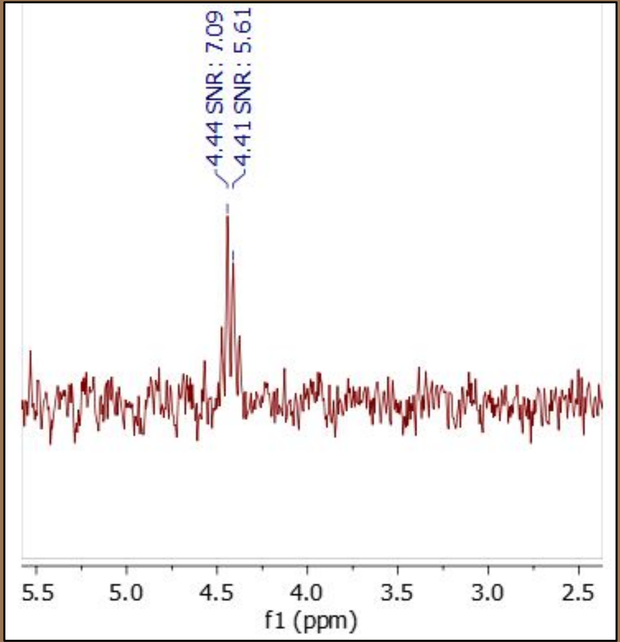




Phase diagram of water

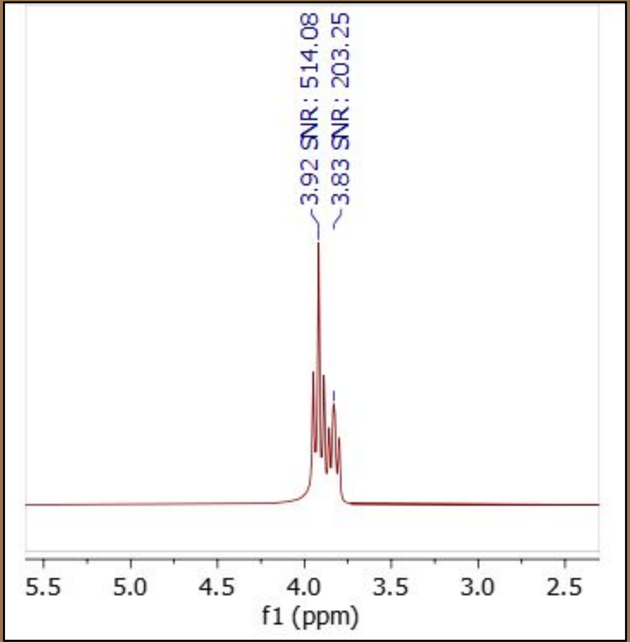
Freeze Drying (Lyophilization) Results

Pre-lyophilization



0.96 mM sample of glucose 6 phosphate prepared in D_2O

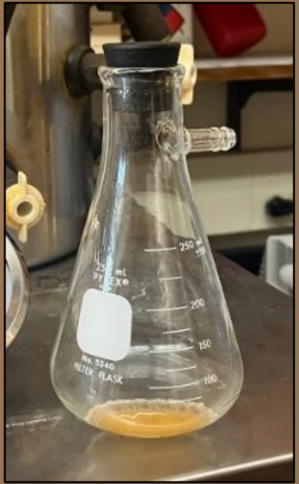
Post-lyophilization



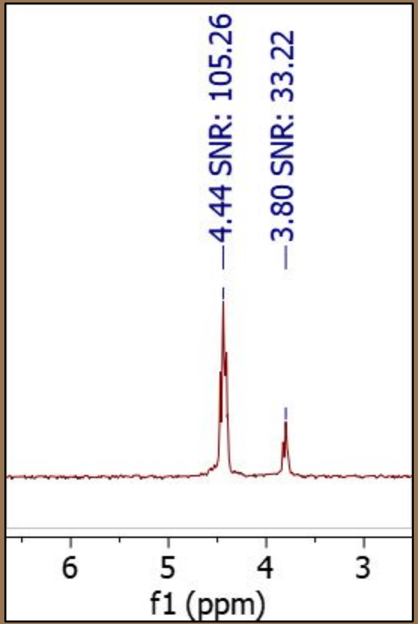
7.70 mM sample of glucose 6 phosphate prepared in D_2O

Iron Removal

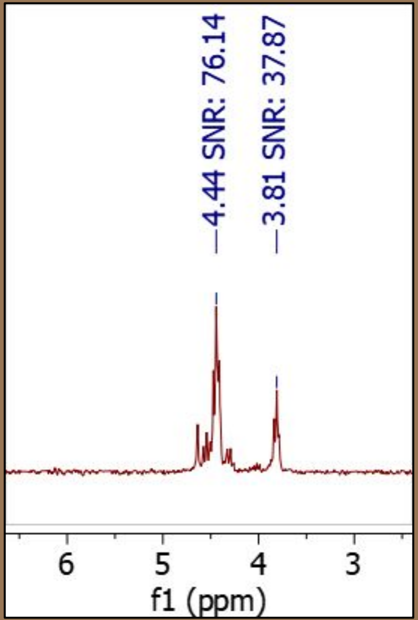
- Iron naturally present in lake sediment
  - Interacts paramagnetically with phosphorus
  - Bad for NMR spectra quality
- Sulfide treatment expected to remove negative effects of iron on ^{31}P NMR



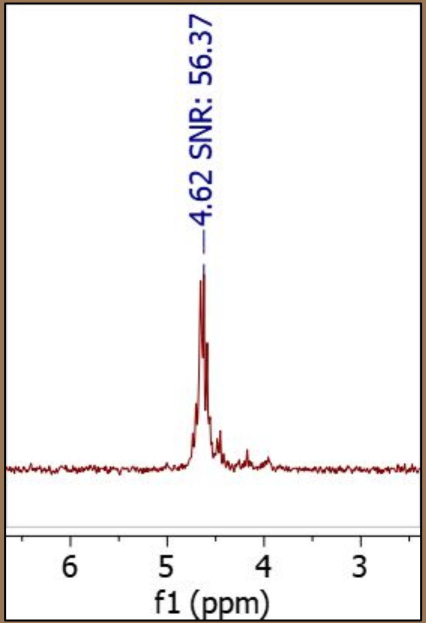
Iron Removal Results



6.2 x 10^{-5} mM $FeCl_3$ and 1 mM G6P solution prepared in D_2O

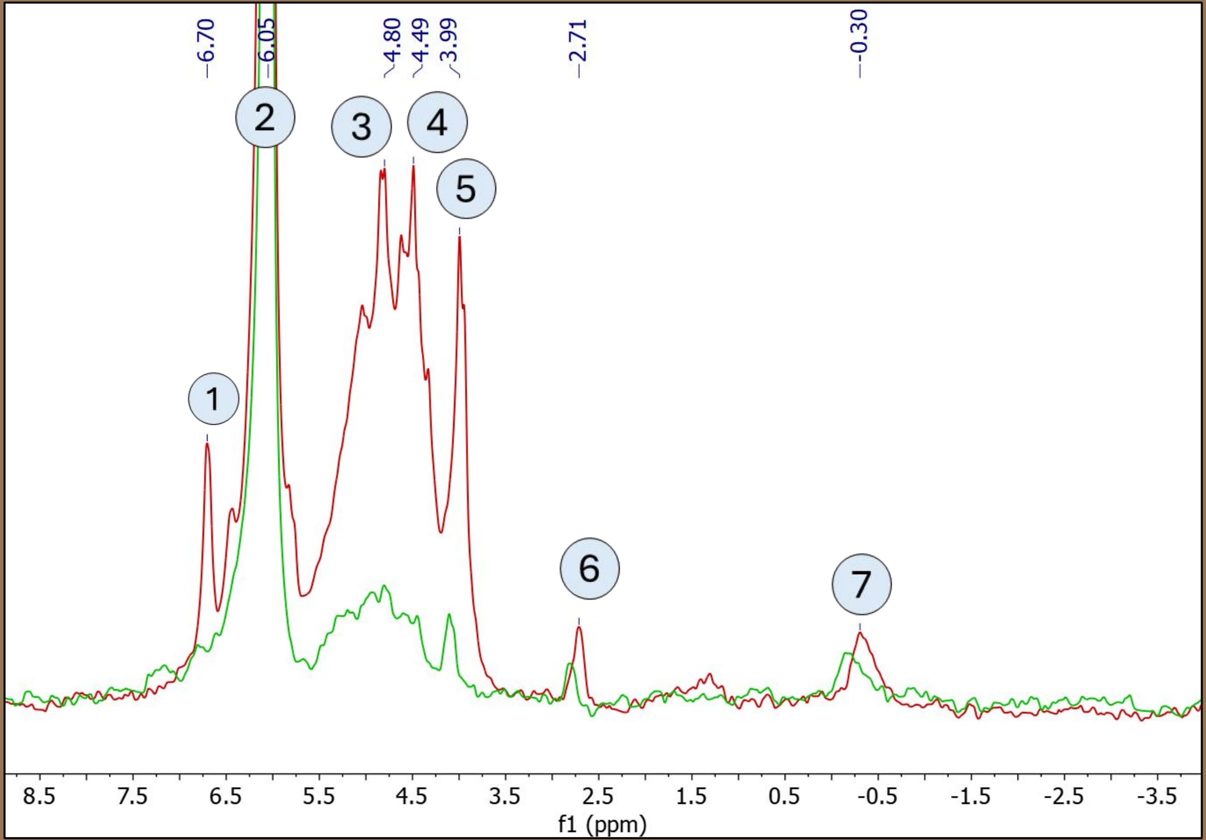


Solution after iron treatment



Treated solution after re-concentrating

Results on Sediment Samples



Tentative ^{31}P NMR Signal Assignments

Peak	Assignment: Previous Methods	Assignment: Updated Methods
1	N/A	Undetermined
2	Orthophosphate (inorganic)	
3	Adenosine monophosphate isomer	
4	N/A	Adenosine monophosphate isomer
5	Choline phosphate	
6	Undetermined	
7	DNA	

Turner, B.; Mahieu, N.; Condron, L.; Phosphorus^{31} Nuclear Magnetic Resonance Spectral Assignments of Phosphorus Compounds in Soil NaOH–EDTA Extracts. *Soil Science Society of America Journal*. 2003, *67*. 10.2136/sssaj2003.0497.

Conclusions and Future Directions

- Able to increase overall ^{31}P NMR spectra quality
  - Reduced line width and increased resolution
- Could identify more forms of organic phosphorus (increased quantification)
- Can apply lyophilization to future sediment samples
- Optimization of sulfide treatment

Creating a Mass Balance for North Pond: A Comprehensive Analysis of Streamwater and Lake Sediment

Cogan Lawler ‘26, Casey O’Connor, Matthew Farragher, D. Whitney King

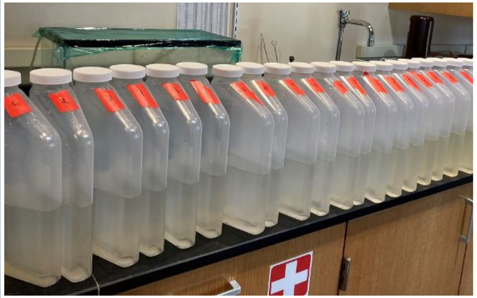
Location – North Pond, Belgrade Lakes, ME

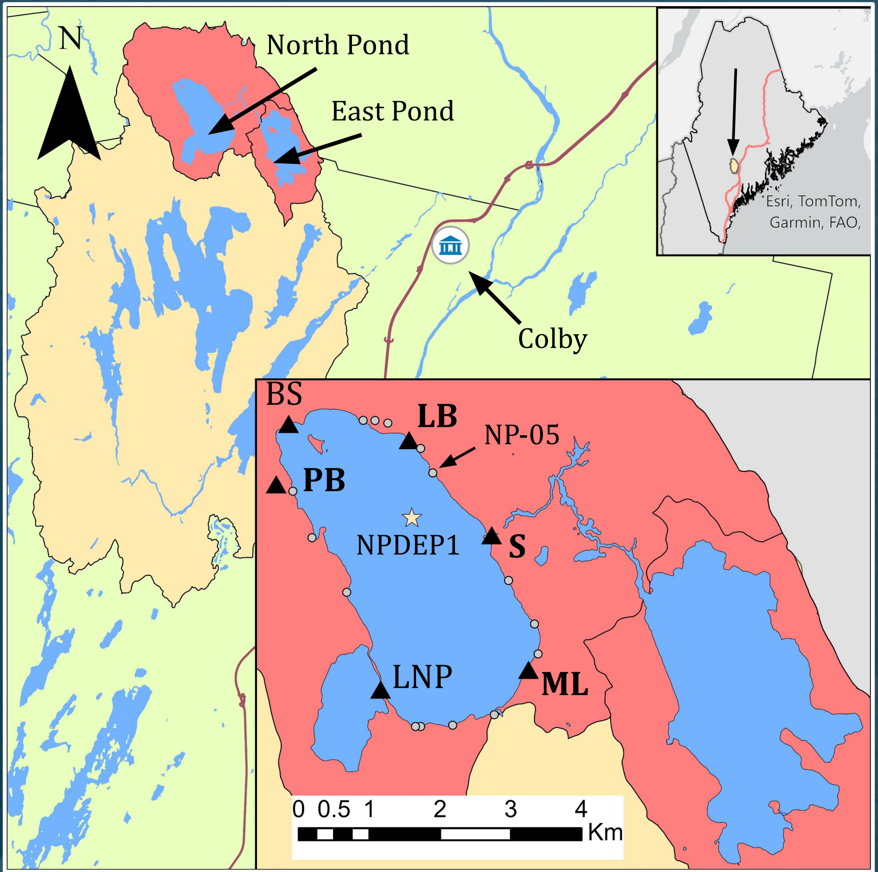
Interconnected lakes and streams

- North Pond: 10.2 km^2, max depth of 5.5m, 34 billion liters of water, 65 km^2 watershed

North Pond's streams: 20+ sites

- 328 stream samples measured so far this year!!
- Sediment: Deep site of North Pond (NPDEP1)





Harmful Algal Blooms

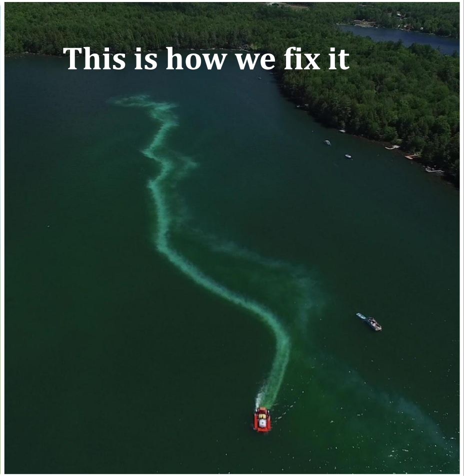
(HABs)

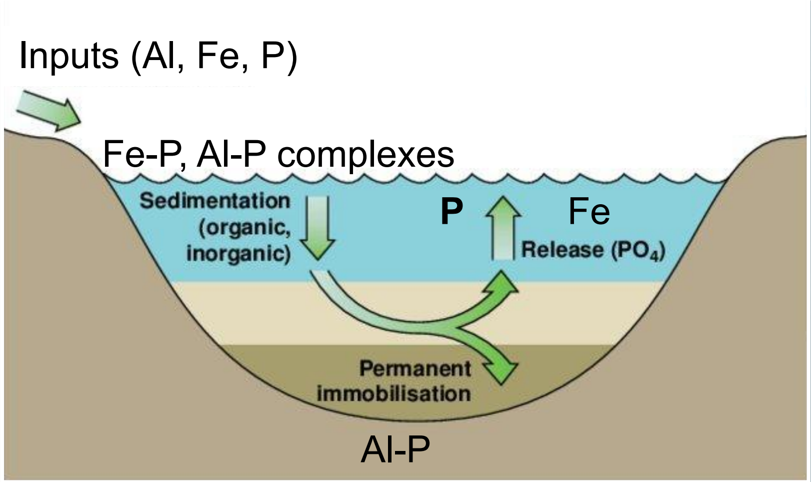
- Rapid proliferation of algae (bloom)
- Biogeochemistry – internal loading

Managing HABs – an interdisciplinary problem

- Al:Fe > 3:1 in lake sediment associated with permanent phosphorus sequestration[1]
    - Al:Fe = 1:1 in North Pond
    - Alum treatment East Pond, 2018

A mass balance helps us identify how much alum and where to add it?



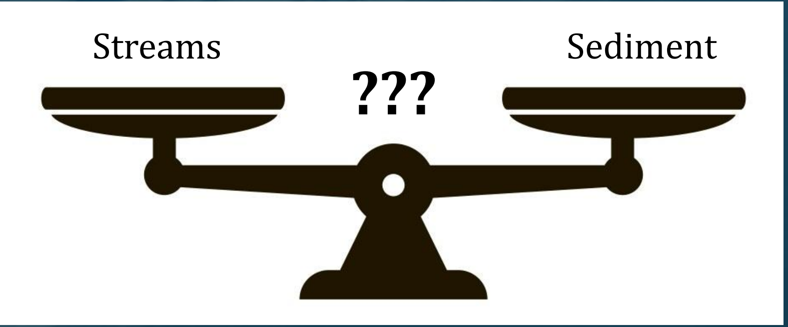


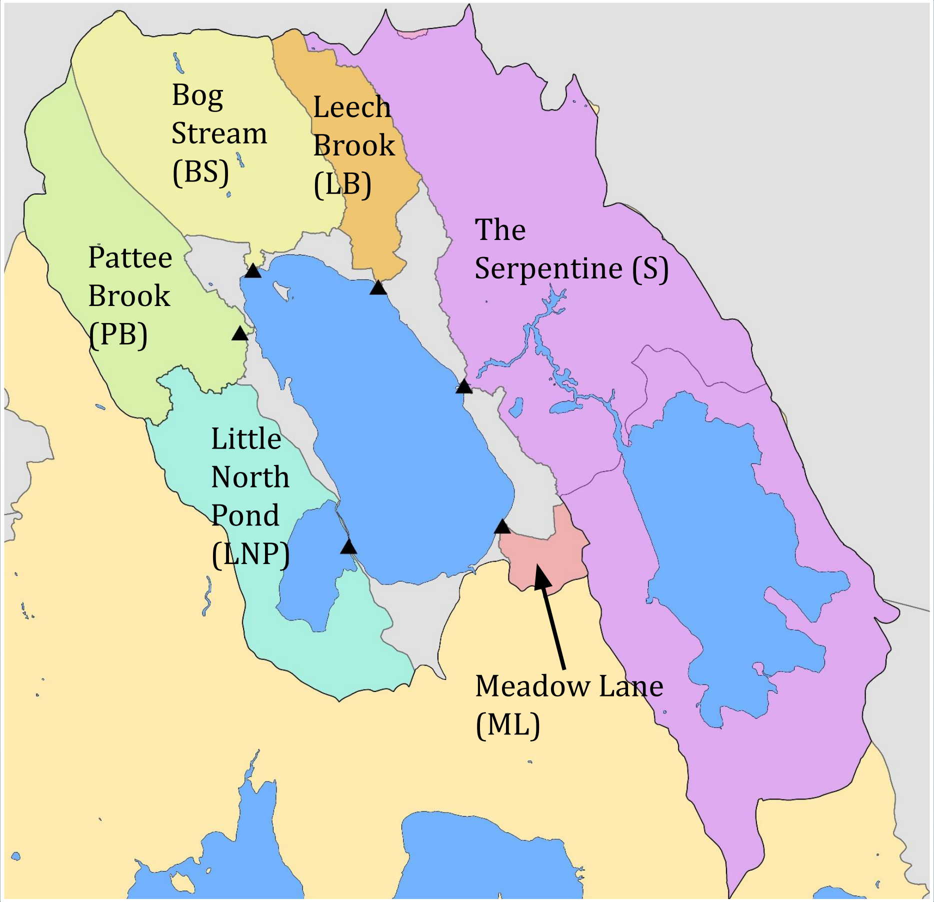
Adapted from: Søndergaard, M.; Jensen, J. P.; Jeppesen, E. Retention and Internal Loading of Phosphorus in Shallow, Eutrophic Lakes. *The Scientific World Journal,* **2001**

1. Aluminum Control of Phosphorus Sorption by Lake Sediments. Kopacek, Borovec, Hejzlar, Ulrich, Norton, Amirbahman. ES&T, 2005.

Research Question(s)

1. **Does the Al, Fe, P that enters the lake from March to July match what is observed in the sediment?**
   - Does the mass balance?
2. **Is there a "point source" for the excess iron in the sediment?**
   - Does one stream input a lot of iron?



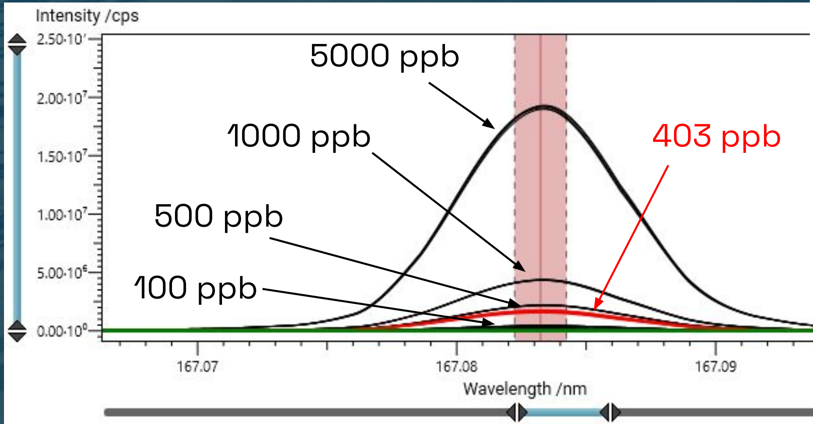


Inductively Coupled Plasma Optical Emission Spectroscopy

(ICP-OES for short)

Emission Spectroscopy measures characteristic emissions

- Like throwing powder into a fire to change its color
  - Intensities indicate concentration (ppb) of a specific element
  - Used to analyze both water (stream) and sediment samples



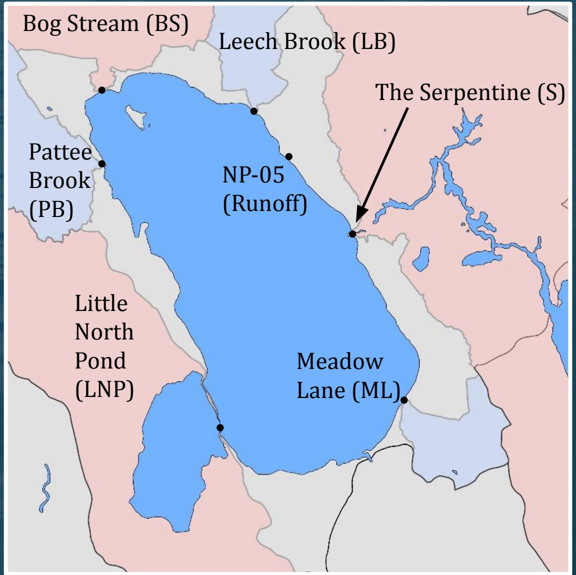
Stream Mass Input

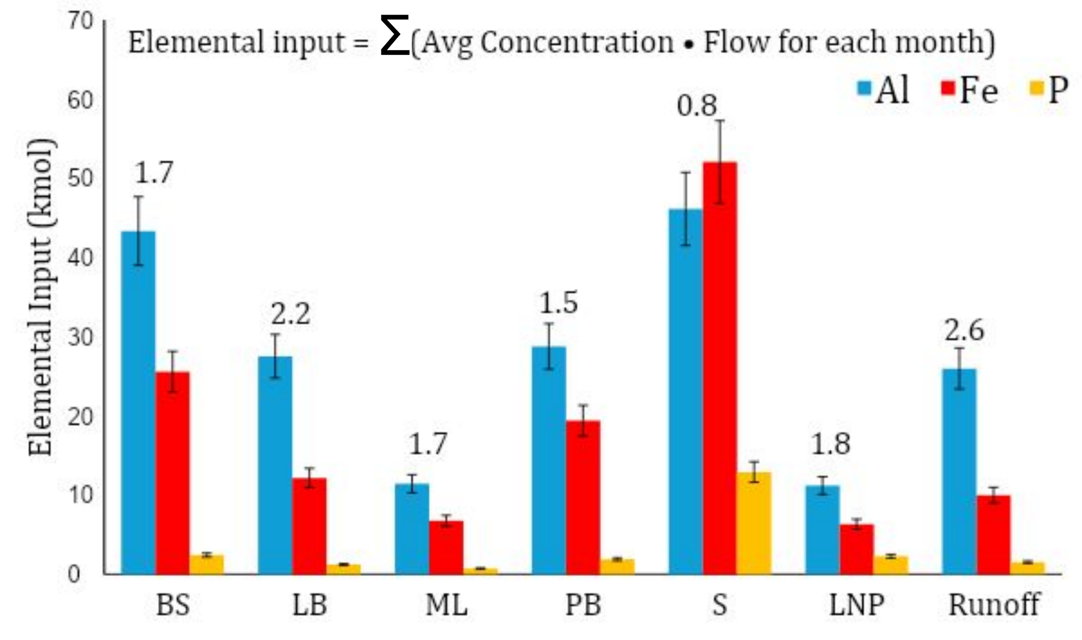
Summed up elemental flows for March-July

- Runoff is approximated by NP-05

Serpentine is interesting!

- Different kinds of inputs





Total Amount (mols)		
Al	Fe	P
$2.0 \cdot 10^5$	$1.3 \cdot 10^5$	$2.3 \cdot 10^4$

Watershed	PB	BS	LB	S	ML	LNP	Runoff
Area (km^2)	6.7	7.8	3.0	33	0.77	6.3	6.8

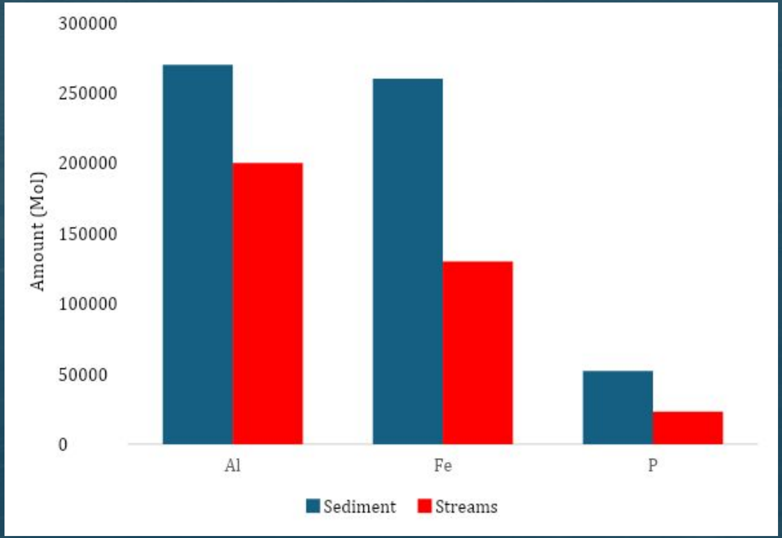
Mass Balance: Sediment vs Streams

Sediment numbers:

- Dry sedimentation rate of 0.03 g/cm^2/year
- **Total Amount** = concentration • sed rate • pond area • 5/12 months (survey time)

- 75% of sediment estimate for Al

- Lower on Fe, P - this is ok



	Al	**Fe**	**P**
Sediment	$2.7 \bullet 10^5$	$2.6 \bullet 10^5$	$5.2 \bullet 10^4$
Streams	$2.0 \bullet 10^5$	$1.3 \bullet 10^5$	$2.3 \bullet 10^4$

Conclusions and Future Directions

Conclusions

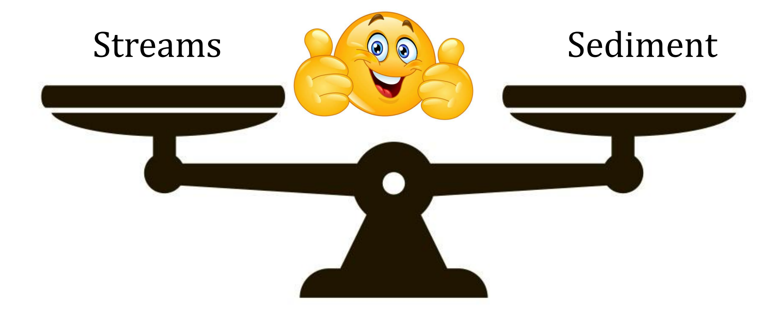
- Al stream vs concentration is pretty good!
- Fe and P are lower than expected in the streams
- Potential Fe point source

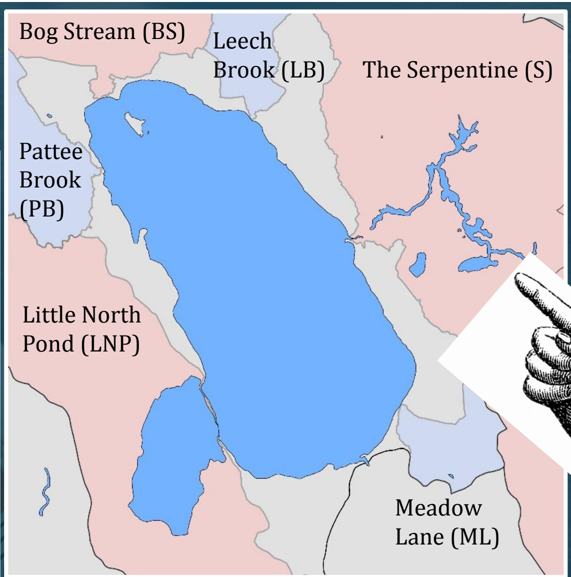
Sources of Error

- Elemental heterogeneity in NP sediment is unclear
- Runoff heterogeneity is also unknown

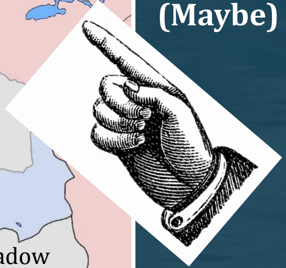
Future Work

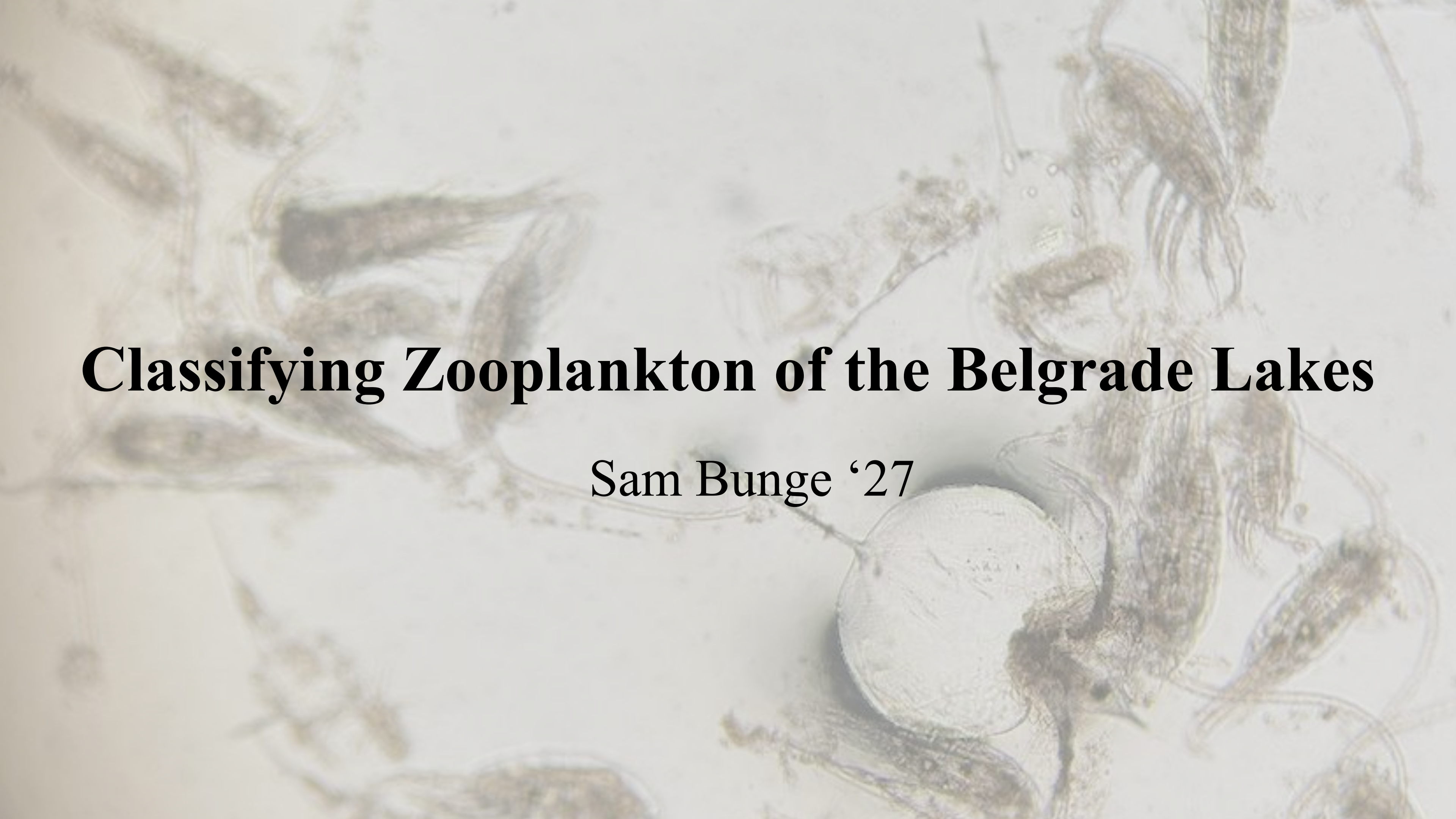
- Year-round stream sampling
- Analysis of additional sediment





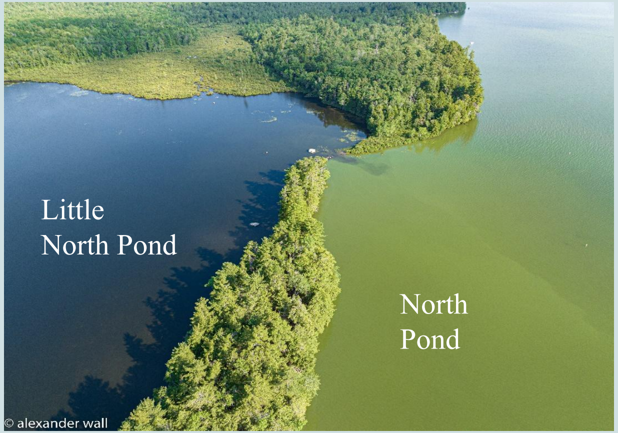
(Maybe)

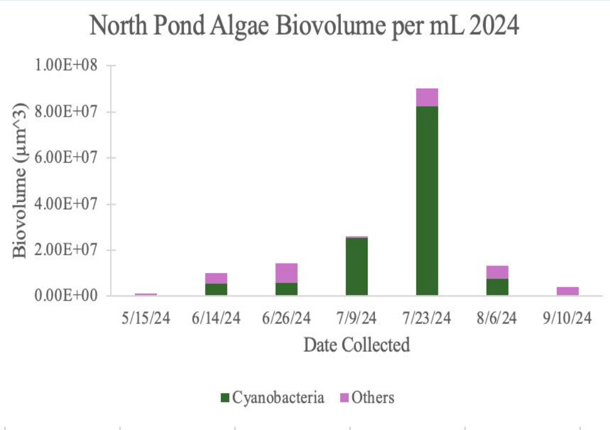


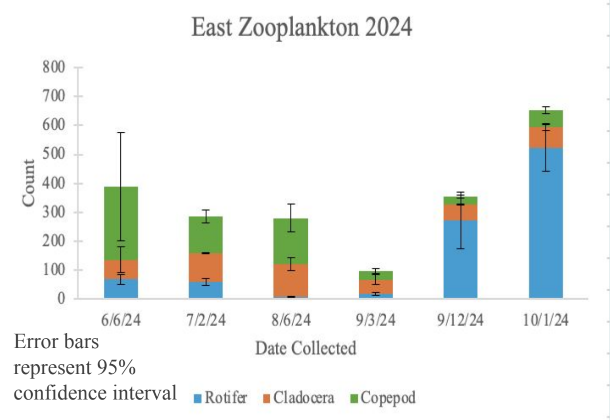


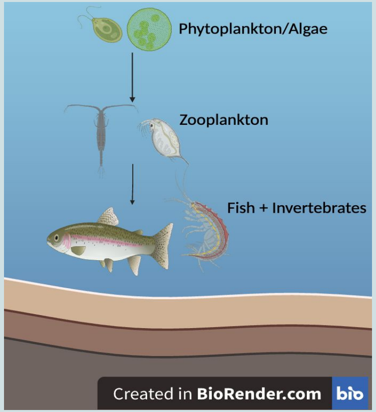
Classifying Zooplankton of the Belgrade Lakes

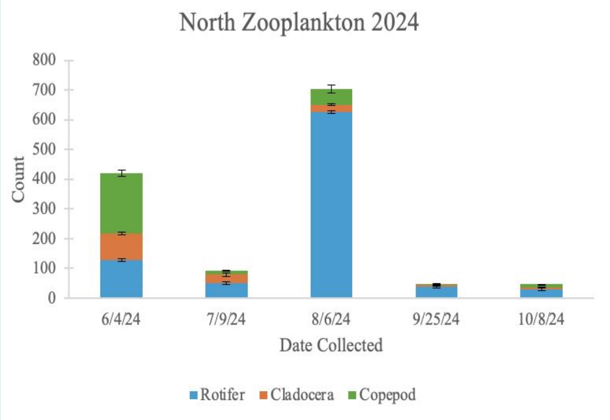
Sam Bunge '27


Little
North Pond
North
Pond
© alexander wall


North Pond Algae Biovolume per mL 2024
Biovolume (µm^3)
1.00E+08
8.00E+07
6.00E+07
4.00E+07
2.00E+07
0.00E+00
5/15/24
6/14/24
6/26/24
7/9/24
7/23/24
8/6/24
9/10/24
Date Collected
Cyanobacteria
Others


East Zooplankton 2024
Count
800
700
600
500
400
300
200
100
0
6/6/24
7/2/24
8/6/24
9/3/24
9/12/24
10/1/24
Date Collected
Error bars
represent 95%
confidence interval
Rotifer
Cladocera
Copepod


Phytoplankton/Algae
Zooplankton
Fish + Invertebrates
Created in BioRender.com


North Zooplankton 2024
Count
800
700
600
500
400
300
200
100
0
6/4/24
7/9/24
8/6/24
9/25/24
10/8/24
Date Collected
Rotifer
Cladocera
Copepod

Monitoring Common Loons on Great Pond and Long Pond in the Belgrade Lakes Region

By Ariana Raschid Farrokhi ‘27 and Makena Logan ‘27

Why Common Loons?

- Species-level climate sensitivity

- Bioaccumulation and Biomagnification: Loons as apex predators
  - Contaminants such as PFAS, lead, and mercury

- Loons as bioindicators of water quality

The Loon Preservation Project

Contributors

- Belgrade Lakes Association
  - BLA Chairman, Loon Preservation Project Board: Dick Greenan
  - Community Volunteers
- Loon Conservation Associates
  - Project Leader: Lee Attix
- Colby College
  - Supervisor: Dr. Cathy Bevier, Department of Biology
  - Student Summer Interns

Mission

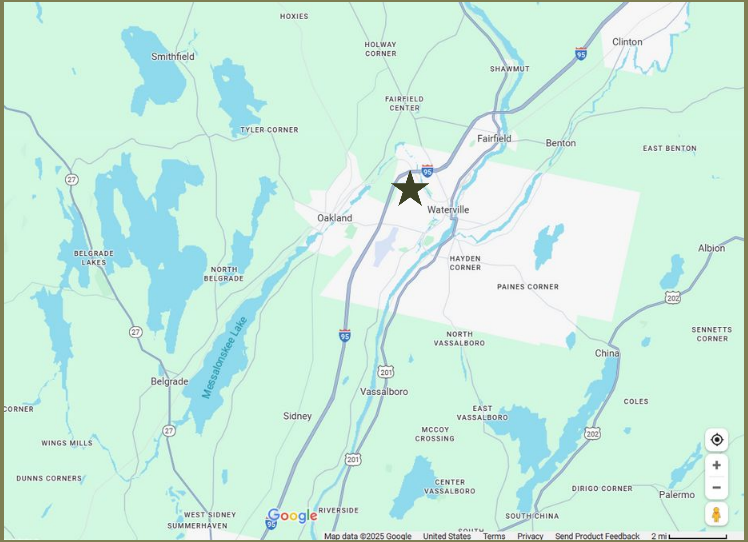
- Monitor Common Loons (*Gavia immer*) on Great and Long Pond in Belgrade, ME
- "Confirm the current population status, identify major threats, and create long-term, sustainable conservation solutions designed to aid the current population"
- "Engaging and educating local volunteers and CC student interns to conduct surveys with professional guidance"

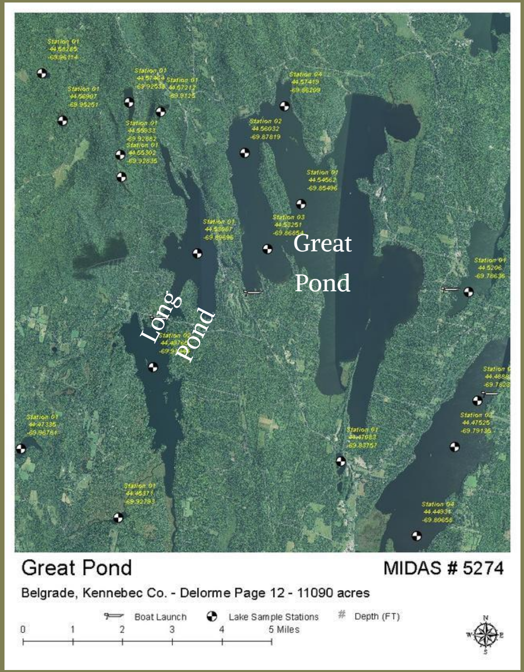
Goal

Determine why the chick survival/overall productivity is low compared to population sustaining average on Great and Long Pond

Study Area

- Great Pond and Long Pond
- Belgrade Lakes Region, Maine





Methods

Data Collection

Typical Week:

- Surveying 28 territories over 2 lakes
- Visiting each territory at least once per week
- Binoculars/visual observation
- Use of motorboat
- Kayaks/canoes for focus areas

Priorities:

- Determining territorial pairs
- Band resighting
- Nest presence/success
- Chick survival

Data Collection cont'd. | Mapping

Specimen Collection:

- Abandoned eggs
- Dead chicks
- Dead adults

Banding:

- Nesting pairs
- Chicks

Key Mapping Updates

- ArcGIS
- Nest coordinates

Community Contributions

Observations:

- Frequent surveys
- Phone calls with nest and chick updates
- Loons in distress

Access to boats:

- Provides opportunities for more in depth surveys

Findings and Conclusions

Current breeding season is not over, so there are no final conclusions. Analysis will be conducted later in the year.

Current Status of Long Pond:

- 8 nests
- 8 chicks hatched from 5 nests
- So far 4 are still alive

Findings and Conclusions

Current status of Great Pond:

- 11 nest
- 8 chicks hatched (potential 9th) from 6 nests
- Currently there are no known alive chicks on Great Pond
- Most likely the year (within the project) with the least chicks surviving

Remaining focus:

- Why is chick survival/overall productivity low on Great Pond and Long Pond?

Thank you!

Loon Conservation Associates

Lee Attix, Dick Greenan, and Cathy Bevier

Volunteers and Community Members on Great and Long Pond!

7 LAKES
BELGRADE LAKES
MAINE

We would like to thank

7 Lakes staff

Colby College staff

Previous Colby students

Volunteer monitors

Lake associations

Supporters!

Colby