Final Abstract

Final Report Approved on November 27, 2024

M.L. 2020 Project Abstract

For the Period Ending June 30, 2024

Project Title: Unprecedented Change Threatens Minnesota's Pristine Lakes

Project Manager: Mark Edlund

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 20a1

Appropriation Amount: $482,000

Amount Spent: $481,243

Amount Remaining: $757

Sound bite of Project Outcomes and Results

We completed a summer of monthly water quality monitoring, a year of continuous buoy and dustfall measurements, and sediment core analysis to study recent unprecedented changes in eight wilderness lakes. We show climate-driven changes in lake behavior are leading to increased incidence of extensive harmful cyanobacterial blooms in mid-depth lakes.

Overall Project Outcome and Results

Ecological changes, including increases in cyanobacteria (blue-green algae), are occurring in our remote northern Minnesota lakes. These changes do not fit the traditional paradigm of nutrient loading and eutrophication and may be the result of recent climate warming or the confounding effects of atmospheric nutrient deposition. Climate change has the potential to severely disrupt Minnesota's aquatic ecosystems directly though changes in temperature and precipitation, indirectly through watershed effects, and in concert with other stressors such as nutrient pollution, invasive species, and land-use change. To explore these drivers, we monitored eight lakes in the Superior National Forest by collecting monthly water quality and atmospheric data and deploying high-resolution buoys to monitor lake temperature from the surface to the lake bottom. We used buoy measurements to assess the thermal structure of the

lakes and determine how often they formed distinct layers based on temperature, known as stratification.

Our novel dataset revealed that mid-depth lakes (5-11 m) are particularly sensitive to nutrient recycling because their temperature profiles continually stratify and mix throughout the summer, which draws nutrients from sediments into the water column. Our project provides a first assessment of the stratification and potential of nutrient recycling in these lakes, highlighting the value in buoy monitoring. Nutrient recycling was significantly higher than atmospheric deposition, indicating that climate-driven temperature changes have a greater effect on nutrient dynamics than external inputs.

Finally, we used climate models to predict how lake temperature would change under future climate scenarios. These climate models, while accurate for very deep and shallow lakes, failed to predict changes in the sensitive mid-depth lakes, suggesting current models may not fully capture climate-driven temperature shifts in these systems. This highlights the need for high-resolution monitoring of mid-depth lakes to refine models and better forecast water quality responses to future climate change.

Project Results Use and Dissemination

Our group spoke within our organizations, introduced the project to government agencies (DNR, USFS, MPCA, BWSR) and stakeholder groups, and maintained a strong social media presence communicating on Twitter and Instagram. We shared findings at the International Conference of Limnology, Conference on Biological Stoichiometry, ASLO, and the MN Water Resouces Conference. We presented our work through outreach at the Science Museum of Minnesota (Water Fest, Fire and Ice). We are preparing manuscripts for publication in scientific journals. The project was highlighted by the press through 2 pieces by MPR and newsletters in the Quetico Superior Wilderness News (see Attachments).

Environment and Natural Resources Trust Fund

M.L. 2020 Approved Final Report

General Information

Date: December 11, 2024

ID Number: 2020-070

Staff Lead: Noah Fribley

Project Title: Unprecedented Change Threatens Minnesota's Pristine Lakes

Project Budget: $600,000

Project Manager Information

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Project Reporting

Final Report Approved: November 27, 2024

Reporting Status: Project Completed

Date of Last Action: November 27, 2024

Project Completion: June 30, 2024

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 20a1

Appropriation Language: The appropriation in Laws 2019, First Special Session chapter 4, article 2, section 2, subdivision 8, paragraph (c), Sauk River Dam Removal and Rock Rapids Replacement, in the amount of $2,768,000, no longer needed for its original purpose is transferred as follows:
(1) $482,000 is transferred to the Science Museum of Minnesota to determine how, when, and why lakes in pristine areas of the state without obvious nutrient loading are experiencing algal blooms;

(d) Transfers and Availability

The transfers under this subdivision are effective June 30, 2021, and the transferred amounts are available until June 30, 2023.

M.L. 2022, Chp. 94, Sec. 2, Subd. 19 Carryforward; Extenstions, (b) The availability of the transfers for the following projects is extended to June 30, 2024: (1) Laws of 2021 First Special Session, chapter 6, article 5, section 2, subdivision 20, paragraph (a), clause (1), Unprecedented Change Threatens Minnesota's Pristine Lakes

Appropriation End Date: June 30, 2024

Narrative

Project Summary: Why are Minnesota's nicest lakes turning green? We determine what's causing this change and which lakes are most at risk.

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Minnesota's most pristine lakes are changing unexpectedly and we don't know why! Where we expect to find hundreds of our most beautiful and remote lakes—with little development or protected within state and national forests and parks—we instead often find green lakes, thick with noxious blooms of cyanobacteria. Lakes turn green when we add nutrients to them, but in protected or remote settings, typical sources of excess nutrients (land use change, erosion, sewage) are not obvious. Based on our work, we predict that climate change is working in concert with atmospheric deposition to drive the changes that have already begun to affect our pristine lakes. Importantly, it is possible that by missing climate and atmospheric effects on lakes we could be misattributing the causes of blooms and misdirecting resource-management efforts and dollars.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We will determine why Minnesota's nicest lakes are unexpectedly turning green using:
1) first of their kind in-lake and atmospheric monitoring systems
2) sediment analysis showing how, when, and why pristine lakes are changing
3) lake simulations determining which lakes are most at risk
4) communication with managers and lake users on how and why nice lakes are changing.

Climate, weather, and atmospheric deposition change everything. Sediment cores from wilderness lakes show two causes of unprecedented noxious algae growth. Climate change results in longer ice-free seasons, stronger stratification, increased tannins, and correlates with alarming increased frequency of noxious algae blooms. In lakes with no watershed runoff we find large increases in mineral matter and greater growth of algae. If that mineral matter and its nutrients did not come from the watershed, it must be coming from dustfall or precipitation.

Nutrients in lakes have many sources—local, regional, global. Climate affects lakes by changing how nutrients are cycled in lakes and watersheds. Elsewhere, long-distance dustfall is linked to dramatic changes in remote lakes. We need to know if our lakes are imperiled by climate and dust-borne nutrients, rule out other causes of wilderness lake change, and not waste management dollars.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The 8 lakes (deep vs shallow lakes, across watershed size, and along an E-W transect) selected for this study will be entirely within northern Minnesota's protected areas, so we can rule out local landuse inputs. Climate change and landuse changes well beyond Minnesota may be working in concert to change our pristine lakes. By linking modern and historical lake ecology, air deposition, and lake simulations, we will solve the unprecedented change question, and determine how to preserve and protect water quality in our pristine lakes. This project will fundamentally change lake management strategies everywhere in Minnesota.

Project Location

What is the best scale for describing where your work will take place?

Region(s): Central, NE, NW,

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Activities and Milestones

Activity 1: Use water and air quality monitoring to assess the cause of changing water quality in our "pristine" lakes

Activity Budget: $228,637

Activity Description:
Water quality in remote lakes is rarely monitored and air quality monitoring in Minnesota does not measure dry deposition (dustfall). We will do high resolution monitoring of water quality for one year on 8 state and national forest and park lakes. We will simultaneously establish a state-of-the-art dustfall network with 4-5 sites in north and central Minnesota in partnership with National Atmospheric Deposition Program (NADP) to measure and map dustfall patterns and nutrient delivery.

Activity Milestones:

Description	Approximate Completion Date
Measure nutrients and algae for one year from 8 remote and wilderness lakes	December 31, 2022
Establish state-of-the-art dustfall monitoring network in north and central Minnesota	January 31, 2023

Activity 2: Use sediment cores to determine if our best lakes are imperiled

Activity Budget: $216,300

Activity Description:
Every lake accumulates sediments that record its history. We will collect sediment cores from 8 remote and protected lakes and determine when and how much they have changed—their biology, nutrient levels, dust inputs—using analysis of multiple biological and geochemical measures. We will reconstruct the influence of climate and dust-borne nutrients through time on each lake to understand why they changed, when they changed, and which lakes are most imperiled.

Activity Milestones:

Description	Approximate Completion Date
Collect, date, and analyze sediment cores from 8 remote lakes	May 31, 2023
Compare climate and dustfall records from cores with monitoring to determine why lakes are changing	May 31, 2023

Activity 3: Use lake simulations to determine which lakes are most at risk and how to protect them

Activity Budget: $37,063

Activity Description:
Computer simulations allow us to understand how lakes have changed in the past and how they might change in the future. MINLAKE is a simulation program that estimates lake thermal and oxygen dynamics. Importantly, input variables in the program let us test interactive effects of other forces that may be affecting our protected lakes such as changing weather patterns and ice-on/off. Model results will be paired with monitoring and sediment core histories to predict which protected lakes are most at risk.

We will spread our findings to help Minnesotans understand what threatens our favorite lakes and how to protect them.

Activity Milestones:

Description	Approximate Completion Date
Create a MINLAKE model for 8 study lakes to measure historical changes in lake function	May 31, 2023
Develop a framework for predicting which protected lakes are at risk	May 31, 2023
Develop reports, factsheets, and outreach to inform managers and Minnesotans on protecting their threatened lakes	June 30, 2023

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
We will develop scientific reports, informational factsheets, and engage social media to inform resource managers and lay-persons on the state and fate of Minnesota's most protected lakes. Edlund and project personnel are periodically invited to give presentations within their organizations, to agencies, at professional meetings, and to outside groups, and they will present this work upon invitation. We will communicate the findings of this study with the public through factsheets, blogs and social media (Twitter and Facebook) accounts associated with the St. Croix Watershed Research Station. We plan on publishing the results of this work as peer-reviewed publications in relevant scientific journals. All dissemination and outreach products will acknowledge ENRTF funding.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
This project establishes a new air-monitoring network, provides the first baseline data on dustfall in northern Minnesota, its effect on our best lakes, and determines which lakes are at risk. This project leverages collaborations with other research groups on dustfall and previous ENRTF and NPS funding on wilderness lakes across northern Minnesota, including the DNR Sentinel Lakes and the NPS Inventory & Monitoring programs. Through reporting, presentations, and outreach, we will spread our findings to help Minnesotans understand what really threatens our favorite lakes and fisheries.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Tracking and Preventing Harmful Algal Blooms	M.L. 2016, Chp. 186, Sec. 2, Subd. 04a	$500,000
Determining Risk of a Toxic Alga in Minnesota Lakes	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 06f	$200,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Edlund, Senior Scientist		Sediment Analysis			45.5%	0.72		$82,453	-	-
Heathcote, Senior Scientist		Water and Air Quality, DNA			45.5%	0.5		$51,464	-	-
Assistant Scientist		Lake Modeling			45.5%	0.3		$27,063	-	-
2 Field and Laboratory Technicians		2 Temporary Field and Laboratory Technicians			45.5%	0.66		$29,961	-	-
Science Communication Specialist		Outreach and Social Media			0%	0.24		$10,000	-	-
Postdoctoral Researcher		Fieldwork, Sediment and water quality analysis			45.5%	1.24		$90,210	-	-
							Sub Total	**$291,151**	**$291,151**	**-**
Contracts and Services										
TBD	Professional or Technical Service Contract	Lab Analysis of Dust Samples: Dust chemistry (mass, P frac, N): 120 samples @ $100 ($12,000; Utah State University or competitive bid)				0		$12,000	$12,000	-
TBD	Professional or Technical Service Contract	Lab Analysis of Pigments Samples: Algal pigment analysis: 80 samples @ $125 ($10,000; University of Regina or competitive bid)				0		$10,000	$10,000	-
TBD	Professional or Technical Service Contract	Lab Analysis of Cyano DNA: 16S sediment DNA sequencing: 8 cores @ $1,250 ($10,000; University of Minnesota or competitive bid)				0		$10,000	$9,304	$696
							Sub Total	**$32,000**	**$31,304**	**$696**
Equipment, Tools, and Supplies										

	Tools and Supplies	Lab / Field Supplies	Bottles, reagents, preservatives, consumables					$6,556	$6,556	-
	Tools and Supplies	Monitoring Buoy Supplies (Qty: 8)	Component sensors for constructing and installing monitoring buoys on lakes					$16,000	$16,000	-
							Sub Total	**$22,556**	**$22,556**	**-**
Capital Expenditures										
		Dust Monitoring, ADS/NTN Atmospheric Deposition Samplers (Qty: 5/$5,000 per)	Dust monitoring, ADS/NTN atmospheric deposition sampling					$25,000	$25,000	-
		YSI EXO Water Quality sonde	measures water quality					$20,000	$20,000	-
							Sub Total	**$45,000**	**$45,000**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**
Travel In Minnesota										
	Miles/ Meals/ Lodging	Atmospheric Monitoring and Network Setup ($2,459), 1 trip, 2 scientists, 6 days, 1,000 miles to north central Minnesota	Atmospheric monitoring and network setup					$2,459	$2,459	-
	Miles/ Meals/ Lodging	Sediment Core Collection ($4,968), 1-2 coring trips, 2-3 field crew, 10 days and 850 miles/trip to northern Minnesota	Sediment core collection					$4,968	$4,907	$61
	Miles/ Meals/ Lodging	Water Quality Monitoring ($19,077), 5 water quality trips, 2-3 field crew, 12 days and 850 miles/trip to northern Minnesota	Water quality monitoring					$10,618	$10,618	-
							Sub Total	**$18,045**	**$17,984**	**$61**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										

							Sub Total	**-**	**-**	**-**
Other Expenses										
		Lab Analysis of Water Samples	Lab analysis of water samples: TN/TP, DIN/SRP, DOC, DIC: 80 samples at $112 per sample ($8960) (unit prices for analysis at SCWRS)					$8,960	$8,960	-
		Lab Analysis of Sediment Samples	Lab analysis of sediment samples: 210-Pb (dating): 8 cores @ $2,400 ($19,200) (unit price for analysis at SCWRS); loss-on-ignition: 8 cores @ $800 ($6,400) (unit price for analysis at SCWRS); biogeochemistry (Sed P, diatoms, BSi): 8 cores @ $4,836 ($38,688) (unit prices for analysis at SCWRS)					$64,288	$64,288	-
							Sub Total	**$73,248**	**$73,248**	**-**
							Grand Total	**$482,000**	**$481,243**	**$757**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
			State Sub Total	**-**	**-**	**-**
Non-State						
In-Kind	All indirect project costs are provided in-kind by the Science Museum of Minnesota (federally negotiated indirect rate of 40.09% on all direct costs = $193,234)	In-kind contribution of indirect costs	Pending	$193,234	$193,234	-
			Non State Sub Total	**$193,234**	**$193,234**	**-**
			Funds Total	**$193,234**	**$193,234**	**-**

Attachments

Required Attachments

Visual Component

File: c99dcd6a-50c.pdf

Alternate Text for Visual Component

Why are Minnesota's nicest lakes turning green? We determine what's causing this change and which lakes are most at risk....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
Institutional Letter of Support, Science Museum of Minnesota	10cae6e3-70d.pdf
Form 990 - Institutional Tax Exempt Form, Science Museum of Minnesota	7177850c-867.pdf
Background Check Certification Form	029bed2a-f70.pdf
Attachment 1 - water monitoring results	c13b408c-a70.pdf
Attachment 2 - atmospheric deposition write up	042bf14a-46b.pdf
Attachment 3 - sediment core geochemical analyses write up	b94420e6-2aa.pdf
Attachment 4 - sediment core diatoms	148613fb-134.pdf
Attachment 5 - sediment core algal pigments	2ff39bba-157.pdf
Attachment 6 - model results	6e0507cc-97e.pdf
Attachment 7 - model results	75acb2a9-c9b.pdf
1.Dissemination - BWSR academy workshop on lake mixing	c3043659-4d6.pdf
2.Dissemination - LoW Forum - mixing regimes and cyanoHABs	a28d513b-180.pdf
3.Dissemination - USFS Aquatics Meeting - historic evidence of blooms in SNF	7b02f99b-97f.pdf
4.Dissemination - Water Resources Conference 2023 presentation - Sediment P	8690e799-d99.pdf
5.Dissemination Media_MPR Quetico	34dc79c3-5f8.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

Modifications include adjusting end date, milestone, and reporting dates to reflect start date in summer 2021 and project length of two years. Scope of project has been adjusted to reflect funding recommendation at $482,000 and two-year project timeline.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

Yes

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the Commissioner's Plan applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Budget • Other • Budget - Capital, Equipment, Tools, and Supplies • Budget - Other	We observed cyanobacterial blooms with toxin concentrations. We request a no-cost amendment to the budget to cover additional genomic analyses on our water and sediment samples to detect cyanobacteria taxa and functional traits that would contribute to nitrogen fixation and toxin production. Covering this metagenomic analyses would include (1) $15764 be moved from the Capital Equipment line to the Lab analysis line and (2) $5100 be moved from the Contract line to the Supplies line.	April 24, 2024	Yes	April 26, 2024
2	Completion Date	Previous Completion Date: 06/30/2023 New Completion Date: 06/30/2024	We need to complete the project as planned.	April 17, 2024	Yes	April 17, 2024

Status Update Reporting

Final Status Update August 14, 2024

Date Submitted: August 30, 2024

Date Approved: October 4, 2024

Overall Update

Our project sought to understand why some of the most pristine lakes in northern Minnesota were unexpectedly turning green. We used a combination of lake monitoring, sediment core analysis, and model simulations to understand whether these lakes are experiencing unprecedented change and how lakes across Minnesota can be protected under future climate scenarios. Specifically, we used water and air quality monitoring to assess water quality and potential for regional inputs of nutrient pollution in pristine, northern lakes. Secondly, we used sediment cores to establish historic changes in the biology and nutrient levels in each lake. Finally, we used lake simulations to determine which lakes are most at risk for water quality impairment and how to best predict and manage them into the future.

We monitored eight lakes within the Superior National Forest for one calendar year between June 2022 - June 2023. Monitoring data were used to quantify the nutrient inputs into each lake (Activity 1). We also used sediment cores to understand how lake nutrient levels and mixing regimes changed over time (Activity 2). Sample data were then used to calibrate lake mixing models that can help us predict how lakes will change in the future (Activity 3).

Activity 1

Understanding change in remote and pristine lakes is limited by the availability of high-resolution data that covers a broad geographic area. In this study, we monitored eight lakes in northeastern Minnesota using high-resolution buoys and established a state-of-the-art dustfall network at four existing air quality monitoring stations. High-resolution buoys collected temperature and oxygen measurements at multiple depths in each study lake every 10 minutes, allowing us to capture the dynamic changes in lake physical structure that drive biological and chemical processes affecting water quality. These novel data indicate that many mid-depth lakes (15-25 ft) lakes form layers of warmer and cooler water, leading to oxygen depletion at the lake bottom. Chemical reactions that occur when water lacks oxygen mobilize nutrients into the water column, fueling algal and toxic cyanobacterial growth (Attachment 1).

Preliminary calculations suggest the nutrients mobilized from the sediments are far greater than the nutrients that are brought in from the air. Airborne, particulate nutrients can be carried from hundreds of miles away; however, our dustfall network captured minor amounts of dust that are dwarfed by the potential mass of nutrients coming from in-lake sediments (Attachment 2).
(This activity marked as complete as of this status update)

Activity 2

Every lake accumulates sediments that record its history. We collected sediment cores from each of the 8 study lakes to determine when and how much they have changed over the last ~150 years. For each lake, we reconstructed the algal ecology using diatoms and algal pigments, nutrient levels, and dust inputs. Diatoms are a beneficial group of algae that are well-preserved in lake sediments and can be used to reconstruct lake conditions that influenced their growth over time. Algal pigments include the relative abundance of major algal groups including diatoms and cyanobacteria.

We found that some lakes were sensitive to changes in climate and nutrient inputs but others have maintained their water quality conditions since pre-industrial times. Lakes that responded to climate and nutrient inputs showed changes in the diatoms that were present over time, shifting from completely mixed and low-nutrient systems to lakes that stratified and higher nitrogen concentrations (Attachment 3). Similarly, algal pigment data show increases in total algal

abundance with parallel increases in both diatom and cyanobacteria abundance. This suggests that these lakes have experienced increased rates of primary productivity since the 1980s, which corresponds with the period of the most rapid warming in Minnesota (Attachment 4).
(This activity marked as complete as of this status update)

Activity 3
Models are an idealized picture of reality – how well these models match (or "fit") actual data can tell us about our ability to predict lake behavior and water quality in the future. We used a combination of five models to simulate lake thermal structure using continuous buoy data, air temperature, and precipitation. We found some lakes fit model simulations well while others did not, suggesting that the assumptions that drive the modeled outcomes are only valid for a portion of Minnesota lakes. Lakes that do not fit these assumptions cannot be modeled well and are therefore at risk for unpredictable future change.

We also used lake modeling to hindcast lake stratification events using historical climate data to help us understand whether lake thermal structure is changing as a result of a changing climate. We used our observed measurements of lake stratification and its relationship to contemporary climate data to model lake stratification using historical climate data. We found that lakes did not show significant changes to their stratification regimes since 1980, indicating that the study lakes were resilient to warming over the last ~40 years (Attachment 5).
(This activity marked as complete as of this status update)

Dissemination
Since March 2024, our group has shared results from this project at the Rainy-Lake of the Woods Watershed Forum, an Indigenous Round Table sponsored by the Science Museum, and the Association for the Sciences of Limnology and Oceanography (ASLO) annual meeting. Each of these presentations shared results and implications for Minnesota lake water quality across a wide audience, from managers at the Watershed Forum, Tribal leaders at the Round Table, and researchers at the ASLO annual meeting. We are also working with the Minnesota Board of Water and Soil Resources (BWSR) to put on a workshop at the upcoming BWSR Academy in October 2024 on the topic of water quality under a changing climate. This workshop will engage lake managers across the state to help manage and mitigate harmful algal blooms under warmer and wetter climate conditions.

We have continued to talk with the public through Science Museum programming, including public museum events, programming for high school student interns, and youth summer camps. We maintain an active social media presence to share our field work and project results. We have written one technical paper aimed at a scientific audience that is in preparation for publication later this summer.

Additional Status Update Reporting

Additional Status Update August 14, 2023

Date Submitted: April 24, 2024

Date Approved: April 26, 2024

Overall Update

Our progress on achieving our outcomes of understanding unprecedented change in northern Minnesota's pristine lakes has been focused on analyzing monitoring and sediment core data to achieve aims set in activities 1 and 2. We completed a summer of monthly water quality monitoring and a year of continuous buoy measurements taken from our 8 sample lakes. We have also collected sediment cores from all lakes and have nearly completed the geochemical analyses necessary to reconstruct historical lake conditions. As part of our monitoring efforts, we observed several, severe cyanobacterial blooms with unexpected toxin concentrations. To explore this further, we request a no-cost amendment to the budget to cover additional genomic analyses on our water and sediment samples to detect cyanobacteria taxa and functional traits that would contribute to nitrogen fixation and toxin production. Covering the this metagenomic analyses would include (1) $15764 be moved from the Capital Equipment line to the Lab analysis line and (2) $5100 be moved from the Contract line to the Supplies line. These additional analyses will help us better understand whether Minnesota's pristine lakes have experienced toxic blooms in the past, provide links to their cause, and help us develop management plans.

Activity 1

Lake sampling was conducted from June-October 2022 and all water chemistry analyses have been completed. Monitoring buoys, deployed in June 2022 to collect continuous temperature and dissolved oxygen data in each sample lake, were retrieved in June 2023. We now have a continuous year of temperature and dissolved oxygen data from vertical profiles of each sample lake which will be used to understand changes in lake thermal structure and primary productivity throughout the monitoring period. To monitor air quality, we established a dry deposition network using four stations within the National Atmospheric Deposition Program in northern Minnesota. These monitoring stations are collecting dry particulate matter from dustfall as well as wet deposition from precipitation monthly for one calendar year. Dry deposition sampling occurred from June 2022-2023. Each monitoring station collected dry deposition during the entire month, so samples represent the total amount of material that was deposited at each station. We expect to begin the analysis of dry deposition samples in spring 2024, once we have organized all the collected material and prioritized analyses based on the total sample mass.

Activity 2

We completed sediment core collection of all eight lakes in September 2023. Sediment cores have been dated using radioisotopes and analyzed for organic and inorganic matter content sediment phosphorus concentrations, and fossil algal pigments. Other analyses include genomic analysis and diatom community change which will be completed by the spring of 2024. We request a no-cost budget amendment to cover additional genomic analyses on water and sediment core samples. The blooms we observed during the summer of 2022 were beyond the expected biomass and toxin levels; therefore, we hope to conduct additional analyses to quantify the historic trends in cyanobacterial abundance, community composition, and functional traits that contribute to bloom dynamics. We request (1) $15764 be moved from the Capital Equipment line to the Lab analysis line and (2) $5100 be moved from the Contract line to the Supplies line. These additional genomic analyses will allow us to conduct qPCR analyses to identify genes related to nitrogen fixation, toxin production, and individual cyanobacteria taxa and will help us understand whether the blooms we observed in 2022 have worsened in the last decade, or if these blooms have been occurring in these remote lakes for centuries.

Activity 3

We have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of project lakes that will be the subject of this lake simulation and modeling activity. We will use our continuous measurements of temperature and dissolved oxygen to help us predict which lakes are most sensitive to bloom formation based on changes to their thermal structure during the monitoring season as well as their historic bloom status and nutrient concentrations, as evidenced through our sediment core analysis. Modeling activities began in the fall of 2023 and will continue through June 2024.

Dissemination

Our group has spoken within our own agencies and organizations, introduced the project to agencies and stakeholder groups, and maintains a strong social media presence to communicate about field work and share photos of project progress on our Twitter and Instagram pages. We have shared preliminary findings at the International Conference of Limnology in August 2022 and the Conference on Biological Stoichiometry in March 2023. We also have presented findings of our work at the Science Museum of Minnesota outreach events, such as the June 2023 “Water Fest” and will be presenting these data at the Association for the Sciences of Limnology and Oceanography Aquatic Sciences meeting in early June 2024. We are currently preparing a manuscript for publication in a scientific journal with an anticipated submission date in April 2024.

Status Update Reporting

Status Update April 1, 2023

Date Submitted: April 24, 2023

Date Approved: April 27, 2023

Overall Update

Our progress on achieving our outcomes of understanding why pristine lakes in northern Minnesota are undergoing unprecedented change continues to be primarily directed at our first two activities . We selected lakes through consultation with state and federal agencies that became the primary monitoring, sediment coring, and lake simulation sites. We completed a year of monitoring those lakes and have collected sediment cores from all of lakes; we will return to the lakes in June 2023 to recover our monitoring buoys. We established and outfitted a new atmospheric dry deposition network in northern Minnesota. With the wrap up of the monitoring portion of the project we move toward data analysis, sediment core analysis, and lake simulation modeling. As these activities continue to progress we will open the door to understanding changes in our lakes and determining how to best preserve and protect these valued Minnesota resources and share that our data and findings with managers, agencies, colleagues, and stakeholders through publication, presentation, media, and outreach.

Activity 1

Lake sampling was conducted through October 2022 and all water chemistry analyses have been completed. Analyses of algal biomass and community composition will be completed by August 2023 using chlorophyll-a concentrations and surface water algal eDNA. Monitoring buoys were deployed in June 2022 and will remain in each sample lake through the spring of 2023 to collect temperature and dissolved oxygen data, which will be used to establish changes in thermal structure and lake productivity. We will be retrieving buoys in June 2023. To monitor air quality, we established a dry deposition network using four sites within the National Atmospheric Deposition Program in northern Minnesota and sampling began in June 2022. These monitoring stations are collecting dry particulate matter from dustfall as well as wet deposition from precipitation monthly for one calendar year. We expect to begin the analysis of dry deposition samples in June 2023, once the sampling period is complete.

Activity 2

We completed sediment core collection of all eight lakes in March 2023. Sediment cores will be dated using radioisotopes and analyzed for historic nutrient concentrations and the change in algal community through time. We anticipate completing sediment core analysis of organic matter burial by August 2023. Other analyses include fossil algal pigments and eDNA, sediment phosphorus concentrations, and diatom community change which will be completed during the winter of 2023-2024.

Activity 3

We have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of project lakes that will be the subject of this lake simulation and modeling activity. Modeling is anticipated to occur during the fall of 2023.

Dissemination

Our group has spoken within our own agencies and organizations, introduced the project to agencies and stakeholder groups, and coordinated with all project partners to discuss sampling strategy, lake selection, and monitoring protocols. We have also maintained a strong social media presence to communicate about field work and share photos of project progress on our Twitter and Instagram pages. We have shared preliminary findings at the International Conference of Limnology in August 2022 and the Conference on Biological Stoichiometry in March 2023. We are currently preparing a manuscript for publication in a scientific journal with an anticipated submission date of June 2023.

Status Update Reporting

Status Update October 1, 2022

Date Submitted: October 14, 2022

Date Approved: October 17, 2022

Overall Update
Progress to date on achieving our outcome of understanding why pristine lakes in northern Minnesota are undergoing unprecedented change has been directed at our first two activities. We have selected lakes through consultation with state and federal agencies that will be the primary monitoring, sediment coring, and lake simulation sites. We have nearly completed a year of monitoring those lakes and have collected sediment cores from a subset of lakes. We have also established and outfitted a new atmospheric dry deposition network in northern Minnesota. As these activities continue to progress we will open the door to understanding changes in our lakes and determining how to best preserve and protect these valued Minnesota resources.

Activity 1
Lake sampling began in June 2022 and will continue monthly through October 2022. Monitoring buoys were deployed in June and will remain in each sample lake through the winter and spring of 2023 to collect temperature and dissolved oxygen data which will be used to establish changes in thermal structure and lake productivity. We expect to analyze water quality samples by March 2023. To monitor air quality, we established a dry deposition network using four sites within the National Atmospheric Deposition Program in northern Minnesota and sampling began in June 2022. These monitoring stations are collecting dry particulate matter from dustfall as well as wet deposition from precipitation monthly for one calendar year. We expect to begin the analysis of dry deposition samples in November 2022.

Activity 2
We have taken half of the sediment cores and we plan to collect the other half during the winter of 2023. Analysis of collected cores began immediately with subsamping for radioisotopic dating, geochemistry, and biological signatures of lake change. All sediment cores will be dated and analyzed for historic nutrient concentrations and the change in algal community through time.

Activity 3
We have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of project lakes that will be the subject of this lake simulation and modeling activity. Modeling is anticipated to being in Year 2 of the project following our summer/fall sampling of each lake in 2022.

Dissemination
Our group has spoken within our own agencies and organizations, introduced the project to agencies and stakeholder groups, and coordinated with all project partners to discuss sampling strategy, lake selection, and monitoring protocols. We have also maintained a strong social media presence to communicate about field work and share photos of project progress on our Twitter and Instagram pages. We have shared preliminary findings at the International Conference of Limnology in August 2022 and will prepare a manuscript for publication in a scientific journal this winter. In all dissemination efforts, we acknowledge the ENTRF and LCCMR for their support.

Status Update Reporting

Status Update April 1, 2022

Date Submitted: May 19, 2022

Date Approved: May 23, 2022

Overall Update
Progress on achieving our outcomes of understanding why pristine lakes in northern Minnesota are undergoing unprecedented change has been directed at our first two activities. We have selected lakes through consultation with state and federal agencies that will be the primary monitoring, sediment coring, and lake simulation sites. We have also established and outfitted a new atmospheric dry deposition network in northern Minnesota. As these activities go on-line we will open the door to understanding changes in our lakes and determining how to best preserve and protect these valued Minnesota resources.

Activity 1
Progress on air and water quality monitoring has been directed at lake selection and establishing the air monitoring network throughout northern Minnesota. For water quality monitoring, we have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of lakes for monitoring from across northern Minnesota and including a range of shallow vs deep and lakes that have and have not experienced cyanobacterial blooms. Sampling of lakes and monitoring buoy deployment will begin in June 2022. We have further added staff (postdoc and lab tech) to assist with project coordination, field sampling, and laboratory analyses. Monitoring staff of NADP sites in northern Minnesota have been contacted to establish Minnesota's first atmospheric dry deposition network. All sites have been provided with standardized protocols, sampling buckets that are compatible with existing deposition samplers or been provided dry deposition samplers for deployment. We anticipate that dry deposition sampling will begin in spring 2022.

Activity 2
We have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of lakes for sampling and sediment core recovery. These lakes will begin to be sampled and have sediment cores recovered in June 2022 in conjunction with our monitoring buoy deployment. Toward these goals we have staffed up the lab (postdoc, lab tech) in anticipation of full field seasons and to assist with lab analyses.

Activity 3
We have met with agency representatives from DNR, USFS, and MPCA to develop a priority list of project lakes that will be the subject of this lake simulation and modeling activity. Modeling is anticipated to occur in Year 2 of the project following our initial visits to each lake in spring 2022.

Dissemination
Our group has spoken within our own agencies and organizations, introduced the project to agencies and stakeholder groups, and coordinated with all project partners to discuss sampling strategy, lake selection, and monitoring protocols.