**Limnology & Oceanography Research Exchange (LOREX) Application**

**Project Title:** Investigating the relationship between methane production and flux through space and time  
**Student Name and Email:** Jessica Briggs, jtbriggs@wisc.edu

**Current Institution:** University of Wisconsin-Madison, Center for Limnology  
**Program (MS, PhD, other) and Year in Program:** PhD Candidate, 3rd year  
**Advisor(s) Name:** Dr. Grace Wilkinson  
**Thesis Title:** Investigating carbon and nutrient cycling in hypereutrophic aquatic ecosystems

**ASLO Member ID:** 14480

**Potential exchange site and collaborator:** University of Québec at Montréal Dr. Yves Prairie & Dr. Paul del Giorgio

**Abstract:**

Inland waters are substantial contributors of methane to the atmosphere. Methane flux is challenging to quantify as a large portion of emissions are from ebullition which is highly heterogenous in space and time. As a result, the understanding of if and how methane production in sediments is related temporally to when methane is emitted is not well understood. I will investigate these dynamics in two lakes of different trophic status, one in Montreal, Canada and one in Wisconsin, USA, by deploying automated bubble traps to capture high frequency flux measurements paired with frequent sediment production assays and passive-diffusion pore water samplers (peepers) at multiple locations around the lakes. These data will provide paired production and flux rate measurements, used to assess how these processes couple or decouple depending on lake conditions. We expect that ebullition will be more strongly related to production rates, but that the temporal coupling will be disrupted by events like water movement and wind disturbance.

**Keywords:** methane, ebullition, bubble traps, sediment, temporal dynamics
Project Description:

Background

Inland waters are important contributors of greenhouse gases to the atmosphere (Tranvik et al. 2009; DelSontro et al. 2018; Rosentreter et al. 2021). In particular, the release of methane (CH₄) from aquatic ecosystems is substantial, accounting for 75% of total radiative forcing contributed by waterbodies (DelSontro et al. 2018). Methane is emitted through two dominant pathways, diffusive evasion of CH₄ that evades oxidation in the oxic portion of a water column and ebullitive flux through bubbles that quickly travel to the surface and into the atmosphere (Bastviken et al. 2004). Despite its importance to global C budgeting, the shorter-term temporal dynamics of CH₄ emissions from inland waters are poorly understood, in part due to the challenging nature of understanding ebullitive flux and its drivers.

Comparatively, small, shallow, productive inland waterbodies, which are the focus of my dissertation research, have the highest CH₄ flux rates and disproportionately contribute to regional C emissions given their size (DelSontro et al. 2018). These ecosystems act as carbon processing hot spots in the landscape, accepting materials from their watersheds, transforming them, and emitting them to the atmosphere or exporting them downstream (McClain et al. 2003). However, these processes are not happening at constant rates due to variation in drivers within and among ecosystems. Much of my work focuses on urban ponds, ecosystems which have low residence time, large and fast changes in water level, and frequent flushing of materials into and out of the basins. In ecosystems like these, hydrology is likely a key control of carbon processing. Nutrient concentrations and resulting productivity can vary over time as well, changing both at long time scales with eutrophication and short time scales through nutrient loading from storms. Both hydrology and nutrient variability mediate hot spots and moments of productivity, which may be linked to CH₄ production in the sediments and subsequent emissions.

A major pathway of CH₄ production in aquatic ecosystems occurs in anoxic sediments as the product of anaerobic decomposition carried out by microbes. Organic matter (OM) availability is an important driver of CH₄ production in aquatic ecosystems, with greater quantities of OM and presence of more simple, labile compounds increasing methanogenesis rates (West et al. 2012, 2015; Bertolet et al. 2022). Eutrophic water bodies generally have higher rates of CH₄ production, due to their comparatively large stores of autochthonous, labile OM and frequent anoxia of the bottom waters (West et al. 2016). Temperature is also a major driver of methanogenesis rates, with increasing temperatures resulting in increased production rates if there is available substrate (Thanh Duc et al. 2010). In a multi-lake survey, production rates were found to have no relationship with diffusive flux but a strong positive relationship with ebullitive flux (West et al. 2016). However, it is unknown if and how these relationships persist or change when considering a single water body over time.

Diffusive flux rates depend on the concentration of dissolved gas in the surface waters and the amount of turbulence throughout the water column. These fluxes are usually measured using flux chambers or calculated using surface water gas concentrations (e.g. Kling et al. 1992; Rasilo et al. 2015). Ebullitive flux rates are highly variable in space and time, being reliant of when bubbles are released from the sediments. This is driven by not only the production rates, but also the depth of overlying water, changes in pressure or temperature, and sediment disturbances (Varadharajan and Hemond 2012; West et al. 2016; Tušer et al. 2017). As such, these fluxes are also more challenging to measure, requiring a high spatial density and frequent sampling to capture dynamics representative of an ecosystem. Bubble traps are most commonly used to measure ebullition but require longer (>1 day) deployment times than flux chambers which can make high frequency measurements challenging. However, recent innovations in creating high frequency autosamplers increase the ability of investigators to understand the dynamics of ebullitive fluxes.
If I am selected for the LOREX program, I will join a new ebullition project where we will pair measurement of CH$_4$ fluxes using new technology with those of sediment CH$_4$ production to understand how these processes relate through space and time. As flux dynamics are dependent on ecosystem productivity, these measurements will be compared between two shallow lakes, one oligotrophic near Montréal, Canada and one hypereutrophic in Wisconsin, USA. As part of my dissertation research, I am investigating the temporal dynamics of CH$_4$ production and diffusive flux in response to storm events, which alter the organic matter, and CH$_4$ production substrate, pool (Sadro and Melack 2012; Xenopoulos et al. 2021). However, we are not currently capturing ebullitive flux, which is known to be an important emission pathway particularly in shallow, productive water bodies (West et al. 2016). This proposed exchange will allow for training in methods of measurement of ebullitive fluxes and increased understanding of how ebullition rates are related to sediment production processes temporally. This work will not only contribute to my dissertation research, but also at a broader scale allow for more accurate upscaling of CH$_4$ effluxes from inland waters.

**Research Question:** What are the control points of the relationship between sediment CH$_4$ production rates and flux rates through space and time?

**Hypothesis:** Diffusive CH$_4$ flux rates will have a weaker relationship with sediment production rates than ebullitive flux rates due to oxidation of CH$_4$ in the water column before emission. Ebullition rates will more strongly relate to production rates in shallow, more eutrophic ecosystems. Ebullition will decouple from production during periods of disturbance such as large changes in water level or high winds.

**Methods**

Sampling will occur on two shallow lakes, Lac Cromwell at the Biology Station of the Laurentides near Montreal, Quebec, Canada and Stricker’s Pond in Madison, Wisconsin, USA. Both lakes have a surface area of approximately 10 ha and mean depths of 3.5 and 1 m respectively. While similar in size the lakes vary drastically in nutrient concentrations, with Lac Cromwell having an average total phosphorus concentration around 7.6 μg/L (DelSontro et al. 2016) and Stricker’s Pond around 450 μg/L. Lac Cromwell is a small (0.1 km$^2$) Canadian shield lake, with a residence time of 0.06 years (den Heyer and Kalff 1998). Stricker’s Pond is a naturally formed kettle basin of similar surface area (0.09 km$^2$) that has been retrofitted to accept stormwater inputs.

To measure ebullitive flux, we will deploy high frequency ebullition samplers on the lakes for a one-month span. Traditionally, ebullition measurements are made by deploying bubble traps under the water surface for several days, then measuring the volume of gas released and the concentration of CH$_4$ in that gas. These automated samplers improve on this design by providing continuous information on the volume and gas concentrations of individual bubbling events, allowing for a much finer resolution study of the ebullitive process. Samplers will be deployed at multiple locations around the lake, capturing flux across the range of present water depths and regions of the lake as littoral, shallow portions of the water column are known to experience higher rates of ebullition (West et al. 2016). Passive-diffusion pore water samplers, or peepers, will also be deployed at each location to measure the vertical gradients in sediment pore water CH$_4$ concentrations. A chain of temperature sensors will also be deployed in the deepest point of each lake to understand stratification dynamics. Water level will be measured in each lake for the duration of the study period.

Water column CH$_4$ concentrations for calculation of diffusive flux will be measured using the headspace equilibration technique (Kling et al. 1992). For each sample, 30 mL of surface water and 30 mL of atmosphere will be collected in a gas tight syringe and equilibrated through shaking for two minutes. Air samples for the atmospheric concentration of CH$_4$ will be collected once per sampling day. Samples will be stored in evacuated exetainers until analysis.
Methanogenesis potential will be measured by combining 20 mL of surface sediment and 20 mL of water collected 0.25 m above the sediment-water interface (collected using a Van Dorn sampler) in a gas tight Wheaton media bottle (West et al. 2016). Headspace is flushed with N₂ for 15 minutes to recreate an anoxic environment. Bottles are then incubated in ambient conditions for 24 hours. Headspace samples for produced CH₄ will be collected at 2 and 24 hours.

Sampling will occur first at Lac Cromwell in Summer 2024, then in Stricker’s Pond in Fall 2024 or Summer 2025 depending on the timing of exchange. By sampling first in Montréal, I will have a chance to learn techniques and operation protocol of the automated samplers before deploying the same methods in the Madison study system.

Feasibility and Project Plan
Half of this project will occur during the 4-6 week exchange period if funded by the LOREX program. This period will include a preliminary week of learning instrument care and protocols before beginning field work at the field station. The University of Montréal’s Station de biologie des Laurentides, a long-standing research site of Dr. del Giorgio and Dr. Prairie, has infrastructure available both in terms of laboratory space and accommodation. Existing grant funds at UW-Madison are available to fund necessary research materials. Collaborators will meet periodically throughout the spring to solidify sampling designs and timeline. Following successful completion of the field campaign, collaboration will continue to meet remotely to analyze the data and prepare the project for publication.

Dissemination of Results
This work will be shared with the broader community through presentation at an ASLO Aquatic Sciences Meeting and publishing by team members in a peer reviewed journal. Experiences will also be shared through LOREX media such as blog and social media posts.
Project Justification

The proposed research with Dr. del Giorgio and Dr. Prairie will provide opportunities for me to grow as a scientist. My research interests are biogeochemical cycling in aquatic ecosystems and its controls and consequences at an ecosystem scale. This exchange would allow me to learn new methods and ideas in collaboration with leading experts in aquatic carbon cycling. Not only would I be learning skills that are new to me, but also methods that are new to the field. The research groups I propose to visit at the University of Québec at Montréal (UQAM) are piloting new technologies to increase our understanding of greenhouse gas emissions from water bodies, which they plan to publish and share with the wider scientific community. Having the opportunity to work directly with those who designed this new equipment will not only allow me to learn about operation and best practices from experts, but also gain understanding about the process of designing environmental sensors. Much of my dissertation field work occurs in highly productive, shallow, urban water bodies. The Canadian field component of the proposed research will give me a chance to work in an oligotrophic, forested lake very different from my own study systems. This dichotomy will also complement existing questions in my dissertation aiming to understand how and why ecosystems across a gradient of nutrient enrichment function differently. Upon return to Madison, I will instrument my own study systems with these methods. While I have done a lot of work with greenhouse gas production assays and surface water samples, we have not yet been able to incorporate measures of ebullition. As our systems are shallow and productive, ebullition is likely to be a significant contributor to total methane flux to the atmosphere. In addition to or in synergy with the planned field work in this proposal, these new methods will enable me to incorporate measures of ebullitive flux into my dissertation research. After having learned from the experts and implemented these new methods in Madison, I can then share what I’ve learned with the community at my home institution and open new opportunities for collaboration.

In addition to the technical skills I will learn with Dr. del Giorgio and Dr. Prairie’s groups, there are many other benefits to working in an international research group. Both collaborators are a part of the Interuniversity Research Group in Limnology (GRIL), one of the largest conglomerates of limnologists working collaboratively in the world. This means in addition to the communities of scientists I will meet in the del Giorgio and Prairie labs and at UQAM, I will also meet and network with other scientists in the larger group. I will also have the opportunity to stay at the University of Montréal’s Station de biologie des Laurentides. Since my study systems in Madison are local, this will be my first experience living and working at a field station. This is an important context for environmental researchers to understand, and will provide me useful perspectives when becoming a principal investigator myself. In the future, I would like to work for a governmental or nonprofit organization working on research questions that shape the management of water quality. I am very interested in working in either the Great Lakes or Chesapeake Bay regions. Both of these areas experience a similar challenge – working with individuals or organizations in different states or countries. The experience in international collaboration I would gain through the LOREX program would make me more prepared to work in these highly collaborative and connected environments.
References
December 29, 2023

Dear Review Committee –

I am writing to express enthusiastic support for Jess Briggs’ participation in the LOREX program. Jess is a third year PhD candidate in my research group in the Center for Limnology at the University of Wisconsin – Madison.

Jess is a meticulous, creative, and curious scientist. During the first years of her PhD program she has made substantial progress and is already having a scholarly impact. In addition to her coursework and working as a teaching assistant, she 1) launched a large-scale field sampling program of greenhouse gas, nutrient, and phytoplankton dynamics in urban ponds, collecting and analyzing thousands of samples, 2) developed methods for sample collection and analysis in support of her research, 3) mentored five undergraduate students, and 4) contributed to two collaborative projects in preparation for publication. These accomplishments are a testament to Jess’s skills as a researcher and collaborator, and her preparation for the LOREX program.

Jess’s proposed LOREX project stems directly from her dissertation research on temporal dynamics of methane production in urban aquatic habitats. Her research has focused on the effects of storms on methanogenesis and harmful algal blooms through hydrologic flushing and nutrient and organic matter loading in urban ponds. By design, these ponds tend to be small, shallow, and rich with organic matter – prime conditions for methane ebullition. However, Jess is not currently measuring ebullitive flux in her study ponds. Jess’s proposed LOREX research will allow her to learn state of the art techniques for measuring ebullition and methane production in the sediments of shallow waterbodies and transfer that knowledge back to the Center for Limnology for her own dissertation research while contributing to ongoing research in Canada. She has the support here at the Center for Limnology to complete the project as described and I am confident it will be a publishable project and highly beneficial collaboration with Drs. del Giorgio and Prairie.

I am confident that Jess will take full advantage of the opportunities throughout the program. She has my full, enthusiastic support for her participation! Thank you for your consideration and time serving on this review committee. Please do not hesitate to reach out with any questions.

Sincerely,

Grace Wilkinson, Associate Professor
Center for Limnology, University of Wisconsin – Madison
Montréal, January 1, 2024

LOREX Selection Committee

Dear Colleagues,

It will be my pleasure to co-host Jessica Briggs with my colleague Paul del Giorgio in our Aquatic Research Group at the Université du Québec à Montréal. We are currently investing significant resources and effort in quantifying various pathways of CH₄ emission in various inland water habitats, and in understanding and modeling the drivers and regulation of these emissions. Among the pathways, ebullitive (or so-called bubble flux) emissions are among the most difficult to quantify because of the enormous temporal and spatial variabilities. Jessica’s research interests are extremely complementary to ours, and the project she proposes is very interesting, because it provides the opportunity to carry out a comparative study of CH₄ production and ebullition between an oligotrophic Canadian Shield lake and a highly human impacted shallow lake in Wisconsin. I believe that we have all much to gain scientifically from such a comparative study, and we are thus eager to host Jessica at UQAM and to provide her with the means to carry out this collaborative project. This includes office space, access to our laboratories at the UQAM, access to field instrumentation, and help with field logistics with a field assistant. Jessica will fully integrate to our research community at the UQAM, which is composed of a very dynamic, diverse and inclusive group of graduate students, postdocs and professionals, and will participate in all group activities. Like other visiting students and scientists, Jessica will also become part of a broader aquatic research community in Montreal and Québec, through our membership to the GRIL (Groupe de Recherche Inter-Universitaire en Limnologie), and she will be able to benefit from the interactions with an extremely diverse and rich aquatic research network, and also from the infrastructure and facilities offered by the network, including access to the lake that will be focal point of her project here and logistics that will greatly help in this project.

Thank you in advance for considering Jessica for the LOREX program, we look forward to hosting at the UQAM and collaborating with her in this interesting project.

Sincerely,

[Signature]

Yves Prairie
UNESCO Chair in Global Environmental Change