Bridging Scales: Conceptualizing microbe-climate links in wetland ecosystems

Pieter Candry[1] (pcandry@uw.edu), Zach Flinkstrom[1], Yi Xiong[2], Sam Bryson[1], Juliet Johnston[3], Britt Abrahamson[1], Ludmila Chistoserdova[1], Chongle Pan[2], Xavier Mayali[3], David Stahl[1], **Mari Winkler**[1]

[1] University of Washington, Seattle, Washington, USA
[2] University of Oklahoma, Norman, Oklahoma. USA
[3] Lawrence Livermore National Laboratory, Livermore, California, USA

Project Goals: Wetlands capture and release large amounts of greenhouse gases (CO_2, CH_4 and N_2O) and predicting their response to climate change induced stressors such as drought and saltwater intrusion is of prime importance. This project aims to link wetland microbial activity to ecosystem-scale processes by developing a reproducible experimental model for lacustrine and estuarine wetland ecosystems to quantify responses to controlled manipulations representing climate impacts. Hydrogel beads, controllable in size, with entrapped wetland microbes and soil plat-like, act as models for sediment aggregates. Bioreactors with real-time gas and liquid metabolite flux monitoring, integrated multi-omics analyses, and stable isotope tracing will be conceptually incorporated into mathematical models to predict how climate change stressors impact C and N fluxes across different wetland spatial and temporal scales.

Abstract: Wetlands play a key role in the global carbon cycle by storing 20-30% of all soil carbon in 4-8% of land surface. At the same time, they are responsible for 40-50% of all biogenic CH_4 emissions, showing the large impact these ecosystems and their microbial community have on global climate processes. The nutrient density (specifically carbon and nitrogen) of these systems also means climate-induced changes in wetlands can result in strong feedbacks, either positive or negative, to climate change. For instance, estuarine wetlands could suffer from seawater intrusion as sea levels rise at increasing rates, while inland wetlands may suffer from higher and more frequent disturbances in water table levels as dry seasons become longer and dryer, while wet seasons become shorter and wetter. Predicting how these changes will affect the microbial community – and by extension GHG fluxes and the global climate – remains challenging, and there is currently no coherent approach to connect wetland microbes to global-scale climate processes. Here, we present a conceptual model of multi-scale climate-microbe interactions and propose approaches to connect this to molecular data of wetland microbial communities, experimental and mathematical models to better connect wetland microbes to climate-scale processes.

As a first step, we developed a conceptual model of wetland microbial conversions. This model holistically integrates carbon cycling with other key biogeochemical nutrient cycles (i.e. N, Mn, Fe, S), using the redox sequence as a spatial factor controlling microbial metabolisms in wetland systems. Furthermore, not only heterotrophic conversions driven by carbon are considered, but we also include an exhaustive analysis of demonstrated chemolithotrophic metabolisms, since these can result in cryptic nutrient cycles (e.g. Fe, Mn & S-cycles) driving further carbon breakdown. This conceptual model for metabolic versatility in wetland systems drove a meta-analysis of wetland metagenomes. We analyzed publicly available data from the JGI IMG/M database to connect the functional potential of wetland microbiomes to spatial organization within the wetland soil and across wetland types. These analyses showed that communities diverging at the phylogenetic level coalesce at the functional level, both for general functionality and when focusing on genomic potential for different redox reactions driving wetland nutrient cycles. The

remaining community divergence on the functional level could then be linked to physicochemical parameters in wetland ecosystems, e.g. sulfate in coastal wetlands. Future analyses will complement these public datasets with our own datasets, both from wetland sediments and lab-scale experimental models for wetland ecosystems, to better connect community structure at the functional level to environmental conditions and GHG fluxes.

Building our metabolic conceptual model of wetland microbial processes around a consistently observed spatial structure (i.e. the redox sequence), we can connect the actions of microbes to centimeter and meter-scale processes. An overview of intermediate scale processes connecting wetland microbes and climate-scale processes was developed, taking into consideration sediment aggregate structure, microbe-root interactions, wetland plant communities, water drainage, local geography and local weather patterns. It is these processes that control the microbial processes responsible for carbon and nitrogen capture, GHG fluxes from (or to) wetland ecosystems, and ultimately connect back to global climate processes. This overview was in turn used to develop wetland-specific microbe-climate feedback loops that integrate impacts of climate change on these multiple scales (Figure 1). Put together, we have developed a coherent multi-scale framework to link wetland microbes to global climate processes, a key step towards developing and testing multi-scale experimental and mathematical models.

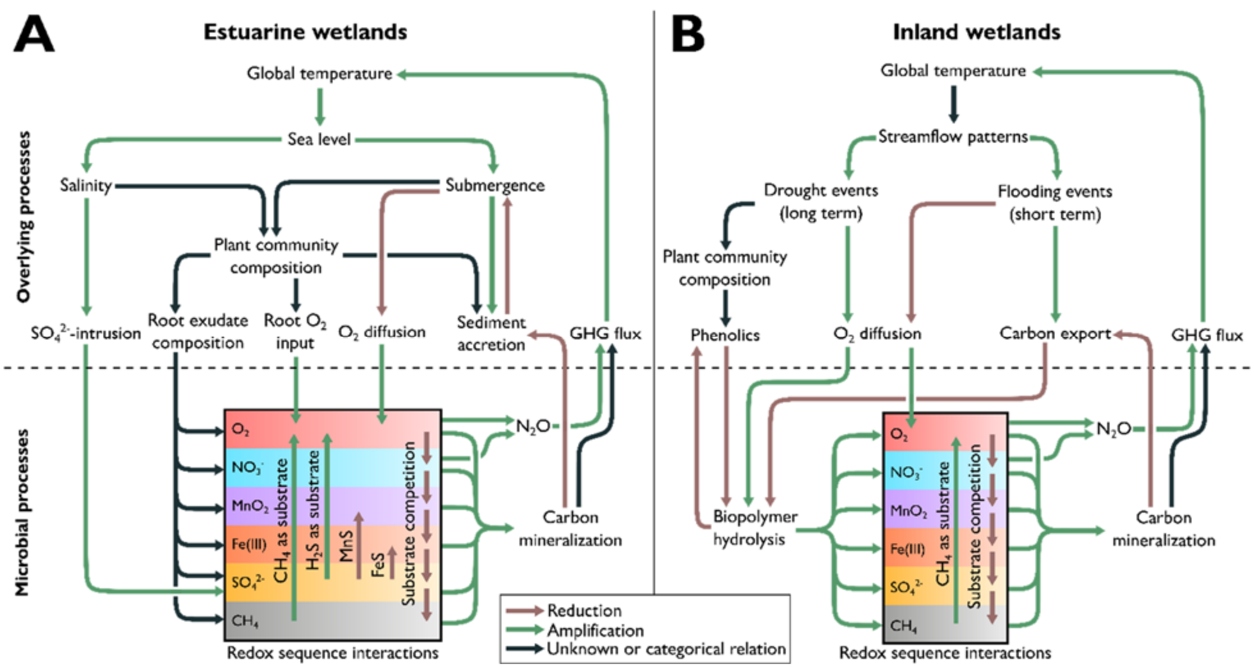

Figure 1. Feedback loops arising from multi-scale interactions in wetland systems. The dashed line separates processes driven by the microbial community (below) from larger-scale processes (above). Panel A shows feedback loops for estuarine wetlands, where rising sea levels are a major driver for changes in GHG fluxes. Panel B shows feedback loops for freshwater wetlands where changes in streamflow patterns due to climate change will affect GHG fluxes.

This work was supported by the U.S. Department of Energy's Office of Biological and Environmental Research Genomic Science Program (Grant #DE-SC0020356); part of this work was performed under the auspices of the U.S. Department of Energy at Lawrence Livermore National Laboratory under Contract DE-AC52- 07NA27344.