Understanding Mechanistic Controls of Heterotrophic CO₂ and CH₄ Fluxes in a Peatland with Deep Soil Warming and Atmospheric CO₂ Enrichment

Jason K. Keller, Chapman University (Principal Investigator)
Scott D. Bridgham, University of Oregon (Co-Investigator)
Qianlai Zhuang, Purdue University (Co-Investigator)

Peatlands are among the most important terrestrial ecosystems in the global carbon (C) cycle. These wetlands currently store roughly one-third of the terrestrial soil C and are a significant source of the potent greenhouse gas methane (CH₄) to the atmosphere. A pressing challenge in global change biogeochemistry remains whether or not a significant fraction of the large soil C pool in peatlands will be mineralized to CO₂ or CH₄ in future climates. Given that CH₄ has 28-times the global warming potential of CO₂, understanding the response of peatland CH₄ dynamics in response to global change is particularly critical for understanding peatland-climate feedbacks. Methane cycling in peatlands is complex. The production of CH₄ is the result of multiple, anaerobic microbial processes in which different groups of microbes ‘cooperate’ by sequentially producing substrates for one another and compete for those substrates. Once produced, a significant fraction of CH₄ can be oxidized to CO₂ within peatlands by different microbial processes. Currently, Earth system models do not adequately capture the complexity of CH₄ cycling in peatlands and are thus ill-equipped to predict the response of peatland CH₄ emissions to global change - including elevated [CO₂] and increased temperatures. The overall objective of this renewal is to expand our mechanistic understanding of how deep warming of peatlands and CO₂ enrichment in a bog affect C mineralization and CH₄ dynamics and to incorporate that understanding into Earth system models.

We will utilize the ongoing DOE Spruce and Peatland Responses Under Climatic and Environmental Change (SPRUCE) experiment to test the following hypotheses: 

**H1:** Warming will have a substantial positive effect on CH₄ production in surface peat but will have a smaller positive effect in deep peat due to its chemical recalcitrance. 

**H2:** Warming will cause a larger increase in anaerobic CO₂ production than CH₄ production due to stimulation of ‘upstream’ microbial processes, and this ratio will increase with depth. 

**H3:** Both warming and CO₂ enrichment will increase the prevalence of acetoclastic methanogenesis over hydrogenotrophic methanogenesis as a result of increased labile substrates and an increase in homoacetogenesis (acetate production from H₂ and CO₂). An increase in the importance of acetoclastic methanogenesis will be coincident with increased overall CH₄ production. 

**H4:** Both treatments will lead to transient accumulations of low-molecular-weight organic acids, including acetate, due to the slow growth of methanogens. 

**H5:** Anaerobic CH₄ oxidation will be an important process below the water table, adding to CH₄ consumption from aerobic CH₄ oxidation in surface soils as an important sink of CH₄. We will explore these hypotheses using a combination of field measurements, including the quantification of key electron donors and acceptors in porewater collected from the SPRUCE treatments, thermodynamic modeling based on these dissolved constituents, and gross CH₄ consumption and production measured using $^{13}$CH₄. Concurrent mechanistic laboratory experiments will explore the temperature sensitivity of methanogenesis and other microbial processes over time in the SPRUCE treatments; changes in soil quality as potential C mineralization in response to climate treatments; the importance of and controls on anaerobic CH₄ oxidation; and the production and fate of low molecular weight organic acids during fermentation. Results of our field and laboratory experiments will be incorporated into our ongoing modeling efforts, and in particular will be used to improve algorithms associated with anaerobic processes and CH₄ cycling within the Terrestrial Ecosystem Model (TEM). Our data are also being used to parameterize anaerobic C cycling and CH₄ dynamics in the Community Land Model (CLM).