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Constructing the redox ladder in Stordalen Mire: A survey of microbial terminal electron acceptors (TEAs) in thawing permafrost

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Study goals

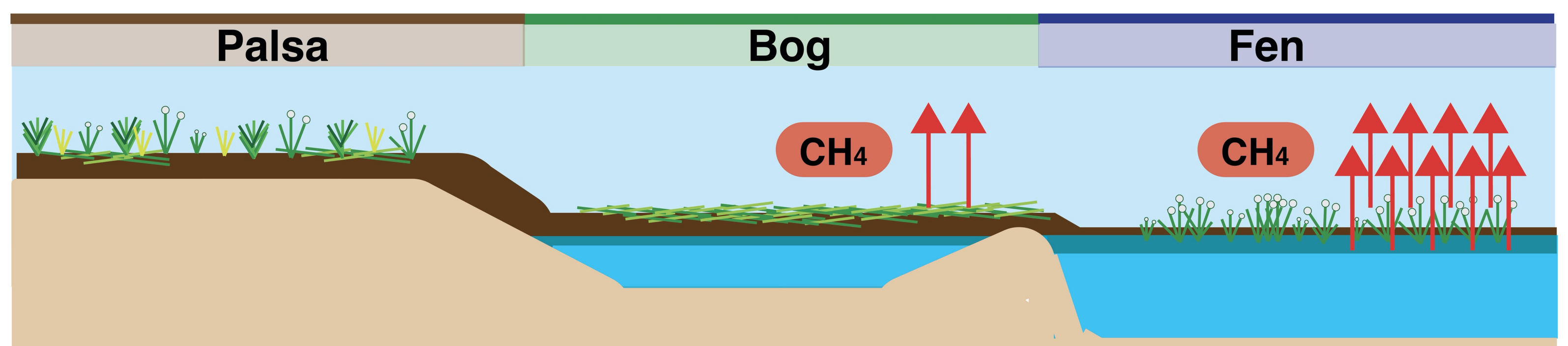

Figure 1. Cartoon representing the discontinuous permafrost thaw gradient found in Stordalen Mire. Red arrows represent historic trends in relative methane emissions across the thaw gradient. As the permafrost thaws, frozen palsas can collapse into more saturated habitat types including bogs and fens.

- Stordalen Mire in Arctic Sweden is a widely studied peatland complex that serves as a model system for understanding northern ecosystem response to climate change.
- Permafrost thaw is actively transforming the Mire, altering greenhouse gas dynamics as dry ecosystems are converted to saturated wetlands.
- Microbial metabolic activity, which drives greenhouse gas production within soil, is impacted by numerous environmental variables including terminal electron acceptor (TEA) availability.
- Evaluating available TEAs can shed light on understanding and predicting active microbial metabolisms, and thus understanding climactically relevant emissions across thawing permafrost.
- **The goal of this study was to analyze porewater samples from the Mire across different habitats spanning varying environmental conditions, to permit the first thorough characterization of microbially available TEAs across the Mire.**

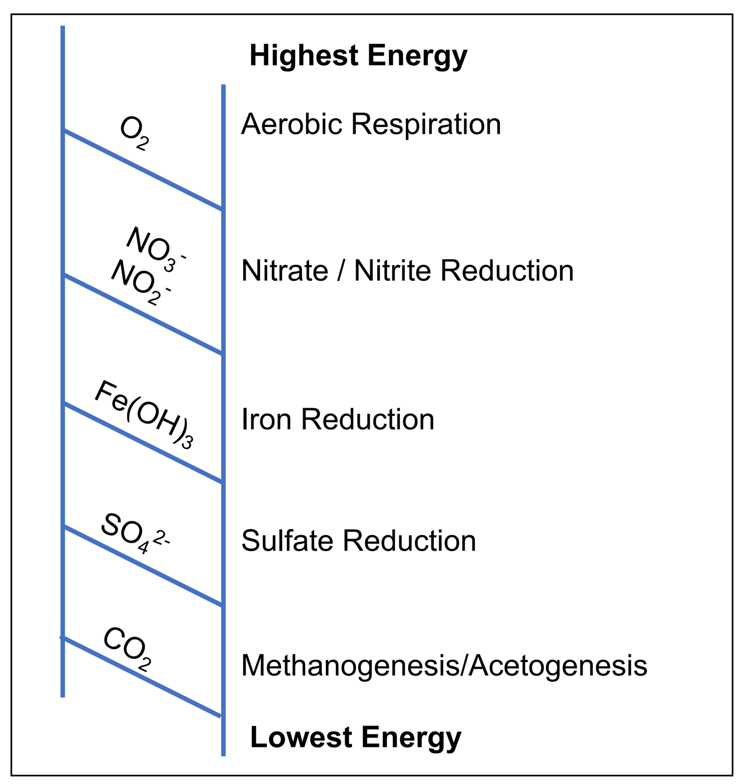

Figure 2. Schematic of the microbial redox ladder, which represents the order of preferential use of terminal electron acceptors (TEAs) based on free energy gained from redox reactions.

Field sampling site characteristics

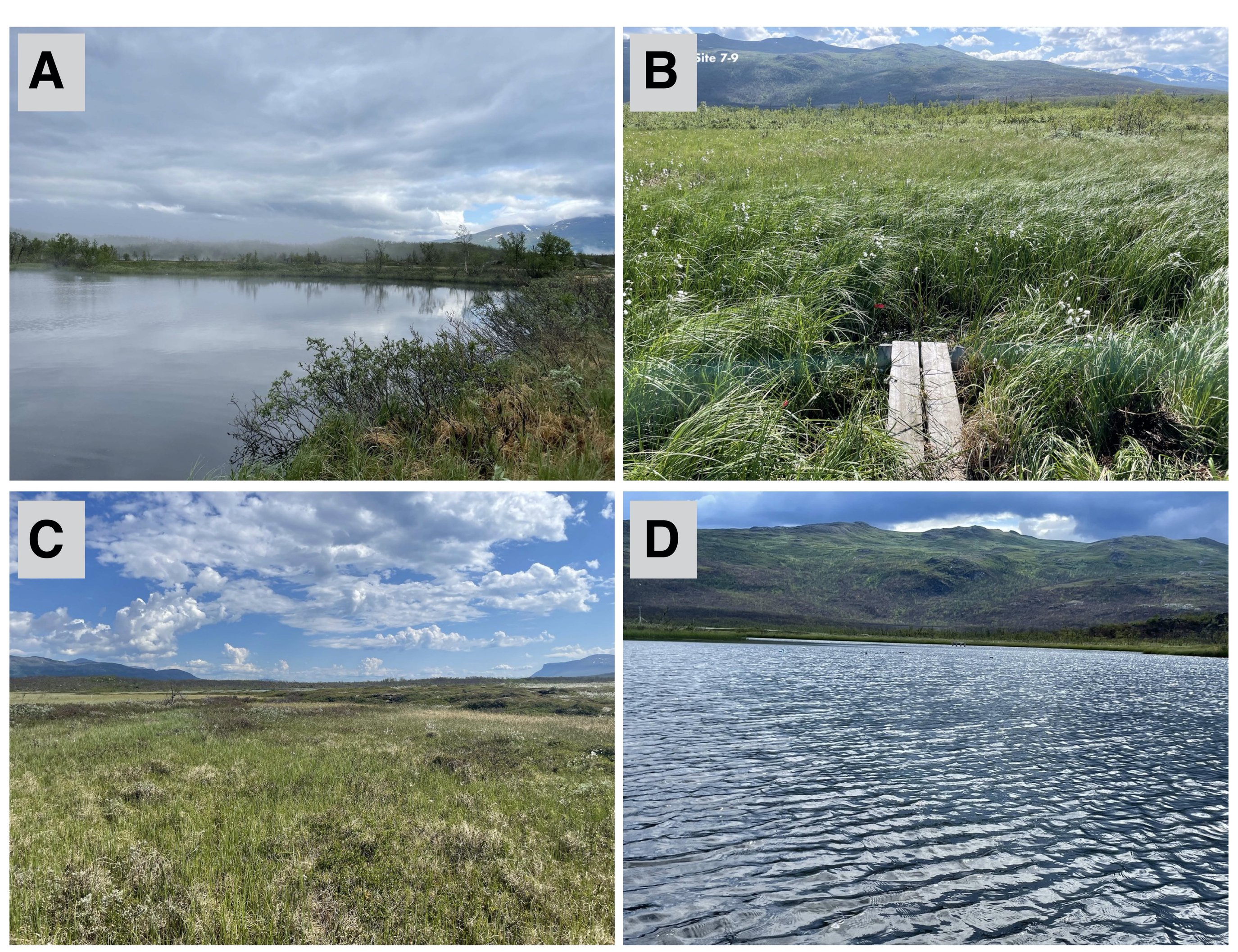

Figure 3. Pictures of various sampling sites demonstrating varying field vegetation and saturation. Photos show **(A)** Inre Lake transect site, **(B)** Avni C site, **(C)** Avni A site, and **(D)** Inre Lake. Inre Lake and Avni C were the wettest sites, while Avni A and Inre Lake Adjacent sites were the driest and required use of a sipper for porewater sampling.

Map of porewater sampling sites across Stordalen Mire

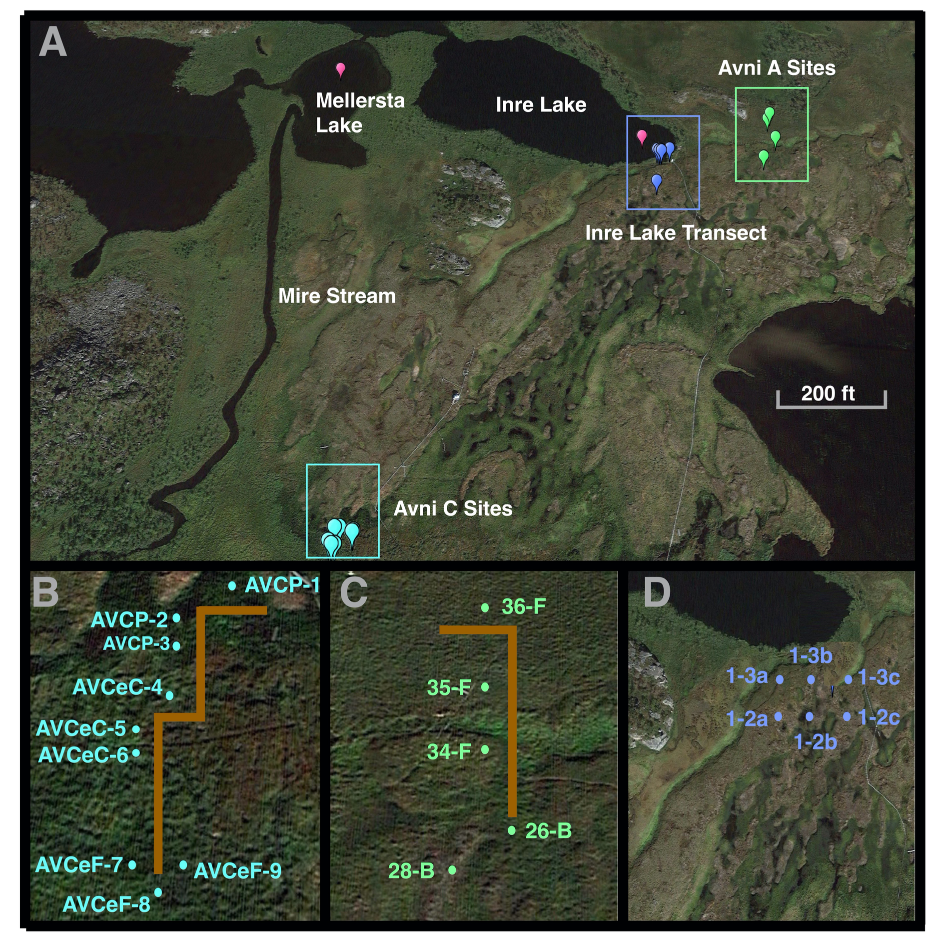

Figure 4. (A) Satellite image of Stordalen Mire with colored pins designating pore water sampling subsites within Inre and Mellersta Lake sediments (pink), Avni A (green) and Avni C (turquoise) permafrost thaw transects, and an Inre Lake adjacent thaw transect (blue). **(B-D)** Inset boxes show relative location of sampling subsites within each site. **(B)** AVCP sites are recently collapsed palsa, AVCeC Sites are old collapsed palsa, and AVCeF are fens. **(C)** F sites represent fens and B sites represent bogs. **(D)** 1-3 sites are in a riparian zone, and 1-2 are lake adjacent thawing permafrost sites. *Satellite imagery obtained from Google Earth Pro.*

Porewater TEA concentrations vary across distinct habitats within the Mire

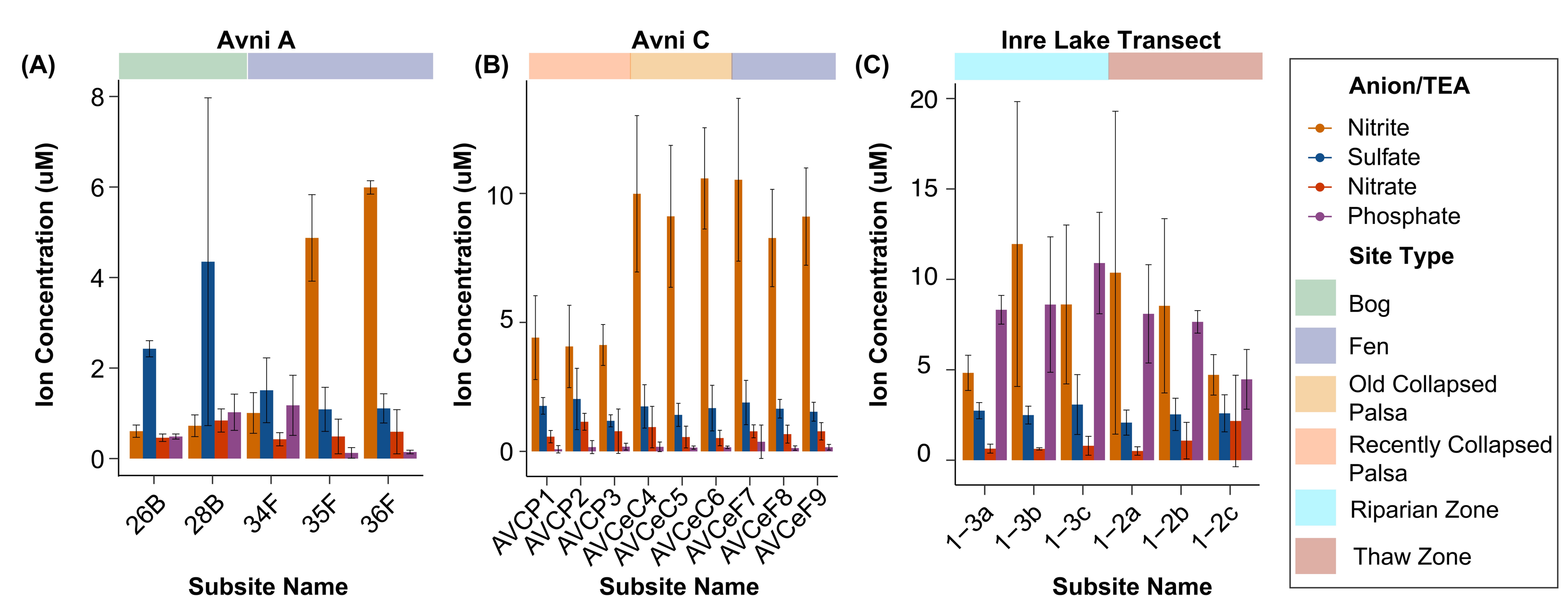

Figure 5. Average concentration of microbially relevant TEAs for subsites within **(A)** AVNI A **(B)** AVNI C and **(C)** the Lake Adjacent sites (see Figure 4). Colored bars represent the habitat type of each subsite from which porewater was sampled and analyzed via ion chromatography. Error bars represent one standard deviation.

Preliminary TEA concentrations are vertically stable within Mire lake sediments

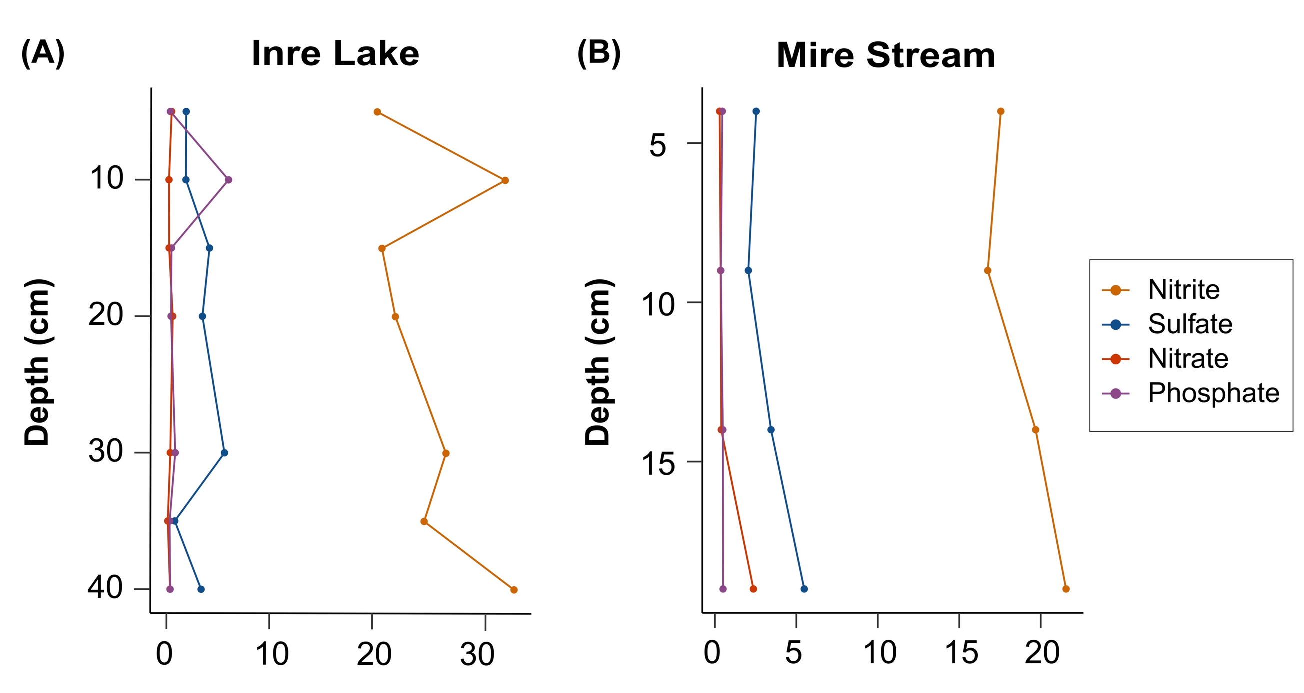

Figure 6. Initial depth-stratified profiles of TEAs in **(A)** Inre Lake and **(B)** Mire Stream both interconnected by a stream running through the mire.

An inverse relationship was found between methane flux and multiple TEAs

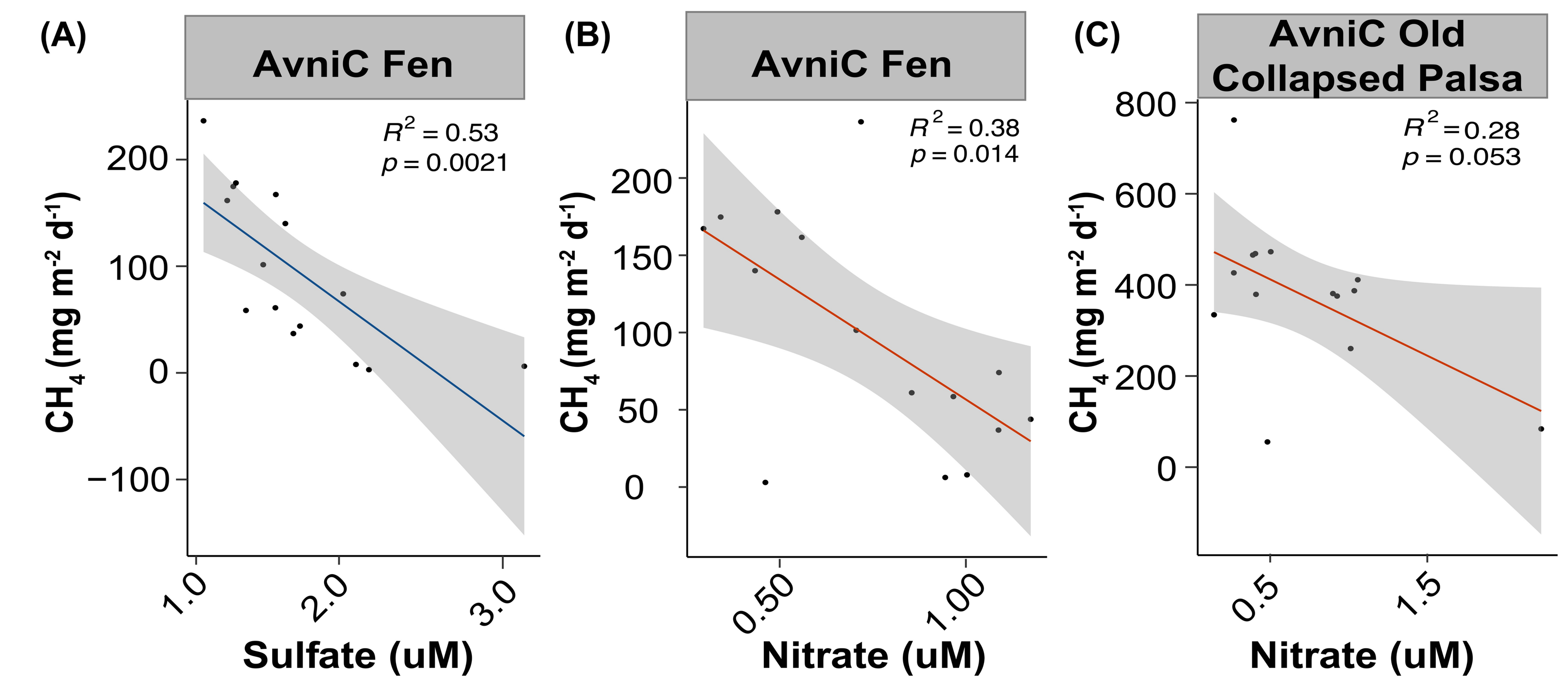

Figure 7. Pearson correlations showing statistically significant inverse relationships between measured methane flux and **(A)** sulfate concentration and **(B)** nitrate concentrations within fen sites as well as **(C)** nitrate concentrations for old collapsed palsa sites. Methane flux data were available for analysis only for AVNI C sites.

Conclusions

- In this study, we performed a thorough sampling of microbially-available TEAs across thawing habitats found within Stordalen Mire
- Habitat-specific patterns were seen in TEA concentrations, however some notable trends:
  - Nitrite was the TEA found in the greatest concentration across the Mire; further work is warranted to validate this work against multi-omic/microbial data.
  - As has been suggested for the Mire prior, sulfate was found higher in the bog sites than the fen and fen-like collapsed palsa sites
  - The collapsed palsa sites look chemically similar to the fens, however more recently collapsed palsa is less similar than older collapsed palsa, potentially demonstrating a temporal chemical shift in these collapsed sites.
  - Within two lakes, nitrite continues to be the most abundant TEA in sediment porewater, however no evident patterns were found in TEA abundance with depth in our preliminary data set.
- Within the AVNI C site, in agreement with the redox ladder/thermodynamic controls of microbial metabolism, significant inverse correlations were found between methane flux and concentrations of sulfate and nitrate within fens. Similarly, nitrate was borderline significantly inversely correlated with methane flux in old collapsed palsa (but not recently collapsed palsa)
- Our data reveal an increase in nitrite levels with thaw across the Mire, which we infer to be due to increased microbial respiration of nitrate in newly saturated peat. We thus anticipate that other anaerobic metabolisms will similarly increase with thaw, ultimately leading to a depletion of TEAs over time, and stimulation of methanogenesis.
- Our data validates that measuring TEAs as an indicator of microbial activity *in situ* is an important and useful proxy for understanding greenhouse gas-producing microbial metabolisms.

Acknowledgements

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