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Subsurface redox dynamics and carbon turnover in rewetted peat

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Peatland drainage represents a major perturbation to long-term terrestrial carbon storage and the source of ~4% of anthropogenic greenhouse gas emissions, as organic matter previously preserved under anoxic conditions becomes susceptible to aerobic remineralisation. Raising the water table has been proposed to restore conditions conducive to carbon retention by suppressing aerobic decomposition, which produces carbon dioxide (CO_2). Following rewetting, a succession of redox processes begins in the subsurface ultimately leading to methane (CH_4) production. High CH_4 emissions from restored peatlands risk partially offsetting the benefits of protecting soil carbon.

We conducted sixteen soil mesocosm experiments to investigate the impact of alternative electron acceptor concentrations on peatland carbon emissions following rewetting. Mesocosms containing humified peat from agricultural sites in the East Anglia Fens (UK), a region comprising ~400,000 hectares of drained freshwater wetlands, were initially maintained in drained conditions before raising the water table to the soil surface for seven months. Emissions of CO_2 and CH_4, and pore fluid chemistry were monitored to investigate redox-driven controls on organic matter remineralisation.

While drained, soils exhibit large CO_2 emissions and small CH_4 uptake. Raising the water table results in a rapid, sustained 97% reduction in CO_2 emissions, indicating strong suppression of aerobic carbon remineralisation. Pore fluid data show sequential reduction of nitrogen, manganese, iron and sulfate following rewetting, demonstrating the activation of anaerobic respiration pathways. Methane emissions remain low until the onset of CH_4 ebullition, which occurs after 86±14 days (mean±2×SE, n=15), after alternative electron acceptors have been depleted. Amendments with nitrate, manganese(IV), and sulfate did not alter the delay in CH_4 ebullition, suggesting that anaerobic oxidation of methane prior to ebullition did not play a large role in limiting subsurface CH_4 build-up. Furthermore, the time required to deplete alternative electron acceptors was not controlled by their initial concentration.

We propose that microbial community dynamics and the mechanics of bubble nucleation and growth contribute to the delayed transition from low to high CH_4 emissions associated with ebullition. The timescale of transitions between mineralisation pathways has important implications for understanding carbon turnover and may underpin the pronounced temporal variability observed in wetland CH_4 fluxes.