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Impact of increasing permafrost thaw and surface ponding on iron speciation and phosphorus bioavailability in Abisko, Sweden

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Progressing permafrost thaw due to increasing temperatures in the arctic can cause changes in hydrological and redox conditions in the soil. Redox sensitive minerals like iron (oxhydr)oxides (henceforth called Fe oxides) can either precipitate or dissolve in response to changing redox conditions. Iron oxides have a high capacity to adsorb phosphate (PO_4^{3-}), a limiting nutrient in many arctic and subarctic environments. Therefore, the bioavailability of phosphorus (P) in soils may depend on dynamic interactions of PO_4^{3-} and redox active Fe oxides.

To explore these complex interactions between permafrost thaw, redox conditions, Fe speciation, and P bioavailability, we conducted an in situ incubation experiment along a permafrost gradient in a subarctic peatland in Abisko, Sweden. The permafrost gradient included an elevated palsa with permafrost located close to the soil surface, a flooded bog with permafrost located deep beneath the soil surface, and a flooded fen with no underlying permafrost. Soil redox conditions were measured continuously for over 34 days. Mesh bags, filled with local Fe-rich sediments comprised of ferrihydrite, organic-bound Fe, and goethite and with either artificial P addition or none, were buried under the topsoil at each site and incubated for one or eight weeks. Incubated materials were subsequently analyzed with sequential extractions to quantify changes in extractable Fe and P pools and with x-ray absorption fine structure (XAFS) spectroscopy to evaluate changes in Fe speciation.

Redox conditions transitioned from Fe oxidizing to Fe reducing conditions as permafrost thaw progressed and caused surface ponding, although redox was variable across the thaw season due to surface drying. In the oxidizing palsa, Fe speciation did not change and extractable Fe and P decreased little (2% Fe decrease). Extractable Fe and P decreased (14-28% Fe decrease) and Fe transitioned from organic-bound Fe to ferrihydrite in the more reducing bog and fen. Conversion from organic-bound Fe to ferrihydrite was intensified by P addition. We conclude that fluctuating redox conditions in the bog and fen topsoils and addition of P facilitated precipitation of new ferrihydrite in the incubated sediments. Bioavailable PO_4^{3-} may adsorb to freshly formed ferrihydrite, potentially limiting plant growth and microbial activity.