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Tracing Critical Raw Material Cycling in a Ditched Boreal Wetland-Headwater System: Insights from Seasonal Isotopic and Geochemical Analyses

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Wetlands play a vital role in regulating element cycling; however, hydrological modifications such as ditching can significantly alter their functions as nutrient and metal sinks or sources[1]. This study examines the transport and biogeochemical cycling of Critical Raw Materials (CRM) in a first-order stream originating from a ditched wetland in a boreal forest catchment. Over a period of two years (March–October), we conducted high-resolution monitoring of CRM concentrations alongside Fe, S, C, O, N, and H isotope compositions to assess seasonal variability and geochemical controls on elements mobility.

Our results indicate that seasonal hydrology strongly influences CRM fluxes, with peak concentrations occurring during spring snowmelt and storm events, driven by high discharge and enhanced export of dissolved and particulate-bound elements. Isotopic analyses reveal distinct seasonal shifts in element sources and transformation pathways. $\delta^{13}C$ signatures and dissolved organic carbon (DOC) data suggest strong interactions between organic matter and CRM transport, particularly in early spring when wetland-derived organic colloids prevail. Oxygen and hydrogen isotopes indicate a transition from snowmelt-driven flow in spring to groundwater contributions in late summer, affecting element retention and export.

Fe and S isotopes provide evidence for dynamic redox processes that control CRM mobilisation. Lighter $\delta^{56}Fe$ values observed in summer indicate Fe(III) reduction, which enhances the formation of Fe-organic colloids. At the same time, $\delta^{34}S$ trends suggest seasonal shifts between sulphide oxidation and microbial sulphate reduction in riparian soils. Elevated REE concentrations in the colloidal phase underscore the role of organic matter and Fe-oxyhydroxides in CRM transport, particularly during high-flow periods.

These findings demonstrate how alterations to wetland hydrology affect element cycling in headwater streams, impacting both local geochemical conditions and downstream water quality. By integrating isotopic and chemical tracers, this study provides new insights into the mechanistic controls on CRM fluxes within watersheds, emphasising the significance of hydrological connectivity and seasonal biogeochemical processes. Understanding these interactions is essential for predicting element transport under changing climatic and land-use conditions, with consequences for sustainable water and land management in boreal landscapes.

[1]Bullock and Acreman (2003) Hydrology and Earth System Sciences 7(3).