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Microbial carbon sources in Arctic permafrost revealed by carbon isotope analysis of phospholipid fatty acids

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Permafrost thaw mobilizes vast stores of previously frozen organic carbon, creating positive carbon feedback for greenhouse gas emissions. Although microbial community composition in Arctic permafrost soils is well documented, isotopic constraints on the carbon sources fueling active microbial biomass across thaw gradients remain limited. This study investigated depth-resolved microbial carbon utilization in a continuous permafrost icing environment near Inuvik (Northwest Territories, Canada) using compound-specific carbon isotope analysis ($\delta^{13}C$) of phospholipid fatty acids (PLFAs) – biomarkers for the active microbial community. Total PLFA concentrations decreased systematically with depth from 66.34 to 1.19 nmol.g^{-1}, indicating a strong decline in viable microbial biomass across the seasonally thawed active layer to permafrost transition. Isotopic values of total organic carbon ($\delta^{13}C_{TOC}$) averaged −26.5‰ in the active layer and progressively decreased to −27.8‰ at depth, suggesting reduced permafrost organic matter decomposition in deeper frozen layers. Heterotrophic bacterial PLFAs (e.g., i15:0, a15:0) exhibited $\delta^{13}C$ values closely aligned with $\delta^{13}C_{TOC}$ (~ −27‰), indicating dominant assimilation of soil organic matter derived from C_3 plants and/or thaw-mobilized dissolved organic carbon. In contrast, certain PLFA biomarkers displayed substantial ^{13}C-depletion relative to bulk $\delta^{13}C_{TOC}$ (~ −40 to−35 ‰), indicative of more ^{13}C-depleted substrate incorporation. Further investigation on the age of assimilated carbon will be obtained through compound-specific radiocarbon ($\Delta^{14}C$) analysis of PLFAs. Incorporation of $\Delta^{14}C$ data will enable quantitative assessment of the relative contributions of modern versus pre-aged carbon sources, allowing evaluation of whether active microbial communities preferentially metabolize more recently fixed or mobilized millennia-old permafrost carbon.