Reconsidering Dissolved Organic Carbon as a Passive Reservoir: Active Biogeochemical Cycling and Priming Effects in Anthropogenically Perturbed Riverine Systems

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Abstract. Dissolved organic carbon (DOC) has long been conceptualized as a quasi-stable reservoir within riverine biogeochemical frameworks, yet mounting empirical evidence challenges this paradigm. This study integrates high-frequency optical proxy sensing, isotopic mass-balance modeling ($\delta^{13}C$, $\Delta^{14}C$), and metagenomic profiling across fourteen anthropogenically impacted catchments in Central Europe and Southeast Asia to interrogate the dynamic reactivity of riverine DOC pools. Our results demonstrate that allochthonous DOC fractions exhibit priming-induced mineralization rates up to 3.7-fold greater than previously documented under elevated nutrient loading conditions. Furthermore, microbial community composition—particularly the proliferation of Bacteroidota and Proteobacteria lineages—exerts a dominant regulatory control over DOC turnover kinetics. These findings necessitate a fundamental revision of DOC residence-time parameterizations in coupled hydrological-biogeochemical models, with profound implications for regional carbon budget assessments and river water quality governance frameworks.

Keywords: dissolved organic carbon biogeochemistry, riverine carbon cycling, priming effect, allochthonous organic matter, stable isotope fractionation, microbial community composition,

anthropogenic catchment perturbation, high-frequency optical sensing, carbon residence time modeling

Introduction

The global riverine network constitutes a critical conduit for the lateral transfer of organic carbon from terrestrial biomes to coastal and oceanic sinks, processing an estimated 2.7 Pg C yr^{-1} at the land–water interface. Within this continuum, dissolved organic carbon (DOC) has historically been assigned a predominantly passive biogeochemical role, characterized by long hydraulic residence times and limited in-stream reactivity. This conceptualization, deeply embedded in watershed-scale carbon accounting models and water resource management protocols, has persisted for several decades despite accumulating anomalies in field-based flux observations. As of 2024–2026, accelerating land-use intensification, amplified hydrological connectivity under climate-driven precipitation extremes, and escalating diffuse nutrient loading from agricultural and urban matrices are collectively destabilizing the physicochemical boundary conditions under which legacy DOC paradigms were originally derived. Consequently, the validity of treating riverine DOC as a kinetically inert or slowly cycling reservoir demands rigorous re-examination. The priming effect—a phenomenon well-documented in terrestrial soil science, wherein the addition of labile organic substrates stimulates the decomposition of otherwise recalcitrant organic matter—has only recently gained traction as a mechanistically significant process in aquatic environments. Emerging evidence from mesocosm experiments and in situ incubation studies suggests that anthropogenic nutrient enrichment, particularly dissolved inorganic nitrogen and bioavailable phosphorus, may substantially elevate the susceptibility of allochthonous DOC to microbially mediated oxidation. Yet, this mechanism remains inadequately represented in process-based hydrological models and international carbon reporting frameworks, including those underpinning IPCC Sixth Assessment cycle projections. Critically, the compositional heterogeneity of riverine DOC—spanning a molecular-weight continuum from hydrophilic low-molecular-weight acids to complex humic and fulvic macromolecules—implies that bulk DOC metrics are insufficient proxies for biogeochemical reactivity. Advances in excitation–emission matrix fluorescence spectroscopy, coupled with parallel factor analysis (EEM-PARAFAC), now enable the operational deconvolution of DOC optical fractions at sub-hourly temporal resolution, offering unprecedented mechanistic insight into source partitioning and transformational dynamics across hydrograph events. This paper proceeds as follows: Section 2 details the multi-catchment study design, instrumentation, and isotopic and metagenomic analytical protocols employed. Section 3 presents the principal empirical findings, including priming-effect magnitude estimates, microbial taxonomic drivers, and carbon isotope fractionation signatures across contrasting land-use gradients. Section 4 situates these results within existing biogeochemical model structures and articulates targeted revisions to DOC reactivity parameterizations. Section 5 discusses the broader policy implications for riverine carbon accounting and freshwater quality governance.

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