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Molecular-Level Insights into Labile and Refractory Organic Matter Cycling in Aquatic Ecosystems

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Aquatic ecosystems exchange energy and nutrients through dissolved and suspended organic matter pools, with dissolved organic matter (DOM), acting as a long-term reservoir of reduced carbon that can persist in the water column for millennia. Recent analytical and computational advances have greatly expanded the ability of the aquatic biogeochemistry community to characterize the molecular complexity of these reservoirs. In particular, high-resolution mass-spectrometry and improved *in-silico* tools enable detection and structural inference of diverse environmental metabolites at scales relevant for linking organic matter composition, microbial community structure, and carbon and nutrient cycling. Leveraging these developments, our work applies liquid chromatography-tandem mass spectrometry (LC-MS/M) to the solid phase-extractable fraction of aquatic organic matter to investigate the cycling of both labile and refractory compounds. In this talk, I will highlight two examples illustrating how expanded access to the environmental metabolome provides new insights into DOM-microbe interactions and the composition of refractory DOM. In the California Current Ecosystem, repeated sampling across productivity gradients reveals that metabolite diversity increases as productivity decreases, mirroring patterns observed in microbial community composition. Microbes and metabolites also appear to be more tightly coupled in nutrient-poor surface waters than in productive regions. Moreover, the composition of detected molecular features explains a substantial portion of the variability in bacterial biomass production demonstrating that metabolite fingerprints can serve as effective indicators of microbial function. A second line of work focuses on the refractory DOM pool. Across diverse aquatic environments, our LC-MS/MS analyses combined with *in-silico* structure prediction identify a set of chemical characteristics consistently enriched in refractory DOM. These features closely resemble terpenoid biosynthetic scaffolds but appear systematically more oxidized than typical biological precursors. This pattern suggests the involvement of widespread sources followed by specific post-production environmental oxidation processes that preserve the underlying terpene framework while generating chemically persistent structures. Together, these examples demonstrate how molecular-level organic matter characterization is transforming our understanding of carbon cycling, microbial ecology, and the processes that generate and maintain the refractory DOM reservoir.