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Modeling Microbial Control of Historical Contingencies and Priming Effects in Biogeochemical Reactions

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This element of the PNNL SFA seeks to provide a mechanistic understanding of the microbial control exerted on biogeochemical dynamics for predictive biogeochemical process modeling. Biogeochemical reactions in the hyporheic zone often show nonlinear dynamics caused by the coupled effects of hydrology and microbiology. Key intriguing aspects of biogeochemical reactions identified by our SFA research include: 1) history-dependent response of microbial respiration to inundation (historical contingencies) and 2) priming effects observed only in a narrow range of mixing ratio between groundwater (GW) (containing relatively low concentration of thermodynamically favorable organic carbon) and surface water (SW) (containing relatively high concentration of recalcitrant organic carbon). Processes that govern these complex subsurface biogeochemical dynamics are yet poorly understood, and consequently poorly represented in current reaction network models. Towards revealing fundamental processes underlying historical contingencies and priming effects, we have developed two microbial community modeling approaches that view microbes and their interactions as key mediators of the complex biogeochemical functions mentioned above.

In the first model, we hypothesized historical contingencies as being driven by the dynamic interactions between two groups of microorganisms with distinct growth characteristics: copiotrophs (fast-growing organisms in high-carbon environments) and oligotrophs (slow-growing organisms adapted to low-carbon environments). The resulting model with copiotroph-oligotroph kinetics predicted the expected population trends and response time as a function of inundation frequency, indicating that historical contingencies in biochemical reactions can be controlled by the interspecies interaction in microbial communities as hypothesized.

In the second model formulated to simulate priming effects, we hypothesized that organic carbon in GW is protected by low concentration whereas organic carbon from SW sources is thermodynamically protected, but GW-SW mixing can simultaneously overcome both limitations. To test this hypothesis, we modeled a microbial community as a dynamic control system in which microorganisms optimally regulate enzyme synthesis to maximize the growth in a varying environment. This new model predicted mixing conditions for priming that matched our field observations, supporting our hypothesis by providing a plausible mechanism for overcoming both thermodynamic and kinetic limitations of carbon oxidation through GW-SW mixing.

To further test the model, we designed batch experiments to constrain interactions between concentration, chemical speciation, and thermodynamic properties in limiting hyporheic zone respiration (Graham et al. poster). This integrated modeling and experimental approach will generate new knowledge and understanding of key processes governing complex biochemical functions, which will then be translated into predictive reactive transport modeling for understanding system behavior across scales.