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Metabolic regime shifts and ecosystem state changes are decoupled in a large river

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Aquatic ecosystem recovery from anthropogenic degradation can be hampered by internal feedbacks that stabilize undesirable states. The challenges of managing and predicting alternative states in lakes are well known, but state shifts in rivers and their attendant effects on ecosystem function remain understudied despite strong recent evidence that such shifts can and do occur. Using three decades of measurements of key state variables such as turbidity, nutrient concentrations, Corbicula fluminea clam densities, and chlorophyll a, including hourly dissolved oxygen, we investigated a sudden shift from phytoplankton to macrophyte dominance in the middle Loire River (France), and its associated effects on the rivers metabolic regime. We show, instead, that despite large and synchronous shifts across all state variables, changes in gross primary production and ecosystem respiration were modest (25% and 14% declines, respectively) and that these shifts lagged the ecosystem state changes by a decade or more. The shift to a macrophyte-dominated state reduced the sensitivity of primary production to abiotic drivers, altered element cycling efficiency, flipped the net carbon balance from positive to negative, and, crucially, weakened the temporal coupling between production and respiration. This weakened coupling, detected using Granger causality, increased the temporal autocorrelation of net ecosystem production, yielding a robust early warning indicator of both state- and metabolic-shifts that may provide valuable guidance for river restoration.