Ecological Assembly and Thermodynamic State of Dissolved Organic Matter in a Hypersaline Lake Dichotomized by Hydrology

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Abstract

Hypersaline lakes on the Tibetan Plateau are significant carbon reservoirs, yet the molecular-level processes governing their dissolved organic matter (DOM) remain poorly understood. This study leverages the hydrologically dichotomous Zabuye Salt Lake as a natural laboratory, comparing the 'pulse-driven' North basin with the 'buffered-stable' South basin using ultrahigh-resolution mass spectrometry (FT-ICR MS) and fluorescence spectroscopy. The study uniquely integrates ecological assembly theory with thermodynamic analysis to reveal how hydrological regimes drive divergent biogeochemical pathways of DOM. Results show that the successional patterns of the two DOM pools are starkly different: the North basin exhibits a pronounced 'winter preservation-summer loss' regime, where core molecules shared across all four seasons constitute only 31% of the total pool, while winter-exclusive molecules are as high as 38%, and its DOM assembly displays a seasonal succession from stochastic to deterministic processes. In contrast, the South basin is dominated by strong, year-round deterministic selection, forming a highly stable DOM pool with season-exclusive molecules accounting for less than 3%. This continuous selective pressure leads to the accumulation of thermodynamically recalcitrant (low nominal oxidation state of carbon, NOSC) yet high-energy molecules. Thermodynamic analysis confirms that the buffered-stable South basin acts as a "thermodynamic sieve," selectively enriching for more energy-rich ($\Delta G_{Cox} \approx$ -65 to -60 kJ mol C^{-1}) DOM molecules year-round, whereas the energy landscape of the pulse-driven North basin shows significant seasonal fluctuations. A random forest model indicates that salinity and dissolved oxygen are the primary drivers controlling

DOM molecular structure, explaining ~38% of the variation in molecular composition. This study provides direct molecular evidence, deeply elucidating the intrinsic mechanism by which hydrological stability, as a master variable, regulates the ecological assembly, thermodynamic state, and persistence of DOM in extreme environments, which is of great significance for predicting high-altitude carbon cycling under climate change.

Keywords: Dissolved Organic Matter; Hypersaline Lake; Ecological Assembly; Biogeochemical Thermodynamics; Hydrological Regime

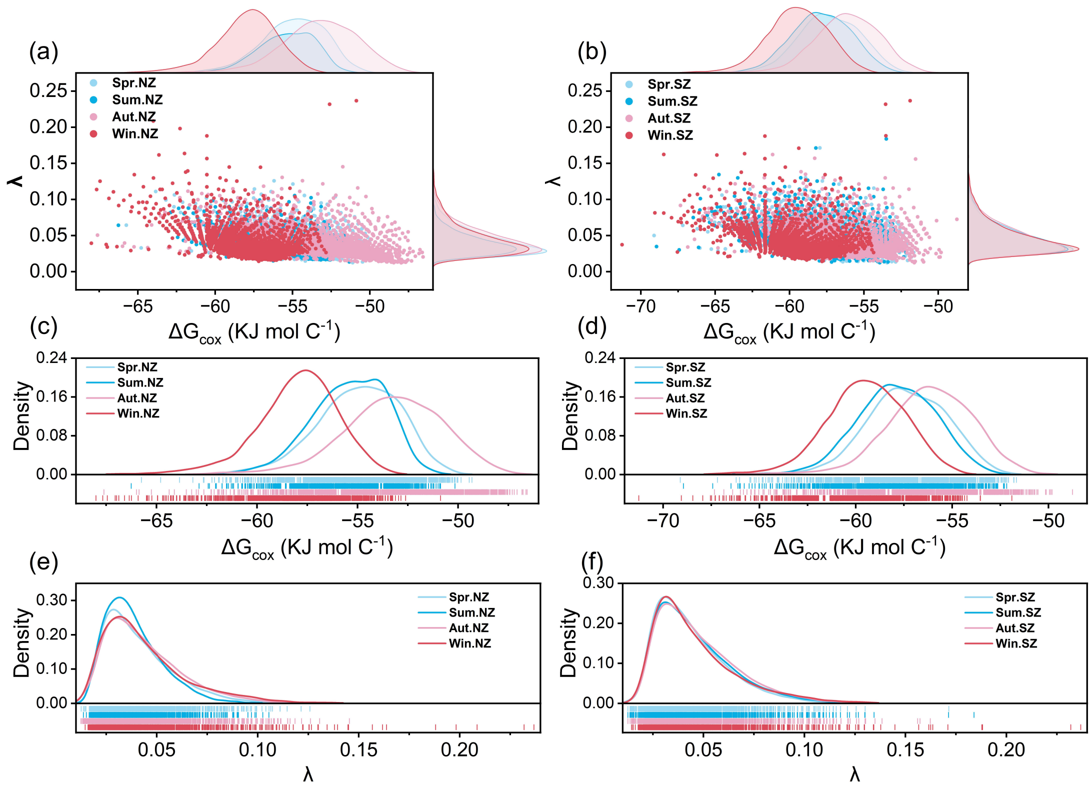

Figure . The relationship between energy content (ΔG_{cox}) and metabolic efficiency (λ) and the seasonal distributions of DOM in the North Lake (NZ) and the South Lake (SZ). In the figure, (a) and (b) show the relationship between ΔG_{cox} and λ of DOM molecules in the North and South Lakes across four seasons. Figures (c) and (d) represent the seasonal kernel density distribution plot of ΔGcox. Figure (e) and (f) show the seasonal kernel density distribution of λ. The legend labels Spr, Sum, Aut, and Win represent spring, summer, autumn, and winter respectively