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Radiocarbon constraints on organic matter sources driving deoxygenation and carbon–climate feedback in a deep temperate lake

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Lacustrine sediments are major reservoirs of organic matter (OM), highlighting their role in mitigating climate change by transferring carbon from the short-term biosphere–atmosphere cycle to the long-term geological reservoir. However, eutrophication-driven increases in OM production, together with warming-induced strengthening of thermal stratification and enhanced decomposition, intensify carbon cycling and may promote ecosystem degradation through deoxygenation.

This study focuses on Lake Biwa, the largest lake in Japan and a temperate monomictic lake. Over the past half century, hypolimnetic water temperatures have increased by approximately 2–3°C, and deoxygenation has progressed in recent years. We estimated the sources of OM responsible for deoxygenation using stable carbon ($\delta^{13}C$) and radiocarbon ($\Delta^{14}C$) isotopes. In addition, temperature-controlled incubations of undisturbed sediment cores were conducted to assess whether future warming could stimulate the decomposition of millennia-old sedimentary OM.

From May 2024 to March 2025, dissolved inorganic carbon (DIC) concentration, $\delta^{13}C_{DIC}$, and $\Delta^{14}C_{DIC}$ were measured monthly at eight depths. During the stratified period, hypolimnetic DIC concentrations gradually increased while $\delta^{13}C_{DIC}$ values decreased, consistent with ongoing mineralization of OM in the hypolimnion. In contrast, $\Delta^{14}C_{DIC}$ values remained similar between surface and deep waters. This isotopic pattern indicates that the OM driving deoxygenation is predominantly modern origin. Incubation experiments further revealed temperature-dependent shifts in the radiocarbon signature of decomposed OM. At the current hypolimnetic temperature of 8°C, the $\Delta^{14}C$ value of decomposed OM was −43.6 ± 50.8‰, comparable to surface-water DIC. However, $\Delta^{14}C$ values decreased linearly with increasing temperature, reaching −182.3 ± 31.1‰ at 18°C. These results indicate that warming enhances the decomposition of aged allochthonous OM. Our findings suggest that while present-day deoxygenation in Lake Biwa is primarily driven by modern OM, future warming may mobilize aged terrestrial OM that has been preserved for millennia, potentially strengthening carbon–climate feedbacks in lacustrine systems.