

Linking anoxia, climate cooling, and marine extinction selectivity across the Kellwasser events using a proxy-constrained Earth System modelling approach

ASHLEY N. PROW-FLEISCHER¹, ZUNLI LU¹, CLARA BLÄTTLER², JONATHAN PAYNE³, JOOD AL ASWAD³, JUSTIN L PENN⁴, ALEXANDRE POHL⁵ AND ANDY RIDGWELL⁶

¹Syracuse University

²University of Chicago

³Stanford University

⁴Princeton University

⁵Université Bourgogne Europe, CNRS

⁶University of California, Riverside

The biodiversity crises at the Late Devonian Frasnian-Famennian boundary, known as the Kellwasser Events, were characterized by extinctions among both tropical reef-builders and nektonic taxa. Geochemical (e.g., $\delta^{238}\text{U}$) and sedimentological (e.g., black shale deposits) evidence suggest that oceanic anoxia played a key role in these extinctions. However, reconstructing the spatial extent of anoxia remains challenging due to paleogeographic biases in preservation and limited paleoenvironment representation. This incomplete preservation of shallow-water records leaves uncertainty in the magnitude of benthic and interior ocean deoxygenation. Additionally, growing evidence that the Kellwasser events coincided with cooling intervals has shifted focus toward understanding large-scale circulation changes that could drive oxygen depletion while aligning with extinction selectivity patterns.

This study uses a proxy-constrained Earth system-ecophysiological modeling approach to link patterns of anoxia and temperature change across the Kellwasser Events to aerobic habitat loss for marine animals. We present new $\delta^{44}\text{Ca}$ data to assess local preservation and I/Ca ratio data – a proxy for local shallow-marine hypoxia – measured at four globally distributed sites to constrain the dissolved oxygen patterns simulated by the Earth system model cGENIE across a range of atmospheric pO_2 levels, ocean PO_4 inventories, and remineralization depths (Fig. 1). During the Kellwasser state, I/Ca data indicate intensified tropical hypoxia, consistent with several plausible shifts in ocean nutrient remineralization and atmospheric oxygen changes in our simulations that lead to global deoxygenation, in accordance with $\delta^{238}\text{U}$ constraints estimating 5–15 % increase in global anoxic areal extent [1].

From the set of plausible environmental transitions, we simulated extinction selectivity using a trait-based model of species' aerobic limits. Model simulations were tested against the selectivity pattern of marine fossil record, which reveals a decreasing extinction intensity toward the Southern Hemisphere pole. This integrative approach allows us to assess the role of

physiological habitat loss in driving biodiversity collapse and to evaluate the relative contributions of temperature stress and reconstructed deoxygenation.

[1] White et al. (2018), *Earth and Planetary Science Letters* 503, 68–77.

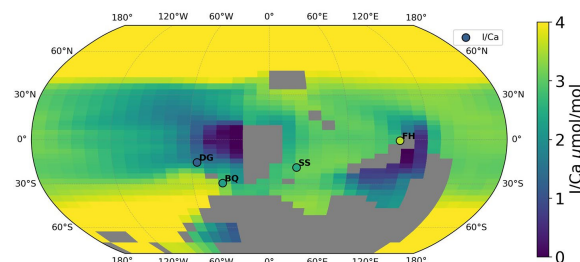


Figure 1: Simulated I/Ca of ocean surface layer for one of the plausible background Devonian climate ($10 \times$ preindustrial pCO_2) and environmental conditions ($0.5 \times$ modern PO_4 , $0.6 \times$ modern pO_2 , $0.75 \times$ modern remineralization depth). Model performance was evaluated through location-dependent comparison of mean proxy I/Ca background values at 4 sites (DG = Devil's Gate, Nevada, USA; BQ = Brans Quarry, Iowa, USA; SS = Steinbruch Schmidt, Germany; FI = Fube, Guangxi, China) to its nearest grid cell using Mielke's score.