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Plant dispersal and biotic interactions across glacial–interglacial timescales: evidences from combining spatio□temporal niche modelling with sedimentary ancient DNA proxy data

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Plant responses to glacial–interglacial climate change are frequently delayed by migration lags and shaped by landscape connectivity and changing biotic interactions. Yet most spatio□temporal species distribution models (SDMs) still assume near□equilibrium with climate, treat dispersal only implicitly, and rarely confront their hindcasts with independent, process□relevant validation data. This limits confidence in both late□Quaternary reconstructions and future projections, especially in regions with complex topography and strong post□glacial ecological reorganization.

Here we present a model–proxy framework that links occurrence□based niche modelling with dynamic, taxa□specific dispersal and connectivity and evaluates predicted trajectories using sedimentary ancient DNA (sedaDNA). We initially parameterize SDMs for Arctic and Tibetan Plateau taxa using modern occurrences and climate (first implementations with MaxEnt), hindcast climatic suitability through late□Quaternary paleoclimate reconstructions, and translate suitability into time□varying accessibility using spatially explicit dispersal models and landscape□configured networks. This enables hypothesis testing on how connectivity, terrain, and interactions modulate community change beyond shared climatic forcing.

Broader high□latitude analyses further indicate recurrent glacial legacy effects on interglacial assemblages, identify persistent hotspots and migration corridors. It also show that future Arctic vegetation may occupy only a small fraction of emerging climate niches due to limited dispersal, leading to extirpation from declining suitability often exceeding new colonizations in driving compositional change. We also evaluate how community assembly shifts from predominantly facilitative interactions during glacial conditions to more negative interactions in the Holocene.This is coincident with post□glacial woody encroachment and trait shifts toward taller, deeper□rooted communities—mechanisms relevant to contemporary “arctic greening”. On the eastern Tibetan Plateau, proxy–model agreement demonstrates that complex terrain and connectivity to refugia are first□order controls on post□glacial vegetation trajectories: steep valley configurations enhance connectivity and reduce migration lags, whereas long gentle terrain can impose pronounced lags despite similar climate.

Finally, we outline how these proxy□validated developments motivate a forthcoming multimodal

deep‑learning foundation model (FOUNA) integrating global occurrences, paleo‑occurrences (including sedaDNA), remote sensing, and (paleo)climate to deliver transferable, decision‑relevant biodiversity predictions from decades to millennia.