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There and back again: Combining hydrogen and strontium isotopes refines the trans-Saharan migratory patterns of the butterfly Vanessa cardui

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Migratory insects serve an important role to ecosystems and economies as they participate in the long-distance transfer of nutrients, pollen, and biomass. However, migratory insects are understudied, especially compared to birds and mammals, partially because traditional tracking techniques (e.g. mark-recapture, biologgers) are often ineffective for insects because insects are small, short-lived, and numerous. Thus, isotope geolocation has become an effective tool for studying dispersing insects. The painted lady butterfly (*Vanessa cardui* (L.)) is a virtually cosmopolitan species that was recently found to make regular, annual multi-generational migrations across the Sahara Desert. Previous work geolocating painted ladies with hydrogen isotopes has shown early spring migratory movements of painted ladies from sub-Saharan Africa to Mediterranean Europe and autumn movements to the sub-Sahara from Europe. However, these previous works using hydrogen isotopes were unable to offer refined estimates of natal origin due to the inherent limitations of the technique. Here, we update previous hydrogen isotope-based geographic assignment by (1) using an updated model of hydrogen isotope variations across the landscape (i.e., isoscape), (2) combining with strontium isotope-based geographic assignment, and (3) expanding the number of geolocated butterflies to include capture locations on both sides of the Sahara Desert across different years. Using this method, we spatially refine previous estimates of the natal origins of successful trans-Saharan migrants and estimate the distances that successful migrants travelled. Overall, this study demonstrates the advantages of combining hydrogen and strontium isotopes for the geographic assignment of migratory butterflies and further advances our understanding of long-distance insect migration.