Climate legacies in macroevolutionary dynamics

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Biodiversity is critically endangered by anthropogenic climate change. One of the core goals of ecological research and conservation science is therefore to enhance the mechanistic understanding of the processes that cause species to go extinct, particularly in light of anthropogenic climate change. However, the presence of non-linearities, multiple equilibria, thresholds, and internal feedbacks within ecological and climatic systems often impedes a mechanistic comprehension. One fundamental issue for extinction studies using contemporary data is that this data is always dependent on past conditions. Within ecology, the dependence of contemporary biodiversity dynamics on past climate is generally termed “climate legacy”. Climate legacies can arise from a multitude of ecological processes, such as time lags, niche conservatism, physiological thresholds, or cascading effects. Further, climate legacies can be assumed to be present in all ecological systems as a consequence of the dynamic nature of ecological patterns and processes. If not accounted for, climate legacies can hinder or even prevent the detection of true ecological responses to climate change. However, few studies on the relationship between extinction dynamics and climate include these climate legacies. Even less studies reach beyond merely discussing potential impacts of climate legacies and include them in their empirical framework. Those studies where climate legacies were included and quantified found a large impact of these legacy effects on extinction dynamics. Here I introduce a methodical framework for the quantification of effects arising from climate legacies in biotic systems of any temporal scale. I first introduce the concept of climate interactions, which describe and quantify the potential dependence of extinction risk on the long-term climatic context. Climate interactions might create a characteristic pattern in extinction dynamics and can arise from climate legacies acting over days to millions of years. They therefore provide a unifying framework for studying the consequences of climate legacies in ecosystems. The expected characteristic pattern consists of higher extinction risk, or related measures, when climatic changes add to previous trends in the same direction (such as a short-term warming adding to a long-term warming trend). It is hypothesized that these synergistic climate interactions first lead to environmental conditions increasingly different from initial adaptations of taxa, which then result in a higher extinction risk for these taxa. An antagonistic climate interaction, where a short-term climate change reverses a previous long-term trend (such as short-term cooling adding to a long-term warming trend), might result in a generally lower extinction risk through climatic conditions being more similar to initial adaptations of taxa. The emergence of expected patterns are then tested in a variety of ecosystems, both marine and terrestrial, taking advantage of the fossil record with its rich information of past responses of organisms to climatic changes.