Climate change is a significant predictor of extinction risk

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The increasing frequency and intensity of climate change in recent decades is a subject of growing concern, with future projections indicating more change for centuries to come. This shift in climate is a significant threat to biodiversity, and climate change has already had a significant impact on many species globally. Despite the significant threat that climate change poses to biodiversity, we do not yet fully understand how climate change causes animals to go extinct.

The geological rock record provides critical insight on past extinctions caused by a variety of climate change events. Fossils therefore offer a rare opportunity to understand the mechanisms of extinction and investigate how climate shifts have led to extinction in the past. Understanding why species went extinct under natural, pre-human conditions is paramount, since human-induced extinction drivers will likely have a cumulative effect on extinction risk. By identifying which traits are important in driving extinction in the past, we can potentially use this knowledge to identify at-risk species in the future to prioritize conservation efforts.

In our latest research article published in *Science*, we analyzed a dataset comprising over 290,000 marine invertebrate fossils, covering the last 485 million years of Earth's history, to directly investigate the traits most crucial for survival in the geologic past.

Although previous studies have highlighted body size and geographic range size as key predictors of extinction risk throughout geological history, physiological proxies have seldom been examined over such extensive periods. We reconstructed the climate (Figure 1) for 81 geological Stages across the Phanerozoic, and utilized these climate models to determine the temperature tolerance and range of temperatures that species can endure. These factors were then compared against geographic range size and body size to assess their relative importance. In addition to these intrinsic traits of organisms, we also estimated an external, abiotic factor that may impact risk of extinction: the magnitude of climate change experienced by each species. We assessed how these intrinsic traits compared to climate change in affecting a species' risk of extinction. This study is one of the first to directly compare species-level traits to external factors in determining extinction drivers.

Our findings revealed that species inhabiting climatic extremes, such as polar or equatorial regions, were particularly susceptible to extinction. Moreover, species

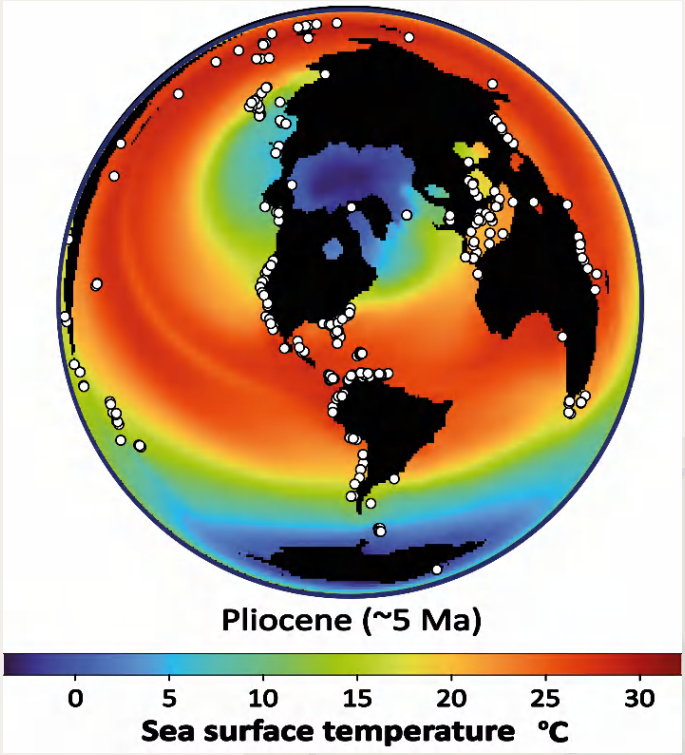

Figure 1. Example of a climate model used in our study from the Pliocene, with continents in black and fossil occurrences as white dots. The climate model derived from the HadCM3BL-M2.1D model of Valdes et al. (2017)

with a narrow thermal tolerance, faced a significantly higher risk of extinction.

Body size emerged as a significant predictor of extinction risk, with smaller-bodied species being more prone to extinction. However, the most important predictor of extinction risk was geographic range size. Species with smaller geographic ranges, occupying more geographically-confined areas, had a higher likelihood of extinction.

Alarmingly, our research has also identified climate change as a significant predictor of extinction, alongside these other species traits. We observed that species subjected to localized climate changes of 7°C or greater across geological Stages were significantly more likely to face extinction. This suggests that surpassing this climate change threshold increases the likelihood of extinction for a species, regardless of its other traits.

The model with the highest statistical support incorporated all the traits we studied, including climate change, indicating a cumulative effect of these variables on extinction risk. This underscores the importance of considering a broad spectrum of factors when assessing vulnerability to extinction. For instance, a species residing in polar regions, characterized by a small geographic range size and body size, and subjected to significant climate change, would face a higher extinction risk than

what might be inferred if considering only a species' geographic range. This holistic approach reveals the interplay between various biological and environmental factors in determining species' survival over geological timescales.

Figure 2. A reconstruction of a late Triassic (approximately 210 million years ago) sea floor community before and after a climate change of approximately 70C, by Maija Karala.

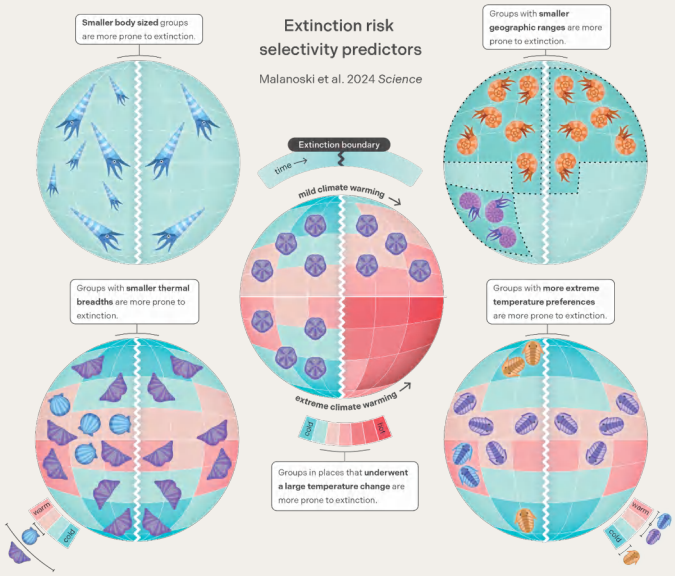

Figure 3. Illustration of the extinction selectivity patterns found in our study. Graphic by Miranta Kouvari (Science Graphic Design).

Our research underscores the urgent challenge climate change poses to global biodiversity. Although this study provides crucial insights into the dynamics of past -- and potentially imminent -- extinctions, it also emphasizes the necessity for continued research. The uncertainties highlighted by our findings underscore the need for further exploration into extinction mechanisms, particularly focusing on recent geological time periods. This additional research is essential to fully leverage our study's implications for contemporary conservation strategies. Without immediate and targeted conservation efforts, informed by a deeper understanding of these mechanisms, we risk moving toward a sixth mass extinction event. Thus, our work provides a pivotal call to action: to mitigate climate change, but also to bolster our understanding of the impacts on vulnerable species through ongoing research.

Reference

Malanoski, C. M., Farnsworth, A., Lunt, D. J., Valdes, P. J., & Saupe, E. E. 2024. Climate change is an important predictor of extinction risk on macroevolutionary timescales. *Science 383*, 1130-1134. DOI: 10.1126/science.adj5763