MACROECOLOGY

Fossils, phylogenies and the evolving climate niche

A dataset that links geographical occurrences, phylogenies, fossils and climate reconstructions for more than 10,000 vertebrate species reveals accelerated rates of climate niche evolution in warm-blooded animals.

Adam C. Algar and Simon Tarr

Climate represents a fundamental challenge for all organisms. With few exceptions, species are restricted to a subset of climatic conditions where they can maintain evolutionary fitness and viable populations, that is, their climate niche. Determining why climate niches have evolved quickly in some groups but slowly in others is central to understanding the uneven geographical distribution of life on Earth and how it will respond to future climate change[1]. Writing in *Nature Ecology & Evolution*, Rolland et al.[2] report evidence that metabolic heat production — endothermy — has allowed mammals and birds to weaken climate's evolutionary shackles. In a study of unprecedented breadth, the authors combined data on climate niches for more than 10,000 species of terrestrial vertebrates to estimate past rates of climate niche evolution. They found that climate niches of endotherms evolved more rapidly than those of ectotherms (Fig. 1).

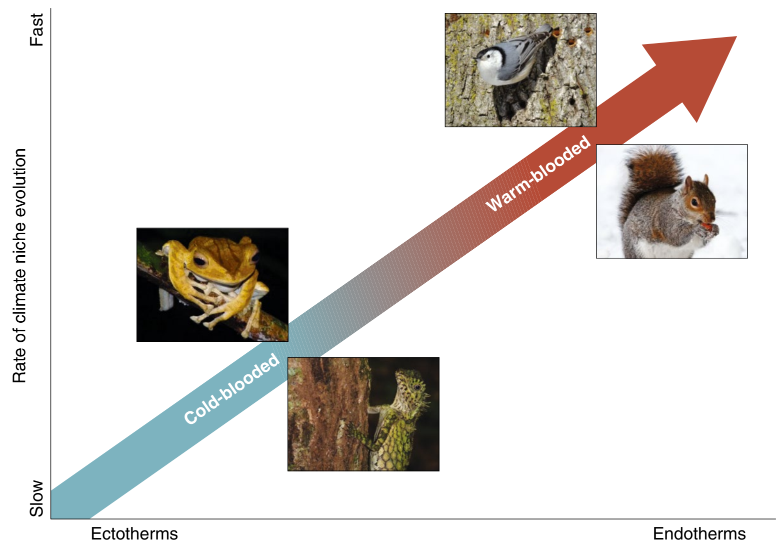

Fig. 1 | Endothermy, the ability to produce internal metabolic heat, has permitted climate niches to evolve much more quickly in mammals and birds than in reptiles and amphibians, who must rely on external heat sources (ectothermy). Credit: James J. Hicks (bird).

Climate niche conservatism — the retention of climate niche characteristics through ecological and evolutionary time — is thought to have played an important role in the origin of multiple biogeographic patterns, including global diversity gradients[1]. It will also play a key role in determining the effects of rapid climate change on species' future survival[3]. However, climate niches are not uniformly conserved: their rate of evolution can vary greatly among clades, with implications for species richness, lineage diversification and trait evolution[4–7]. Previous work has hypothesized that the ability to produce metabolic heat, and thus decouple internal body temperature from the external environment, may have allowed endotherms to invade hostile climates more easily, enhancing rates of climate niche evolution[3].

Rolland et al. test this hypothesis on an impressive scale. They estimated climate niches using geo-referenced occurrences for 11,465 bird, mammal, reptile and amphibian species. Traditionally, to estimate rates of divergence, evolution of these climate niches would be modelled along a phylogeny. Although this approach can detect niche divergence between species, it is poor at detecting directional evolution[8] and it ignores climate change throughout Earth's history. Recent work with morphological traits has demonstrated that linking fossils with phylogenies can improve estimates of past trait evolution[8], but to apply this approach to climate niches Rolland et al. had to overcome a major barrier. Climate niches, unlike some morphological traits, cannot be directly measured from fossils. Even if you know where a fossil was found, climate change and plate tectonics mean that the climate experienced by that species may be very different from present-day conditions. Rolland and colleagues resolved this problem by integrating plate tectonics, mountain uplift and past climate change to estimate fossil niches. They then integrated modern and fossil niches to reconstruct niche change along each branch of a phylogeny, allowing them to estimate both rate and direction of climate niche evolution. They found that endotherms (mammals and birds) had much higher rates of climate niche evolution than the ectotherms (reptiles and amphibians). However, even these higher rates of climate niche evolution could not completely decouple biogeography from climatic constraints. By reconstructing historical latitudinal diversity gradients, Rolland et al. found that all groups expanded towards the poles during warmer periods in the Earth's history and contracted towards the Equator as the Earth cooled, with stronger effects in ectotherms.

The integration of fossil and extant species' niches provides new insights but also presents challenges. In particular is the need to rely on estimates of climate niches from species' occurrences and climate maps. This approach measures the realized niche, which may reflect biotic interactions or dispersal limitation rather than fundamental, physiological limits[9]. While fundamental niches can be estimated for extant species[10], the relevant physiological and behavioural traits are not preserved in the fossil record. Realized niches may shift faster than fundamental niches[9], which could produce apparent differences in evolutionary rates if endotherms fill their fundamental niches less than ectotherms. Whether this is the case, especially at the broad taxonomic breadth studied by Rolland and co-workers, merits further attention. A second area for further enquiry is using fossils not just to inform ancestral climate niche reconstructions, but also to test them. Rolland et al. tested the reliability of their method using simulations with known rates. However, evaluation of ancestral climate niche reconstructions by predicting climate niches of fossil species not included in model fitting will go further in determining the potential of fossils to inform estimates of climate niche evolution. Finally, as Rolland et al. recognize, future consideration of multiple climate niche axes — beyond average temperature — will provide a more detailed picture of niche evolution through time.

The centrality of niche conservatism for understanding the past and future of Earth's biogeography makes understanding climate niche evolution more important than ever. The integration of fossils and phylogenetic data to estimate rates of climate niche evolution represents an exciting step forward. The discovery, for such an extensive range of species, of endothermy's relationship with accelerated niche evolution unlocks substantial potential for further investigation of how metabolic heat production interacts with other intrinsic (organismal traits) and extrinsic (environmental) drivers of climate niche evolution. As Rolland and colleagues note, their results suggest that endotherms' responses to future climate change may be less predictable than those of ectotherms. However, a cautionary note: although ecologists can look to the past to understand the future, the past is not a panacea. Whether integrating fossils and phylogenies can improve future predictions is still very much unknown, but Rolland et al.'s work brings us closer to answering such questions. ❐

Adam C. Algar* and Simon Tarr
School of Geography, University of Nottingham, Nottingham NG7 2RD, UK.
**e-mail: Adam.Algar@nottingham.ac.uk*

Published online: 29 January 2018
https://doi.org/10.1038/s41559-018-0480-z

References

1. Wiens, J. J. et al. *Ecol. Lett.* **13**, 1310–1324 (2010).
2. Rolland, J. et al. *Nat. Ecol. Evol.* https://doi.org/10.1038/s41559-017-0451-9 (2018).
3. Jezkova, T. & Wiens, J. J. *Proc. R. Soc. B* **283**, 20162104 (2016).
4. Cooper, N., Freckleton, R. P. & Jetz, W. *Proc. R. Soc. B* **278**, 2384–2391 (2011).
5. Lawson, A. M. & Weir, J. T. *Ecol. Lett.* **17**, 1427–1436 (2014).
6. Title, P. O. & Burns, K. J. *Ecol. Lett.* **18**, 433–440 (2015).
7. Cooney, C. R., Seddon, N. & Tobias, J. A. *J. Anim. Ecol.* **85**, 869–878 (2016).
8. Slater, G. J., Harmon, L. J. & Alfaro, M. E. *Evolution* **66**, 3931–3944 (2012).
9. Saupe, E. E. et al. *Syst. Biol.* https://doi.org/10.1093/sysbio/syx084 (2017).
10. Kearney, M. & Porter, W. *Ecology* **85**, 3119–3131 (2004).

Competing interests

The authors declare no competing financial interests.