Nature Climate Change, Volume 15, Issue 8, August 2025, pp. 816-817
DOI:10.1038/s41558-025-02382-2

Subject strapline: Carbon-climate feedbacks

Title: Warmer Ecosystems Save Their Breath

Alice S.A. Johnston, Cranfield Environment Centre, Cranfield University, Bedfordshire, UK.
email: a.s.johnston@cranfield.ac.uk

Standfirst

Land stores vast amounts of carbon, and how much is released as temperatures rise could accelerate climate change. Now research shows ecosystems are more adaptable to climate warming than previously thought, potentially reducing future carbon-climate feedbacks.

Main

Terrestrial ecosystems 'breathe' carbon: plants take in carbon dioxide through photosynthesis, while all living components – including plants, animals and microbes – release it through respiration. As the climate warms, ecosystems are projected to release carbon faster than they absorb it, triggering a self-reinforcing feedback loop. Climate warming and reduced rainfall have already weakened the land carbon sink by 27% over the past decade, diminishing nature's capacity to buffer anthropogenic emissions[1]. Now, writing in *Nature Climate Change*, Xi and colleagues[2] present evidence that some ecosystems are adapting to respire more efficiently in a warmer world.

Ecosystems are fundamentally constrained by temperature, which regulates enzyme activity and the metabolism of individual organisms. At the ecosystem level, the collective metabolism of individual organisms comprising diverse communities is expressed as ecosystem respiration. Earth System Models account for temperature-driven increases in ecosystem respiration in their carbon–climate feedback projections but often assume a static exponential relationship with warming[3]. Substantial uncertainties persist in Earth System Models, however, with future projections ranging from an enhanced land carbon sink to land as a source of carbon to the atmosphere[4,5]. One uncertainty has been whether ecosystems adjust to warmer conditions over time, either via short-term thermal acclimation or by altering the long-term baseline via thermal adaptation[6].

Clear evidence exists for thermal acclimation at the organismal level. Experimentally acclimated boreal and temperate trees, for example, show markedly lower leaf respiration rates under warmer conditions than their non-acclimated counterparts[7]. Decades-long soil experiments have also observed acclimation in soil carbon losses under experimental warming conditions due to shifts in resource availability, soil microbial community composition, biomass and carbon use efficiency[8]. These observations suggest that the mechanisms nature employs to deal with warming could dampen the positive feedback between anthropogenic warming and carbon release from terrestrial ecosystems.

The study by Xu *et al.*[2] builds on these observations to examine the temperature response of ecosystem respiration across the globe. The team leverage data from 221 globally distributed eddy covariance sites, which monitor carbon dioxide exchange between ecosystems and the atmosphere, constituting over 1350 site years and a mean annual temperature range from -7 to 28 °C. Temperature-ecosystem respiration curves were fitted for each site year to estimate two key parameters: the temperature sensitivity (quantified as the Q_{10} value) and the reference basal ecosystem respiration rate at a given reference

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temperature. Both parameters were found to decline with increasing temperature, providing evidence for thermal adaptation at the ecosystem scale.

In colder regions, the authors observed higher apparent temperature sensitivity of ecosystem respiration than in warm regions, meaning warmer ecosystems respire less carbon per degree of warming than colder ecosystems. Patterns of thermal adaptation held across Q_{10} values and three reference temperatures, distinct timescales and ecosystem types and were not explained by differences in substrate availability or water limitation, indicating a robust and generalisable adaptation mechanism.

Xu and colleagues[2] further explored the implications of their findings under various future warming scenarios. Differences between modelled ecosystem carbon release with and without adaptation suggest that thermal adaptation could offset roughly 18–31% of the expected ecosystem carbon release driven by warming (Fig. 1). This translates to a potential overestimation of future ecosystem release between 850 million and 11.8 billion metric tons of carbon per year – equivalent to 10-100% of current anthropogenic carbon emissions[1].

Incorporating thermal adaptation into Earth System Models could therefore reduce major uncertainties associated with the temperature-driven increase in ecosystem respiration. A weaker carbon–climate feedback, however, is no substitute for cutting anthropogenic carbon emissions. Ecosystem respiration will still rise with warming, just not as sharply. Adaptive downregulation was also limited for cold high-latitude ecosystems which store vast amounts of carbon, indicating potential hotspots of vulnerability to climate-driven carbon losses.

Despite the encouraging news, the study comes with important caveats. Thermal adaptation has major implications for long term carbon-climate feedbacks because it suggests a shifting baseline of how much carbon is respired per degree of warming. The analysis conducted by Xu *et al.*[2], however, relies on space-for-time substitution in which present-day latitudinal patterns are used as a proxy for long-term temporal changes. This approach provides valuable insights but assumes future warming will reflect current ecosystem conditions and cannot account for novel environmental shifts. Long-term warming experiments have also demonstrated thermal acclimation to reflect only a short-term transitional phase in soil carbon responses, followed by carbon loss peaks[8]. The authors acknowledge that more research, including long-term experiments and monitoring, are essential to fully test the presence and magnitude of thermal adaptation in real ecosystems.

Nature is not a passive recipient of anthropogenic change but actively responds to environmental perturbations from local to global scales with an adaptive capacity not captured in Earth System Models. The work of Xu et al.[2] offers new evidence of thermal adaptation at the ecosystem level, while also highlighting the need to integrate key ecological processes into climate models to improve the accuracy of long-term forecasts.

Competing Interests statement. The author declares no competing interests.

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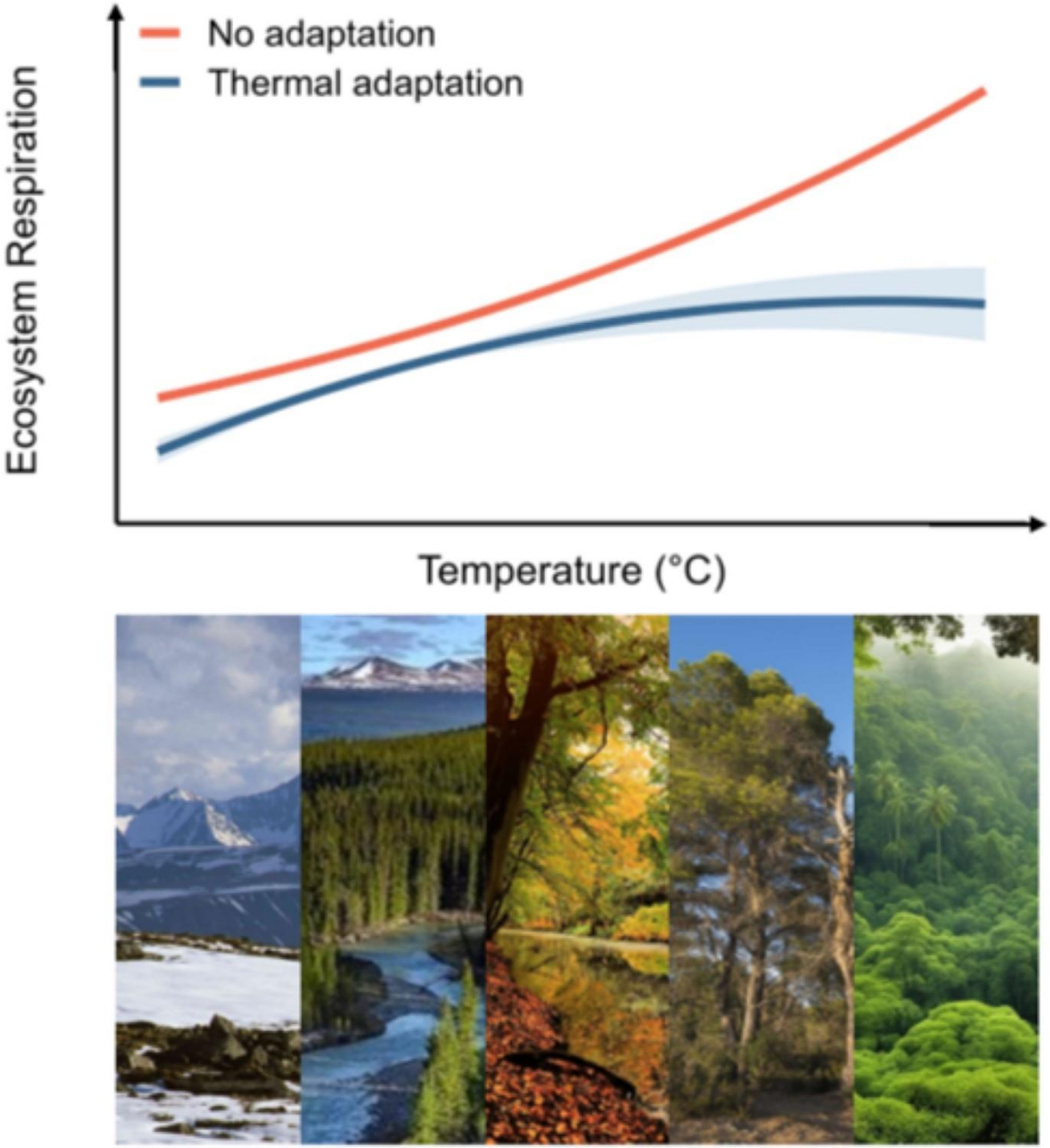
Fig 1. Illustration of the influence of thermal adaptation on temperature-driven increases in ecosystem respiration shown by Xu and colleagues. The plot demonstrates how modelled ecosystem respiration responds to increasing mean annual temperature. Thermal adaptation (blue line) reduces the predicted temperature response of ecosystem respiration, compared to not accounting for adaptation (red line). Images display the climate gradient, ranging from tundra to tropical ecosystems (left to right) included in the dataset of Xu et al.[2].


No adaptation
Thermal adaptation
Ecosystem Respiration
Temperature (°C)

https://dspace.org/

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Johnston, Alice S. A.

2025-08-01
Springer
https://doi.org/10.1038/s41558-025-02382-2
Johnston ASA. (2025) Warmer ecosystems save their breath. Nature Climate Change, Volume 15, Issue 8, August 2025, pp. 816-817

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