

2424 Main Mall  
Vancouver, BC Canada V6T 1Z4  
Ph: 604.827.5246



Dear Dr. Wake:

Please consider our manuscript, “A simple explanation for declining temperature sensitivity with warming,” for consideration as a Brief Communication for *Nature Climate Change*.

Climate change has shifted many biological events (1), and recent observations that species sensitivity to temperature is declining have raised concerns that fundamental biological processes are now also changing. Studies suggest warming has altered the main drivers of leafout in temperate plants (2; 3; 4) and altered carbon uptake in the tundra due to increased light limitation or shifts in photosynthesis (5; 6). The potential for such ecosystem effects is alarming, but they are rarely reported with strong evidence beyond declines in temperature sensitivity.

Here we show that current observations of declining sensitivities—used as evidence of fundamental shifts in underlying biological processes—are an illusion. We combine simple theory and simulations with data from plant development experiments and long-term records to show that declining sensitivities are the null expectation from current methods. This is because many biological events are the outcome of threshold processes and thus will occur more quickly with warming. This in turn will lead to lower estimated responses per degree C when using linear models, without any changes in the underlying biology. When using simple non-linear methods, we find no evidence of declining sensitivities across several empirical datasets (including using the same dataset used in 2) .

We believe this confusion in interpreting observed declining sensitivities is currently rampant throughout the phenological (e.g., 2; 4; 7) and related literature (e.g., 5) and may apply more broadly to many fields using linear methods and fixed time periods with warming. Our understanding of this problem only came through close cross-disciplinary collaboration between biologists (Wolkovich group) and statisticians (J. Auerbach and A. Gelman).

Based on the manuscript’s cross-disciplinary nature, we have suggested reviewers with biological (David Inouye, Theresa Crimmins and Toby Ault) and statistical (Richard McElreath and Jarrod Hadfield) backgrounds. Prior to submission Jonathan Davies, Yongshuo Fu, David Lipson, Christy Rollinson and Yann Vitasse reviewed the manuscript. This manuscript is not under consideration elsewhere. All authors approved of this version for submission. Empirical data are already publicly available through several major data portals, and we provide a link in the main text to our simulation code.

Sincerely,

A handwritten signature in black ink, which appears to read 'Elizabeth M. Wolkovich', is positioned below the word 'Sincerely,'.

Elizabeth M Wolkovich  
Associate Professor of Forest & Conservation Sciences

## References

- [1] IPCC. *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014).
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- [3] Güsewell, S., Furrer, R., Gehrig, R. & Pietragalla, B. Changes in temperature sensitivity of spring phenology with recent climate warming in Switzerland are related to shifts of the preseason. *Global Change Biology* **23**, 5189–5202 (2017).
- [4] Samplonius, J. M. *et al.* Phenological sensitivity to climate change is higher in resident than in migrant bird populations among European cavity breeders. *Global Change Biology* **24**, 3780–3790 (2018).
- [5] Piao, S. *et al.* Weakening temperature control on the interannual variations of spring carbon uptake across northern lands. *Nature Climate Change* **7**, 359 (2017).
- [6] Zhu, P. *et al.* Recent warming has resulted in smaller gains in net carbon uptake in northern high latitudes. *Journal of Climate* **32**, 5849–5863 (2019).
- [7] Meng, L. *et al.* Urban warming advances spring phenology but reduces the response of phenology to temperature in the conterminous United States. *Proceedings of the National Academy of Sciences* **117**, 4228 (2020).