comment

The increasing relevance of phenology to conservation

Shifts in phenology can impact organism fitness, ecosystem function, and goods and services from nature. Climate change management must better integrate phenology to optimize conservation outcomes as these impacts increase.

A. K. Ettinger, C. J. Chamberlain and E. M. Wolkovich

Shifts in phenology — the timing of life-history events such as spring leaf-out, salmon spawning and bird migration — are the most widely observed biological consequences of climate change. Phenology of many species in marine and terrestrial ecosystems has shifted at rates of 4 to 6 days per decade[1,2], with continued climate change projected to produce more severe shifts[3]. Phenology is critical to conservation as further shifts in time, alongside shifts in space (range shifts, often to higher latitudes or altitudes), will probably be necessary for many organisms to survive climate change. Phenology affects individual fitness, mortality, reproduction and population success across diverse taxa[4,5], and climate-change-induced phenological shifts invoke direct and indirect impacts on communities and ecosystems. Shifts in phenology are already altering human experiences in nature for livelihood and recreation (for example, see refs. [6,7]).

Although scientific understanding of phenological shifts is advancing, there has been less attention on the translation of this knowledge into management practices that bolster biological resilience to climate change. Similarly, only a small proportion of the large climate change and conservation literature available incorporates phenology (Fig. 1). Here, we describe three areas of conservation where there are opportunities to improve climate change planning through the integration of phenology research: managing and restoring nature, quantifying cost-effectiveness and return on conservation investment, and prioritizing conservation actions at landscape scales.

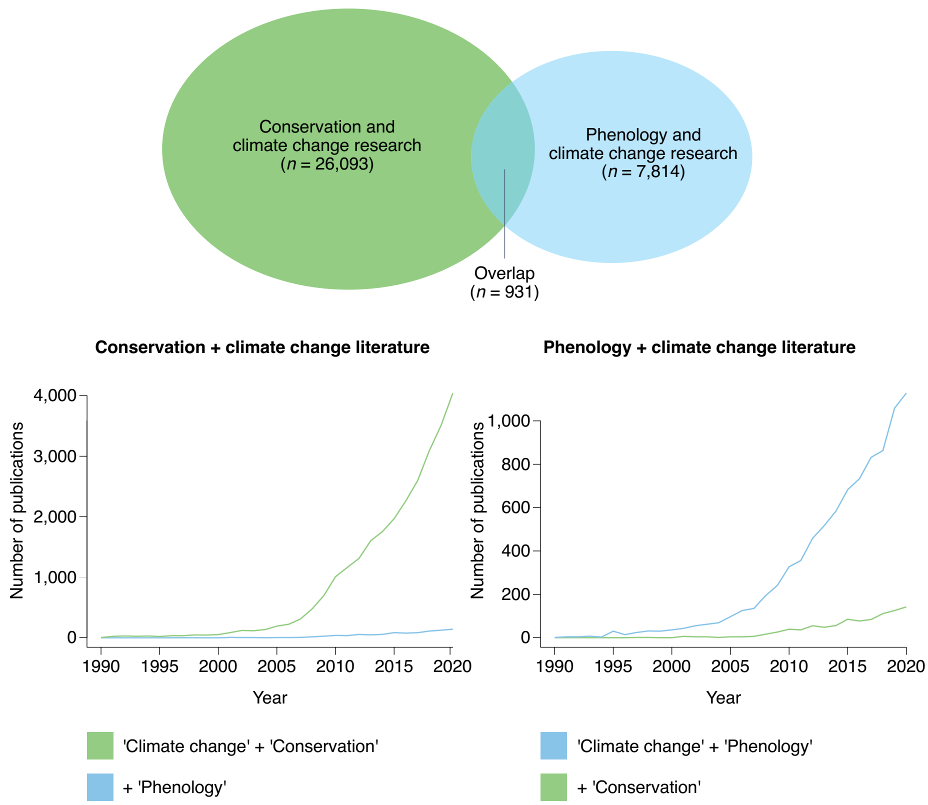

Fig. 1 | Many opportunities exist for increasing overlap of conservation and phenology in climate change research. Overlap is currently small (top panel). Scientific interest in climate change and conservation has increased dramatically over the past 30 years (1991–2021, as measured by scientific publications identified using Web of Science search terms), but research that also focuses on phenology has increased much more slowly (bottom left panel). Similarly, the dramatic increase in publication on climate change and phenology is not matched by research that also incorporates conservation (bottom right panel).

Phenology and management

Historically, conservation policies have focused on monitoring and management of natural resources in space (for example, by protecting areas of critical habitat), with recent efforts incorporating expected distribution shifts with climate change. In many cases, management actions may already be designed around particular phenological events, such as distinct hunting and fishing seasons during the year; management that explicitly incorporates phenological responses to climate change is likely to be more effective. Understanding climate change impacts on breeding phenology of sensitive species can inform tourism planning to prevent ecological and/or economic harm (for instance, tourism in caves that provide bat breeding habitat[8]). Climate-change-induced shifts in phenology will lead to new management challenges as historically observed seasonal patterns are disrupted (for instance, temperature-related shifts in the timing of whale movement led to increases in entanglements with fishing gear during recent marine heat waves[9]).

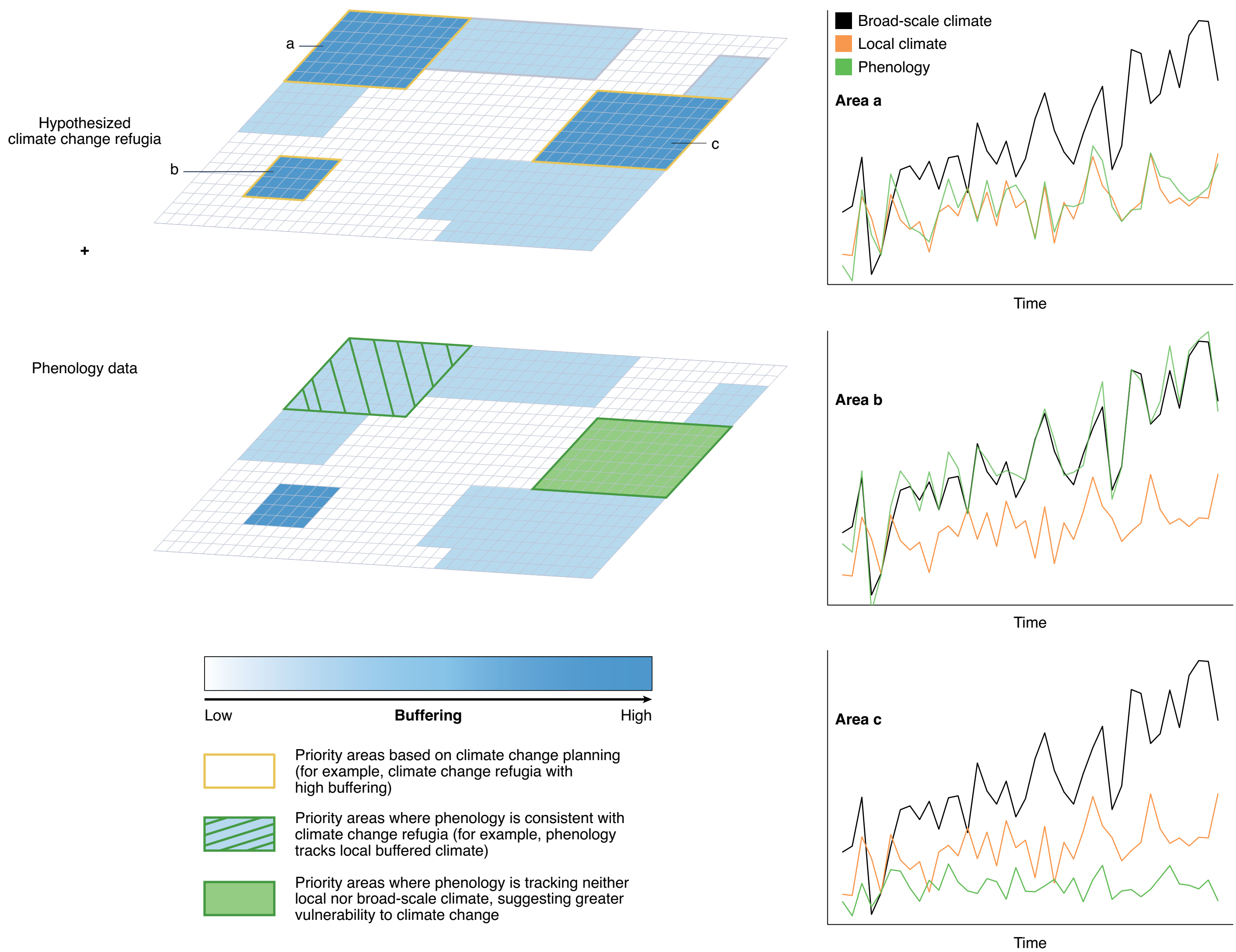

Fig. 2 | Climate change conservation planning approaches, such as climate change refugia, may be improved by integrating phenology data. Climate change refugia have been used in conservation planning to identify small-scale areas of habitat where local climate is not shifting as much as the climate of the surrounding landscape (for example, regional or broad-scale climate). Incorporating phenology data into refugia assessments may help analyse how organisms are responding to hypothesized climate change and thus the potential value of refugia. In this hypothetical example, common approaches — which do not use phenology data — identified areas a, b and c as potential refugia; adding phenology data provides further insights. In one case, phenology is consistent with a climate change refuge (that is, phenology tracks local buffered climate rather than broad climatic shifts, as shown in area a), while in another phenology is inconsistent with a true climate change refuge (that is, phenology tracks broad climate better than the local variables used to identify the refugia, as shown in area b). In cases where phenology is tracking neither local nor broad-scale climate conditions (area c), management may be critical to enhance climate change resilience as, even though local climate is somewhat buffered, organisms are not tracking climatic shifts and therefore may be more vulnerable to climate change.

Explicitly integrating phenological shifts into planning can help optimize future management to address such challenges.

Phenological data are an essential part of the conservation toolbox for sustained climate change resilience[10]. Natural resource managers often conduct climate change vulnerability assessments, in which conservation goals are evaluated relative to expected climate change impacts to organisms (for example, see ref. [11]). Incorporating phenology into these assessments is particularly important, because phenological tracking can be predictive of performance under climate change[12] and may be a measure of adaptive capacity[13]. In addition, populations, communities or ecosystems with high phenological diversity (that is, high variation in phenology) may be more resilient to climate change, as a portfolio of phenological strategies can result in a higher probability of survival with uncertain climate change[14]. We therefore need to incorporate phenological diversity into management planning (for example, in selecting seed sources for plant restoration).

Phenology and cost-effectiveness

Limited resources necessitate prioritizing where, when and how to implement conservation actions. Cost-effectiveness analysis, where a measure of the likely 'benefit' of an option is divided by its cost, is frequently used to make informed and justifiable conservation investments[15]. Shifts in phenology with climate change can alter many of the benefits we derive from nature, such as tourism (for example, wild-flower viewing[6]) and agroforestry[16]. Perhaps most importantly, phenological shifts impact carbon storage, scaling up to affect climate change itself. This links directly to 'natural climate solutions', which include management practices such as ecosystem restoration and avoided conversion of habitats to potentially reduce greenhouse-gas emissions, and is shaping conservation priorities and climate financing[17]. In some forests, phenological shifts may cause increased growth and greater carbon uptake[18], although other forests are likely to undergo reductions in carbon uptake with climate change[19]. Phenological shifts, their consequences and associated uncertainty should be incorporated into carbon-accounting practices, as the magnitude of these effects may be large (for example, shifts in net primary production of 32–52% with forecasted phenological shifts[20]). Adding further complexity, phenological shifts can vary greatly across species and locations[1,2]. A probability-based framework, which would allow for more complete risk assessment, may offer advantages over current standard practices for carbon accounting, as a way to incorporate this variation and uncertainty (for example, if fire were to occur[21]).

Phenology and prioritization strategies

In addition to cost-effectiveness, conservation action may be prioritized on the basis of various approaches, such as conserving geodiversity[18], climate change refugia (areas that are relatively buffered from contemporary climate change to allow species persistence[22]) and habitat corridors[23]. Although these approaches focus on space, integrating temporal aspects via phenology will provide important information on how species and ecosystems are responding to contemporary climate change on the ground (Fig. 2). For example, phenological data can be used to test hypothesized locations of climate change refugia (for instance, by quantifying interannual variance in phenology such as green-up date in refugia versus surrounding areas (Fig. 2)). In addition, phenology can be assessed when designing corridors to ensure that connectivity exists temporally as well as spatially. With additional research on how and when phenological tracking links to higher fitness[12], new conservation tools could leverage phenological tracking to promote climate change resilience. Integrating phenology in these ways does not necessarily require new data collection efforts (although further research is needed in tropical regions); rather, on-the-ground data (such as data from USA National Phenology Network, the Pan European Phenology Project and the PhenoCam network), as well as remote-sensed phenology datasets (such as MCD12Q2 v.006), are already available.

Explicitly incorporating what is known about phenology and climate-change-induced shifts in phenology is necessary for effective conservation and offers avenues for connection between scientific research and frontline communities experiencing impacts of climate change (for instance, https://wwfclimatecrowd.org/). By seizing the opportunities available now to synthesize advances in phenology research with human experiences of ongoing phenological shifts, we can enact more cost-effective and resilient conservation that enhances the contributions of nature to people. ❐

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References

1. Kharouba, H. M. et al. *Proc. Natl Acad. Sci. USA* **115**, 5211–5216 (2018).
2. Poloczanska, E. S. et al. *Nat. Clim. Change* **3**, 919–925 (2013).
3. Morin, X. & Chuine, I. *Glob. Change Biol.* **11**, 1493–1503 (2005).
4. Chuine, I. *Phil. Trans. R. Soc. B Biol. Sci.* **365**, 3149–3160 (2010).
5. Lane, J. E. et al. *Nature* **489**, 554–557 (2012).
6. Lambers, J. H. R. et al. *Clim. Change Ecol.* **2**, 100008 (2021).
7. Fitchett, J. M. & Ebhuoma, E. *Int. J. Biometeorol.* **62**, 1115–1119 (2018).
8. Furey, N. M., Mackie, I. J. & Racey, P. A. *Acta Chiropt.* **13**, 341–354 (2011).
9. Samhouri, J. F. et al. *Proc. R. Soc. B Biol. Sci.* **288**, 20211607 (2021).
10. Rosemartin, A. H. et al. *Biol. Conserv.* **173**, 90–97 (2014).
11. Foden, W. B. et al. *WIREs Clim. Change* **10**, e551 (2019).
12. Cleland, E. E. et al. *Ecology* **93**, 1765–1771 (2012).
13. Aubin, I. et al. *Environ. Res.* **24**, 164–186 (2016).
14. Schindler, D. E., Armstrong, J. B. & Reed, T. E. *Front. Ecol. Evol.* **13**, 257–263 (2015).
15. Fonner, R., Bellanger, M. & Warlick, A. *Ocean Coast Manag.* **194**, 105222 (2020).
16. Birch, J. C. et al. *Proc. Natl Acad. Sci. USA* **107**, 21925–21930 (2010).
17. Griscom, B. W. et al. *Proc. Natl Acad. Sci. USA* **114**, 11645–11650 (2017).
18. Lawler, J. J. et al. *Conserv. Biol.* **29**, 618–629 (2015).
19. Anderegg, W. R. et al. *Science* **349**, 528–532 (2015).
20. Duveneck, M. J. & Thompson, J. R. *J. Geophys. Res. Biogeosci.* **122**, 2298–2313 (2017).
21. Buchholz, T. et al. *Mitig. Adapt. Strateg. Glob. Chang.* **27**, 4 (2022).
22. Morelli, T. L. et al. *PLoS ONE* **11**, e0159909 (2016).
23. Stralberg, D., Carroll, C. & Nielsen, S. E. *Conserv. Lett.* **13**, e12712 (2020).

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Competing interests
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Tree harvesting is not the same as deforestation

Millions of people rely on potentially sustainable harvesting for their income and energy. Yet specious assumptions about deforestation continue to drive ineffective bans on these practices. This occurs at the peril of the climate and the poor.

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COP26 in Glasgow, Scotland, marked a renewed international focus on reducing emissions from the world's forests and woodlands, with a wide coalition of nations committing US$12 billion over the next four years to halt deforestation[1]. Although a welcome boost for emission reduction targets, intensified efforts to end deforestation herald a time of great risk and uncertainty for hundreds of millions of people in the Global South who rely on the harvesting of trees from natural forests