The ARNOLD ARBORETUM of HARVARD UNIVERSITY

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Dear Editor:

Please consider our paper, 'Spatial and temporal shifts in photoperiod with climate change' for publication as an 'Opinion' in *Global Change Biology*. This work emerged from a synthesis of growth chamber experiments testing effects of temperature and photoperiod on spring phenology (Wolkovich et al. 2019). It addresses a critical question in global change research: What are the implications of the altered photoperiod that organisms experience as they shift their ranges and/or seasonal activities with climate change?

The two most-observed biological impacts of climate change are shifts in space (altitudinal, latitudinal range shifts) and time (phenological shifts, Poloczanska et al. 2013, Chen et al 2011, Parmesan et al 2006); both result in altered experienced photoperiod (Saikkonen et al 2012). Altered photoperiods have the potential to dramatically affect performance and fitness, however, the magnitude of effects from shifts in photoperiod with climate change are unknown or unquantified for the vast majority of species. We quantify expected changes in experienced photoperiod due to shifts in space versus time, given observations of spatial and temporal shifts to date (Chen et. al 2011, Parmesan and Yohe 2003), and put them in a novel, global context. Recently published work has focused on photoperiod changes due to shifts in species distributions (e.g., Way and Montgomery 2015, Saikkonen et al 2012), yet we demonstrate that changes in experienced photoperiod due to temporal shifts may be orders of magnitude larger than those due to spatial shifts (e.g., 1.6 hours versus one minute of change).

Our work is especially timely and important because it focuses on spring phenology (as do the following recently published papers: Chamberlain et al 2019; Richardson, A.D., et al. 2018; Fu et al 2019). To date, the role of photoperiod has received far more detailed attention for end-of-season activities, such as growth cessation in the fall, than for spring activities. Though photoperiod cues dominate in the fall for many organisms, fall phenology responses to climate change have been muted. In contrast, spring phenology responds strongly to temperature and thus has advanced substantially with warming—causing cascading, and generally unexplored, effects on photoperiod experienced at the start of spring. With continued warming photoperiod limitations could come into play, however, and cause the rapidly advancing springs to abruptly slow or stall. We demonstrate that incorporating photoperiod into forecasts is possible by leveraging existing experimental data: for example, growth chamber experiments on woody plant spring phenology often have data relevant for climate change impacts We highlight how new modeling approaches can improve predictions of when, where, and how much photoperiod is likely to affect future spring phenology and can be combined with new empirical work to advance our understanding of the role of photoperiod in a warming world.

Our paper falls squarely within the scope of *GCB*: climate change induced shifts in photoperiod would have wide-reaching impacts on many plant and animal species. Photoperiod acts as a cue for the spring emergence and migration timing of diverse species, and alterations to experienced photoperiod can affect development, growth, and fitness for plants, insects, fish, and mammals, among other organisms. Thus, understanding these changes is critical for biologists forecasting species responses, policy-makers dependent on these forecasts for adaptation strategies, and those dependent on the services provided by these species. Yet, photoperiod has rarely been included in forecasts of responses to climate change and implications of climate-change-induced shifts in photoperiod are largely unexplored, especially for early-season spring events, where changes will be most dramatic.

Co-authors are D. Buonaiuto, C. Chamberlain, I. Morales-Castilla, and E. Wolkovich. We suggest the following potential reviewers: Josep Penuelas, David Inouye, Ally Phillimore, Mark Schwartz, Christian Korner, and Andrew Richardson. Thank you for considering our paper.

Sincerely,

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