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Editorial: Changing seasons: how is global warming affecting forest phenology?

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Editorial on the Research Topic
Changing seasons: how is global warming affecting forest phenology?

Phenological synchronization with changing seasons is critical for the survival and fitness of temperate and boreal trees and they have evolved to use environmental cues, e.g., temperature and photoperiod, to regulate phenological events (Lambers and Oliveira, 2019). Ongoing global warming, however, may change the timing of environmental triggers and phenological events (Inoue et al., 2020; Garrigues et al., 2023). A good understanding of how global warming affects the phenological synchronization of trees with new local climate conditions and the limitations of phenological plasticity is critical for projecting the future distribution and performance of boreal and temperate trees.

In this special issue, Chu et al. suggest that the relationships between spring phenology and growing season length may differ from the common view that earlier budburst will result in a longer growing season. They point out that plant phenological responses in the spring are strongly influenced by temperatures at the time of species events, with low temperatures associated with large responses and high temperatures with small responses. Therefore, changes in spring phenology do not necessarily translate to increases in growing season length or growth potential. The effects of chilling on phenological responses depend on chilling level and species chilling-forcing relationships but are not necessarily associated with functional groups. The impacts of photoperiod are limited and variable, and often result from evaluation of phenological responses based on changes in timing of species events, rather than changes in cumulative temperatures.

Hu et al. report the impact of seasonal changes in dormancy depth and cold hardiness on frost risk in five deciduous tree species during the winter. They used experimental data based on twigs to establish, and then historic observations to verify, chilling-forcing relationships. Their modeling results showed that spring budburst advanced significantly from 1952 to 2021 while dormancy depth in early spring increased due to reduced chilling accumulation associated with climate warming. They found that the maximum dormancy depth occurred between early October and early December, followed by an exponential decrease. Cold hardiness reached its peak in mid-winter through cold acclimation and decreased during spring. Cold hardiness declined due to higher temperatures, but frost risk was not affected due to simultaneous advances in late spring low-temperature events and budburst dates (Ford et al., 2016). Their analyses and several published reports conclude that the risk of damaging spring frosts is likely to vary among geographic regions and may not increase in all areas.

Walde et al. examine how winter chilling, spring forcing temperature, and photoperiod govern spring phenology in nine temperate tree species (six genera) in two locations (six species near Zurich, Switzerland, three near Beijing, China). East Asian species exhibited lower forcing requirements than European species of the same genus, suggesting that the requirements are influenced by the local climate of the species. In contrast, European species had higher forcing and chilling requirements, likely to prevent early responses to fluctuating temperatures and unpredictable spring frosts in Europe. Beside chilling and spring forcing temperature, *Fagus sylvatica* was also sensitive to photoperiod, especially under warm temperatures and/or low chilling, indicating the compensatory role of high chilling or longer photoperiods. Photoperiod effects were also observed in *Betula pendula* and *Quercus robur*. These findings provide valuable insights into the complex interactions between chilling, forcing, and photoperiod in temperate tree species' dormancy release and budburst.

The resilience of tree populations to climate change depends on their intraspecific genetic variation and phenotypic plasticity. In a study by Harrington et al. the cambial phenology of *Pseudotsuga menziesii* across different environments was investigated in common gardens in Washington and Oregon, USA, specifically focusing on the impact of extreme heat and seasonal conditions. The diameter growth in their latest measurement year was notably higher than in the previous year, potentially attributed to the premature growth cessation triggered by the previous year's heat dome event. Furthermore, diameter growth rates were found to vary based on site and provenance interactions, influenced by disease susceptibility and environmental factors. A similar extreme event with high temperatures during summer resulted in growth cessation of young Douglas-fir (Ford et al., 2017). This highlights that predicting future diameter growth responses of genotypes to future climates will require detailed information on genotypic responses, including sensitivity to environmental events and biological pests such as insects and diseases.

The impacts of climate change on forests can be positive through longer periods of active growth under higher temperatures (Chu et al.) or negative through greater occurrence of extreme events such as frosts (Chu et al.) and heat/drought (Harrington et al.). Most frost research on trees focuses on post-budburst events (Man et al., 2021). Hu et al. used the relationships between measured cold hardiness and cold hardiness index calculated from temperatures and photoperiod to estimate freezing damage prior to budburst, which is observed in some areas (Man et al., 2009, 2013). While chance of frosts may or may not change with warming (Chu et al.; Hu et al.), a general increase in drought is expected for many parts of the world (IPCC, 2014), which can slow down advance of spring budburst with warming climate (Huang et al., 2019; Ganjurjav et al., 2020). The studies presented in this special issue indicate the complexity and importance of understanding the mechanisms and variations of phenological responses to climate warming in boreal and temperate tree species. Research in this area is still in the early stages, however, and much more work needs to be done. Because of large variations in climate conditions and species biology among different regions, a combination of field and controlled-environment studies and close collaboration among researchers in different regions may be an efficient approach to study changes in tree phenology in response to future climate warming. In addition, collaboration among different disciplines such as molecular genetics as well as plant physiology, plant pathology, ecology and forestry may help determine when genes associated with various aspects of phenology are being expressed and thus, the underlying factors important in sensing and responding to environmental cues (Sung and Amasino, 2006; Cronn et al., 2017).

Author contributions

CH: Writing—original draft, Writing—review and editing. Q-LD: Supervision, Writing—original draft, Writing—review and editing. RM: Writing—original draft, Writing—review and editing. SI: Writing—original draft. BT: Writing—original draft.

Conflict of interest

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