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Modelling leaf phenology in 22 North American tree species during the 21st century

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Impacts of current anthropogenic climate change have been observed in a variety of ecosystems and biological processes. Because phenological events are strongly responsive to temperature, they have been among the first documented fingerprints of climate change. Phenological changes in temperate forests are likely to affect ecosystems productivity and functioning, as well as cold hardiness of trees and species' distribution. As forests play a major role in the terrestrial storage of carbon, any changes in their distribution will have important implications, not only for forest products and biodiversity, but also for the global climate itself. Accurate predictions of tree phenology therefore are necessary to understand the impact of climate change on forest ecosystems. Most of prevailing analyses are phenomenological and approximate, only correlating temperature records to imprecise records of phenological events. To advance our understanding of phenological responses to climate change, more reliable predictions made with process-based models are required.

In the present study, we developed, calibrated and validated process-based models of leaf unfolding for 22 North American tree species. Using daily meteorological data predicted by two scenarios (A2: +3.2°C and B2: +1°C) from the HadCM3 GCM, we predicted and compared range-wide shifts of leaf unfolding in the 20th and 21st centuries for each species.

Model predictions suggest that climate change will affect leaf phenology in almost all species studied, with an average advancement during the 21st century of 5.0 days in the A2 scenario and 9.2 days in the B2 scenario. Our model also suggests that lack of sufficient chilling temperatures to break bud dormancy will decrease the rate of advancement in leaf unfolding date during the 21st century for many species. Some temperate species may even have years with abnormal budburst due to insufficient chilling. Species fell into two groups based on their sensitivity to climate change: 1) species that consistently had a greater advance in their leaf unfolding date with increasing latitude and 2) species in which the advance in leaf unfolding differed from the center to the northern versus southern margins of their range. At the interspecific level, we predicted that early-leafing species tended to show a greater advance in leaf unfolding date than late-leafing species; and that species with larger ranges tend to show stronger phenological changes.

Our results suggest that the changes observed in the phenology of tree species during the 20th century will continue during the 21st century, but with significant differences among species and between climate scenarios. Some trends in phenological changes may be reversed by the end of the century because of the bimodality of temperature influence on both chilling and warming cues for phenological control systems. This result is especially important as it can dramatically alter the predictions of process-based models using phenology, especially Dynamic Global Vegetation Models that are coupled with atmosphere-ocean models used to predict climate change. This result highlights the importance and utility of process-based models in studying the impact of climate change on organisms.

In this study, we have demonstrated that broad trends in phenological responses to warming can emerge across diverse tree species despite variation in both species-specific controls on phenology and in the geographic distribution of species. These predicted changes in phenology have significant implications for the frost susceptibility of species, their interspecific relationships, and their distributional shifts.