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The effect of growing-season productivity on autumn phenology in temperate trees

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Phenological shifts in plants greatly affect biotic interactions and lead to multiple feedbacks to the climate system. Increases in growing-season length under warmer climates are expected to drive changes in water, nutrient, and energy fluxes as well as enhancing ecosystem carbon uptake. Yet, future trajectories of growing-season lengths remain highly uncertain because the intrinsic and extrinsic factors triggering autumn leaf senescence, including lagged effects of spring and summer productivity, are poorly understood. Here, we use 434,226 spring leaf-out and autumn leaf senescence observations of temperate trees from Central Europe between 1948 and 2015 to test the effect of seasonal photosynthetic activity on leaf senescence, thereby exploring the extent to which growing-season lengths are internally regulated by constraints on productivity. We found that spring and summer productivity was a critical driver of autumn phenology, with earlier leaf senescence in years with high seasonal photosynthetic activity. Our new process-based model, incorporating information on growing-season photosynthesis, increased the accuracy of existing autumn phenology models by 22–61%. Furthermore, the physiological constraint of growing-season photosynthesis reversed the predictions of autumn phenology over the rest of the century. While current phenology models predict that leaf senescence will occur 7–19 days later by the end of the 21st century, we estimate that leaf senescence will, in fact, advance by 3–6 days. Our results reveal important constraints on future growing-season lengths and the carbon uptake potential of temperate trees and enhance our capacity to forecast long-term changes in ecosystem functioning, which is critical to improve our understanding of Earth System dynamics in response to climate change.