Forest phenology

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Microclimate regulates when autumn leaves fall

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Climate influences when leaves change colour and fall, but not all trees lose their leaves at the same time. Combining field data, mathematical models and remote sensing, researchers show how local-scale variation in tree canopies and understory temperatures alters the start and duration of autumn leaf colouration and forecast reduced autumn delays under climate change.

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The vibrant colours of autumn leaves are an annual attraction that signals a change of season in temperate-latitude climates. As with many ecological phenomena, this hallmark of autumn is affected by climate change[1], which may influence the schedule of when deciduous plants drop their leaves. The exact timing of leaf colour change and fall, however, varies across tree species and locations[2]. Writing in *Nature Climate Change*, Xiaoyong Wu and colleagues[3] report how the physical structure of tree canopies and the microclimatic temperatures experienced by individual trees jointly determine when different trees lose their leaves.

As climates change, the timing (or phenology) of ecological events shifts[2,4]. Much research has focused on the springtime effects of climate change on phenology, including when flowers bud, insects breed and birds migrate[5]. Climate change effects on autumn, conversely, have received less research attention[1], and such effects are idiosyncratic. In Europe and China, for instance, half of all forest records show autumn shifting earlier, while the other half indicate a later autumn[2]. Predicting when leaves will fall matters beyond knowing when to jump in the camper to head for the colourful hills; better understanding of autumn phenology informs estimates of carbon storage and sequestration[6] and can improve management of pests that invade during the fall[1].

Wu and colleagues studied fall phenology within six temperate forests: five in the USA and one in China. For these sites, they collated aerial snapshots of forest canopies from PlanetScope daily satellite imagery at 3-m resolution across 5 years, totalling approximately 100 billion image pixels. From these images, they quantified the start and duration of fall, measured according to the colour of each individual tree crown, which they validated using on-the-ground observations[7]. Although they discovered substantial spatial variation in when fall starts and ends, 92% of all such variation was intraspecific (that is, occurring within rather than between tree species). This indicated that the local environment of each tree, rather than just species identity, may play a strong role in orchestrating autumn phenology.

Wu and colleagues hypothesized that this intraspecific variation may be explained by microclimate: the hyper-local climatic conditions that each tree experiences. The temperatures inside forests can be substantially different to the open-air macroclimate outside forests, as measured by weather stations[8], given that vegetation can shade out daytime heat and light, and trap warm air in at night[9]. Although macroclimate data from weather stations are highly useful for globally standardized meteorological baselines, they may not represent the shaded conditions within forests. Furthermore, forest microclimate can be highly spatially variable, contingent on the physical structure of tree canopies – patches of forest with taller or denser trees create more shade, keeping the understory cooler than sparser forest areas.

To quantify the vegetation density and microclimate experienced by individual trees, Wu and colleagues employed airborne lidar data – aeroplane- and drone-mounted scanning lasers that detect three-dimensional structures – to calculate tree canopy heights and the amount of plant matter per unit area (plant area index) at the metre scale. Using these measurements with satellite imagery through time, they parameterized a mathematical forest microclimate model[10] and a light transmission model[11] to construct realistic vertical profiles of below-canopy temperatures and sunlight, respectively. They found that the forest microclimate was usually buffered from the macroclimate (that is, 2–4 °C less variable inside forests than outside forests), but the amount of thermal buffering varied across distances of only a few hundred metres within forests.

Theory and intuition suggest that tree physiology is attuned to the thermal and light environment within the tree's canopy and understory, which triggers leaf colour change and loss[6]. Wu and colleagues developed piecewise structural equation models to explicitly represent the causal process by which canopy structure influences forest microclimate and, in turn, fall phenology. These models indicated that areas of dense forest vegetation resulted in more thermally buffered forest understories, which delayed the start of fall but not the end of fall, resulting in short fall seasons. This finding held true across regions in the USA and China. The models therefore served as a quantitative representation of a canopy–microclimate–phenology causal pathway.

Previous work has highlighted uncertainty of whether climate change may cause fall to begin earlier or later[2]. Here, the authors forecasted fall phenology using process-based models, both with and without their newly proposed pathway. Ignoring microclimate led to forecasted delays of fall by about 0.15 days per decade, whereas incorporating microclimate improved prediction performance and reduced these delays by on average 35%. Such minimal delays of fall contrast with recent reports on spring tree phenology, which is dramatically advancing earlier by 5–10 days per decade[2,5].

To arrive at their findings, Wu and colleagues took an integrative approach that combined systematic in situ tree monitoring, high-resolution airborne and satellite imagery, and theory-based mathematical models. Assimilating local and remote data in this manner facilitates the process of scaling up insights while maintaining detailed ecological realism, including microclimates. Across forestry, agronomy and biology, those studies that measure the microclimates most relevant to a given organism or ecosystem have proven to be accurate and useful — soil temperatures for crop yields[12], water temperatures of small stagnant pools for mosquito larvae[13] and urban heat islands for human heat stress[14], to name a few.

Growing attention towards microclimate ecology has been spurred in part by the advent of new microclimate models and databases[15]. Yet, at present, most climate change research infrastructure and theory remain focused on macroclimate. Uptake of microclimate tools and insights, as done by Wu and colleagues, is a crucial first step in understanding the impacts of climate change as experienced by life on Earth.

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Competing interests

The author declares no competing interests.