News & views

Ecology

The early arrival of spring doesn't boost tree growth

Cyrille B. K. Rathgeber & Patrick Fonti

Analysis of when and how fast temperate deciduous trees in North America grow suggests that the earlier onset of the growing season induced by climate change does not result in extra carbon sequestration from wood production. **See p.552**

Earth's forests have a major role in absorbing human-produced carbon dioxide and thus make a key contribution towards mitigating global warming. Dow *et al.*[1] report on page 552 the results of their investigation into whether the extended length of the growing season due to global warming affects the amount of carbon sequestered when wood grows.

Every year, forests remove from the atmosphere the equivalent of about one-quarter of the carbon produced by human activities[2]. This happens when trees, to support their growth towards the Sun's light, take up CO_2 into their leaves and transform this carbon into sugar, which constitutes the carbon source of the tree. This sugar circulates in the tree, feeds its carbon reserves and fuels the production of woody structures, such as the stem, branches and roots. These constitute the main carbon sinks, where the carbon can remain trapped for hundreds of years. Quantifying the contribution of forests to the global carbon budget is essential to assess the consequences of climate change in the years ahead. At present, global warming is already advancing the time at which leaves emerge in spring[3]. This results in an earlier start to CO_2 absorption, which might therefore promote tree-stem growth, wood production and carbon sequestration[4].

Dow and colleagues carried out a retrospective study to assess the growth of temperate deciduous forests in eastern North America. Their findings show that earlier tree growth in spring does not necessarily translate into notable increased annual carbon sequestration in terms of wood production (Fig. 1). Dow *et al.* used remote-sensing data to confirm that leaf emergence in spring had been occurring earlier in the year at two iconic deciduous forests (the Smithsonian Conservation Biology Institute forest near Front Royal, Virginia, and the Harvard Forest in Petersham, Massachusetts). Then, the authors explored tree-stem radial growth (growth of the stem circumference), assessing the incremental change at weekly time intervals, using data from nearly 500 trees, collected over 6 years (Harvard Forest) or 10 years (Smithsonian Conservation Biology Institute forest). The results show, as expected, a corresponding trend of an earlier start of stem growth in warm springs.

However, the authors found that, despite spring's earlier onset, the length of the peak growing season, the maximum growth rates and the total annual tree growth did not change significantly. To confirm that the rise in spring temperatures had little effect on the final annual tree-ring widths, an indicator of growth, the authors quantified climate–growth relationships of more than 200 centennial-long tree-ring chronologies from more than 100 sites across the temperate deciduous forest belt in eastern North America. This analysis showed that, compared with the effect of spring temperatures, these forest sites were more sensitive to summer temperatures — which slowed woody growth — during the peak growing season. Dow and colleagues' unexpected results challenge current ideas about carbon allocation in trees.

It is commonly assumed that, when deciduous trees bear leaves, they steadily allocate over time a large part of the sugar generated through the process of photosynthesis to the growth of annual tree rings. Thus, if leaves appear earlier, it could be assumed that the rings would grow correspondingly wider during the year. However, such an oversimplified concept of tree growth does not fully encompass processes that occur during the course of the growing season.

As the authors report, the relationship

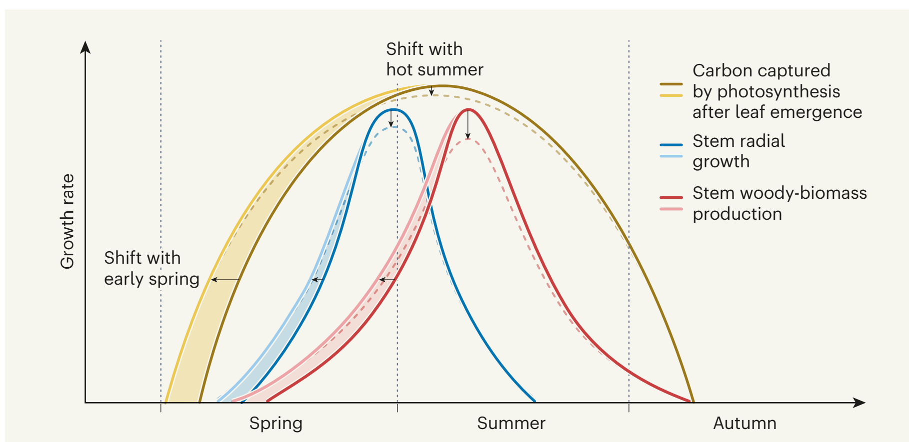

Figure 1 | How early spring due to climate change affects tree growth. To understand the effects of climate change on the carbon sequestered annually by trees, Dow *et al.*[1] investigated the consequences of an early start to the growing season in deciduous forests. Leaf emergence is followed by carbon uptake by the process of photosynthesis. Over time, carbon can be captured for long-term sequestration if it contributes to radial growth (growth in the stem circumference) and wood formation. The areas under the curves for annual growth represent growth in terms of: the amount of carbon captured by leaves; annual radial growth (tree-ring width); and increase in woody biomass. The authors report that the early arrival of spring, shifting the margins of the growing season (lighter curves), had little impact on the final annual tree-ring width or the amount of woody biomass produced, whereas high temperatures in summer had a negative effect on radial growth (dotted curve). Other studies[11,14] (also plotted here as dotted curves) indicate that high temperatures and related drought can suppress carbon capture and woody-biomass production — carbon capture is less affected than is radial growth, which, in turn, is less affected than is growth in biomass.

between temperature and ring width is dominated by the negative impact of the warmer months (May to July). This not only shows that the dynamics of wood formation, and the amount of wood produced, changes during the growing season, but also indicates that warmer temperatures can have different effects depending on the time of the year (for example, stimulating wood growth in spring, but hindering it in summer). As shown by studies monitoring wood formation[5], the ring-widening process follows a bell-shaped curve that peaks around the summer solstice. Therefore, an early start of growth will make only a minor contribution to the final annual ring width.

Two elements further complicate efforts to associate the timing of leaf development (leaf phenology) with the dynamics of tree-ring formation. First, the ability to transform the carbon captured by leaves into woody structures depends on a process called xylogenesis, which occurs in a tissue called the vascular cambium and generates wood cells for water transport, mechanical support and storage of reserves, including water and carbon. In other words, carbon acquired through photosynthesis can be converted into woody biomass only to the extent that xylogenesis allows[6]. Moreover, there is a high degree of autonomy between the carbon sinks and sources, thanks to the role of carbon reserves that accumulate in wood tissues. In addition, coarse roots and branches (which also contain large quantities of carbon) might exhibit different growth dynamics from the stem[7].

Second, at a seasonal scale, growth encompasses two distinctive processes involved in wood formation[8]: on the one hand, cell proliferation and enlargement are responsible for growth in terms of size; on the other hand, cell-wall thickening and deposition of complex organic polymers called lignins are responsible for growth in terms of weight. To add to the complexity, these two processes exhibit different dynamics and are related to different environmental factors – their seasonal maxima synchronize with the maximum length of daylight (photoperiod) in the case of growth in size, and with temperature for weight gain[5].

Dow and colleagues' study provides evidence that warmer springs have advanced the leaf emergence of temperate deciduous forests but have not substantially increased their wood production. This suggests that the extra CO_2 uptake does not contribute to sustainable carbon sequestration in the trunks of long-lived trees. The fate of this extra carbon is unknown, but another group has proposed that carbon taken up by trees might be directly emitted back into the atmosphere[9].

The results obtained by Dow *et al.* challenge our current representations of carbon allocation in trees, and contradict certain projections from dynamic global-vegetation models, which are essential tools for assessing and interpreting the responses of terrestrial ecosystems to global changes and their feedback to the climate system. These models generally assume that plant growth depends principally on the amount of sugar produced by photosynthesis (but see ref. 10, for a contrasting example). However, different climatic factors influence photosynthesis and xylogenesis – mainly sunlight intensity and CO_2 concentration for photosynthesis, and temperature and water availability for xylogenesis[11]. We think that current insights into the process of wood formation and its sensitivity to environmental factors can help efforts to reformulate vegetation models[12]. Such insights might improve the structure and outputs of these models, and enhance our knowledge about the carbon cycle and the climate system[13].

Cyrille B. K. Rathgeber is at the University of Lorraine, AgroParisTech, INRAE, SILVA, 54000 Nancy, France. **Patrick Fonti** is at the Research Unit Forest Dynamics, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, 8903 Birmensdorf, Switzerland.
e-mails: cyrille.rathgeber@inrae.fr; patrick.fonti@wsl.ch

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Condensed-matter physics

Carbon's lesson from a heavy friend

Aline Ramires

Electrons in a pure-carbon material display properties that are reminiscent of those in heavy-element compounds. A model inspired by this link hints at how a single-element material can exhibit complex electronic behaviour.

Carbon is a special element: it exists as diamond, the hardest natural material, but also as graphite, which is fragile enough to slide from pencil tip to paper with minimal pressure. Graphite comprises stacks of single layers of carbon atoms, and each sheet, known as graphene, has exceptional properties[1]. When two sheets are twisted relative to each other by a 'magic' angle, a plethora of phases of matter arises[2,3]. Finding such wide-ranging phenomena in a single elemental material is surprising, because such complexity is usually reserved for systems with complicated structures and composition. Writing in *Physical Review Letters*, Song and Bernevig[4] report that a model for magic-angle twisted bilayer graphene can be mapped to a model for materials containing heavy elements, in structures that are much more complex than that of graphene.

Heavy-fermion materials (or, simply, heavy fermions) are compounds containing elements that are found near the bottom of the periodic table – most commonly, cerium, ytterbium or uranium (Fig. 1a). These elements have electrons (which are particles known as fermions) that are highly localized, meaning that they can access only a very small region around the nucleus of a given atom. The strong interactions between localized electrons, and the mixing of these electrons with the delocalized electrons of other atoms, generates hybrid electrons that behave as though they have masses that are up to 1,000 times that of an electron at rest[5]. These interactions also give rise to a range of intriguing behaviours that make heavy fermions key materials for studying phenomena such as magnetism, superconductivity (the ability of a system to conduct electricity without loss) and phase transitions[5].

By contrast, the electronic properties of graphene are dominated by delocalized electrons, suggesting that heavy fermions and graphene systems have little in common. But twisted bilayer graphene has a