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Disentangling carbon uptake and allocation in the stems of a spruce forest

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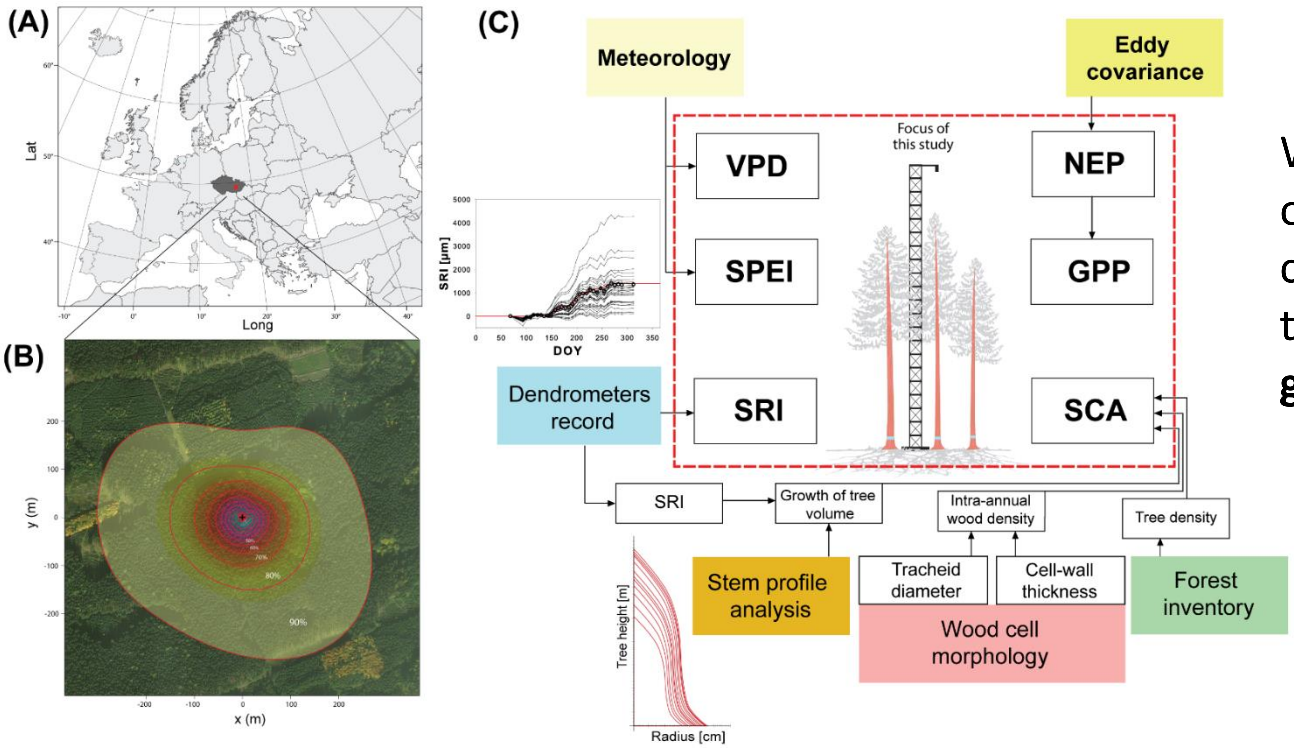
Although forests **store significant amounts of carbon in tree stems**, the extent to which stem growth depends on **carbon assimilation and environmental factors is poorly understood.**

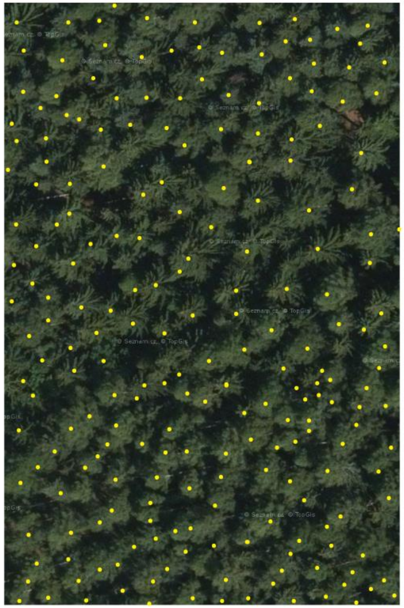


We examined the carbon balance of spruce using a comprehensive combination of methods to link the **underlying processes of tree growth and carbon allocation**.

Eddy covariance
Dendrometer
Wood cell morphology
Forest inventory
Micrometeorology

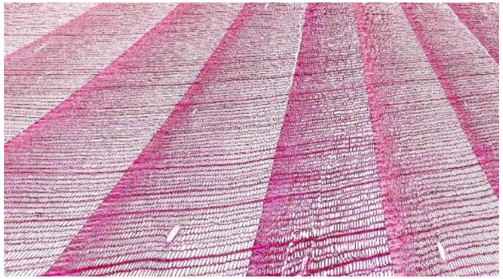
$$\frac{\Delta V}{\Delta t} = \frac{a(DBH_1 + 2\Delta SRI_{t_2-t_1})^b - a(DBH_1)^b}{t_2 - t_1}$$

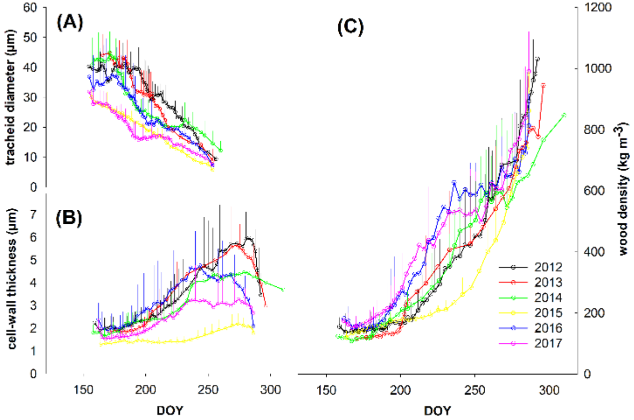
Given the initial diameter DBH_1 at time t_1 and the increase in SRI (ΔSRI), the resulting diameter at time t_2 is $DBH_2 = DBH_1 + 2\Delta SRI_{t_2-t_1}$, and the corresponding change in the stem volume on the interval $\Delta t = t_2 - t_1$ is denoted in the equation



Stem Carbon Allocation

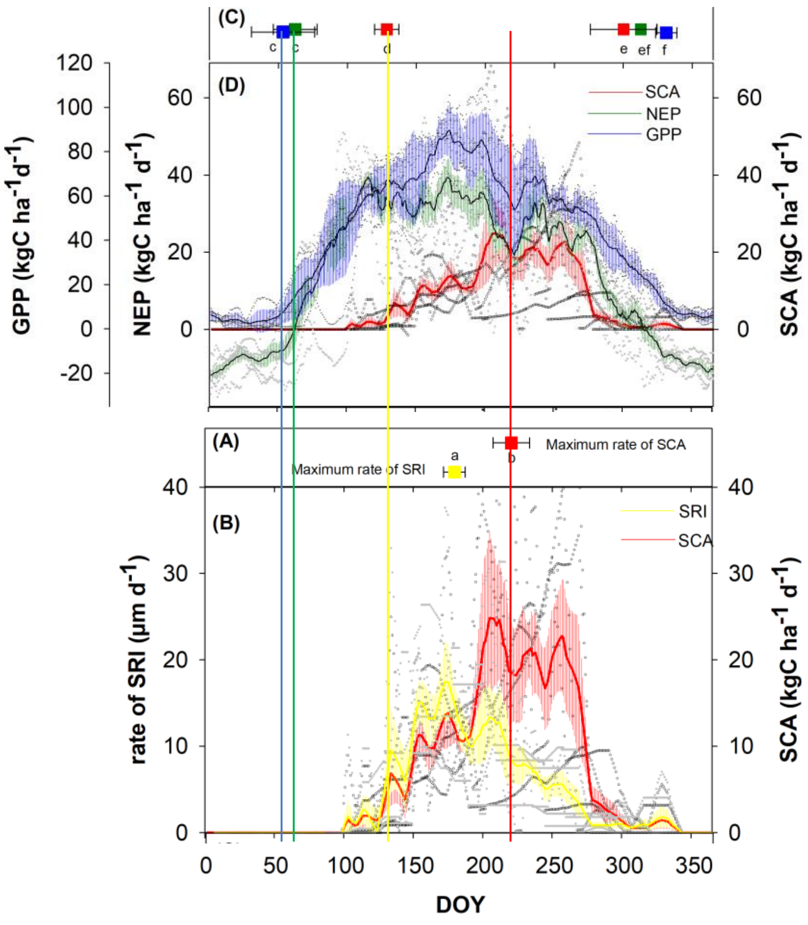
$$\boxed{SCA_{(t)} = \frac{\Delta V}{\Delta t} \times \quad Gwood_t \times SD_t \quad \times \quad k_{CC}}$$





$$G_{Wood} = \frac{2CWT}{CRD} \quad G_{CW}$$

Wood density (G_{wood}, kg m^{-3}) was determined as the morphometric density of individual tracheids, where CWT is the radial cell wall thickness; CDR is the cell radial diameter; and G_{CW} is the density of the cell wall (G_{CW} assumes a fixed density of 1450 kg m^{-3} of cell wall material (Dinwoodie, 1981))



Photosynthesis-driven GPP was the first to rise at the beginning of March

Only 1–2 weeks later, the forest became a carbon sink (positive NEP), i.e., CO2 uptake was larger than the respired CO2.

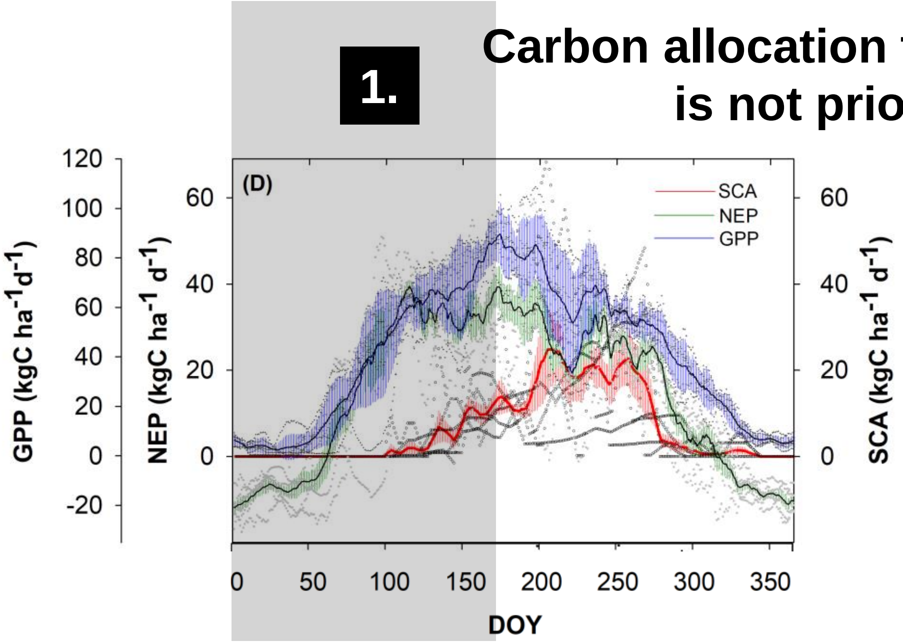
Stem radius increase (SRI_{day}), did not begin until late April when net ecosystem productivity (NEP_{day}) was near its seasonal peak.

Another three months passed until the peak of carbon allocation in the stem (SCA_{day}) was reached in July.

three consequences can be derived

Carbon allocation to the stem is not priority in the first half of the year

1.



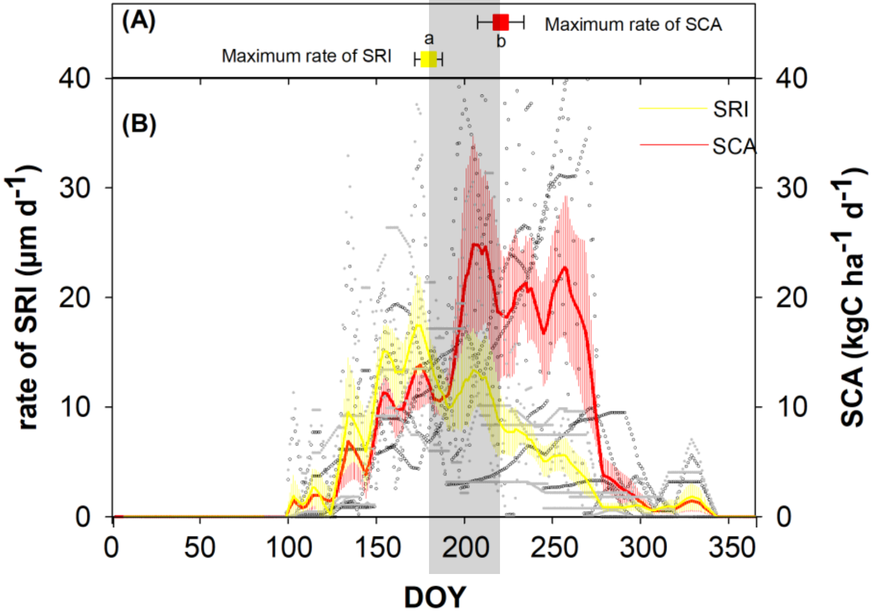
The carbon uptake during the first half of the vegetation period (approximately 46% of the annual NEP uptake until DOY 170) was only marginally invested for wood growth (15% of annual allocation).

This means that there were priorities other than stem growth for carbon allocation at this time of year.

new leaves and roots

carbon reserves (NSC pool)

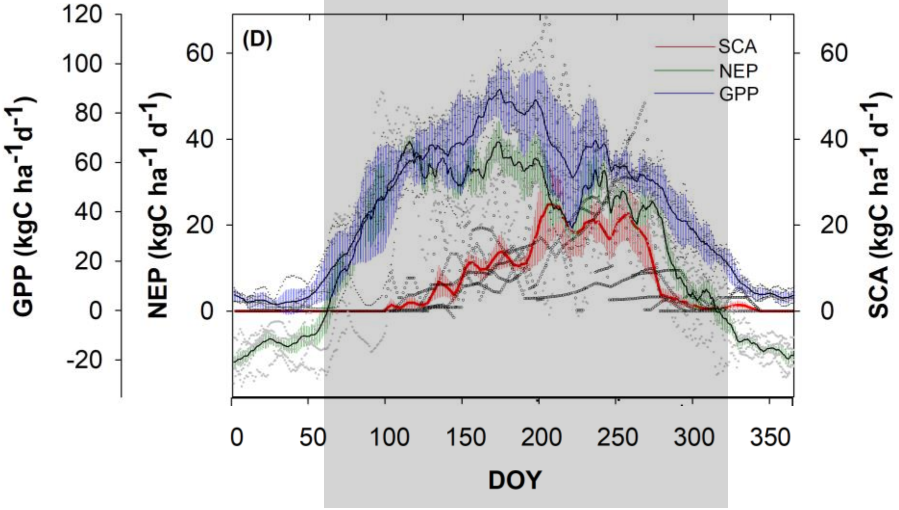
2. Carbon allocation to the stem is delayed after radial increase



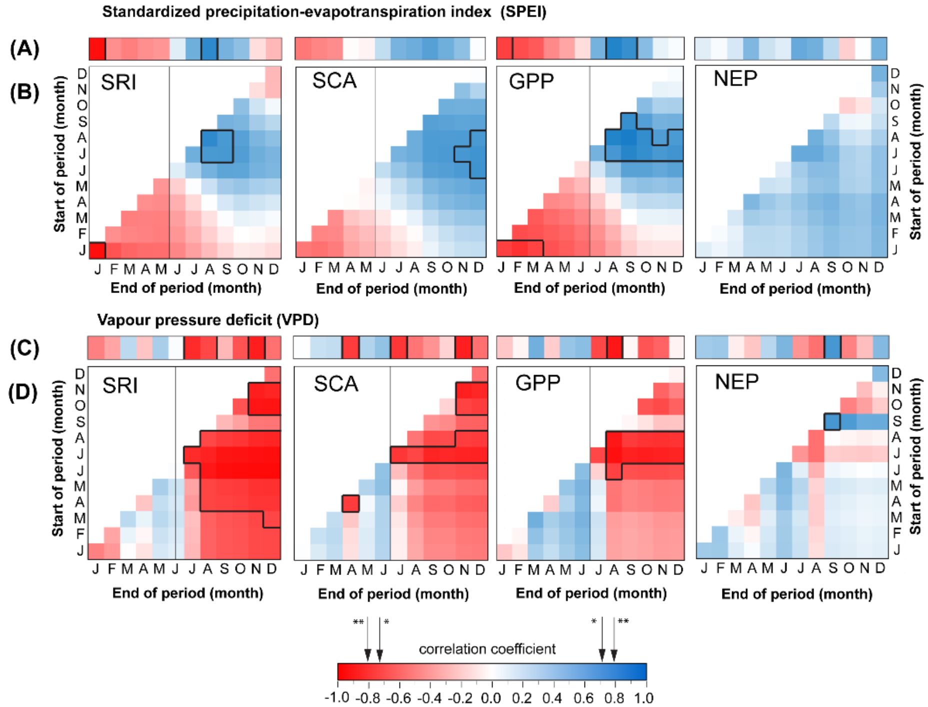
SRI at the beginning of the stem growth period, which mainly involves **cell division** and expansion, is a **process that depends on less carbon** than the **process of lignification and thickening of the xylem that follows**.

There was a consistent time lag between the maximum SRI and the maximum SCA of **approximately 40 days.**

3. Timing of drought alters carbon source-sink dynamics



Different timings of the seasonal courses of carbon uptake (GPP and NEP) and carbon allocation to the stem SCA lead to a partial decoupling of these processes from each other and to an individual responses to environmental conditions.



Dry conditions during the first half of the year had a positive effect on SCA_{annual} and GPP_{annual} but exerted a negative effect in the second half.

Therefore, dry conditions (low SPEI) may also indicate more sunlight and higher temperatures in spring and thus a positive effect on these variables.

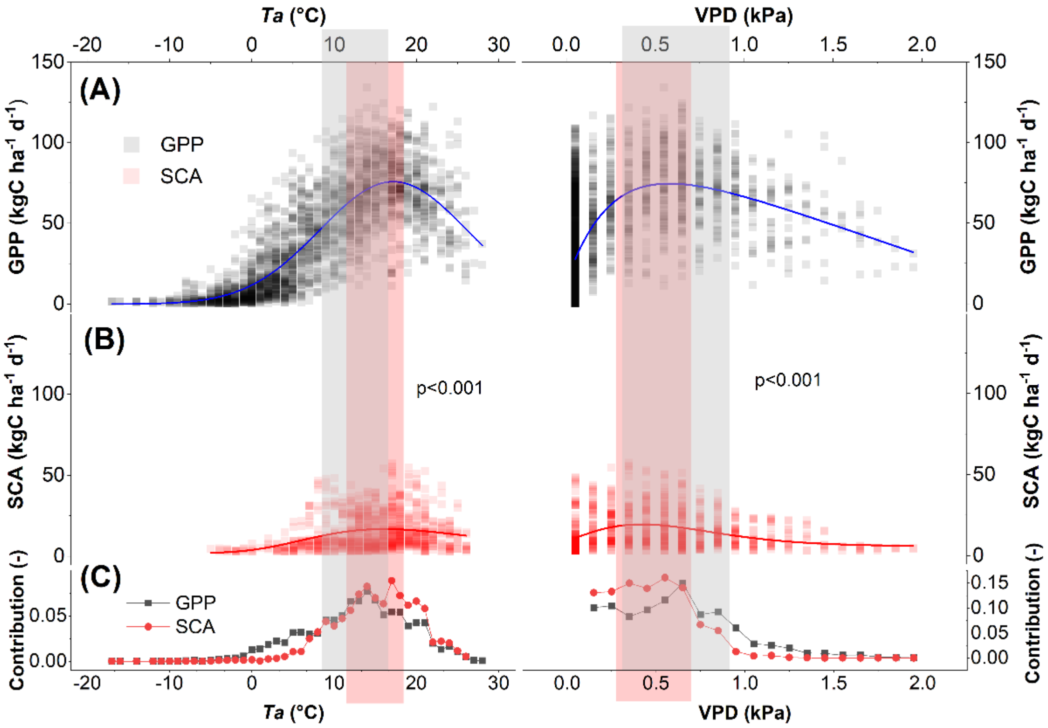
3. Timing of drought alters carbon source-sink dynamics

We found different sensitivities of GPP and SCA to the environmental conditions of mean daily Ta or VPD.

The GPP values > 10 kgC ha^{-1} d^{-1} were observed only during days with Ta > 0 ◦C.

There was almost no SCA for Ta < 5 ◦C. The main GPP (about 50% of annual uptake) occurred between 9 and 16 ◦C,

The main SCA occurred at 2–3 ◦C higher temperatures.



Range of responses of GPP and SCA to environmental conditions. (A) Daily gross primary production (GPPday) in relation to temperature (Ta) and vapour pressure deficit (VPD). (B) Daily stem carbon allocation (SCAday) in relation to Ta and VPD. (C) Relative contributions of GPP and SCA for specific Ta and VPD (Ta bin: 1 ◦C, VPD bin: 0.1 kPa). The vertical bands represent the range of conditions for Ta (left) and VPD (right) contributing 50% to total GPP (grey) and SCA (red).

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take-home message

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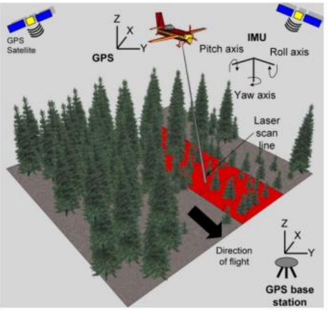

Estimation of **stem carbon allocation**
required a combination of different methods.

Stem growth is more affected by water deficit
than by photosynthesis,
carbon assimilation **may remain active for longer time**.

Dry conditions during the early growth phase
firstly manifest in reduced stem growth
prior to **also reducing carbon assimilation**.

Tree carbon dynamics are primarily explained by the
seasonal timing of dry periods
rather than the intensity of these events

Thank you for your attention

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