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Drought impacts on forest carbon sequestration and water use – evidence emerging from quantification of tree-ring formation

Patrick Fonti, Kerstin Treydte, Marco Lehmann, Andreas Rigling, and **Elisabet Martínez-Sancho**
Swiss Federal Research Institute WSL, Forest dynamics, Birmensdorf, Switzerland (patrick.fonti@wsl.ch)

The impacts of climate extremes on forest ecosystems are still poorly understood but important for predicting carbon and water cycle feedbacks to climate. Despite evidences of the different climatic thresholds of tree carbon source and sink activities, implementations of mechanistic growth components into dynamic global vegetation models (DGVM) remain challenged by lacking observational data into the most important terrestrial biological sink, i.e.; into the cambial zone of tree stems.

In this study, we aim to provide a framework for mechanistic understanding of drought impacts on carbon and water dynamics based on accurate analyses of the physiological processes that indirectly regulate these budgets. We quantified the drought impact and resilience of intra-annual carbon sequestration and water use in four mature Norway spruces from a Swiss subalpine site by comparing high-resolution growth (i.e., xylogenesis and wood anatomy) and physiological (i.e., stable carbon isotope ratios) data from an exceptional dry summer (year 2015) with those from a regular growing season (year 2014).

Our observations described the cascade of impacts from leaf physiology to cambial activity during and after a 41-day period of physiological water deficit. During water deficit, all wood formation processes were strongly reduced diminishing carbon sequestration by 67% despite a 11% increased water-use efficiency. However, with the recovery of the positive hydric state in the stem, we observed a fast recovery of the rates of the different cell formation phases at the expenses of the accumulated assimilates produced during the drought event.

Our results clarify how the interaction between source and sink is modulated via external environmental factors and provide evidence that, under specific circumstances, tree growth can be extremely resilient. These novel findings should provide a framework to improve sink model components in DGVMs and consequently help to bridge understanding of carbon and water fluxes between atmosphere and forest ecosystems.