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Impacts of recurrent extreme drought events on the dynamics of radial growth, wood anatomy and stable isotopes in beech trees from 2013 to 2022 in northeastern France

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Extreme drought events are responsible for widespread forest dieback and large-scale tree mortality events across the globe, which can have detrimental effects on both short-term forest functioning and long-term ecosystem dynamics. An unprecedented decline of European beech (Fagus syl*vatica* L.) has been observed in central Europe following the 2018-2020 drought event, and beech trees may have reached a tipping point where many individuals are no longer able to survive. A better understanding of the physiological mechanisms that allow beech trees to resist and to cope with severe water deficits and those that lead to the tree death is essential.

The main objective of this study is to gain insight into the physiological properties involved in the resilience or death trajectories of the beech trees in response to an extreme and prolonged drought episode. We retrospectively analysed multi-proxy traits including tree ring width, a proxy for tree cambial growth, wood anatomical traits, a proxy for the xylem hydraulic performance, and tree ring isotopic composition, a proxy for water use efficiency (WUE).

A total of 60 trees were selected which are distributed in four stands in North-eastern France with different levels of soil water deficit which were quantified retrospectively by the BILJOU© water balance model. Tree cores at 1.3m were taken for radial growth analysis and retrospective xylem anatomical measurements in the last 10 tree rings (rings before, during and after drought). Stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes were also measured in these rings to determine, respectively, the annual WUE and the water and carbon constrains on WUE variation. Tree resistance, recovery and resilience to drought were quantified for cambial growth, specific hydraulic conductivity and WUE.

Over the past 10 years, we determined that 2015 and 2018-2020 were drought years by calculating annual soil water deficits at the stand level. Decreased tree growth and increased WUE were observed due to soil water shortage, whereas xylem vessel size and specific hydraulic conductivity did not show obvious changes. Vessel density was negatively correlated with annual ring width and was highly sensitive to drought. In severe drought sites, recurrent drought severely affected resistance of tree growth and the post-drought recovery of hydraulic conductivity and water use efficiency. Furthermore, growth resilience of beech trees could not be explained by vessel-related

anatomical traits and isotopic composition. Overall, our study shows that beech xylem structure responds to drought by adjusting the number, rather than the size, of vessels, and highlights the impact of prolonged or recurrent drought on xylem hydraulic and WUE recovery. This work contributes to the understanding of how drought-sensitive trees cope with extreme drought events in terms of their carbon-water relations in the context of climate change.