Combining carbon isotopes with tree ring analysis – insights into water use efficiency and drought stress

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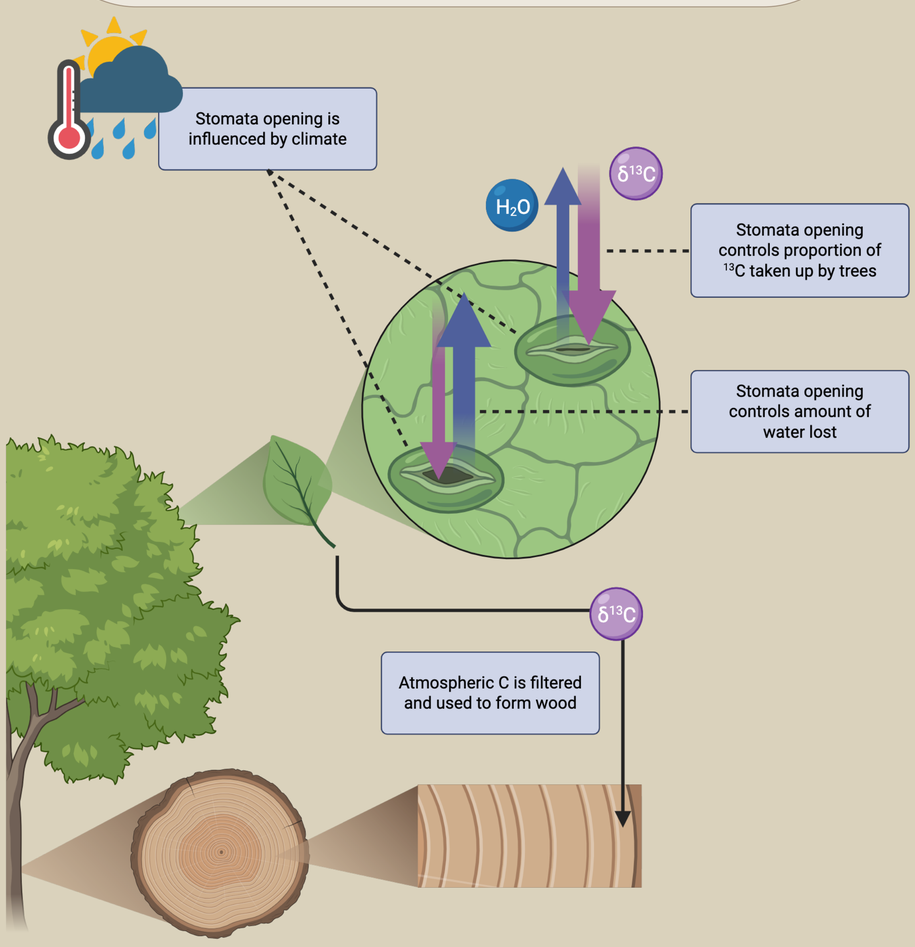
Introduction

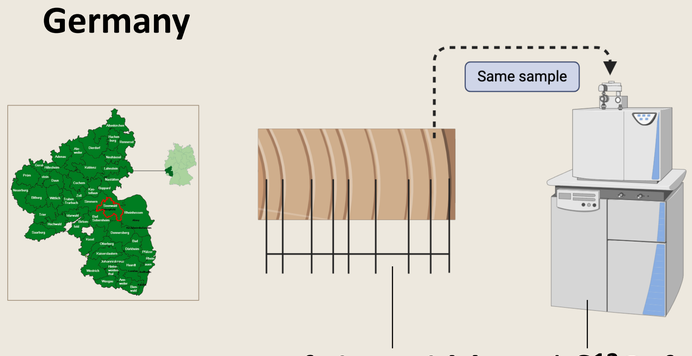
To ensure future forest resilience, species-specific responses to drought must be better understood. This study combines tree-ring width and stable carbon isotope ($\delta^{13}C$) analysis to assess growth and intrinsic water-use efficiency (iWUE) in five major tree species in Germany. Long-term data enable insights into both short-term variability and long-term adaptation strategies.



Simplified illustration of the relationship between wood $\delta^{13}C$ and climate

Methods

- Study area: Soonwald in **South-western Germany**



- measurement of **ring width** and **$\delta^{13}C$** for every year and every tree tree from 1978 to 2022 (3 trees per species, n = 675)
  - → Simultaneous discrimination against heavier ^{13}C and loss of water allows for calculation of iWUE.
  - → ring width index (RWI**): short-term** variability
  - → basal area increment (BAI): **long-term** adaptation
- **annual** climate data (precipitation and temperature) for growing season and atmospheric CO_2 concentration (Ca)

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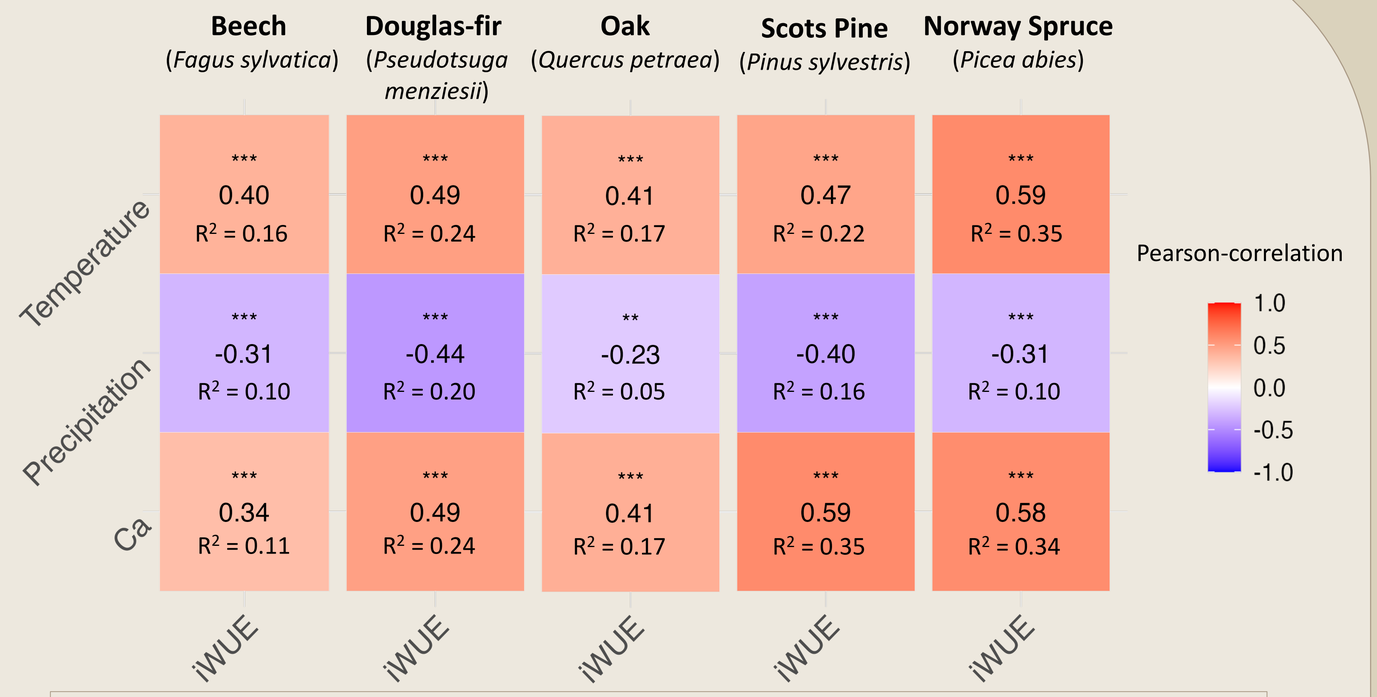
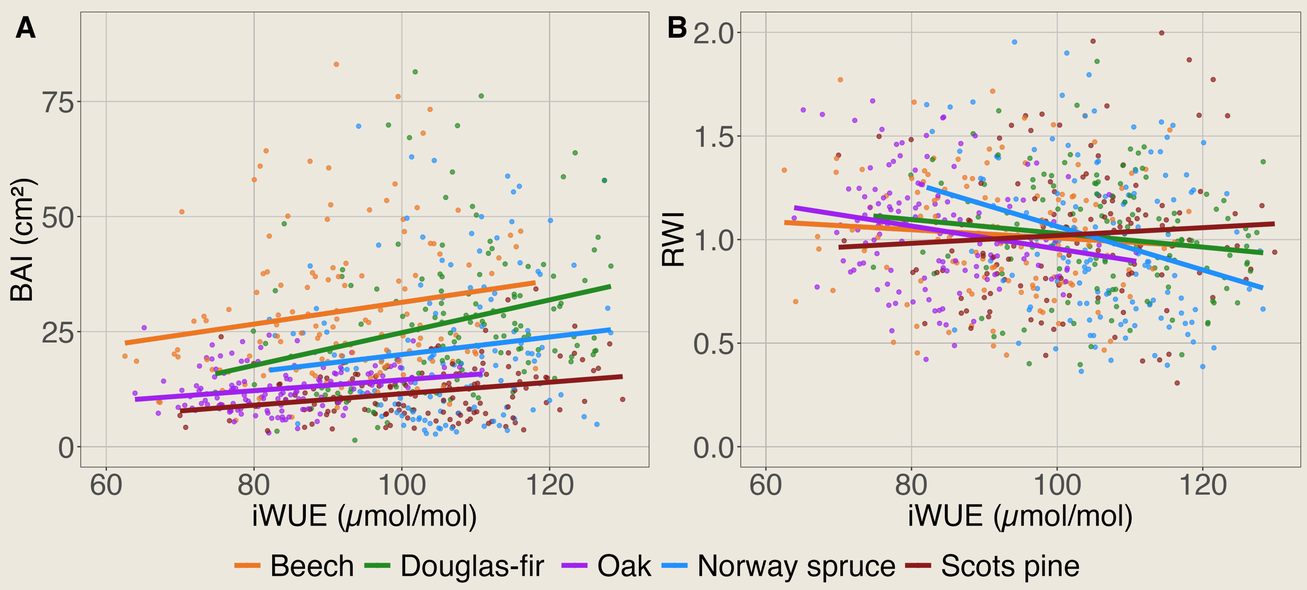
Results



Pearson-correlations and R^2 from linear regression between iWUE and environmental variables per tree species

All species drew **significant relationships** between iWUE and the environmental variables:

- highest values between **iWUE and temperature**
- similar influence of Ca on iWUE
- slightly lower values for deciduous trees
- the correlations of the environmental variables with the growth parameters were **generally weaker** and less consistent



Linear relationships between iWUE, BAI (A) and RWI (B) per tree species

Positive iWUE - BAI correlation in all species (except spruce), but weak overall (R^2 = 0.05 - 0.07)

- Oak: only species with independent iWUE - BAI link

iWUE - RWI relationships were **inconsistent**:

- spruce (R^2 = 0.06) and oak (R^2 = 0.04)
  → higher iWUE linked to short-term growth reductions
- No significant relationship for beech, pine, or Douglas-fir.

Conclusion

Species-specific patterns shape the relationship between intrinsic water-use efficiency (iWUE) and tree growth. While iWUE shows a weak positive link to **long-term growth (BAI)** in most species, **short-term growth (RWI)** is largely decoupled, suggesting indirect or non-linear effects. The **signal-to-noise ratio is higher for iWUE** than for growth metrics, indicating clearer climate responses in physiological traits compared to growth dynamics. Spruce shows the clearest drought signal: strong iWUE sensitivity to temperature, but reduced RWI under stress. In beech and Douglas-fir, observed correlations may reflect shared responses to rising atmospheric CO_2 rather than direct water-use strategies.

To better understand growth dynamics, future analyses should integrate additional factors such as **stand structure and competition** over a long period as well.