Isotope evidence for temperature-dependent hydraulic constraints to growth of bristlecone pine

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Introduction
Altitudinally separated bristlecone pine populations in the White Mountains (California, USA) exhibit differential growth responses to 20th century climate variability. These populations provide a natural experiment to explore the physiological responses of this unique and ancient tree species to climate variability and atmospheric CO2.

We developed annually resolved chronologies of tree ring width, and cellulose stable carbon and oxygen isotope signatures from bristlecone pine growing at the tree line (~3500 m) and approximately 200 m lower for the period AD 1700-2010. Isotope signals were interpreted with a dual-isotope model and a leaf gas exchange model. Method details are provided in Table 1.

![Figure 1: 20th century growth anomalies in bristlecone pine growing in localities at the modern tree line (sites 1A and 1B) and approximately 200 m lower (site 2). (a) Site average annual ring width (mm) and the number of trees sampled per growth locality. (b) Pre-industrial (1750-1849) and 20th century (1900-2000) average radial growth (mm\textsuperscript{\text{-}1}century\textsuperscript{-1}) at the three growth localities. (c) Pre-industrial and 20th century average Basin Area Increment (BAI; m\textsuperscript{2}century\textsuperscript{-1}) at the three growth localities.](image1)

Table 1: Materials and methods

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<td>Cellulose core samples from 17 Pinus longaeva D. K. Bailey (bristlecone pine) individuals</td>
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<td>Samples were taken from three sites. Trees in sites 1A (N=5) and 1B (N=6) are situated at elevations between 3482 m and 3523 m (modern tree line), trees in site 2 (N=6) grow at slightly lower elevations between 3293 m and 3338 m (see map)</td>
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![Figure 2: Interpretation of signals conveyed in the results of δ-isotope evidence for temperature and atmospheric CO2. (a) Relationship between c\textsubscript{w} and the deviation in δ13C derived c\textsubscript{w} from the ‘activating’ constant c\textsubscript{w}\textsuperscript{ac} response of δ13C to ε\textsubscript{c} term Δc\textsubscript{w}. Significant positive response of Δc\textsubscript{w} to ε\textsubscript{c} were observed in period 1, whereas in period 2 (I) to shift non-significant or negative response was observed. (b) Relationship between δ-isotope δ13C and δ18O.](image2)

![Figure 3: Modelled responses of leaf gas exchange to 20th century changes in atmospheric CO2 growing season temperature and VPD. (a) Leaf-level time-integrated photosynthesis (A) as modelled in the baseline ‘CO\textsubscript{2}, T’ and VPD’ simulation. (b) Modelled changes in A expressed as percentage (%) with respect to the period 1901-1930. The ‘CO\textsubscript{2}, ‘CO\textsubscript{2}, ‘CO\textsubscript{2}, T’ and VPD simulations used different combinations of boundary conditions that represent 20th century changes in each variable. (c) Leaf-level time-integrated transpiration (E) as modelled in baseline simulation. (d) Modelled changes in E expressed as % with respect to the period 1901-1930. (e) Leaf-level stomatal conductance to water vapor (g\textsubscript{s}) as modelled in the baseline and with the average of 10,000 Monte-Carlo type simulations using GPPM-BG based ranges climate boundary conditions. (f) Leaf-level stomatal conductance to wind vapor (g\textsubscript{w}) expressed as % with respect to the period 1901-1930.](image3)

![Figure 4: Discussion: Our tree ring chronologies from altitudinally separated bristlecone pine populations corroborate previous work on seasonal patterns that reflect waning temperature limitation near the tree line and moisture limitation at lower elevations (LaMarche & Stockton, 1974; Hughes & Funkhouse, 2003; Salzer et al., 2009). We propose that the differential growth responses are indicative of constraints on tree hydraulics; warming alleviates temperature constraints on xylem sapflow at the tree line (Petit et al., 2011), while the associated atmospheric drying increases transpiration beyond the tree hydraulic capacity at lower elevations (Meinzer et al., 2009; Carnicer et al., 2013).](image4)

References


References


