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Multi-scale Responses of Tree Growth to Climate Change and Their Hydraulic Mechanisms in Semi-Arid to Semi-Humid Regions of Northern China

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The semi-arid to semi-humid transition zone in northern China exhibits strong interannual climate variability and frequent drought events, making it a critical ecological transition zone where tree growth is highly sensitive to drought stress. Analysis of long-term climate records from multiple sites indicates that annual precipitation in the study area has shown a significant decline over recent decades, accompanied by a marked decrease in the regional average SPEI. As annual mean temperature and vapor pressure deficit (VPD) increase, the vessel diameter and hydraulically weighted diameter of non-porous wood species have significantly decreased. This indicates that under intensified atmospheric drought conditions, non-porous wood species become more sensitive to climatic stress through adjustments in their hydraulic structure. Tree growth exhibits the most pronounced response to medium-to-long-term drought signals. Notably, SPEI12 during the growing season shows a significant positive correlation with RWI, indicating that water deficit has become the dominant climatic factor limiting tree growth in the study area. Sliding correlation analysis further reveals that tree growth sensitivity to drought-related factors such as VPD, temperature, and solar radiation significantly increases within specific interannual time windows, highlighting the time-nonstationarity of the climate-growth relationship. At the regional scale, tree radial growth exhibited widespread negative anomalies during drought periods, with growth declines exceeding 10% in some years. This aligns with signals of reduced vegetation productivity, indicating that drought stress impacts on growth extend from the individual to the regional scale. Further analysis of growth variability revealed that the coefficient of variation in tree growth significantly decreased in the semi-humid zone, while no significant trend was observed in the semi-arid zone. This indicates that the modulating effect of inter-individual resource competition on growth heterogeneity under drought conditions exhibits significant regional differences. In summary, this study reveals the mechanisms by which climatic drought stress, hydraulic restructuring, and biological interactions jointly drive tree growth changes in the semi-arid-semi-humid transition zone, providing multi-scale evidence for understanding the responses of transitional forest ecosystems under intensifying drought conditions.