How Do Wood Anatomical Traits in Salix Vary in Response to Flooding? A Case Study from the Yenisei River, Siberia

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Abstract

Recent, record-breaking discharge in the Yenisei River, Siberia, is part of a larger trend of increasing river flow in the Arctic driven by Arctic amplification. These changes in magnitude and timing of discharge can lead to increased risk of extreme flood events, with implications for infrastructure, ecosystems, and climate. To better understand the changes taking place, it is useful to have records that help place recent hydrological changes in context. In addition to an existing network of river gauges, extreme flood events can be captured in the wood anatomical features of riparian trees, which help identify the most extreme flood events. Along the Yenisei River, Siberia we collected willow (Salix spp.) samples from a low terrace that occasionally floods when water levels are extremely high. Using these samples, we use an approach known as quantitative wood anatomy to measure variation in radial cell dimensions, including vessel area, wood fiber size and cell wall thickness. We then compare these measurements to observed records of flood stage. We hypothesize that (1) characteristic patterns of wood fiber size and cell wall thickness in Salix rings are present during flood years, (2) these patterns can be quantified by measuring wood fiber size and cell wall thickness, and (3) quantified variations in cell anatomical properties can be related to flood magnitude and duration. Understanding how riparian vegetation responds to extreme flood events can help us better manage riparian ecosystems and understand changes to the Arctic hydrological regime.

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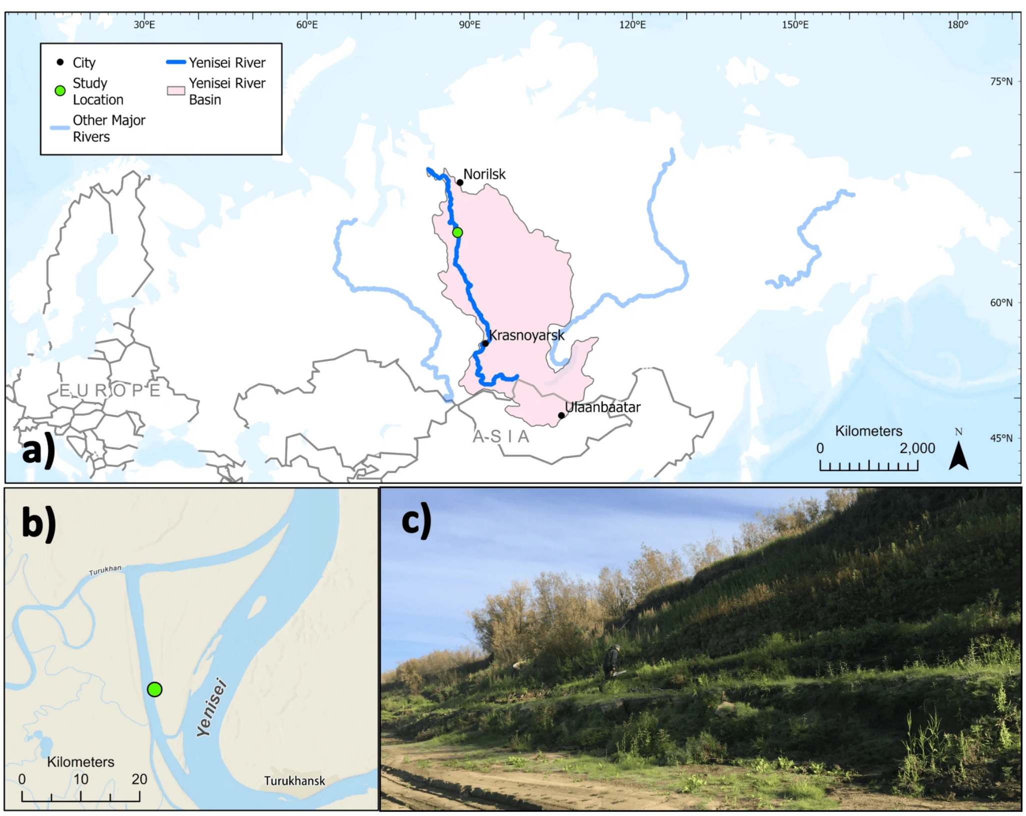
PRESENTED AT:

Frontiers in Hydrology

1) CHANGES IN PAN-ARCTIC HYDROLOGY, RECORDED BY TREE RINGS

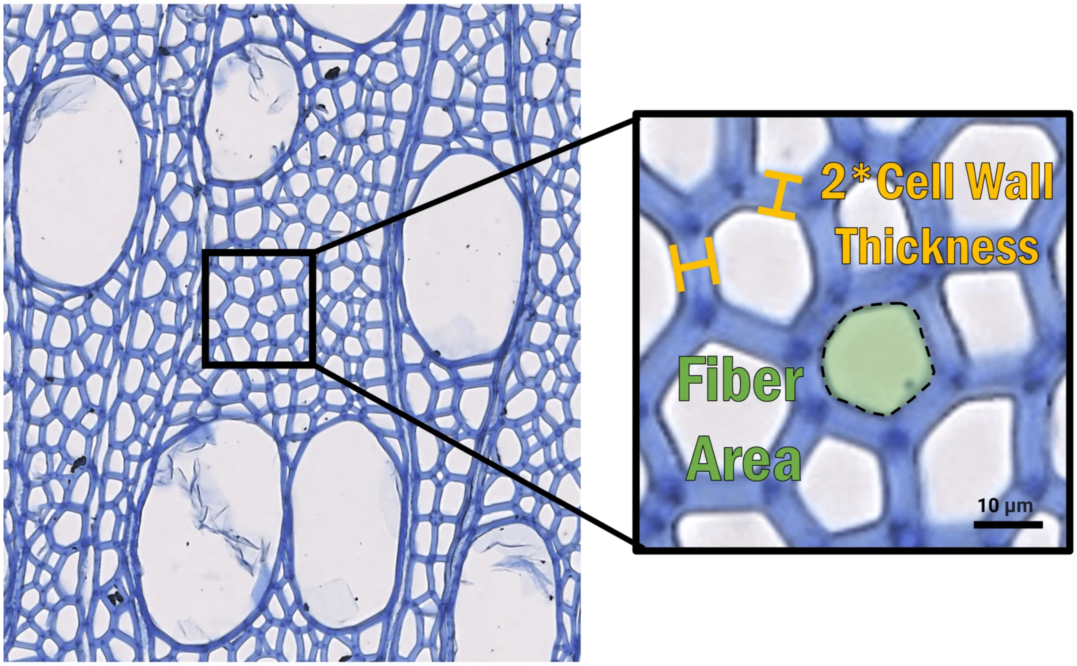
The hydrology of Arctic rivers continues to change significantly (IPCC, 2021). Recent, record-breaking discharge in the Yenisei River, Siberia, is part of a larger trend of increasing river flow in the Arctic driven by Arctic Amplification (AA) (Screen and Simmonds, 2010; Shiklomanov et al., 2013). These changes in magnitude and timing of discharge can lead to increased risk of extreme flood events, with implications for infrastructure, ecosystems, and climate (Smith and Stephenson, 2013; Coumou et al., 2018; Weijer et al. 2020; Fan et al., 2020).

Tree rings can be a useful tool to help us understand these changes because they help place these recent changes in a long-term context (Meko et al., 2012). Ring width records from conifer species have revealed important changes to the magnitude and seasonality of river flow (Panyushkina et al. 2021). While conifers are often preferred because of their long records, tree rings from riparian angiosperms can also shed light on these changes.

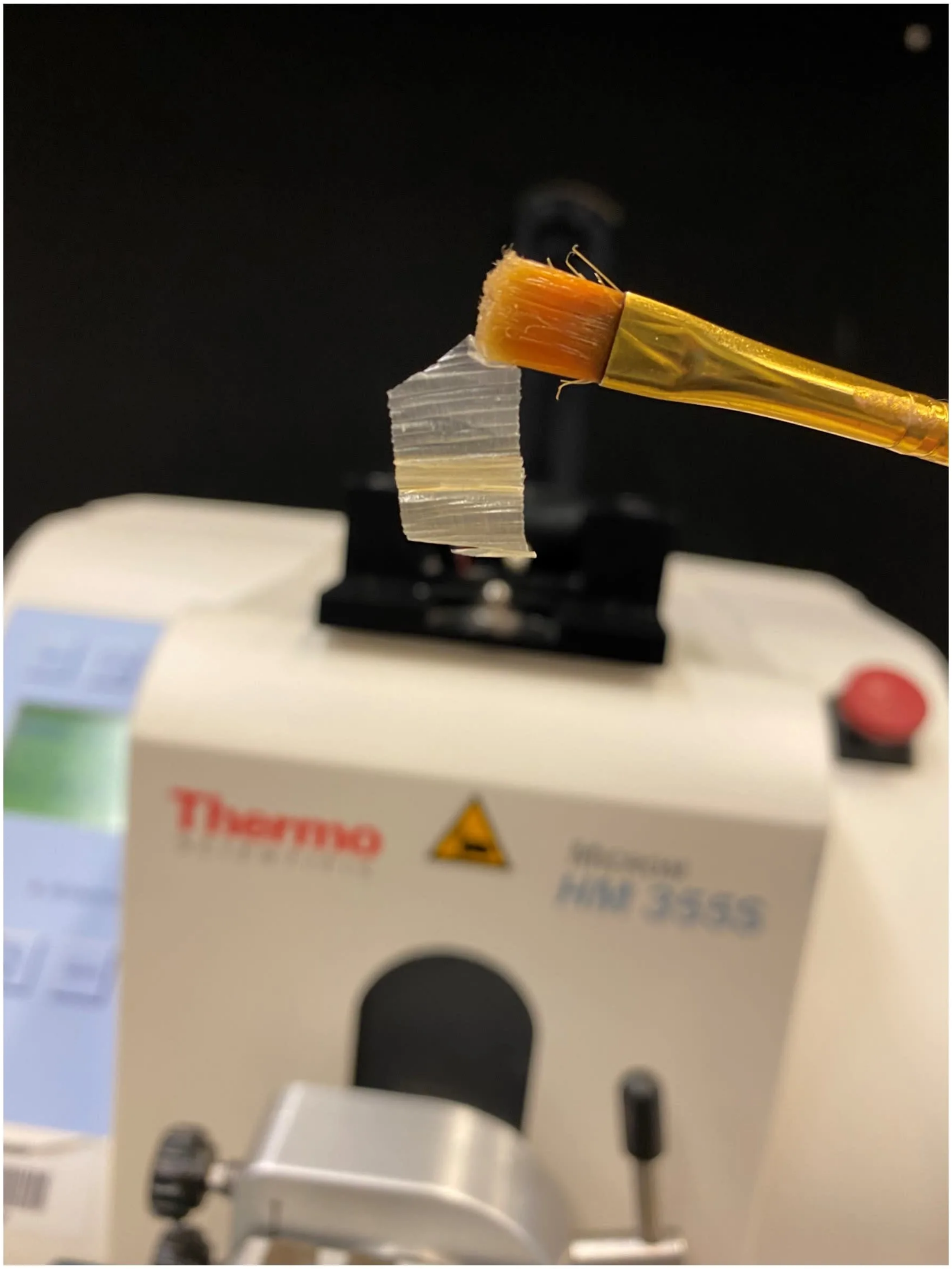


Although riparian species tend to be much younger than conifers, their proximity to the river makes them more likely to record extreme hydrologic events such as flooding (Meko et al. 2020). We targeted *Salix alba* (white willow) growing on a large, terraced island in the middle of the Yenisei River with the intention of understanding changes in the flood regime. The riparian forest rests 12-15 meters above the water's surface (ArcticDEM; Porter et al. 2018), and is subject to flooding that occurs during peak flows in June and July. We took cross-sections from 7 trees, no more than 10-20 m apart.

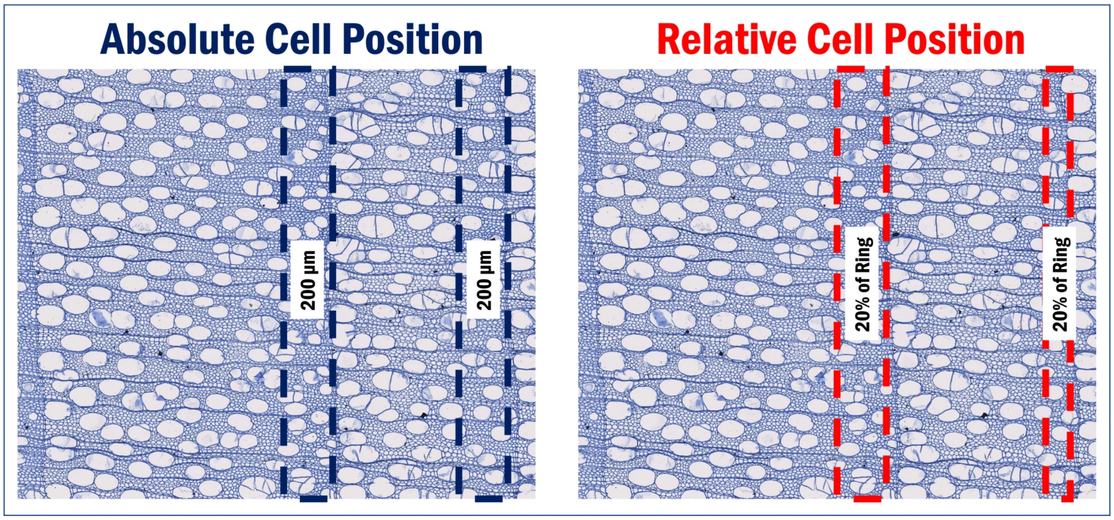
3) MEASURING CELLS IN TREE RINGS WITH QUANTITATIVE WOOD ANATOMY



To better characterize these anomalous rings we used an approach known as quantitative wood anatomy (QWA). This technique identifies and measures each individual cell that comprises a tree ring. Measurements, as shown in the above figure, include the lumen area (LA) and cell wall thickness (CWT) of wood fibers cells.



To make these measurements, we must first use a microtome to cut thin sections from our tree cores that are 12 microns thick (above). Each thin section is then stained with cresyl violet acetate (hence the blue cells!) and permanently mounted to microscope slides. Each thin section is then imaged and those images are fed into the program ROXAS, which automatically identifies and measures all the cells in the image (von Arx & Carrer 2014). After manual editing of the ROXAS images we generate a table of measured parameters for each cell.

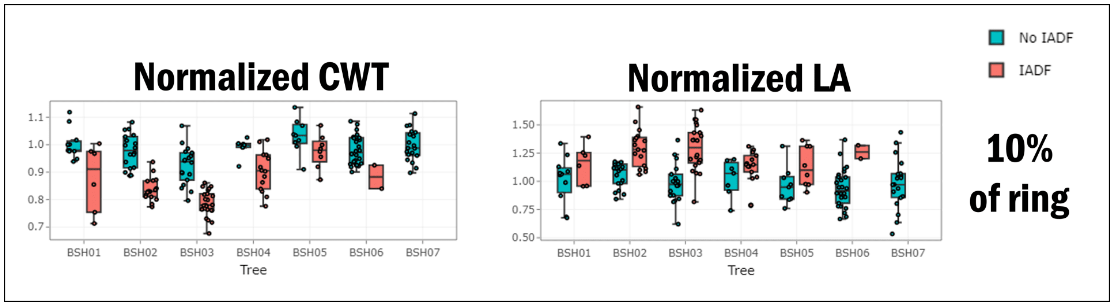


First, we were interested in knowing which cell parameters best distinguished between rings with and without terminal white bands. In addition, we wished to know if using a cell's absolute vs relative position in the ring made a difference, and if normalizing cell parameters by the average value for the ring further improved identification of these features.

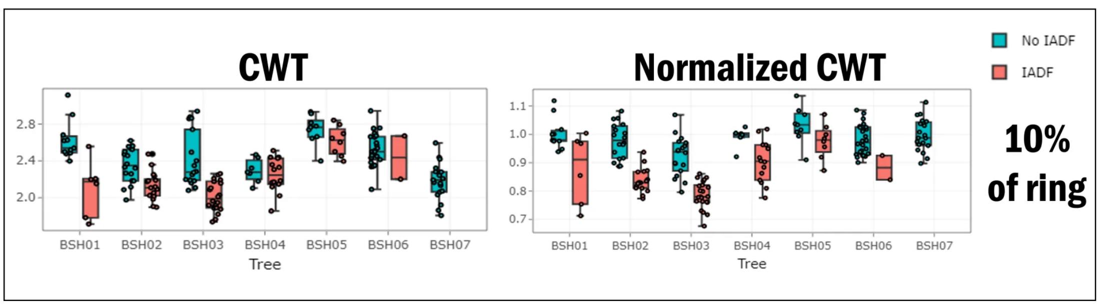
With this information, we could then choose the cell parameter and measurement method most closely associated with white bands and compare that to time series of flood durations.

4) CELL WALL THICKNESS BEST CAPTURES YEARS WITH TERMINAL WHITE BANDS

We used biserial correlation (Bedrick, 2005) to compare the ability of different cell measurement types (LA and CWT) and sectoring approaches (absolute and relative cell positions) to identify terminal white bands in Salix. The r value of biserial correlation is commensurate to the r value obtained by Pearson correlation (Jacobs and Viechtbauer, 2016). Methods with higher absolute r values were interpreted to better quantify terminal white bands.

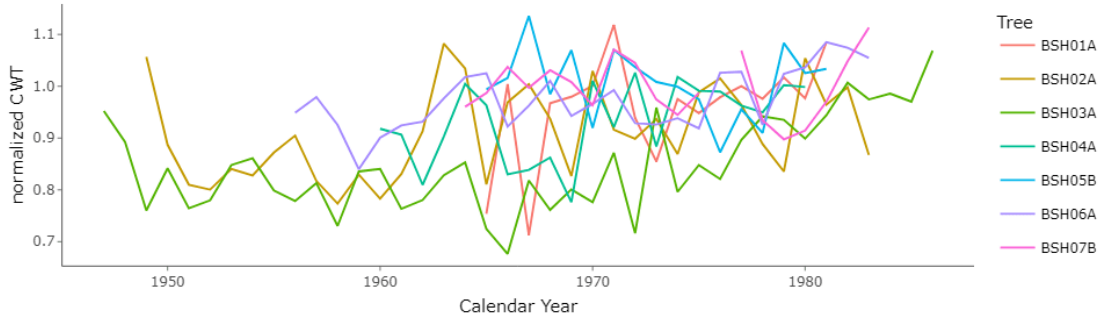


Fiber CWT more strongly correlates with the prescence of terminal white bands than LA (above; red boxplots are rings where terminal white band was identified, blue boxplot are rings where no white band was identified). Regardless of sectoring approach, CWT better differentiated between rings with and without this feature. This suggests CWT is the preferable metric for analysizing white bands.

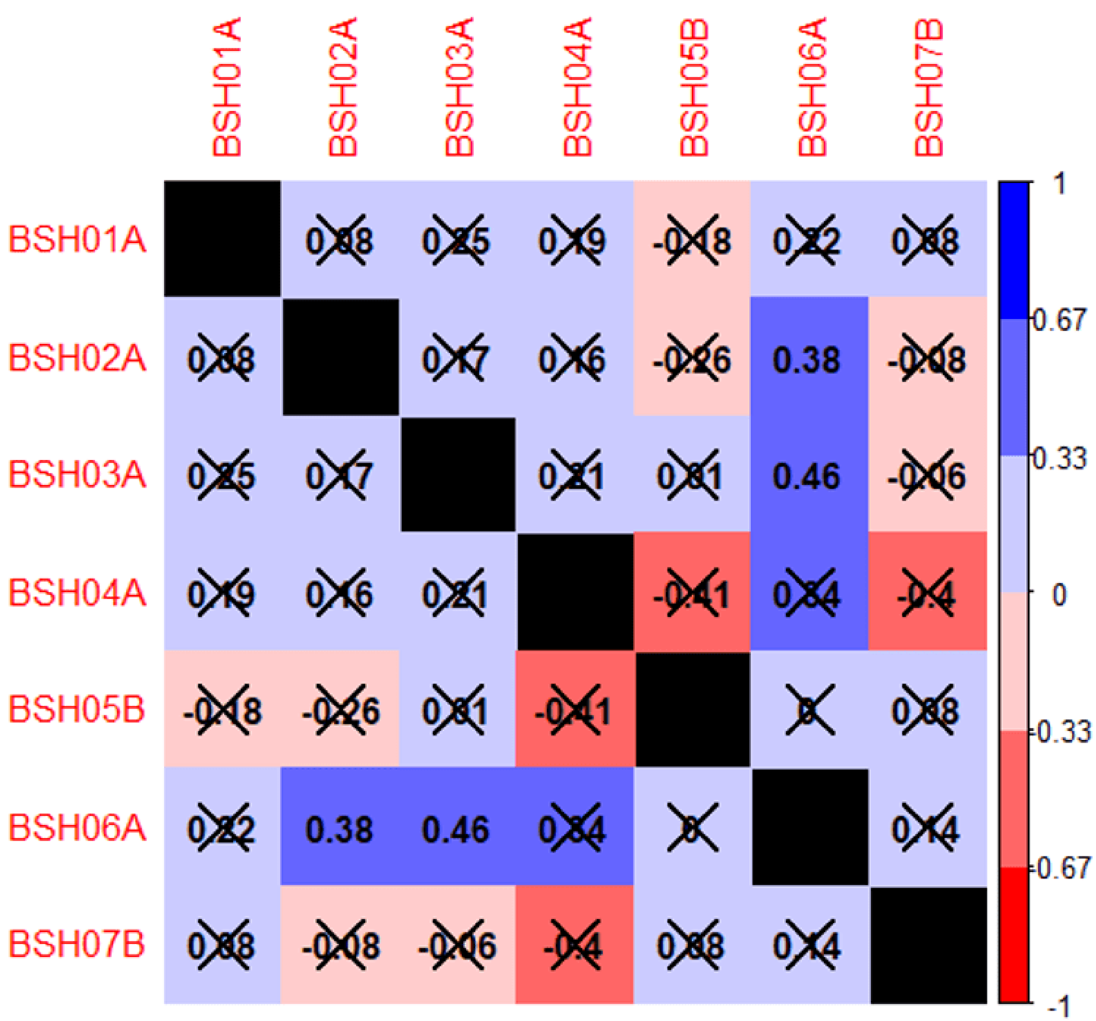


For our analysis, sectoring rings based on absolute and relative cell positions were largely comparable. Although there were slight differences in r values between methods, these were minor. On the other hand, normalizing cells always improved the strength of the correlations (above). While absolute and relative cell positions may be largely interchangeable, normalization should always be employed to improve quantification of white bands.

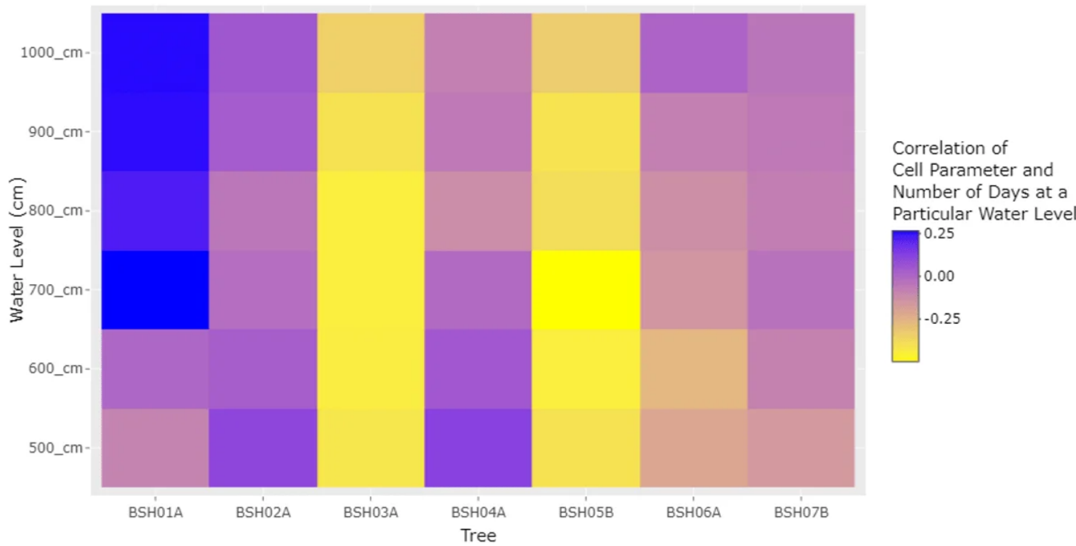
5) CELL WALL THICKNESS CORRELATES WITH JULY FLOOD DURATION... IN SOME TREES



To understand the relationship between terminal white bands and late-summer flooding, we used normalized CWT averaged over the last 10% of each ring (above). This measurement accurately accounts for white bands and also enables better comparison of rings of different sizes.

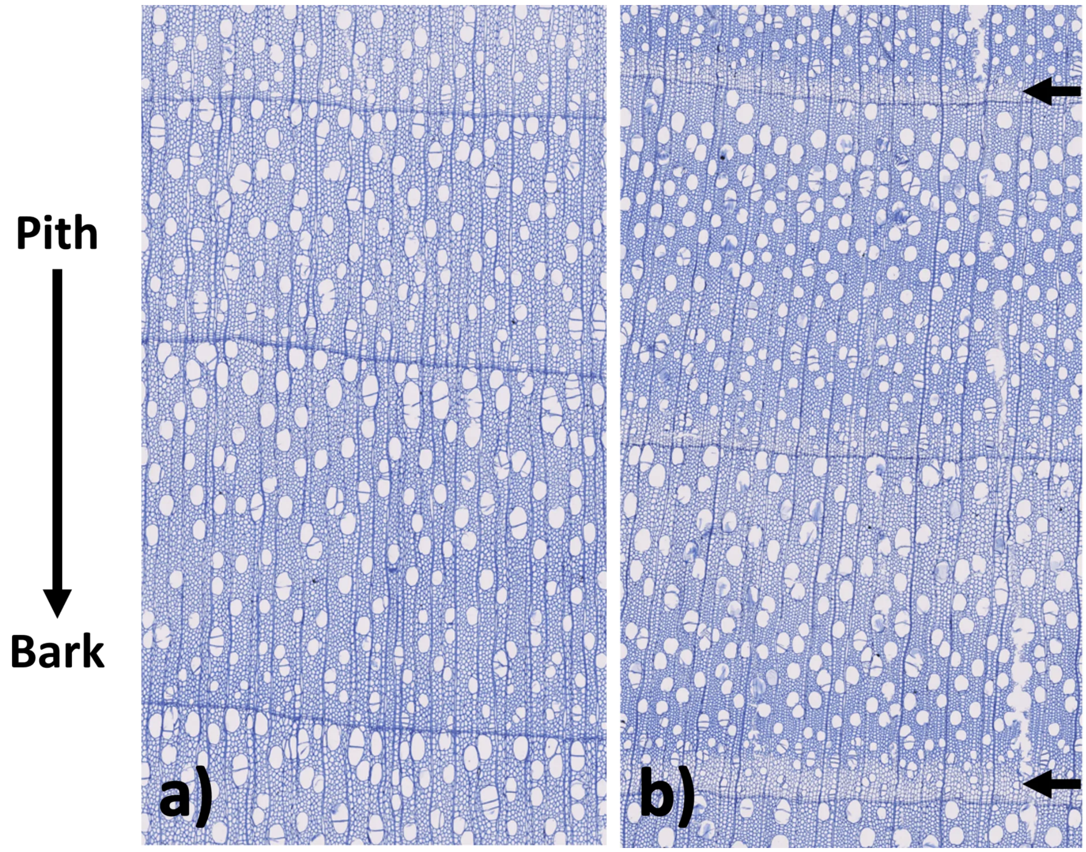


We found this time series did not correlate strongly between trees (above; blue squares are positive correlations, red are negative correlations, and black X's are non-significant correlations). The majority of correlations were positive but not significant, suggesting that CWT is recording information at the tree's particular microsite and not at the site level.

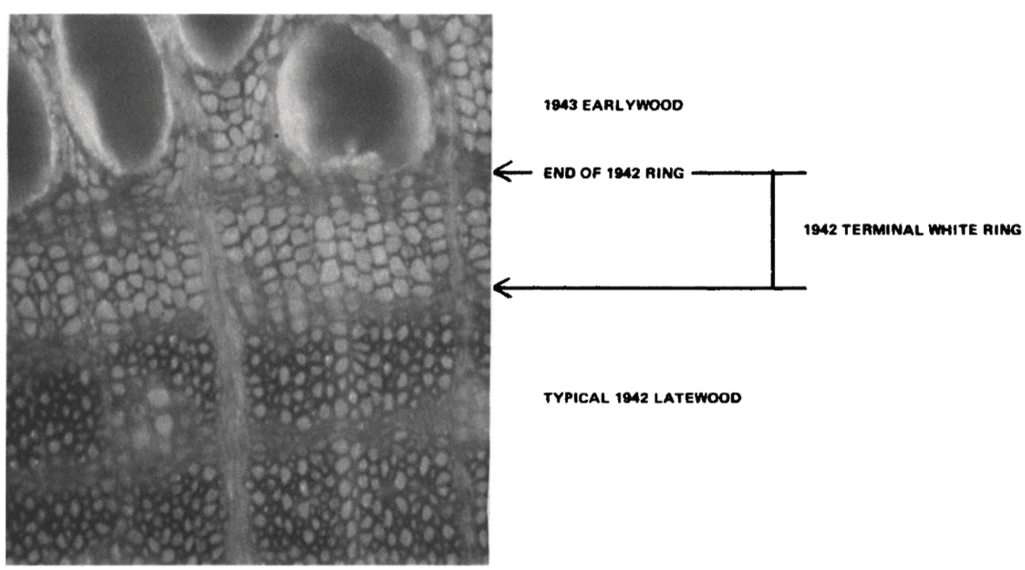


We related our normalized CWT for each individual tree to daily mean temperatures, daily precipitation, 10-day water temperature data, and the number of days flood reached a certain height in July and August. There were no consistent relationships between normalized CWT and these variables across trees, and relationships that did exist were largely weak and insignificant. The only interesting relationship was between normalized CWT and July flood durations (above). Two trees (BSH03A and BSH05B) showed consistent negetative relationships with July flooding (yellow squares), with correlations peaking for the number of days water levels exceeded 7-8 m (r = -0.4).

2) TERMINAL WHITE BANDS IN SALIX ALBA APPEAR RELATED TO FLOODING

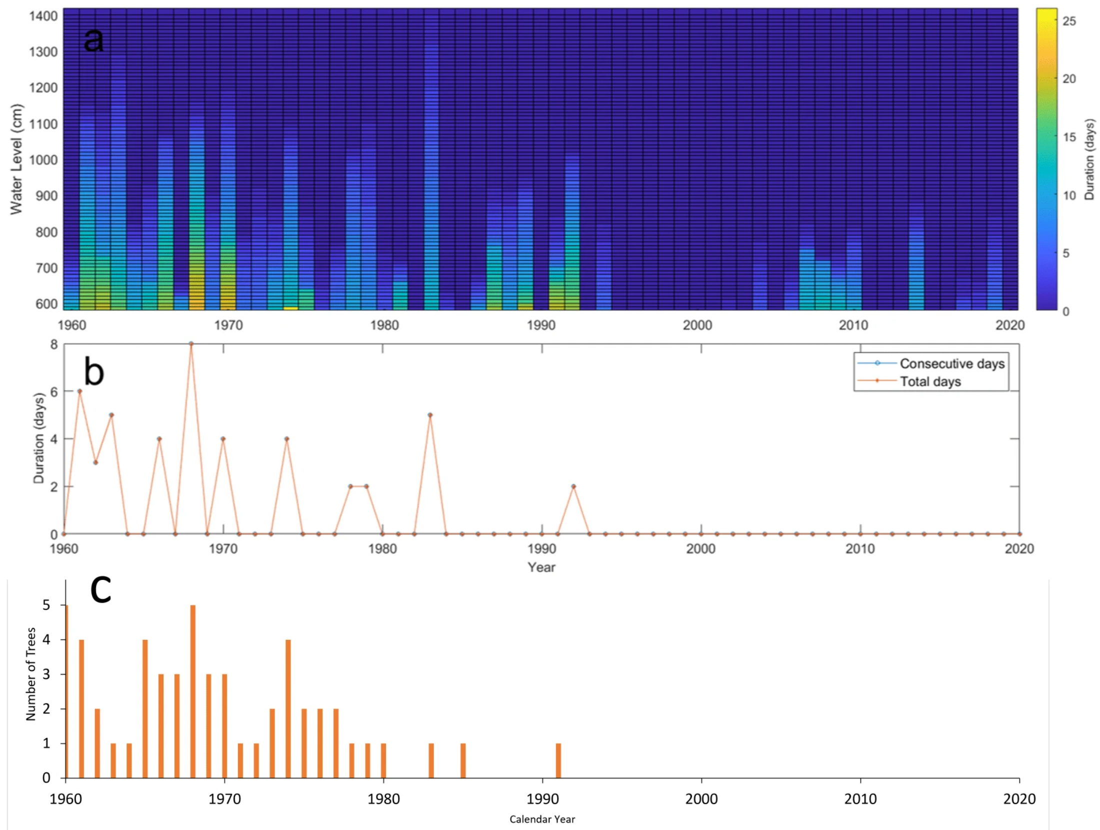


The Salix trees we sampled exhibited distinct white bands at the end of particular growth rings (above, Panel b). These white bands were a type of intra-annual density fluctuation (IADF; de Micco et al. 2016) characterized by increased fiber cell lumen area (LA) and decreased fiber cell wall thickness (CWT).

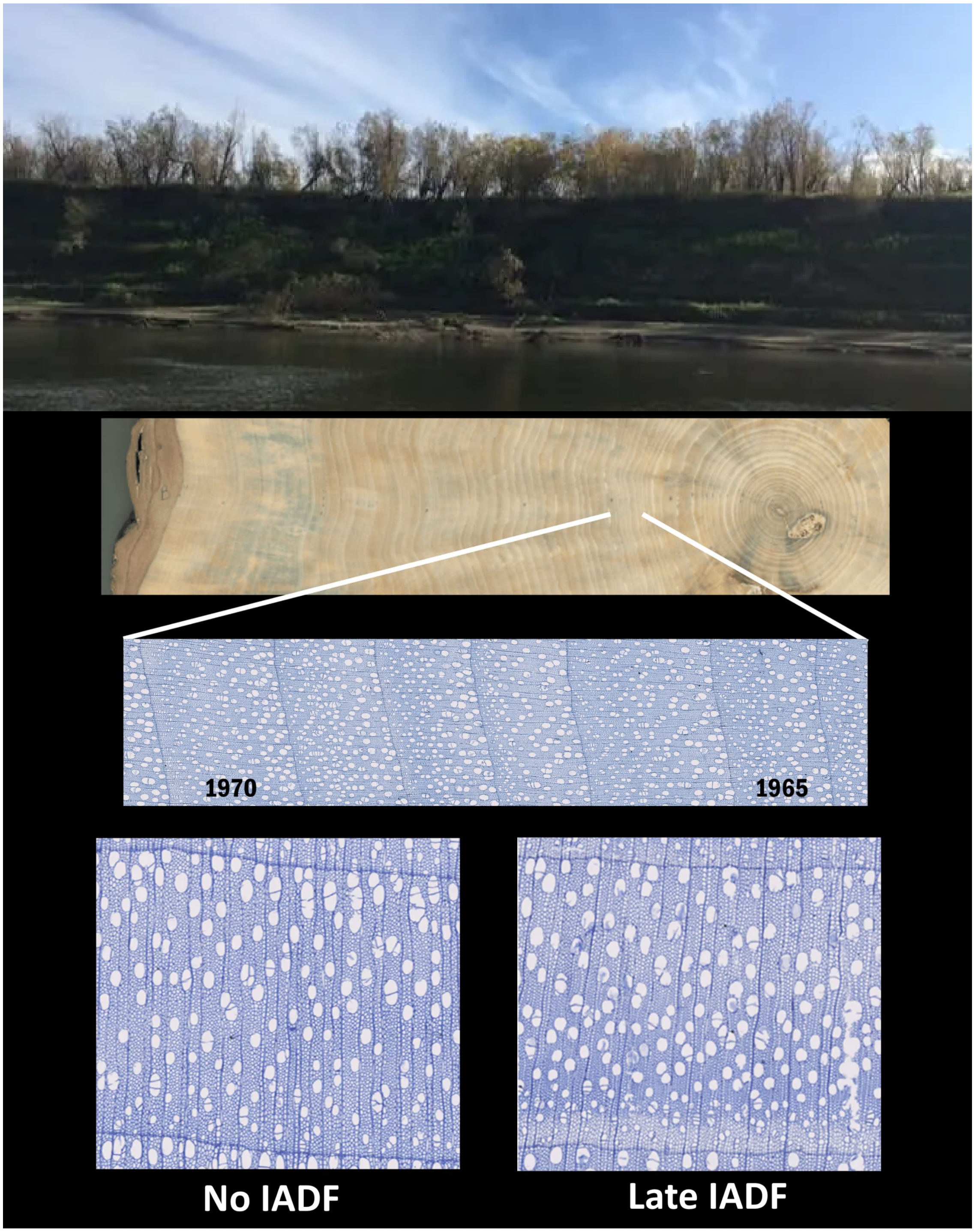


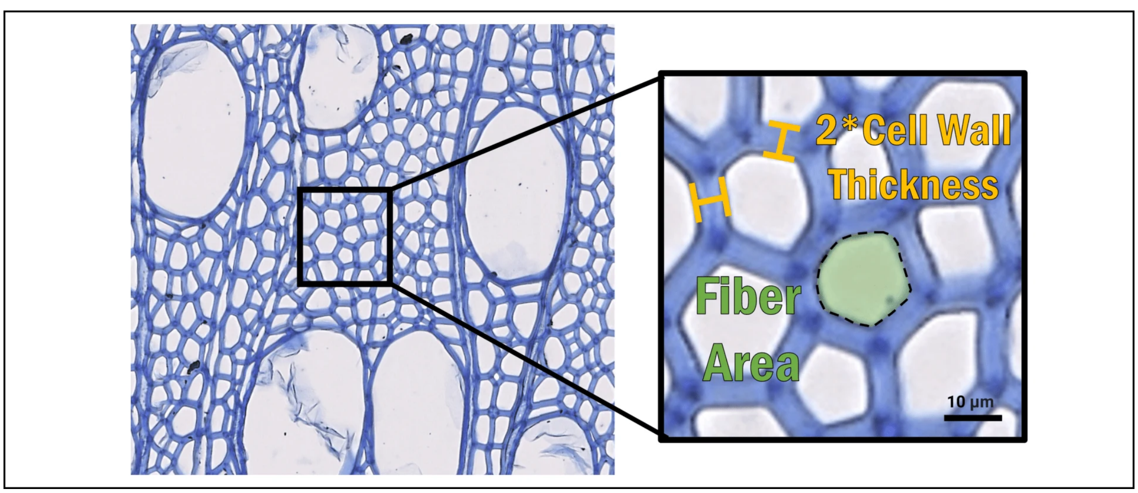
B. Terminal white ring in a growth increment formed in 1942 (X230). Large diameters and thin walls of white-ring fibers

These white rings are similar to those identified in ring porous (wood distinct earlywood and latewood) species. Work by Yanosky (1986) related the occurence of these white bands to late-season flooding (above). In essence, white bands were a growth spurt in which trees took advantage of excess water during the growing season. Are the white bands we find in *Salix*, which lacks distincts earlywood and latewood, caused by a similar phenomenon?



We identified years with terminal white bands in all 7 trees and compared the frequency of white bands to the duration of July flooding above 10 m (above). Both the number of trees with white bands (Panel c) and the number of days of flooding (Panels b) had similar declining trends toward the present. Both white bands and flood duration peak in the 1950-60s and decline toward the present, with almost no white bands or flooding occuring after 1980. These similar patterns hint at a relationship between wood anatomical features and late-season flooding.


1970
1965
No IADF
Late IADF


2*Cell Wall Thickness
Fiber Area
10 µm

6) CONCLUSION: WOOD ANATOMY IDENTIFIES THE 'WHAT' BUT NOT THE 'WHY'

Although we can quantify terminal white bands, their relationship to flooding remains ambiguous. CWT identifies terminal white bands better than LA, and this further improves when CWT is normalized by the average CWT of the entire ring. Terminal white bands are largely indifferent to sectoring method, and it is adequate to aveage normalized CWT from all cells with in the last 10% of each ring.

Our time series of normlized CWT from the last 10% of each ring did not correlate strongly between trees or with various climatic variables. There may be a relationship between terminal white bands and the length of time July floods surpass 7-8 m, but this was ony found for certain trees. Although trees were sampled within 10-20 m of each other, our results suggest that microtopography may be an important factor in the formation of terminal white bands in *Salix alba*. Further research into other anatomical features such as vessels may provide more insight into the conditions forming terminal white bands and the relationship of this riparian species to flooding.

Acknowledgements

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ABSTRACT

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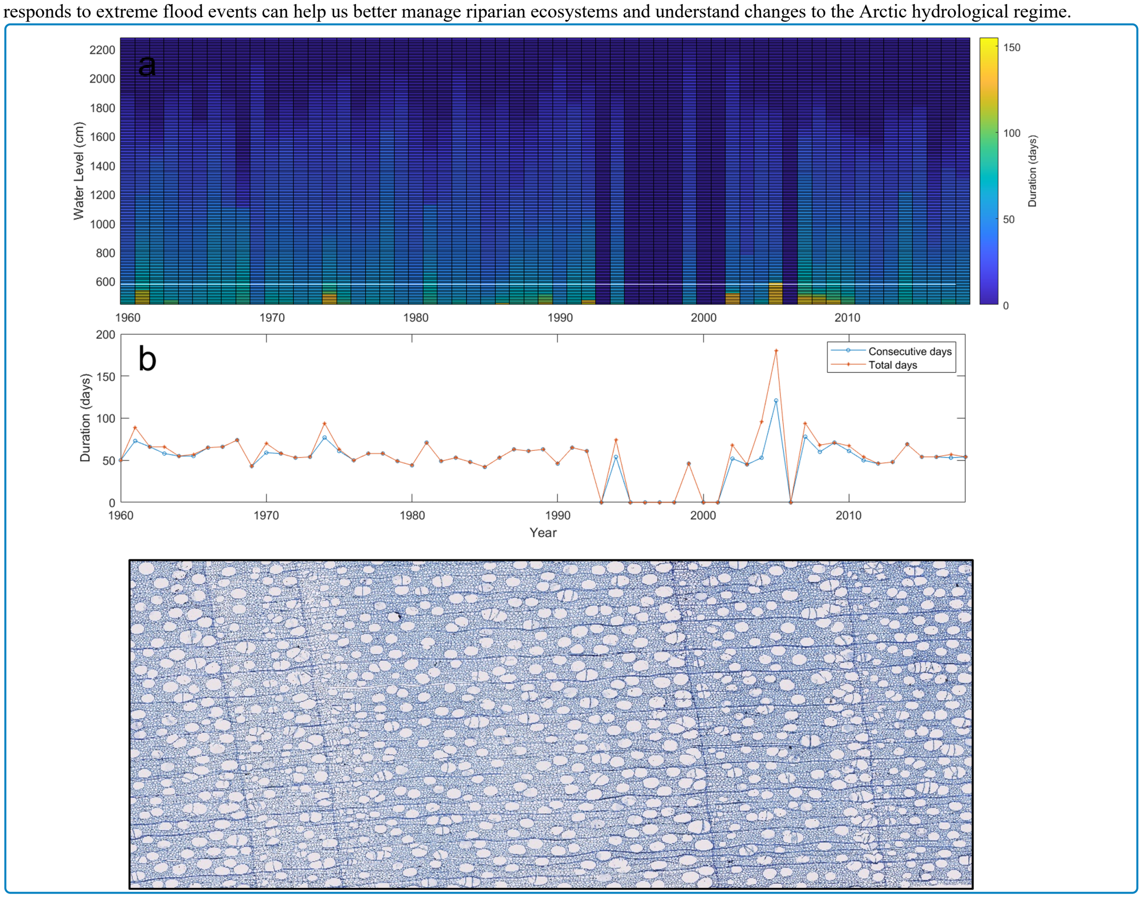

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