

Evaluating seasonal variability of sapwood properties in red oak and eastern white pine

Katie Accashian, Cameron McIntire, and Heidi Asbjornsen

Dept. Natural Resources and the Environment, University of New Hampshire, Durham, NH.

Objectives

The goal of this project was to evaluate if physical properties of sapwood change throughout the growing season in two common tree species: eastern white pine and northern red oak. The three variables of interest were the percent moisture content (m_c , %), dry density (ρ , kg m^{-3}), and thermal diffusivity (k , $\text{cm}^2 \text{s}^{-1}$). Each of these variables are needed for determining sap velocity using heat based sap flow techniques such as the heat ratio method (HRM, Burgess et al. 2001). Variation in wood properties can create error rates in sap flow estimates, particularly when transpiration measurements are scaled to higher orders of organization such as the plot or stand level. These errors can compound over long study periods when daily sap flow measurements are integrated to monthly or seasonal estimates of tree water use. Therefore, the accuracy of point measurements are crucial for confident estimates of transpiration and forest water balance. Since measuring wood properties is destructive to the bole of the tree, we also assessed the difference in wood properties between increment cores collected at breast height and the stump level. This study addressed two novel questions that are of interest to plant physiologists measuring tree water use:

1. Do wood properties differ between breast height and stump?
2. Do wood properties change throughout the growing season?

Methods

Sampling Design

Ten trees of each target species were selected from UNH's East Foss Farm property in Durham, NH. Throughout the 2015 growing season increment cores were taken from DBH (1.3 m above ground level) and near the stumps (0.2 m) of sample trees during four different sampling dates. Wood cores were cut to isolate the outer 2.0 cm of sapwood and weighed to determine fresh weight to 0.001 g precision. Cores were then oven dried for at least 48 hours at 70 °C and subsequently measured for dry weight. Sapwood moisture content and density were measured gravimetrically following standardized protocols. Sapwood thermal diffusivity was determined as:

$$k = \frac{k_w(m_c - m_{c_FSP}) \frac{\rho}{\rho_w} + 0.04186 * (21.0 - 20.0 * F_{v_FSP})}{\rho c}$$

Where k is the thermal diffusivity of the sapwood ($\text{W m}^{-1} \text{K}^{-1}$), k_w is the thermal conductivity of water ($\text{W m}^{-1} \text{K}^{-1}$), m_{c_FSP} is the moisture content at fiber saturation point (%), ρ and ρ_w are the dry and wet densities of wood respectively (kg m^{-3}), F_{v_FSP} is the void fraction fiber saturation point (%), and c is the specific heat capacity of fresh sapwood ($\text{J kg}^{-1} \text{K}^{-1}$) according to Vandegehuchte et al. 2013.

Sensitivity Analysis

Wood properties determined from each sampling date were used to conduct a sensitivity analysis on a time series of heat-based sap flow data in order to evaluate the relative effects of collection date on estimates of whole tree water use. For this study, the HRM equation (Burgess et al. 2001) was applied to a 24 hour time series:

$$V_h = \frac{k}{x} \ln\left(\frac{v_1}{v_2}\right) 3600$$

Where V_h is the heat pulse velocity, k is the thermal diffusivity of the sapwood ($\text{cm}^2 \text{s}^{-1}$), x is the distance between heat source and thermocouples (mm), v_1 and v_2 are the differences in temperature after a 60 second heat pulse between the upper and lower thermocouple respectively (°C).

$$Q = \frac{V_h \rho (C_w + m_c C_s)}{\rho_s C_s} \times A_{sw}$$

Where Q is the sap flux ($\text{cm}^3 \text{h}^{-1}$), ρ_s is the density of sapwood (kg m^{-3}), C_w and C_s are specific heat capacity of the wood matrix and water respectively ($\text{J kg}^{-1} \text{°C}^{-1}$), m_c is water content of sapwood, ρ_s is the density of water, and A_{sw} is the cross sectional sapwood area (cm^2).

Results

Variation between species and sample location

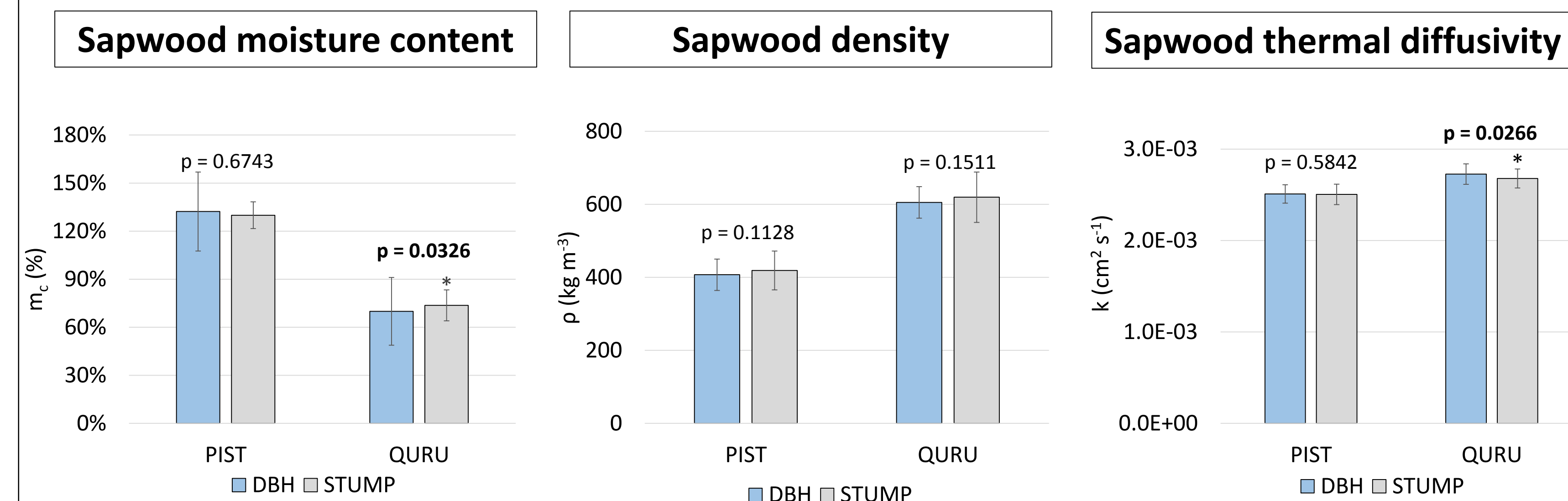


Figure 1. Seasonal means for all wood properties measured for each species and core location. A t-test was conducted between core positions for each species. Differences in sapwood moisture content and thermal diffusivity were found to be statistically significant between the dbh and stump cores in red oak. The mean measured thermal diffusivity for white pine ($0.00249 \text{ cm}^2 \text{ s}^{-1}$) and red oak ($0.00269 \text{ cm}^2 \text{ s}^{-1}$) are very close to the assumed nominal value of $0.0025 \text{ cm}^2 \text{ s}^{-1}$ (Marshall 1958).

Variation through time

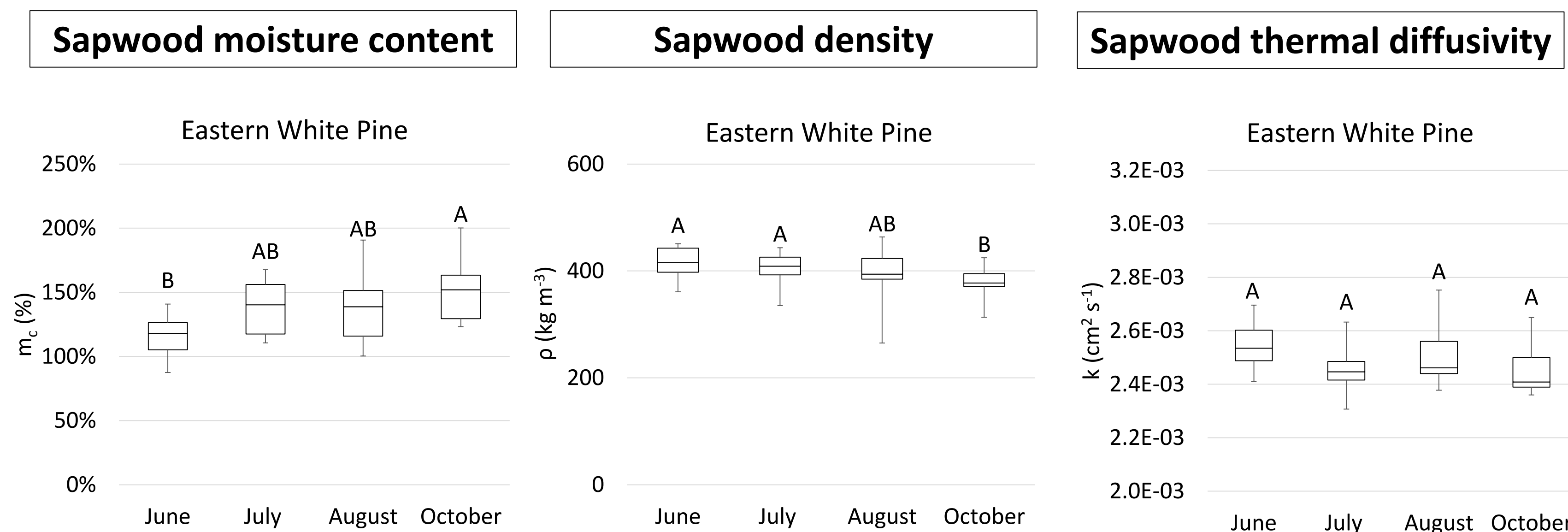


Figure 2. Sapwood properties measured at breast height throughout the course of the 2015 growing season in eastern white pine. A t-test was conducted between sampling dates for each metric. A letter difference between sample dates corresponds to a statistically significant p-value (<0.05). A significant trend of increasing sapwood moisture content was observed throughout the growing season, as well as a decline in sapwood density.

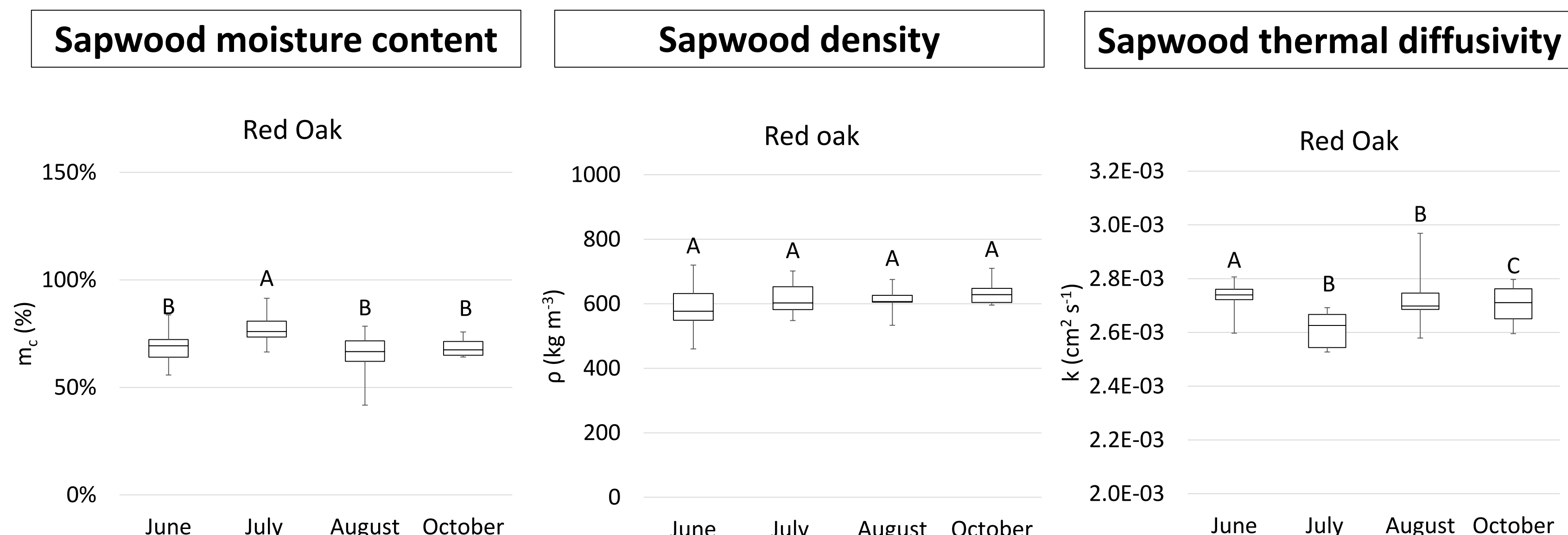


Figure 3. Sapwood properties measured at breast height throughout the course of the 2015 growing season in red oak. A t-test was conducted between sampling dates for each metric. A letter difference between sample dates corresponds to a statistically significant p-value (<0.05). Significant variability was detected in both the sapwood moisture content and thermal diffusivity

Sap flow sensitivity analysis

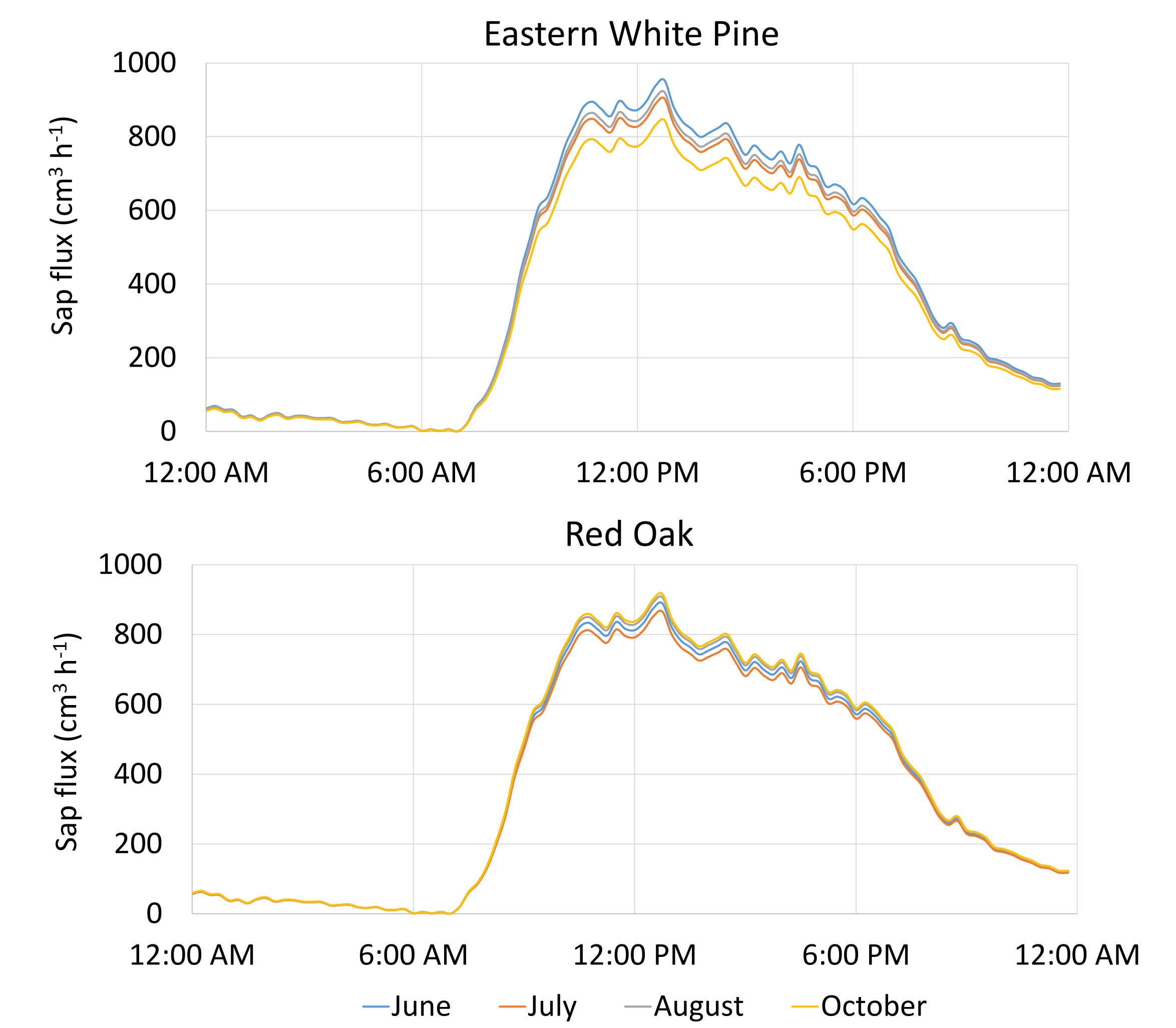


Figure 4. Sensitivity analysis of sap flux rates in white pine and red oak over a 24 hour period. Measured sapwood properties (m_c , ρ , k) were adjusted for each sample period and applied to a time series of heat ratio data collected in the field. The greatest influences occurred during mid-day periods of peak transpiration.

Eastern White Pine				
Sampling Date	m_c (%)	ρ (kg m^{-3})	k ($\text{cm}^2 \text{ s}^{-1}$)	Total Sap Flux (L day^{-1})
June 4, 2015	117%	423.00	0.00254	9.57
July 1, 2015	137%	414.53	0.00245	9.09
August 3, 2015	132%	413.71	0.00250	9.25
October 12, 2015	143%	387.59	0.00245	8.50
AVERAGE	132%	409.71	0.00249	9.10

Red Oak				
Sampling Date	m_c (%)	ρ (kg m^{-3})	k ($\text{cm}^2 \text{ s}^{-1}$)	Total Sap Flux (L day^{-1})
June 4, 2015	68%	592.74	0.00275	8.89
July 1, 2015	76%	612.47	0.00261	8.68
August 3, 2015	68%	617.32	0.00270	9.07
October 12, 2015	68%	621.23	0.00271	9.16
AVERAGE	70%	610.94	0.00269	8.95

Table 1. Summary table of measured wood properties at breast height showing the mean of ten trees for each species on each sampling date. Total sap flux is the integration of sap flux over the 24 hour period used for the sensitivity analysis. The error rate is less than a 7% deviation from the mean when using wood properties measured from any single sampling date.

Acknowledgements

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