SPATIAL UNCERTAINTY IN SAP VELOCITY MEASUREMENTS AND TREE WATER USE UPSCALING IN AMERICAN BEECH

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ABSTRACT

We examined the variation in sap velocity radially, azimuthally, at different heights and across different tree sizes for the species *Fagus grandifolia*. The results demonstrate that the main sources of variability are radial variability and tree size. The implications for scaling up routine point measurements of sap velocity to the whole-tree and stand levels are discussed.

INTRODUCTION

Where whole-plant transpiration measurements are required, sap flow methods hold important advantages over other techniques. However, there are many uncertainties about their accuracy at multiple scales stemming from the within-plant variability in measured sap velocity, which in turn influences water use calculations at higher levels such as whole plants, stands and watersheds (Smith and Allen, 1996). Variation in sap velocity has been addressed in tree stems radially (Phillips et al. 1996), azimuthally (Lu et al. 2000) and with height (Loustau et al. 1998), but the relative importance of each uncertainty and their implications for extrapolation to larger scales have not been addressed altogether. Further, scaling water fluxes from individual trees to the stand requires an appropriate sampling design to effectively capture stand structure and spatial distribution associated with trees of differing size, dimension, social position, leaf area and species (Köstner et al. 1998). Specifically, tree size (e.g. DBH, sapwood depth) is used as a scaling parameter as it is usually related to sap velocity (Meinzer et al. 2001, Jung et al. 2011). The main objective of this work was to examine within-tree sap velocity variation (radially, azimuthally, and with height) and variability across different tree sizes to assess the potential associated errors when scaling sap velocity from routine single-point measurements to the whole-tree and stand levels. Relatively little is known about the water relations of our study species, *Fagus grandifolia,* despite its dominance and ecological importance in the northeastern hardwood forest region of USA.

METHODOLOGY

The research was conducted at one plot of 50 x 50 m at the Bartlett and Hubbard Brook Experimental Forests in New Hampshire (USA) in summer 2011. The forest composition is typical of mature USA northeastern hardwoods, with an overstory dominated by sugar maple (*Acer saccharum*), American beech *(F. grandifolia*) and yellow birch (*Betula alleghaniensis*). The soils are Typic Haplorthods (Yanai et al. 2008). The climate is humid continental (mean annual precipitation 1280 mm) with warm summers and cold winters (http://www.pnet.sr.unh.edu/climcalc/).

Sap velocity measurements: To assess the radial, azimuthal and height variability of sap velocity (v_s, cm^3 cm^{-2} h^{-1}) we installed four Heat Ratio sap flow probes (Burgess et al. 2001) in two *F. grandifolia* individuals (Group1; Tree1: DBH=7.55 cm, DOY=223-228 and Tree2: DBH=6.90 cm, DOY=229-234), at two different azimuthal orientations (N, S) and at different heights starting 25 cm above the ground surface. The vertical distance between probe pairs with the same orientation was 86-89 cm. Twelve additional *F. grandifolia* trees of different sizes (Group2) were instrumented with one probe each installed with N orientation and at 1.3 m (DOY=234-273). For comparison purposes we divided the trees into four size classes according to their DBH: <10 cm (v_{s0}), 11-20 cm (v_{s1}), 21-30 cm (v_{s2}) and >30 cm (v_{s3}). For further analysis, sapwood depth at which v_s was measured was expressed relative to the maximum sapwood depth of each sample tree. Sensors were connected to several multiplexer (AM 16/32B, Campbell Scientific Inc., Logan, UT, USA) and datalogger (CR1000, Campbell Scientific Inc.) arrays. Our custom-made Heat Ratio sap flow probes measured sap velocity at three depths: 1 cm (v_{souter}), 2.2 cm ($v_{smiddle}$) and 3.5 cm ($v_{sinterior}$) from the cambium. We observed no $v_{sinterior}$ in the smallest trees, and thus only v_{souter} and $v_{smiddle}$ were used for the analyses.

Statistical analyses: We used generalized linear mixed models (R package, nlme R, Pinheiro et al. 2011) to analyse the effects of radial position, azimuthal orientation, height and size on v_s.

RESULTS AND DISCUSSION

Radial variability: Group1 analyses showed that v_{souter} was always significantly higher than $v_{smiddle}$ ($p<0.0001$; Fig. 1). Accordingly, a similar trend was documented for all Group2 trees ($p<0.05$; Fig. 2a). After normalizing v_s radial positions by sapwood depth and clustering data into 4 groups of sapwood proportions (outermost-0.25, 0.25-0.5, 0.5-0.75, 0.76-innermost sapwood), we observed a decreasing trend in v_s with sapwood depth (Fig. 2b). However, significant differences were only observed between v_s measured from the outermost-0.75 sapwood and v_s measured in the innermost proportion of sapwood ($p<0.01$; Fig. 2b). This radial variability observed along the sapwood depth may be related to the type and arrangement of sap conducting tissue (i.e. vessel diameter, spatial distribution of the vessels within a given growth ring, etc. (Swanson 1994)) or/and to the vertical distribution of foliage in the crown (Fiora and Cescatti, 2008).

Size variability: Group2 results revealed that v_{s0} was significantly lower than v_{s1} and v_{s2}, which were similar between them but lower than v_{s3} (Fig. 3, $p<0.05$). No interaction was found between size and radial location ($p>0.05$). This positive relationship between tree size and v_s is consistent with other works (Jung et al. 2011) although negative relationships have also been reported (Meinzer et al., 2001) probably due to reduced photosynthesis and stomatal conductance in old stands *versus* young stands (Bond et al. 2000). The increasing v_s with tree DBH and thus, with height, found in our study is likely a consequence of better crown illumination, higher wind speeds, lower humidity and thus, better atmospheric coupling leading to higher transpirations rates (Jung et al. 2011).

Orientation and height variability No significant differences between N and S arose. Neither a height effect nor an effect of the interaction between radial and azimuthal measurements was observed in Group1, which may partially be explained by the small size of the trees.

CONCLUSIONS

The main sources of v_s variability documented in this study were radial variation and tree size, with v_s being consistently lower towards the heartwood and with smaller tree size. In order to establish a more effective experimental design for the placement of the sap flow sensors to reduce the uncertainty when upscaling point v_s measurements (e.g. tree water use and stand water balance estimation) mainly radial v_s differences and tree size should be considered.

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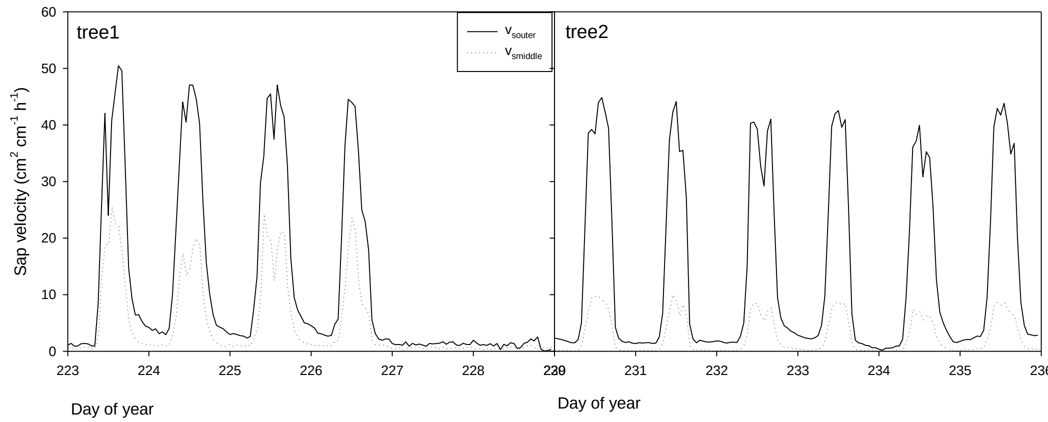

Figure 1. Temporal dynamics of sap velocity at two different sapwood depths in Group1 trees.

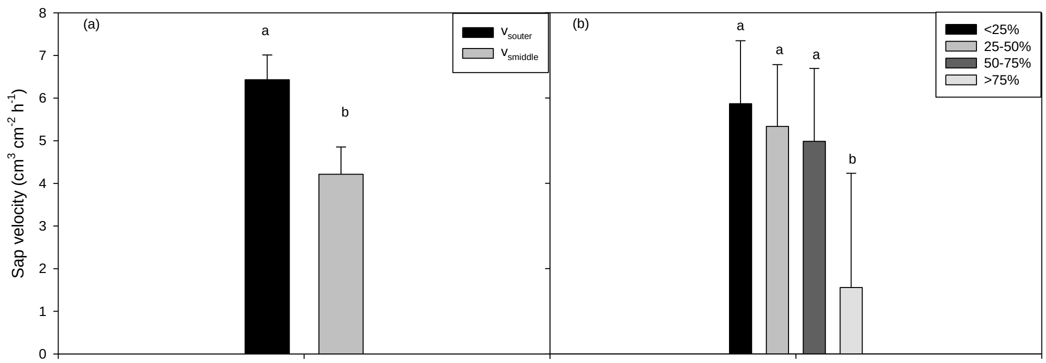

Figure 2. Comparison between v_s measured at 1 cm and 2.2 cm sapwood depth (a) and comparison of v_s normalized by DBH at different sapwood depths in Group2 (b). The error bars represent 95% confidence intervals of mean v_s. Different letters indicate significant differences ($p<0.05$).

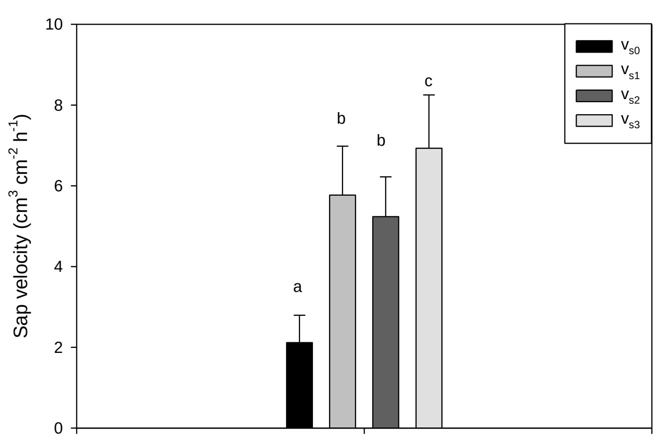

Figure 3. Mean v_s measured in trees of different size. The error bars represent 95% confidence intervals of mean v_s. Different letters indicate significant differences ($p<0.05$).