From Forest Nursery Notes, Winter 2009

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New Phytologist

Height-related trends in leaf xylem anatomy and shoot hydraulic characteristics in a tall conifer: safety versus efficiency in water transport

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Received: *17 March 2008*
Accepted: *14 May 2008*

Summary

- Hydraulic vulnerability of Douglas-fir (*Pseudotsuga menziesii*) branchlets decreases with height, allowing shoots at greater height to maintain hydraulic conductance (K_{shoot}) at more negative leaf water potentials (Ψ_l).
- To determine the basis for this trend shoot hydraulic and tracheid anatomical properties of foliage from the tops of Douglas-fir trees were analysed along a height gradient from 5 to 55 m.
- Values of Ψ_l at which K_{shoot} was substantially reduced, declined with height by 0.012 Mpa m^{-1}. Maximum K_{shoot} was reduced by 0.082 mmol m^{-2} MPa^{-1} s^{-1} for every 1 m increase in height. Total tracheid lumen area per needle cross-section, hydraulic mean diameter of leaf tracheid lumens, total number of tracheids per needle cross-section and leaf tracheid length decreased with height by 18.4 μm^2 m^{-1}, 0.029 µm m^{-1}, 0.42 m^{-1} and 5.3 µm m^{-1}, respectively. Tracheid thickness-to-span ratio $(t_w/b)^2$ increased with height by 1.04×10^{-3} m^{-1} and pit number per tracheid decreased with height by 0.07 m^{-1}.
- Leaf anatomical adjustments that enhanced the ability to cope with vertical gradients of increasing xylem tension were attained at the expense of reduced water transport capacity and efficiency, possibly contributing to height-related decline in growth of Douglas fir.

Key words: embolism, foliar anatomy, growth limitation, hydraulic conductance, *Pseudotsuga menziesii*, water stress.

New Phytologist (2008) **180**: 90–99

doi: 10.1111/j.1469-8137.2008.02551.x

Introduction

Growth and aboveground biomass accumulation follow a common pattern as tree size increases, with productivity peaking when leaf area reaches its maximum and then declining as tree age and size increase (Ryan & Waring, 1992). Age- and size-related declines in forest productivity are major considerations in setting the rotational age of commercial forests, and relate to issues of carbon storage, since changes in forest structure can influence large-scale biomass accumulation. Despite the ecological and practical significance of the ontogenetic decline in tree growth, the mechanisms responsible for it are not well understood (Ryan *et al.*, 2006). However, available evidence suggests that ontogenetic trends in growth are mainly a function of tree size (height) rather than age (Koch *et al.*, 2004; Woodruff *et al.*, 2004; Bond *et al.*, 2007; Mencuccini *et al.*, 2007).

Height-related changes in leaf function may have an impact on tree growth and forest productivity because leaf stomata are responsible for maximizing photosynthetic carbon gain while simultaneously dealing with the antagonistic task of constraining transpirational water loss to avoid damaging