Tree stomatal regulation and water use in a changing climate

From tropical to boreal ecosystems

Thomas Berg Hasper

Institutionen för biologi och miljövetenskap
Naturvetenskapliga fakulteten

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Abstract

Rising levels of atmospheric carbon dioxide concentration ([CO_2]) and temperature have the potential to alter stomatal behavior and tree water use, which has implications for forest hydrology and climate. Many models assume decreases in stomatal conductance (g_s) and plant water use under rising [CO_2], which has been invoked as the causes for the positive global trend in river runoff over the past century. Plant water use is, however, also affected by changes in temperature, precipitation, land use and management and climate change-induced alterations in ecosystem structure. Still, there is no consensus about the contribution of different drivers to temporal trends of evapotranspiration (ET) and river runoff. There is great variation in stomatal and photosynthetic responses to [CO_2] and temperature among plant species, and the factors controlling it are still poorly understood, in particular for boreal and tropical tree species.

This thesis investigated the effects of elevated [CO_2] and temperature on the stomatal functioning, tree hydraulics, canopy leaf area and whole-tree water use of mature *Picea abies* and young *Eucalyptus globulus* trees grown in whole-tree chambers in boreal and temperate areas, respectively. In the boreal study, the tree-level experiment was complemented with data on historical trends and patterns in ET of large-scale boreal landscapes, using climate and runoff data from the past 50 years, in order to assess water-use responses to past climate change in Swedish boreal forests. The thesis also explored the temperature responses of photosynthesis as well as the taxonomic and functional controls of the large interspecific variation in stomatal CO_2 responsiveness and photosynthetic capacity in a broad range of tropical woody species.

Results demonstrated that neither mature *P. abies* nor young *E. globulus* saved water under elevated [CO_2], and that warming did not increase their transpiration as decreased g_s cancelled the effect of higher vapour pressure deficit in warmed air. Also, Swedish boreal ET increased over the past 50 years while runoff did not significantly change, with the increase in ET being related to increasing precipitation and forest standing biomass over time. In *E. globulus*, neither elevated [CO_2] nor warming treatment affected g_s, stomatal density or length, or leaf area-specific plant hydraulic conductance. Furthermore, elevated [CO_2] increased both total canopy leaf area and tree water use, while warming did not have any significant influence on either of these variables. In the tropical studies, the optimum temperature for the maximum rate of photosynthetic electron transport (J_{max}) was lower in the native than in the exotic species. The daytime peak leaf temperatures greatly exceeded (by up to 10 °C) the photosynthetic optimum temperatures, in particular in the native montane rainforest species. Lastly, all studied plant taxonomic groups exhibited stomatal closure responses to increased [CO_2], but none of the functional characteristics investigated could explain the variation in stomatal CO_2 responses among tropical woody species. The interspecific variation in photosynthetic capacity was related to within leaf nitrogen allocation rather than to area-based total leaf nutrient content.

The findings of this thesis have important implications for the projections of future water use of forests, showing that changes in tree structural responses (e.g. size, canopy leaf area and hydraulics) are more important than the effects of elevated [CO_2] or warming on leaf transpiration rates. The lack of reductions in g_s under elevated [CO_2] in *P. abies* and *E. globulus* conflicts with the present expectation and model assumption of substantial leaf-level water savings under rising CO_2. In the tropical biome, the evidence of pronounced negative effects of high temperature on the photosynthesis of native montane tree species indicates high susceptibility of these ecosystems to global warming. Furthermore, the results on stomatal and photosynthetic responses in a broad range of tropical species contribute with important data for this comparatively poorly researched biome.

Keywords: Climate change, carbon dioxide, temperature, transpiration, water use, whole-tree chamber, stomata, stomatal conductance, V_{cmax}, J_{max}, tropical, temperate, boreal, trees