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Effects of future climate on carbon assimilation of boreal Norway spruce

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Abstract

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In boreal forests, the main factors limiting biomass production are the harsh climate, which combines a short growing season and low annual levels of incoming solar energy, and the limited availability of nitrogen. These limitations will be directly affected by climate change, and may in turn substantially affect the carbon budget of the boreal forests, the production of wood and biofuel, biodiversity and other ecosystem services.

This thesis addresses the effects of climate change on the rate of carbon assimilation by boreal Norway spruce, *Picea abies* (L.) Karst. The study focussed on examining how the mechanisms regulating uptake of CO_2 in mature, field-grown trees are affected by exposure to elevated concentrations of atmospheric carbon dioxide [CO_2] and air temperature. The experiment was conducted at the Flakaliden research site in northern Sweden. Twelve whole-tree chambers (WTCs) were used to impose combinations of [CO_2] and temperature treatments as predicted for the region in the year 2100. Shoot CO_2 gas exchange was measured continuously within the chambers, using shoot cuvettes. The effect of the climate change treatments on developing shoots was studied during their first growing season; the effect of the treatments on spring recovery and annual photosynthetic performance in 1-year old shoots was also examined.

The elevated temperature induced an earlier start and completion of the structural development of the current year's shoots, as well as an earlier shift from negative to positive net carbon assimilation rate (NAR) by one to three weeks. The elevated CO_2 increased photosynthetic performance by 30% in high season. Consequently, the current year's shoots had assimilated their own mass in carbon 20-30 days earlier under the climate change conditions than under the current climatic conditions. For the 1-year old shoots, an increase in the maximum photosynthetic rate of ~50% was recorded, and the spring recovery of photosynthetic capacity was completed three to four weeks earlier than under the current climatic conditions.

Multiple environmental variables constantly affect the NAR. A model incorporating the most important variables – light, temperature and vapour pressure deficit – was fitted to the data from the 1-year old shoots. This linked changes in the carbon assimilation rate to each of the tested variables. An artificial neural network was used to reduce the noise present in the field data, and to benchmark the performance of the model. The climate change treatment increased the temperature optimum for gross carbon assimilation from 19.7 to 24.7 °C, and the model apparent quantum yield increased from 0.042 to 0.077 mol mol^{-1}. In total, the annual gross carbon uptake increased by 84%, compared to that under current conditions. The lengthening of the growing season increased annual gross carbon uptake by 22%.

Finally, the influence of canopy processes on the rate of soil respiration and its carbon isotope signal ($\delta^{13}C$) were investigated. The results indicated that canopy processes are likely to have a considerable influence on soil respiration rates, and it is suggested that ecosystem carbon balance models should include plant root allocation and aboveground productivity as driving variables with respect to soil respiration and carbon sequestration.

Keywords: *bud development, climate change, empirical models, gas exchange, photosynthesis, Picea abies, seasonality, whole-tree chambers*