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Species-specific fine root biomass distribution alters competition in mixed forests under climate change

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The importance of mixed forests in European silviculture has increased due to forest conversion policies and multifunctional forest management. Concurrently, evidences for substantial impacts of climate change on forest ecosystems accumulate. Projected drier and warmer conditions alter the water relations of tree species, their growth and ultimately their inter-specific competition in mixed stands. Process-based models are scientific tools to study the impact of climate change on and to deepen the understanding of the functioning of these systems based on ecological mechanisms. They allow for long-term, stand-level studies of forest dynamics which could only be addressed with great difficulty in an experimental or empirical setup.

We used the process-based forest model 4C to simulate inter-specific competition in mixed stands of Douglas-fir (Pseudotsuga menziesii) and Common beech (Fagus sylvatica) as well as Scots pine (Pinus sylvestris) and Sessile / Pedunculate oak (Quercus petraea and Quercus robur) under a) historical climate for model verification and b) under climate change scenario realizations of the climate model STAR 2.0 in Brandenburg, Germany. Some of the climate change scenario realizations feature a substantially drier and warmer summer climate which decreases the climatic water balance during the growing season. We assumed species-specific fine root biomass distributions which feature broadleaved fine roots in deeper soil layers and coniferous fine roots in upper soil layers according to several root excavation studies from mixed stands. The stands themselves were constructed from yield tables of the contributing species.

The model verification provided good results for the basal area predictions under the historical climate. Under climate change, the number of days when the tree water demand exceeded the soil water supply was higher for the coniferous species than for broadleaved species. Furthermore, after 45 simulation years the basal area covered by the broadleaved species increased by 2-7% under the climate change scenarios in comparison to the initial stand composition. This indicates a higher competitive potential of the broadleaved species. Moreover, broadleaved net primary production (NPP) was also less affected by drier and warmer conditions than the NPP of the conifers.

The model verification shows that 4C is suitable for analyzing inter-specific competition under climate change in terms of basal area covered. Our assumption on species-specific fine root biomass distribution is a crucial element of the climatic influence on water relations, growth and competition but is in accordance with published root excavation studies. Artificially switching the fine root biomass distribution – hence allotting the broadleaved fine roots to the coniferous trees and vice versa inverts the competition pattern. Under drier and warmer summer conditions, the deeper fine root biomass distribution of the broadleaved species enables them to maintain their growth rates, whereas the coniferous species do not acquire enough water to satisfy their water demand and are partly outcompeted. These effects are largely determined by drier and warmer conditions and to some extent reversed if the climatic water balance in the summer is less severely reduced. None of the contributing species is however threatened by the simulated climate change, although it has to be borne in mind that in real forest drought-stressed trees may be more susceptible to other biotic or abiotic risks, which can amplify the climatic effect found here.

We conclude that the differentiated response to climate change and the complementary use of the rooting space display the importance of mixed-species systems for climate change adaptation. Furthermore, a realistic formulation of below-ground conditions in process-based models is a first step towards mechanistic modeling of competition.