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Meta-analysis of simulated forest productivity changes under global change

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Forest productivity is a crucial element of the terrestrial carbon cycle and closely linked to water and nutrient availability. Process-based forest models have been widely used to project forest productivity under changing environmental conditions. However, there are different types of uncertainties associated with these studies: 1) future climate uncertainty as expressed by the choice of the climate scenarios and the underlying General and Regional Circulation Models (GCM/RCM), 2) model structural uncertainty as a consequence of different possible formulations of ecological processes (such as the magnitude and persistence of the CO2-fertilization effect), and 3) model parameter uncertainty (e.g. parameters based on few experimental studies or expert assessment applied to a wide range of conditions). This uncertainty affects the reliability of model projections of future productivity changes and their usefulness for vulnerability assessments, decision-making and management.
We carry out a systematic literature review of stand-level, process-based simulation studies that use scenarios of climate change, atmospheric CO2-concentration, and nitrogen deposition to project forest productivity changes. We then conduct a meta-analysis of the projected productivity shifts relative to simulated past productivity.
As of the year 2010, about 50 process-based, stand-level simulation studies on forest productivity under global change are available in the Web of Science database. Most of the studies cover temperate and boreal forests in Europe and Northern America and focus on common tree species. Simulation studies in tropical forests are almost entirely lacking. We present a meta-analysis of the results of these studies in terms of 1) multi-model mean productivity changes for geographic regions and biomes, 2) individual-model mean productivity changes for geographic regions and biomes (if several runs of the same model are available), and 3) mean productivity shifts for changes of individual environmental drivers (e.g. per degree warming) and their combination. This approach permits capturing a wide range of climate change scenarios, model structures, and model parameters, which in turn allows for a quantification of productivity shift's uncertainties.
We discuss the model results in light of their underlying model structure and model processes and compare them with measurements of past forest productivity changes. Furthermore we display their relevance for terrestrial biogeochemical cycles. Ultimately our results show the sensitivity of forest productivity and forest carbon cycling in temperate and boreal forests to CO2-fertilization effects, water availability and drought, temperature-induced increases in photosynthesis, lengthening of the vegetation period, nitrogen depositions, and interactions of these factors. Furthermore, we unravel possibilities for model enhancement, highlight key knowledge gaps for model formulations, and stress the need for model inter-comparisons and improved methods for scenario, model structure and model parameter uncertainty quantification.