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The impact of atmospheric deposition and climate on forest growth in Europe using two empirical modelling approaches

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Abstract

Most recent studies show increasing forest growth in central Europe, rather than a decline as was expected due to negative effects of air pollution. While nitrogen deposition, increasing temperature and change in forest management are discussed as possible causes, quantification of the various environmental factors has rarely been undertaken.

In our study, we used data from several hundreds of intensive monitoring plots from the ICP Forests network in Europe, ranging from northern Finland to Spain and southern Italy. Five-year growth data for the period 1994-1999 were available from roughly 650 plots to examine the influence of environmental factors on forest growth. Evaluations focused on the influence of nitrogen, sulphur and acid deposition, temperature, precipitation and drought. Concerning the latter meteorological variables we used the deviation from the long-term (30 years) mean. The study included the main tree species common beech (Fagus sylvatica), sessile or pedunculate oak (Quercus petraea and Q. robur), Scots pine (Pinus sylvestris) and Norway spruce (Picea abies). Two very different approaches were used. In the first approach an individual tree-based regression model was applied (Laubhahn et al., 2009), while in the second approach a stand-based model was applied (Solberg et al., 2009). The individual tree-based model had measured basal area increment of each individual tree as a growth response variable and tree size (diameter at breast height), tree competition (basal area of larger trees and stand density index), site factors (e.g. soil C/N ratio, temperature), and environmental factors (e.g. temperature change compared to long-term average, nitrogen and sulphur deposition) as influencing parameters. In the stand-growth model, stem volume increment was used as the growth response variable, after filtering out the expected growth. Expected growth was modelled as a function of site productivity, stand age and a stand density index. Relative volume growth was then calculated as actual growth in % of expected growth. The site productivity was either taken from expert estimates or computed from for each species from three site index curves from northern, central and southern Europe. Requirements for plot selection were different for both methods, resulting in 382 plots selected for the tree-individual approach and 363 plots for the stand growth model approach.

Using a mixed model approach, the individual tree-based models for all species showed a high goodness of fit with Pseudo-R2 between 0.33 and 0.44. Diameter at breast height and basal area of larger trees were highly influential variables in all models. Increasing temperature showed a positive effect on growth for all species except Norway spruce. Nitrogen deposition showed a positive impact on growth for all four species. This influence was significant with $p < 0.05$ for all species except common beech, where the effect was nearly significant ($p = 0.077$). An increase of 1 kg N ha-1 yr-1 corresponded to an increase in basal area increment between 1.20% and 1.49% depending on species.

The stand-growth models explained between 18% and 40% of the variance in expected growth, mainly with a positive effect of site productivity and a negative effect of age. The various models and statistical approaches were fairly consistent, and indicated a fertilizing effect of nitrogen deposition on relative growth, with a slightly above 1 percent increase in volume increment per kg of nitrogen deposition per ha and year. This was most clear for spruce and pine, and most pronounced for plots having soil C/N ratios above 25 (i.e. low nitrogen availability). Also, we found a positive relationship between relative growth and summer temperature, i.e. May–August mean temperature deviation from the 1961–1990 means. Other influences were uncertain. Possibly, sulphur and acid

deposition have effects on growth, but these effects are eventually outweighed by the positive effect of nitrogen deposition, because of co-linearity between these variables.

Considering an average total stem carbon uptake for European forests near 1730 kg per hectare and year, the increase in growth in the individual tree-based models implied an estimated sequestration of approximately 21–26 kg carbon per kg nitrogen deposition. Using the growth data and the relative stem growth predicted in the stand growth models, values for the various models ranged between 16 and 24 kg (mean 19 kg) carbon uptake per kg nitrogen deposition. Both approaches, although being very different and using a different set of plots and different methods to estimate the N induced carbon uptake in stem wood resulted in very similar results. In summary, our results indicate a clear fertilization effect of N deposition on European forests, mainly on sites with high C/N soil ratios. It is in line with approaches focused on the fate of N in forest ecosystems and with results of N fertilizer experiments but much smaller than had recently been reported in other field studies (De Vries et al., 2008). Increasing temperature was also found to have a positive influence on forest growth, but this effect seemed to be less clear.

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