Continental-scale forest growth in Europe is driven by management and further modulated by nitrogen deposition

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Abstract

Our analysis of continental-scale forest growth data provided further evidence that management-related stand characteristics like stand density index and stand age are key to explain annual forest increment. For some species a clear relationship of growth with atmospheric N deposition appeared, with an overall positive, but in some cases non-linear response with a tipping point at 24-34 kg N ha^{-1} yr^{-1}, indicating that N deposition is at least as important as climate to impact tree growth at continental scale in Europe.

Keywords: air pollution, observational study, climate change

European temperate and boreal forests represent a globally important component of the terrestrial carbon sink and pool (Luyssaert et al., 2010). Understanding which factors drive and modulate forest growth is therefore critical to predict how forest ecosystems can respond to climate change. Uncertainty exists on the role of altered environmental drivers, such as climate and air pollution, in affecting forest production at the continental scale (Zak et al., 2011; De Vries et al., 2017), especially in interaction with site- and stand characteristics.

We conducted a continental-scale analysis of ICP Forests growth data obtained over the period 1995-2010 from nearly 100,000 trees distributed in 442 even-aged, almost pure beech-, oak-, spruce- and pine-dominated permanent observation plots distributed in managed forests across 23 countries in Europe.

We used multivariate statistical approaches, such as mixed effects models and structural equation modelling to investigate how European forest growth (*ΔVol*) respond to changes in 11 predictors, including stand characteristics, climate conditions, air and site quality, as well as their interactions. We expected to detect whether, and to what extent, environmental drivers, such as climate (precipitation, temperature, drought events) and air quality (N deposition, ozone) have direct and/or indirect impacts on growth once stand characteristics (stand density, age, altitude) are accounted for.

We found that, despite the large environmental gradients encompassed by the forests examined, stand density and age were key drivers of forest growth. We further detected a positive, in some cases non-linear effect of N deposition, most pronounced for beech forests, with a tipping point at ca. 30 kg N ha^{-1} yr^{-1} (Etzold et al. 2020). N deposition was involved in interactions with site quality indicators and had indirect negative effects on *ΔVol* by altering soil pH and foliar nutrient concentrations. With the exception of a consistent temperature signal on Norway spruce, climate-related predictors and ground-level ozone showed much less generalized relationships with *ΔVol*.

Our results show that, together with the driving forces exerted by stand density and age, N deposition is at least as important as climate to modulate forest growth at continental scale in Europe, with a potential negative effect at sites with high N deposition. It highlights the need for continuous, concurrent and co-located monitoring of site-, stand-, environmental- and response variables to investigate continental forest growth patterns. Text is based on Etzold et al. (2020).

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