Nitrogen deposition increases drought sensitivity in Swiss forests

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Abstract

A network of forest monitoring plots was established in Switzerland in 1984, covering gradients in drought, nitrogen deposition, ozone, age, altitude and soil chemistry. Data are available from 95 plots with European beech (*Fagus sylvatica*) and 76 plots with Norway spruce (*Picea abies*). The results of this long-term forest monitoring programme show that nitrogen (N) deposition (range 8.5-81 kg N ha^{-1} yr^{-1}) clearly increased the drought sensitivity of beech stem increment. The mortality of beech was increased after drought and when foliar P concentrations were low. As the latter may be a consequence of high N deposition this is an indirect N effect. Under drought conditions, spruce mortality increased significantly with high N deposition, as a consequence of bark beetle infestations.

Keywords: N deposition, drought, *Fagus sylvatica*, *Picea abies*, growth, phosphorus, potassium

1. Materials and Methods

1.1 Observation plots

Growth trends and mortality of European Beech (95 plots) and Norway spruce (76 plots) have been observed in the Intercantonal Forest Observation Programme in Switzerland for 37 years (Braun, Schindler and Rihm, 2017). Foliar nutrient concentrations and diameter at breast height were measured at intervals of 4 years. Stem volume was calculated using tree height and diameters at 1.3 and 7 m above ground. Mortality was observed every year and related to the population of the preceding year.

1.2 Nitrogen deposition

Total nitrogen (N) deposition per year was modelled at a spatial resolution of 1 ha (Rihm and Künzle, 2019). Nitrogen deposition in the plots varied between 8.5 and 81 kg N ha^{-1} yr^{-1}.

1.3. Drought calculation

Indicators of drought for forest sites were calculated using a hydrological model (Wasim-ETH, Schulla, 2018) on a daily basis. The best indicators were minimum site water balance of a year (cumulative sum of <prec – Evapotrans-piration(pot) + nFK>; SWBmin) and the average ratio between actual and potential evapotranspiration during the first 90 days of the season or the whole season (ETa/ETp, Braun, Remund and Rihm, 2015).

1.4. Statistics

Data were analysed using multivariate mixed linear and binomial regression models including site as random and year as fixed or random factors. Significant predictors were tested systematically for interactions and linearity.

2. Results

2.1 Fagus sylvatica

Volume increment in European beech was mostly negatively correlated with N deposition, with a relatively flat dose-response curve around 20-25 kg N ha^{-1} yr^{-1} and a steeper decrease at deposition rates of >25 kg N ha^{-1} yr^{-1}. Volume increments were lower and the decrease stronger when it was dry (ETa/ETp=0.7).

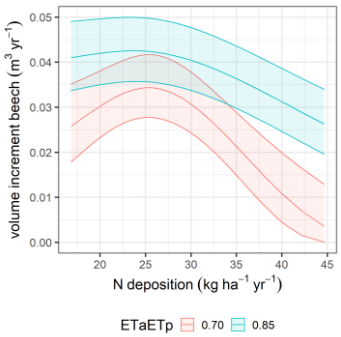

Fig. 1: Volume increment of beech in relation to N deposition, including the interaction effect of drought. From the model, estimates for ETa/ETp values of 0.7 (dry; red) and 0.85 (moist; blue) were extracted. This model contains 27887 observations for 6133 trees on 76 plots (8 increment periods of 4 years each).

Mortality of European beech was increased with drought (decreasing site water balance), averaged over three preceding years. The relation was stronger when foliar phosphorus (P) concentrations were low. As foliar P concentrations are related with N deposition this result suggests a role of N deposition increasing drought sensitivity.

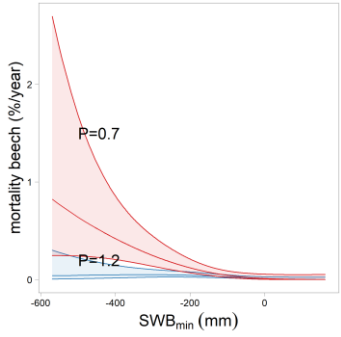

Fig. 2: Estimates (with 95%-confidence interval) of mortality of European beech as a function of drought (SWBmin), including the interaction effect of foliar P concentration (blue: sufficient, red: deficient). This model contains 185034 tree observations during 37 years, 95 plots, 212 dead trees.

2.2 Picea abies

Mortality of Norway spruce was increased with drought (decreasing ETa/ETp), averaged over the current and three preceding years. This relation was clearly stronger when N deposition was high.

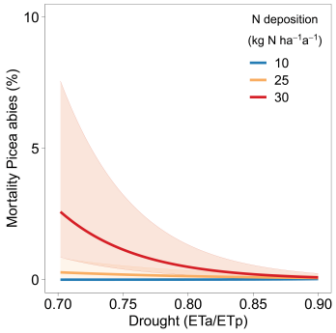

Fig. 3: Estimates (and 95%-confidence interval) of mortality of Norway spruce as a function of drought (ratio between actual and potential evapotranspiration), including the interaction effect of N deposition. This model contains 131819 tree observations during 36 years, on 76 plots and 1132 dead trees.

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