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Mapping correlations between nitrogen concentrations in atmospheric deposition and mosses for natural landscapes in Europe

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ABSTRACT

Recent investigations proved that nitrogen (N) concentrations in mosses are primarily determined by atmospheric deposition. The correlations are country- and N compound-specific and agree well with spatial patterns and temporal trends across Europe as a whole and in single European countries. This study investigates whether correlations between the concentration of N in atmospheric deposition and mosses within the units of an ecological land classification of Europe can be established. To this end, N measurements from the 2005 European moss survey and modelled N atmospheric deposition in 2005 were intersected with a map of European landscapes. Then, considering minimum numbers of sampling sites required across Europe, in single European countries and within the landscapes of Europe and accounting for spatial auto-correlation, the correlations between the N concentration in mosses and corresponding deposition were calculated and mapped for each of those landscape units containing moss sampling sites. Using an example of one landscape with positive correlation and one landscape with no correlation between N concentrations in deposition and in mosses, influencing factors were ranked based on investigating the multivariate interactions between moss concentrations and, amongst others, atmospheric deposition, land use, elevation or moss species by classification and regression trees. From this study it could be concluded that the numbers of sampling sites within Europe and most participating countries as well as within most of the landscapes covering Europe are sufficient. Spatial patterns of correlations between the atmospheric N deposition and N concentration in mosses could be proven to vary across the landscapes of Europe. Where clear positive correlations between N concentrations in deposition and mosses exist in landscapes, multivariate ranking identifies the deposition as main influencing factor. In cases with no correlation between deposition and N concentrations in mosses, other factors such as e.g. moss species collected may be of importance. Therefore, mosses were proved to serve as biological indicators for atmospheric depositions and ecologically defined land classes could be identified as more complex indicators which allow relating exposure monitoring with effects assessment.

1. Introduction

Nitrogen (N) is an essential plant nutrient. The N cycling in ecosystems is derived from biological N fixation, mineralization, and atmospheric deposition. Atmospheric deposition was a relatively unimportant N source until the beginning of the agricultural and industrial revolution with an increasing population and demands for food and energy. Since 1860, atmospheric deposition got more and more an important N source for ecosystems and can also be the dominant source. The shape of the effects of atmospheric N deposition depends on: duration, total amount, and N form of the deposition; sensitivity of plant species exposed to deposition; abiotic conditions in the ecosystem which can be influenced significantly by both past and present land use. Therefore, sensitivity to N deposition can vary between ecosystems or landscapes, respectively, as reviewed for the Global 200 priority ecoregions for conservation (Bobbink et al., 2010): changes in species composition; direct toxicity of N gases and aerosols; long-term negative effects of increased ammonium and ammonia availability; soil-mediated effects of acidification; susceptibility to secondary stress and disturbance.

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To avoid ecological damages due to atmospheric N deposition, the Gothenburg Protocol of the Convention on Long-range Transboundary Air Pollution (LRTAP) was developed with respect to the abatement of acidification, eutrophication and ground-level ozone. The implementation of the Gothenburg Protocol is monitored and evaluated by the European Monitoring and Evaluation Programme (EMEP), by collating emission data from parties, measuring air and precipitation quality and modelling atmospheric transport and deposition. Deposition of N is calculated from emission data compiled by EMEP by use of the EMEP chemistry and atmospheric transport model and then verified against concentrations in air and precipitation. In 2005, 53 EMEP stations measured the concentration of N compounds in precipitation and wet deposition, whereas up to 41 stations reported air concentrations of N compounds (Fagerli and Hjellbrekke, 2007). Finally, the EMEP modelling results are mapped on grids of 50 km by 50 km.

Within the LRTAP Convention, the Working Group on Effects (WGE) provides information on the impacts of air pollutants on human health and the environment. The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) has been coordinating the European moss survey since 2000. Within that survey, conducted every 5 years since 1990, naturally growing mosses are used as indicators of atmospheric deposition of pollutants. In 2005, mosses were sampled at ca. 6000 sites in 28 countries and analyzed for heavy metals (Harmens et al., 2010) and, for the first time, for N concentrations at ca. 2800 sites in 16 countries (Harmens et al., 2011). Compared to the EMEP monitoring network, the spatial resolution of the European moss survey in terms of extent, i.e. area covered by sampling sites, and grain, i.e. number of sampling sites, is much higher.

Although the N concentrations in mosses provide no direct quantitative measurement of atmospheric deposition, the moss survey data yield an indication of the spatial patterns and temporal trends of N deposition from the atmosphere to terrestrial systems (Harmens et al., 2011; Schröder et al., 2010b, 2011, 2012). Thus, for environmental impact assessments the moss survey data could help characterizing the N exposure of large areas, especially if they could be related with information on ecological characteristics of the receiving environmental systems. Factors other than atmospheric depositions also contribute to the variation of elemental concentrations in mosses (Holy et al., 2010; Schröder et al., 2008, 2010a,b). For nitrogen, these factors were discussed in more detail in Harmens et al. (2011) and Schröder et al. (2010a). As these factors and their influence on the relationship between deposition and moss concentrations might be different for landscapes with different ecological characteristics, we hypothesize that the correlations between both N concentrations in depositions and mosses are landscape-specific. Therefore, the current study investigated the relationship between N concentrations in atmospheric deposition and in mosses for up to 40 ecologically defined land classes covering Europe. Our approach for Europe provides further detail to the global approach presented by Bobbink et al. (2010) for the G 200 ecoregions (Olson and Dinerstein, 2002).

2. Materials and methods

2.1. Moss sampling and chemical analyses

Mosses were sampled according to the guidelines described in the protocol for the 2005 European survey (ICP Vegetation, 2005). Since the sampling sites cover a broad range of ecologically different habitats, several carpet-forming moss species were collected (Fig. 1).

Although participants of the European moss survey generally aimed to only use the last two to three years' growth of moss

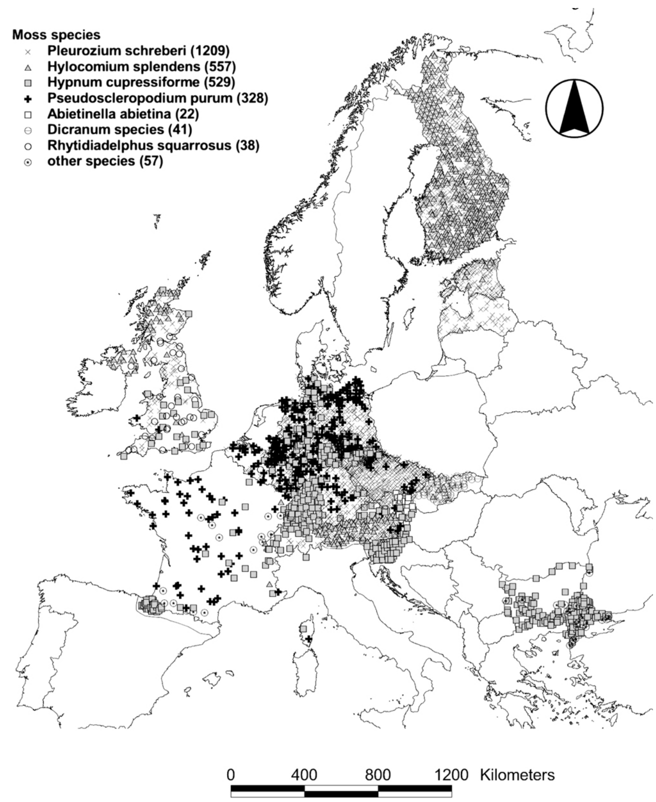

Fig. 1. Geographical distribution of mosses sampled for N analyses. *Other species* containing those with $n < 20$, i.e. *Br* – *Brachythecium rutabulum* ($n = 12$); ***Brach sp.*** – mosses of the genus *Brachythecium* ($n = 14$); ***Hom sp.*** mosses of the genus *Homalothecium* ($n = 12$); ***Scler sp.*** – mosses of the genus *Scleropodium* other than *Pseudoscleropodium purum* ($n = 2$); ***Ta*** – *Thuidium abietinum*, ($n = 2$); ***Tt*** – *Thuidium tamariscinum* ($n = 15$). For full names cf. Fig. 6.

material for nitrogen analysis, variations in environmental conditions between countries and years sometimes made it hard to identify years of growth accurately (Harmens et al., 2011). Each sampling site was located at least 300 m from main roads and populated areas and at least 100 m from any road or single house. The majority of mosses were sampled in forests (coniferous, broad-leaved or mixed), followed by 'moors and heathland' and natural grassland. In forests, samples were collected as far as possible in small open spaces to preclude any significant effect of canopy drip. Samples were generally dried at room temperature and stored under those conditions until N analysis, although some countries did refrigerate or deep-freeze the samples. For the determination of N, moss tissue was dried at 40 °C and concentrations were determined according to either the Kjeldahl method or via elemental analysis following the Dumas method; for details of methods used in each country see Harmens et al. (2011). N concentrations are expressed as percentage N based on dry weight and were only determined in the last 2–3 years' growth.

In 2005/6, a quality control exercise was conducted for assessing the analytical performance of the participating laboratories (Harmens et al., 2011). Moss reference material M2 and M3 (Harmens et al., 2010; Steinnes et al., 1997) were distributed amongst participating laboratories. In addition, some laboratories used other certified reference material for quality assurance. For determination of the total nitrogen concentration in the reference material, laboratories followed the same analytical procedure as used for the collected moss samples. Generally, data obtained indicated good agreement between laboratories: the recommended values for reference materials M2 and M3 showed a variation of 7.4% and 7.6% respectively (Harmens et al., 2010). Only for one