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Zoning of forest health conditions based on a set of soil, topographic and vegetation parameters

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Abstract

Saxony, a federal state in the east of Germany, includes regions with a history of high deposition rates of total acidity and conspicuous impairments of the health status of forests and forest soils. Both the reduction of SO_2 immissions and extensive forest liming campaigns have led to a visible regeneration of forests, especially in the Saxon low mountain ranges. There is a strong need for maps with landscape-related information about the forest health status as a basis for an ecological underpinning of forest management practices. The aim of the analyses presented was to derive a zoning of forest health conditions in Saxony on the basis of soil, topographic and vegetation parameters.

The upscaling approach of the present paper is based on multiple linear regression analyses coupled with geostatistics using a two-stage procedure with global and regional transfers. First, the forest soil monitoring data of Saxony were evaluated using variables derived from a digital terrain model, geological information and soil and stand related parameters available in high spatial resolution as independent variables. In a second step the influence of environmental factors on the medium-term crown defoliation was analysed using the modelling results from step 1 (regionalized soil chemical attributes) as additional auxiliary variables. Spatio-temporally limited damaging events were diminished by the plot-wise and temporal aggregation of defoliation values. Unlike soil chemical data, it was not possible to detect clear auto-correlative spatial structures for defoliation measurements due to the influence of stand age. About 70–80% of the total variance of defoliation could be explained by the multiple linear regression models. Methodological limitations and interpretations are discussed. Stand age, with 35–64% of the explained variance, showed by far the highest influence. This confirms the necessity to quantify the influence of the stand age as a systematic and intrinsic natural factor if the relationship between defoliation and stress factors is intended to be examined. The model performance of the regression algorithms was examined using both an independent validation procedure and cross-validation terms. Finally, the modelled ‘‘mean level of defoliation’’ was mapped using the mean stand age of forests in Saxony (60 years) by means of regression equations as scenario models.

Keywords: Crown condition; Forest health; Defoliation; Regionalization; Soil status; Upscaling

1. Introduction

Saxony, a federal state of Germany (Fig. 1), includes regions with a history of high deposition rates of total acidity. The emissions of particles and gases from power plants in combination with immission of pollutants from other neighbouring European countries resulted in such catastrophic destruction in South Saxony and the neighbouring areas of Poland and the Czech Republic that this region became known as the ‘‘Black Triangle’’ (Godzik and Sienkiewicz, 1990; Hruška and Cienciala, 2003). Forest management practices were strongly influenced by these air pollution loads, particularly in the higher altitudes of the Ore Mountains. Then the current management practices had to be changed including changes in tree species composition. Excessive and long-term input of acidity had decisively induced acidification and nutrient depletion of forest soils (SMUL, 2004). During the last 15 years (from 1989 to 2003) a decrease in emissions of sulphur dioxide (93%), nitrogen oxides (78%) and solid particles (97%) has been observable in the whole tri-border region of the Czech Republic, Poland and Germany, as far as major stationary sources are concerned (Abraham et al., 2004). Today, the air quality in the Black Triangle has reached a level comparable to the EU member states. Both the reduction of SO_2 immissions and extensive forest

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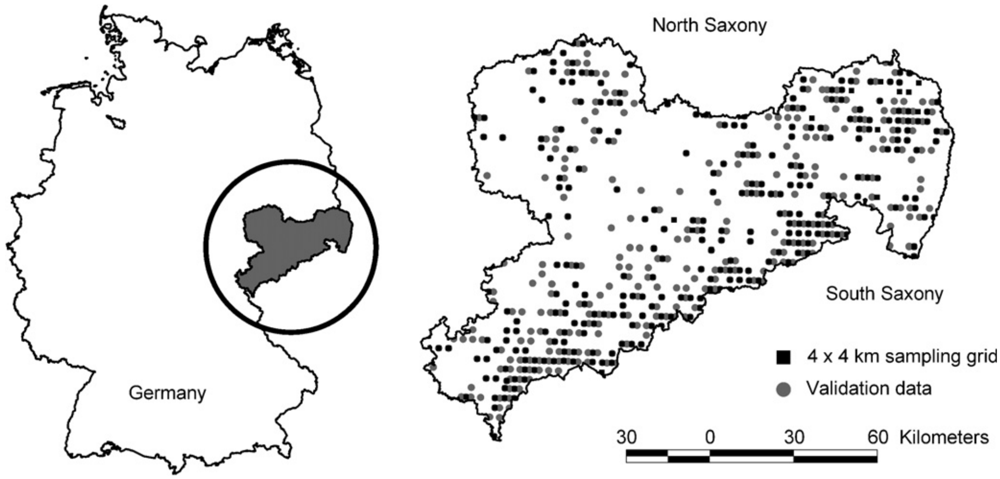

Fig. 1. Location of the federal state Saxony in Germany (left, encircled), regional stratification of Saxony for the upscaling of medium-term defoliation (North/South Saxony, right) and distribution of the split data set of the year 1992 with a view to validate the statistical approach (right).

liming campaigns have led to a visible recovery of spruce stands in the Saxon low mountain ranges (SMUL, 2004).

The restoration or improvement of forest ecosystem functions requires an increased operational effort in forest management practices, which have to be applied as effectively as possible against the backdrop of scarce financial means. Data about forest health are an essential basis for an ecological underpinning of forest management practices. The International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) provides these data as point-related information on a systematic network of more than 6000 plots across Europe. But these data have to be processed and analysed for both forest practice and politicians. As forest management practices display their effects at landscape level, their planning and control need landscape-related (GIS) evaluations of spatial and temporal variations. Upscaling techniques based on statistical methods (‘‘regionalization’’ or point to area transfer) have a fundamental function. They allow the assessment of the environmental effects of forest management strategies in terms of landscape-related scenarios (Zirlewagen and von Wilpert, 2004).

Various (integrative) studies on the effects of environmental factors were carried out at European level with different statistical approaches to evaluate the large scale European monitoring data (Seidling, 2000; de Vries et al., 2002). The aim of the present study was to derive a zoning of forest health conditions in Saxony on the basis of soil, topographic and vegetation parameters in regression models. The objective of using regression methods is to utilize plot inventory and landscape (map) data in a multidimensional way in different evaluation steps in order to efficiently detect and filter the main influencing factors on forest health conditions. There is also the challenge of recognizing process-related patterns at landscape level. Even if statistical models cannot imitate processes in the sense of process-based modelling, they are able to describe relevant indicators (Becher, 1999). Finally, the modelling results should be visualized by GIS and should serve as a basis for management decisions.

2. Methods

2.1. Forest monitoring data (crown condition and soil status)

Since 1991 the crown condition of forest trees in Saxony has been recorded on an annual basis in the nation-wide representative grid network (Level 1 in the UN/ECE ICP Forests system; PCC, 1998). The core variable is defoliation whereas the parameter discoloration is less important and was not considered in our study. Defoliation, the amount of foliage missing in comparison to a full-leaved reference tree, is terrestrially estimated in 5% classes for individual trees using binoculars (normally 20–24 trees per sample plot; PCC, 1998). By the plot-wise and medium-term temporal aggregation of defoliation values, spatio-temporally limited damaging events (caused e.g. by extreme meteorological conditions) should be diminished and should give an overall estimation of the average status of tree crown condition at a site (cf. Seidling, 2001). The evaluation of two observation periods (1991–1998 versus 1999–2003) should enable the analysis of temporal trends in an aggregated way. Defoliation values were not evaluated separately for the main tree species, but the evaluation included tree species effects on defoliation using metric covariables for upscaling purposes (regressor variables: amount of pine, spruce and deciduous trees in stand composition; Table 1). Also, the data set was separated for North and South Saxony due to great differences in natural site condition.

The forest soil monitoring (BZE) has, to date, been carried out once between 1992 and 1997. All aims and methods of the BZE (field sampling, laboratory analyses) are described in detail in BML (1990). Both inventory types (crown condition and soil status) used the standard methodology of ICP Forest, but with a denser grid of sampling points ($4\,km \times 4\,km$ systematic grid with about 280 sampling points; Raben et al., 2000). For economic reasons the dense grid of the crown condition survey could not be maintained in the years 1993, 1995 and 1996. These data sets have not been used for the