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Spatial explicit evaluation of potential future developments of forests due to climatic change and nitrogen deposition

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Abstract

Climate change and atmospheric nitrogen deposition can impact the integrity of ecosystems. Therefore, the EU Biodiversity Strategy foresees that Member States map and assess the state of ecosystems and their services in their national territory. By example of Germany, this article presents a quantitative, spatially explicit as well as nationally, regionally and site-specifically applicable methodology for **classifying and mapping forest ecosystems** and identifying changes of their integrity comparing their reference states (1961-1990) with measured (1991-2010) und potential future conditions (2011-2017). To this end, measured environmental data were complemented by **dynamic modelling** of future climate and soil conditions. A **fuzzy rule-based model** for estimating spatial patterns and temporal trends of soil moisture was developed and tested at the federal and regional level. Forest ecosystem conditions were evaluated and ordinated at three levels (indicators, functions and ecosystem type) with regard to functionality, chemical and biological characteristics, stress tolerance against climate change and nitrogen deposition scenarios for the years 1961-1990, 1991-2011 and 2011-2070.

Keywords: Ecosystem classification, integrity, dynamic and fuzzy modelling; Geographic Information System.

1. Introduction

Climate change and atmospheric nitrogen deposition can impact the integrity of ecosystems, i.e. their dominant structures and functions, and thus limit their services for human societies. Therefore, action 5 of the EU Biodiversity Strategy to 2020 foresees that Member States map and assess the state of ecosystems and their services in their national territory. By example of Germany, this article presents a quantitative, spatially explicit as well as nationally, regionally and site-specifically applicable methodology for **classifying and mapping forest ecosystems and ordinating changes of their integrity** as compared to the reference states (1961-1990) of 61 ecosystem types covering about 85 % of the forested area mapped. The methodology was based on data derived by nation-wide vegetation surveys, digital maps and long-term monitoring programmes. Measured environmental data (1991-2010) were complemented by **dynamic modelling** of future climate and soil conditions. A **fuzzy rule-based model** for estimating spatial patterns and temporal trends of soil moisture was developed and tested at the federal and regional level. Forest ecosystem conditions were assessed with regard to functionality, chemical and biological characteristics, and stress tolerance to nitrogen deposition and climate change. For defined climate and nitrogen deposition scenarios (2011-2070) potential future ecosystem developments were projected and evaluated.

The aim of **dynamic modelling** of soil parameters under the influence of changing atmospheric nitrogen (N) deposition with simultaneous climate change at sites each representing a specific ecosystem type is to derive knowledge about the expected development of ecosystem conditions up to a possible change of the current ecosystem type.

2. Methods

The methodology for **classifying and mapping forest ecosystems and ordinating changes of their integrity** under the influence of climate change and atmospheric N deposition was based on 14 indicators for six ecosystem functions: habitat function, net primary function, carbon sequestration, nutrient and water flux, resilience. It allows assessments of ecosystem integrity changes by comparing current or prospective ecosystem states with ecosystem-type specific reference states as described by quantitative indicators for 61 forest ecosystem types based on data collected before 1991.

Dynamic modelling was performed with the model VSD+ (Very Simple Dynamic Soil model) Version 5.3.1 (Posch & Reinds 2009; CCE 2012). The selection of 15 modelling sites was focused on the availability and completeness of the dataset for parametrizing the VSD model. They dataset should include measured data from various years as much as possible due to calibrate the model runs, and to improve the information value for interpreting their results and to compare them with the parallel performed statistical modelling of soil indicators from vegetation survey data. The simulation period was 1920-2070. The time series of the dynamic driving parameters, i.e. climate change and dynamically modelled chemical und physical soil characteristics, were detected.

Soil moisture is an essential environmental factor affecting the condition of forests throughout time. Dynamic modelling of soil moisture even with rather simple models such as VSD / MetHyd need numerous data which are often not available for areas of large spatial extent. Therefore, a methodology for modelling and mapping soil moisture which can be applied with available data covering the whole territory of Germany and which can be specified for the regional scale was developed. This was reached by a **fuzzy rule-based model** allowing the combination of a pedological and an ecological soil moisture classification. The fuzzy modelling approach was applied for mapping average soil moisture at two the regional and national scale (Kellerwald National Park, Germany).

3. Results

Atmospheric N deposition has led to N saturation at all 15 sites selected for **dynamic modelling** - with the exception of one site, being part of the International Cooperative Programme Integrated Monitoring (ICP IM). Currently, there is no recognizable relationship between C/N ratio and humus form any more. There is no linear (negative) correlation between atmospheric N deposition and C/N ratio. There is also no directed correlation between the level of acidifying deposition and the course of the corresponding soil parameter values. The reference state of base saturation in 1920 has a decisive influence on the course of base saturation and pH value. The progressive acidification at all study sites even after 2010, even with a sharp decline in atmospheric S and N deposition, is due in particular to the fact that the depositions of basic cations will fall far below the 1920 level from 2010 onwards because the basic fly ashes from coal and wood combustion is decreasing.

Soil moisture was modelled and mapped on a scale of 1 : 500.000 across Germany and regionally specified on a scale of 1 : 25.000 for the Kellerwald National Parc for the time intervals 1961-1990, 1991-2010, 2011-2040 and 2041-2070. The model validation gave a Root Mean Squared Error (RMSE) of 0.86 and a Coefficient of determination (Pseudo R^2) of 0.21. Average soil moisture declined significantly until 2070 concerning soils influenced by ground water and by stagnant water, in particular at sites on steep slopes (> 25 %) and on southerly slopes (120-240°).

Integrating the measured and modelled data mentioned above, the **ordination and mapping of ecosystem integrity** was made possible by the example of Germany at the site level, at the regional level (Thuringian Forest and Kellerwald National Parc) as well as nationwide (Germany).

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