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Modeling dynamics of forest ground vegetation diversity under different forest management regimes

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Abstract

Forest ground vegetation constitutes the largest number of plant species that participate in forest dynamics. Single species or species groups of forest ground vegetation can be used as indicators for site conditions. Ground vegetation has to be accounted in forest simulation modeling if biodiversity dynamics are evaluated to serve the purpose of sustainable forest management. The usual approach is to segregate ground vegetation into plant functional types. However, there are other methods that could be used. In our contribution we propose to split ground vegetation into ecological-coenotic species groups. An application of the ecological-coenotic approach allowed for a forecasting of the dynamics of forest ground vegetation diversity on the basis of forest ecosystem modeling outputs, standard forest inventory data, and regional phytosociological data sets. A new software BioCalc designed for the forecasting of dynamics of forest ground vegetation diversity, and the EFIMOD model of the forest growth and element cycling in the forest–soil system is used for simulating the forest ecosystem parameters under different forest management regimes.

An application of the proposed method for a study area situated in the Central European Russia is discussed. Two hundred-year dynamics of ground vegetation composition, forest types and species diversity is analysed under four forest management scenarios: NAT, natural development; SCU, selective cuttings; LRU, authorized by Russian legislation clear cuttings; ILL, non-authorized by the legislation but widespread clear cuttings. The simulation results showed that the total number of forest types is higher in all scenarios with cuttings relative to the NAT scenario. However, the NAT strategy leads to the growth of coniferous-broad-leaved forests close to the climax forest type of the study area. Cuttings hinder the development of climax forest structure due to the low level of deadwood in harvested forests and the absence of species-rich forest units dominated by nitrophilous tall herbs in the understorey. The NAT strategy leads to the highest species diversity in ground vegetation if a free forest development has taken place for rather long time, i.e. more than 100 years in the study area. The sum of species diversity is rather low for SCU, LRU, and ILL scenarios. It is 0.8, 0.7, and 0.6, respectively, in comparison with the NAT scenario. The SCU scenario lead to a simplification of ground vegetation together with a conservation of nemoral and boreal species. Scenarios with clear cuttings (LRU and ILL) maintain piny and meadow groups in ground vegetation.

None of the forest management scenario leads to the maintenance of the whole set of ecological-coenotic groups in ground vegetation. Only a spatial combination of different management regimes in the forest area is necessary for the biodiversity restoration and maintenance.

Keywords: Understorey vegetation; Plant functional types; Ecological-coenotic groups; Forest types; Species diversity; EFIMOD; BioCalc

1. Introduction

It is well known that a comprehensive estimation of ecosystem and species diversity is extremely important to reach the goals of sustainable forest management (SFM) (Canadian Forest Service, 1995; Lindenmayer et al., 2000; MCPFE, 2003; Schulte et al., 2006). However, it has rarely been applied in the forest management context. There are parameters of forest plant biodiversity which can be estimated on the basis of forest inventory data from merchantable (target) trees, such as the diversity of tree species dominants, the overstorey composition, tree size, age classes, etc. However, unlike the tree and stand parameters, ground (understorey) vegetation diversity are usually difficult to estimate due to the absence/scarcity of the relevant information in the forest inventory data. The reason is that in general, standard forest typology does not acknowledge the floristic and/or phytosociological aspects of forest stand. However, in the last fifty years there have been a few forest typology systems developed acknowledging the vegetation-ecological aspects of forests.

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In Russia, in the middle of 20th century, such a system was suggested by Vorobjev (1953). It is based on an ecological classification of forest sites and a classification of forest types using tree and herb dominants. However, the proposed classification of forest types was not detailed enough and therefore it has not been used in practical forest inventory. As a result, the system cannot be used for a comprehensive biodiversity assessment.

Another vegetation-ecological forest typology system (the so-called ‘‘stand-level forest type approach’’) has been developed in Italy (Barbati et al., 1999; Corona et al., 2004). This approach also acknowledges both vegetation and ecological-silvicultural aspects of forests and modifies the forest inventory process including phytosociological parameters. Whereas the stand-level forest type approach clearly allows for successful biodiversity estimation, its application requires a number of forest policy and economics decisions. The later is not always possible, and in this paper we propose to use the large volume of phytosociological data, which exists independently from forest inventory data, and to supplement incomplete forest inventory data with the information from the phytosociological research.

To meet the SFM goals, it is also necessary to forecast dynamics of vegetation diversity under different forest management regimes in regards to biodiversity conservation. The modeling of vegetation dynamics is an indispensable part of the forecasting of biodiversity changes, although modeling of ground vegetation can be a complicated task. There are only a few attempts at such modeling (e.g., Kellomäki and Väisänen, 1991; Kellomäki et al., 1992, 1993; Fisher, 2001; Mikhailov, 2001; Brang et al., 2002; Bugmann, 2005). A promising approach of modeling ground vegetation for SFM needs is a simulation of forest understorey vegetation using gap models (Botkin et al., 1972; Shugart, 1984) that base their simulations on plant species functional groups. Using of plant functional groups is the most common way for predicting the consequences of different land-use management and/or climate change (review in Lavorel et al., 2007).

Plant functional groups are also widely used in Russian vegetation research. One of the approaches is splitting plant species into ‘‘the ecological-coenotic groups’’ proposed by Russian botanist Nitscenko (1969). He stated that plant species with similar ecological characteristics and close frequency of occurrence in similar plant communities can be considered as ecological-coenotic groups of species (closely related to ‘‘plant functional response groups’’ proposed by Lavorel and Garnier, 2002). The ecological-coenotic group concept has been often used with variants of the group specification. We use the groups’ separation developed by Smirnova (2004) and Zaugol’nova (2000) and further verified by Smirnov et al. (2005, 2006) with the help of multivariate statistical analysis. For verification, Ellenberg’s (1996) indicator values and species ordination scores produced by a non-metric multivariate scaling of several thousand phytosociological relevés (collected in European Russian forests) were processed with discriminant analysis and decision tree techniques.

As a result of the numerical analysis, the following groups of vascular plants inhabiting the European Russian forests were obtained: (1) boreal group (Br) includes species that grow in understorey of spruce (*Picea* sp.) and fir (*Abies sibirica*) forests on soils of various trophic status and mesic moisture regime; (2) nemoral group (Nm) includes species that grow on rich soils in understorey of broad-leaved trees like oak (*Quercus robur*), lime (*Tilia cordata*), elm (*Ulmus* sp.), and ash (*Fraxinus excelsior*); (3) nitrophilous group (Nt) includes species growing in moist to wet sites with rich soils, they are usually species of flooded forests with European alder (*Alnus glutinosa*) as a dominant tree; (4) piny group (Pn) includes species growing in understorey of pure pine (*Pinus sylvestris*) forests on dry and poor soils; (5) meadow group (Md) includes species growing on wet to dry soils of different trophic status in woodless areas — meadows, forest edges, and clear-cut areas; (6) water-marsh group (Wt) formed by species of coastal and intra-water habitats and bogs; (7) oligotrophic group (Olg) formed by plants of oligotrophic bogs and mires. The two latter groups were joined into one group (Wt/Olg) in the case study reported due to the lack of the relevant data.

In this paper, we used ecological-coenotic groups with two objectives: firstly, to simulate dynamics of forest ground vegetation in the framework of forest ecosystem modeling, and secondly, to link forest inventory data and phytosociological data for a detailed estimation of biodiversity. We were specifically interested in:

(i) developing an algorithm for the estimation of forest ground vegetation diversity,
(ii) developing an algorithm and a special software to forecast the dynamics of the forest ground vegetation diversity on the basis of the outputs of forest ecosystem simulation, and
(iii) testing the proposed algorithms and the developed software for the simulation of the ground vegetation diversity in the case study in 300-ha forest lot under different forest management regimes in Central European Russia.

2. Study area and silvicultural scenarios

A forested area with 104 stands (forest inventory compartments) on 273.4 ha in the ‘‘Russky Les’’ State Forest was selected for the case study (Fig. 1). It is located in Central European Russia, on the Central Russian Plain, 100 km south of Moscow, on the left bank of the Oka River. It belongs to the South-Western subregion of the Atlantic continental climatic region and represents mixed coniferous and broad-leaved forests developed on the sandy and loamy soddy-podzolic soils (Spodosols and Alfisols). The forests of the case study area have been intensively exploited since the 17th century, especially in the 20th century. Secondary forests are now prevailing in the ‘‘Russky Les’’. Species composition and age structure of these forests depend on the date of the last clear cutting, forest fires, and on the type of forest regeneration.

Inventory data from 1990 were used as input parameters for the simulations. According to the inventory data, Scots pine (*Pinus sylvestris*) and birch (*Betula* sp.) dominated in the majority of the stands (respectively, 86% and 11% of the area);