Modelling dynamics of ground vegetation diversity in forest ecosystems

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1. Introduction

A comprehensive estimation of vegetation diversity is well known to be extremely necessary for the goals of sustainable forest resource management (SFM). While the main data sources for forest management are rather crude forest inventory data, we claim the results of fine biological studies to be adaptable for the forest management needs. The objectives of our study were (i) to develop an algorithm for estimation of forest ground vegetation diversity which would be based on the supplementation of standard forest inventory data by the information from vegetation research, and (ii) to elaborate an algorithm for forecasting dynamics of forest ground vegetation diversity on the base of outputs of forest growth simulations.

2. Methods

2.1. Ecological-coenotic approach to estimation of ground vegetation diversity

To assess ground vegetation diversity for the SFM need, we have proposed to use plant species ecological-coenotic groups (ECG) introduced in (Nitscenko, 1969) as a tool for linking forest inventory data to the results of phytosociological research. By the ECG we understand groups of plants with similar ecological features and similar phytocoenotic positions. These groups is a case of plant functional types similar to the functional response groups (Lavorel, Garnier, 2002). The concrete algorithm of the above mentioned linking of the data and biodiversity estimation consisted of three following steps.

First, for each forest stand in a model forest, its forest type was assessed by combining dominant tree species in overstorey and dominant ECG in understorey. While dominant species both in overstorey and understorey were taken from forest inventory data, the species in understorey were further qualified in terms of the ECG (the latter was done with the help of the group lists). Second, the same principles of the forest type classification (according to dominant tree species and dominant ECG) were applied to the regional phygional phytosociological releves, and indices of vegetation diversity were computed for each forest type. Finally, the computed indices of vegetation diversity were linked to the ecological-coenotic forest types obtained at the initial step, and thereby the ground vegetation diversity was assessed for each forest stand in the model forest. We used average plant species richness per square unit and also designed a discrete scale of species diversity ranging from 1 to 5, where 1 corresponded to the least number of species per square unit, and 5 - to the greatest number of species per square unit, with increase of 10 species per step.

An additional remark has to be done regarding dominant species in understorey. They are not an obligatory parameter of the Russian forest inventory. Nevertheless, we revealed it possible to assume dominance of a given ECG in ground vegetation according to two obligatory parameters of the forest inventory: forest site index and dominant tree species. Forest site index is composed from fixed values of soil fertility (from the poorest A to the richest D) and soil moisture (from the driest 1 to the wettest 5), and forest inspectors are supposed to define the index value by understorey vegetation amenably to a number of specific rules (Vorobjev, 1953). We have suggested assigning a dominant group in ground vegetation according to the regional probabilistic tables of correspondence between forest site index and dominant ECG (constructed for different dominant tree species).

2.2. Algorithm of estimation of dynamics of ground vegetation diversity

We have proposed to estimate dynamics of ground vegetation diversity according to changes in forest overstorey (tree dominant) and understorey (dominant plant functional group). In our study, the individual-tree based model of the forest-soil system EFIMOD (Komarov, et al., 2003) has been used for simulating dynamics of forest ecosystem parameters. The structure of the model makes it possible to use information from standard forest inventory data as input variables. The model outputs are the dynamics of stand main dendrology parameters (mean height, diameter etc.), tree species composition, coarse woody debris, soil organic matter, soil moisture and fertility etc. under different forest management regimes. The proposed algorithm for modification of the dominant ECG in ground vegetation along the simulation outputs was realized in the BioCalc software.

Input data for the BioCalc are the following: (i) tables of probabilistic distribution of the ECG according to the tree dominant and the forest site index; (ii) a correspondence table between the forest types and ranks of plant species richness; (iii) a time series table of forest stand ecosystem parameters. Further processing of the input data presupposes creation of rules for modifying ECG according to the time series tables. A user of the BioCalc software creates the rules selecting from the time series tables – in an interactive mode – thresholds for a number of ecosystem parameters. The reaching of these thresholds causes a change of the dominant ECG. Output data of the BioCalc are the dynamics of the following parameters: ECG in ground vegetation, forest types and ranks of species diversity.

2.3. Case study area and simulation scenarios

For the case study, there has been selected a forest lot with 104 stands of a total area of 273.4 ha in the "Russky Les" Forestry located on the central Russian Plain. According to the inventory data, pine and birch dominated on the majority of the selected stands. Little less than a half of the stands were situated on dry and poor soils. There was practically no deadwood due to cuttings and ground fires usual for dry pine forests.

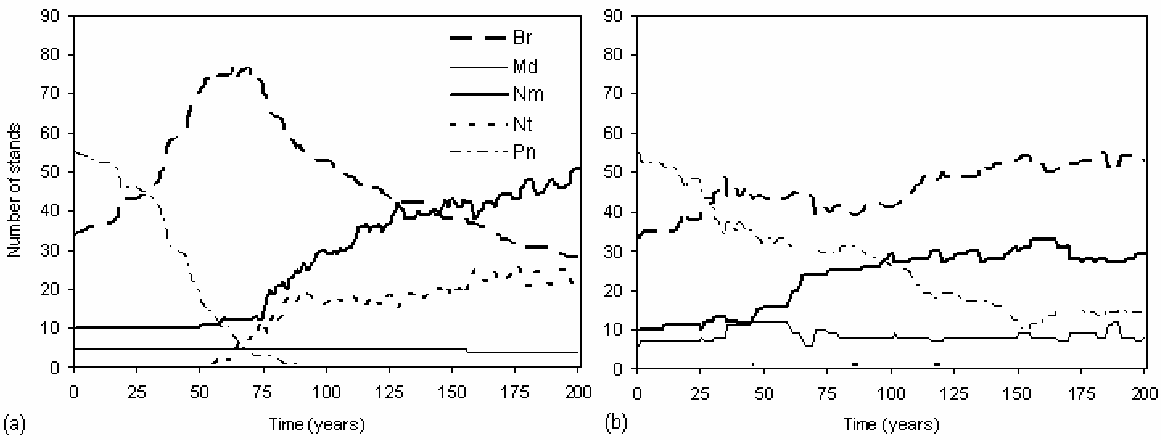
To estimate dynamics of forest ground vegetation diversity, two simulation scenarios have been compiled: a) a natural development scenario, b) a clear cutting scenario. The first scenario suggested that tree stands were not subjected to cutting or any other disturbing impacts. To model the natural regeneration of tree stands, artificial planting of the main tree species was performed every 30 years. The clear cutting scenario suggested that tree stands were subjected to four tender cuttings and then to a clear cutting. A year after the clear cutting, the artificial planting was performed at the felling places. Particular proportion of the planted trees was the same for both scenarios and depended on site conditions.

We tested the following rules modifying the ECG in ground vegetation: (i) domination of nemoral herbs in ground vegetation followed domination of lime and oak, (ii) meadow group switched to boreal group when spruce began to dominate, (iii) piny group switched to boreal group when deadwood overpassed the first threshold value, (iv) any group switched to nitrophilous group when deadwood overpassed the second threshold value, (v) nitrophilous group changed to nemoral group when deadwood fell below the second threshold value. Threshold values of deadwood were defined as percentage from the growing stock simulated under the natural forest development: 10 and 30 percent were taken as the first and the second threshold values respectively. In the clear cutting scenario there was one more rule: after the clear cutting, the dominant ECG was taken from the specially designed probabilistic table of the ECG distribution in ground vegetation.

3. Results and discussion

The natural development scenario (Pic. 1a) was accompanied by (i) the decrease followed by the total disappearance of stands with domination of piny group in ground vegetation,

(ii) the increase followed by the decrease of the number of boreal stands, and (iii) the increase of the number of nitrophilous and nemoral stands with the nemoral stands leadership. The number of boreal stands continuously increased at the beginning due to the fact that the deadwood accumulation caused the switch of piny group to the boreal one. At the end of the first third of the simulation span, the growth of the number of boreal stands stopped and then this number began to decrease due to the switch the boreal group to the nitrophilous or the nemoral group under the continued increase of the deadwood. Augmentation of the number of stands with domination of oak and lime, in its turn, also led to the augmentation of the number of stands with domination of nemoral herbs. The clear cutting scenario was accompanied (Pic. 1b) by (i) the decrease followed by the stabilization of the number of stands with domination of piny group in ground vegetation, (ii) the increase followed by the stabilization of the number of boreal and nemoral stands, (iii) the minor increase and oscillation of the number of stands with meadow group domination. Unlike the natural development scenario, the stands with domination of nitrophilous group did not show up because of rather low level of the deadwood pool in the clear cutting scenario. Stands with domination of piny group in ground vegetation did not vanish due to clear cutting impacts at the sites with poor and moderate soil fertility, and the meadow group increase was caused by the clear cutting impacts at the sites with high soil fertility. The gradual increase of the number of stands with domination of nemoral herbs was caused, firstly, by the oak tender cuttings at the sites with high soil fertility and, second, by the augmentation of the number of stands with oak and lime domination.



Pic. 1. Dynamics of the dominant ECG in ground vegetation: (a) natural development scenario (b) clear cutting scenario.

Species diversity ranks changed in accordance with the dynamics of the forest types. At the initial step of the simulation, there prevailed pine forest stands poor in species (species diversity ranks 1 and 2). Then, up to the 75th step, species diversity ranks increased almost to the same extent in both scenarios due to the increase of the number of stands with boreal and nemoral group domination (the latter stands were richer in the number of plant species in comparison with pure piny forest stands). After the 75th step, the sum of species diversity ranks under the natural development scenario became remarkably bigger than the sum of species diversity ranks under the clear cutting scenario. At the end of the simulation, in the first scenario average species diversity rank was 3.4, while prevailing were the forest stands with species diversity rank 4. In the second scenario, final average rank was 2.6, while prevailing were the forest stands with species diversity rank 2. The reason for the difference between the scenarios was the increase of the number of rich (in species) nemoral and nitrophilous stands under the natural development, and the absence of nitrophilous stands accompanied by the moderate increase of the number of nemoral stands under the clear cutting.

4. Conclusion

We developed an algorithm for estimation of forest ground vegetation diversity based on the supplementation of standard forest inventory data by the information from vegetation research. This allowed for formulation of an algorithm for forecasting dynamics of forest ground vegetation diversity on the base of outputs of forest growth simulations. The modelled results on dynamics of forest types, understorey vegetation and biodiversity values under opposed forest management regimes generally agree with the inferences obtained in various vegetation studies (e.g., Halpern, Spies, 1995; Smirnova, 2004).

Acknowledgements

This work was supported by the INTAS project SILVICS 01-0633, the Russian Foundation of Basic Research projects 05-04-49284, 05-04-49289, and the Program of Basic Research of RAS Board “Biodiversity”.

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