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Recovery of Tree Stand After Clear-cutting in the Ural Mountains

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Abstract

For the mountain forests of the Middle Urals (Russia) recovery of tree stand after clear-cuttings was studied. Two options of the drained habitats have been studied: steep slopes of the southern exposition with small stony soils and the lower parts of gentle slopes with thick soils. For the description of biomass dynamics of pine (*Pinus sylvestris* L.) and birch (*Betula pendula* Roth*, B. pubescens* Ehrh.), their interference in the course of forest stand formation were constructed on the basis of systems that connected logistic equations of the model of their coexistence. We have developed mathematical descriptions of two alternative ecodynamic series of forest vegetation formation in clear-cutting: regeneration of initial forests (after cuttings in cowberry shrub pine forests) and the formation of long-derivative grass-reed grass birch forests (after cuttings in grass pine forests).

1. Introduction

The increasing human impact on the biosphere leads to the growing climate changes, variations in the structure of natural ecosystems and impoverishment of biological diversity. The main factors of forest reduction in Russia are clear-cuttings and fires (Sannikov, 1992). The mechanisms for resolving these problems are much-needed (Jiang et al*.,* 2012; Reside et al*.,* 2012). Scenarios of the transitions to the stable use of natural resources can be developed on the basis of universal models of ecosystems (Lankin, 2013).

The aim of our research is to build on the basis of a system of interconnected differential equations, quantitative mathematical model of joint growth of two forest-forming species. The main task is to develop objective quantitative methods for the appreciation of the probability of dominant-forming species changing.

2. Material and methods

The research site is situated in the Zauralsky (Trans-Ural) hilly piedmont province (Middle Ural, Russia) between 57°00´-57°05´N; 60°15´-60°25´L. It is div ided in foothills formed by the alternation of meridian heights and ridges (Kolesnikov et al*.,* 1974). Absolute heights are 200-500 m above sea-level. The climate is temperately cold, temperately damp. A frostless period of 90 to 115 days occurs, average annual temperature is+1^{0}C (Kolesnikov et al*.,* 1974).

We have studied two variants of drained places of residence:

1. Steep slopes of the southern exposition with small stony soils and very unstable water conditions. Cowberry shrub pine forests are the natural forest type.

2. The lower parts of gentle slopes with thick soils (more than 50 cm) and stable water conditions. Grass pine forests grow here.

We described earlier, these forests (Ivanova, Zolotova, 2013).

Restoration age dynamics from clear-cuttings (4-5 years old) up to tree stands of 65-160 years old has been studied for these places of residence. We have laid the 40 sample plots. Area plot was 0.25-0.5 hectares. We studied the tree stand and young woody plants. Biomass in absolutely dry condition has been used as the integral characteristic of the phytocenotical role of plants. The mass of forest forming tree species was determined by the way of calculation (Iziumsky, 1972; Usoltsev, 1997).

In order to describe the dynamics of density (biomass) of a pines (*Pinus sylvestris* L.) and a birches (*Betula pendula* Roth and *B. pubescens* Ehrh.), their mutual influence in the process of tree stand formation we constructed models of their joint existence on the base of the systems of connected logistic equations. We used the following system of differential equations (the Lotka-Volterra Model) (Lotka, 1956):

$$\frac{dx_1}{dt}=A_1x_1-B_1x_1^2+C_1x_1x_2$$
$$\frac{dx_2}{dt}=A_2x_2-B_2x_2^2+C_2x_1x_2$$

where x_1 is a density (overground mass, g/m^2 in absolutely dry condition) of a pines; x_2 is a density of a birches; A, B, C are parameters which are determined in the process of the solution of the inverse task. Bazykin (1985) conducted a comprehensive analysis of the models. A quantitative description of the formation of stand structure after clear-cutting carried out in the catastrophe theory according to Bystrai methods (Bystrai and Ivanova, 2010; Ivanova and Bystrai, 2010). We evaluated the model parameters according to the residual functional:

$$F(t) = \sqrt{\sum_i (Yi(t)-Yi)^2}$$

3. Results and Discussion

In view of great diversity, dynamics, and polyvariance of ecosystems (Figure 1), the development of a general theoretical approach to their description and analysis seems to be a challenging problem.

Temporal dynamics of forest vegetation formation after clear-cutting cowberry shrub pine forest is shown in Figure 2. The dynamics is studied up to 200 years old tree stand, beginning with 5 years old cuttings. Figure 2 shows clearly that pines predominate obviously by mass in all the studied interval of restoration-age changing. The difference in densities of the studied tree species is of 1-2 orders. However, the complete birch vanishing out of the structure of forming forests is not observed.

The time trends of forest vegetation formation after clear-cutting of grass pine forest in the lower parts of gentle slopes with thick (more than 50 cm) drained soils is shown in Figure 3. The dynamics is dealt with up to the tree stand of 80 years old, beginning from 5 years old cuttings. Opposite correlation

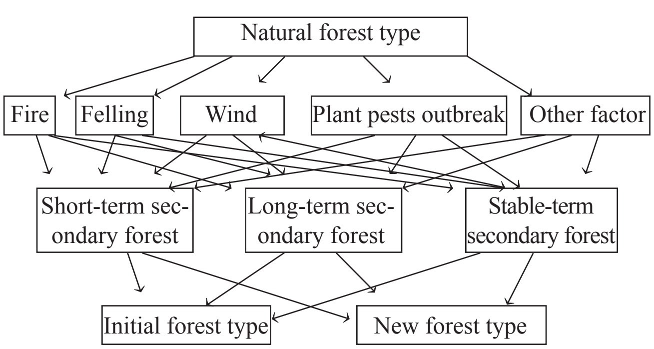

Figure 1: Hypothesis of divergence and convergence of forest vegetation in the Middle Ural

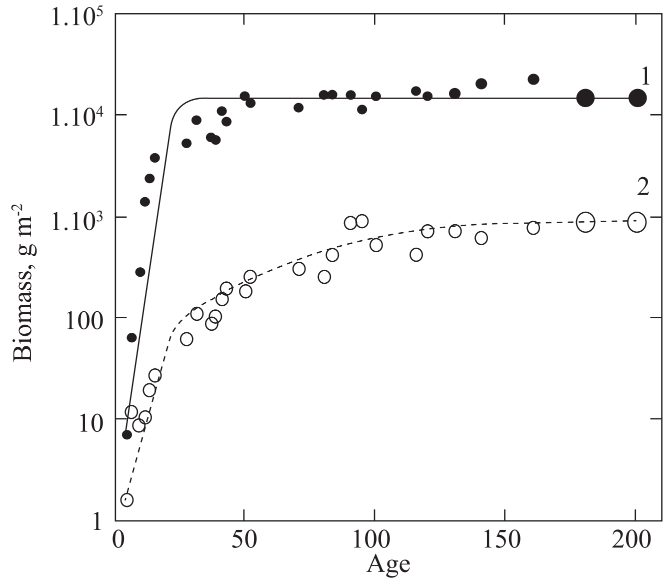

Figure 2: Regeneration-age dynamics of density (biomass) of a pines (*Pinus sylvestris* L.) and a birches (*Betula pendula* Roth and *B. pubescens* Ehrh.) in the steep slopes of the southern exposition with small stony soils (10-15 cm): 1-pines density (g m^{-2}), 2-birches density (g m^{-2}); points-statistical data; lines-the results of the solution of the system of non-linear dependent logistic equations. The two last points in each line indicate the prognosis for 20 and 40 years in advance). Equation coefficients: A_1=0.438; B_1=0.0000312; C_1=0; A_2=0.231; B_2=0.0000438; C_2=–0.0000138

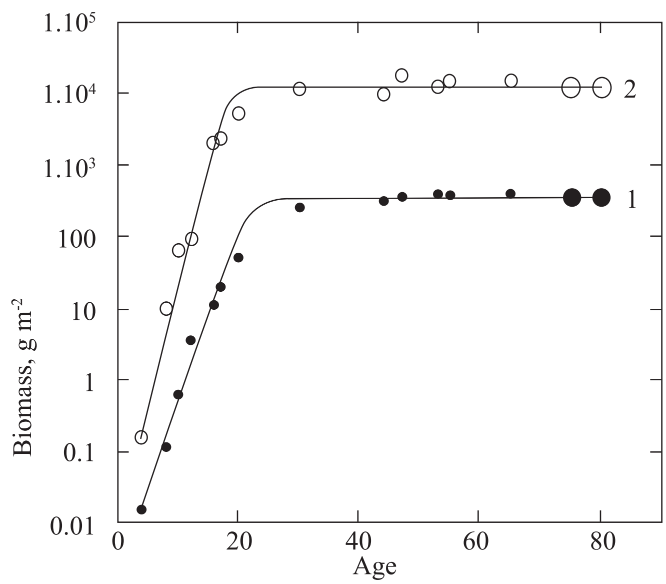

Figure 3: Regeneration-age dynamics of density (biomass) of a pines and a birches in the lower parts of gentle slopes with thick (more than 50 cm) drained soils: 1-pines density (g m^{-2}), 2-birches density (g m^{-2}); points-statistical data; lines-the results of the solution of the system of dependent non-linear logistic equations. The two last points in each line indicate the prognosis for 10 and 15 years in advance). Equation coefficients: A_1=0.575; B_1=0.0017; C_1=0; A_2=0.805; B_2=0.000069; C_2=0

of tree species densities is observed in these forest growth conditions: birches prevail, pines are oppressed by them. Long derivative grass-red grass birch forests with strongly oppressed pines in the second layer are formed.

4. Conclusion

Thus, we have showed a mathematical description (on the base of the system of logistic equations) of two alternative ecodynamic series of forest vegetation formation in clear-cutting: regeneration of the initial forests (after cuttings in cowberry shrub pine forests) and the formation of long-derivative grass-reed grass birch forests (after cuttings in grass pine forests). Addition of interconnections with other species or factors to the model complicates the structure of equations. With increasing number of species and factors, this traditional approach to constructing of equations rapidly makes the model immense. The problem is very deep and requires nontrivial solutions, up to the change in the prevailing scientific paradigm. This problem will be addressed in our further investigations.

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