Kozak I., Menshutkin V., 2001. Investigation of spruce forest dynamics in Bieszczady Mountains using a computer modelling. Ecology, Bratislava, vol 20. No 4, 371-378.

ISSN 1335-342X

EKOLÓGIA /Bratislava/

Medzinárodný časopis pre ekologické problémy biosféry

VOL. 20 2001/4

socio
eco
bio
abio

International journal
for ecological problems of the biosphere

ECOLOGY /Bratislava/

SAP SLOVAK ACADEMIC PRESS
VYDAVATEĽSTVO
SLOVAK ACADEMIC PRESS spol. s r. o.
BRATISLAVA

INVESTIGATION OF SPRUCE FOREST DYNAMICS IN THE BIESZCZADY MOUNTAINS USING A COMPUTER MODELLING

IHOR KOZAK,[1,2] VLADIMIR MENSHUTKIN[1]

[1]International Centre of Ecology, Polish Academy of Sciences, Warsaw, Poland
[2]Institute of Ecology of the Carpathians, National Academy of Sciences of Ukraine, Lviv, Ukraine

Abstract

Kozak I., Menshutkin V.: Investigation of spruce forest dynamics in the Bieszczady Mountains using a computer modelling. Ekológia (Bratislava),Vol. 20, No. 4, 371-378, 2001.

This work presents the results of investigation of spruce forest dynamics in the Bieszczady Mountains in Poland, using our FORKOME* model. The model was verified according to field observations in 1998-1999 in spruce forest in the forest district Procisne. The FORKOME model confirmed the short time of growth of man-made spruce forest in the Bieszczady Mountains. The transformation of man-made spruce forest to beech forest was showed. The model predicted cyclical interchange between beech and fir in the Bieszczady Mountains. The model predicted that regeneration of beech forest on the place of spruce was more intensive in the variant of cutting of all trees in the first year of model time than without cutting.

Key words: computer modelling, forest, spruce, Bieszczady Mountains

Introduction

Since the sixties a progressive mathematization of the field of ecology started to develop, resulting in different models that have been constructed (Sullivan, Clutter, 1972; Solomon, 1974; Mitchell, 1975; Suzuki, Unemura, 1974; Horn, 1975; Waggoner, Stephens, 1970; Shugart, West, 1977).

The forest gap model approach has proven to be useful in many respects (Shugart, 1984). Canopy gaps are essential for forest regeneration in many temperate and tropical forests. The phenomenon of forest regeneration in gaps has recently received more attention, as it is important for both, natural and managed forests. In managed forests the regeneration processes are based on the natural regeneration in the gap created after cutting one or several trees (Szwagrzyk, 1994).

* FORest+KOzak MEnshutkin

The first models (Botkin et al., 1972) have been rather simple, but subsequent research has led to more complicated models, culminating in models including detailed information such as soil processes (Pastor, Post, 1985), phytosociological concepts (Kienast, 1987), explicit modelling of tree crown structure (Leemans, Prentice, 1989), and detailed treatment of ecophysiological (Friend et al., 1993) and biophysical processes (Bonan, van Cleve, 1992; Martin, 1992) and intraspecific competition (Pawłowski, 1996). The increasing complexity of forest gap models may have helped to make detailed and presumably more accurate projections of forest succession. A development of an ecological model of forest stand applicable under environmental conditions prevailing in the Polish forest stand was presented (Brzeziecki, 1991).

The main aim of the present study was an investigation of the dynamics of spruce forest in the Bieszczady Mts in different cutting conditions by means of our FORKOME model.

Materials and method

Permanent research plot was situated in the Biszczady Mountains (Poland) on the slope of Kosowiec (forest district Procisne). The plot was located on the north slope of the mountain (inclination 7^0) at the altitude of 630 m a. s. l. Brown soils over the Carpathian flish are characteristic of the plot. Dominating tree species was spruce (*Picea abies* L.), and the average age of the stand was 40 years.

In our FORKOME model we investigated the forest changes on a small plot (Menshutkin, Kozak, 1997; Kozak, Menszutkin, 1999) within a GAP (25 m x 25 m). The model algorithm includes nine blocks (Fig. 1). The block " INPUT PARAMETERS" represents the estimation of tree and forest community parameters. One of them was the maximal tree diameter at standard height of 130 cm over the ground (D max). Maximal height (H max), maximum age (AGE max) and minimal and maximal sums of degree-days (D G D min, D G D max) were also considered. Since this model is stochastic, the study of its dynamics requires running through many variants (block "NEW VARIANT"). In application to investigations and for prediction purposes it may simulate the period of up to 600 years. These processes are controlled by the block entitled "NEW YEAR". The model regards processes of mortality, birth, and growth for any year of the run. The mortality of trees is the stochastic process depending on the tree age and conditions of growth in the previous year. Simulation of tree reproduction (block "BIRTH") is represented in the model as a stochastic process depending on the species of tree seedling, conditions of ground surface and average temperature at the litter level. The growth rate of each tree (block "GROWTH") depends on its dimensions, tree species, and conditions of light, temperature, and supply of nutrients. After the realisation of all variants of the model, the programme carries out a statistical analysis of the results (block "STATISTICS"). In the simplest case the analysis consists of calculation of the mean and standard deviation values, whereas in more complicated cases serial-and crosscorrelation functions are calculated.,

The interface of FORKOME model has different pictures (Fig. 2) for ONE REALIZATION: "PARAMETERS", "INITIAL STATE", "SHOW GRAPHICS", "PRINT GRAPHICS". In the "PARAMETERS" the general parameters of the forest are presented and also parameters of each tree species. It is possible to change those parameters before simulation. "INITIAL STATE" allows to put data on different study areas. "SHOW GRAPHICS" presents the distributions of age, height, tree numbers and biomass of trees and "PRINT GRAPHICS" allows to print it together with leaf area and light intensity data. It is possible to save the simulation and return from 600 years simulation to the first year. It is also possible to stop simulation at any time and to run it again. After having pressed the left button of the mice in the position of each tree at the picture it is possible to get information about age, height and diameter of the tree. The right button of the mice allows cutting of the tree.

The statistical elaboration can simulate up to 200 runs with cutting tree species at different maximal and minimal height and age and also to show and to print average tree numbers and average biomass of trees with standard deviations for each year.

Different variants simulated the scenario for a spruce permanent plot. Variant one was taken as a control, variant two assumed cutting all trees in the first year of model time.

Each variant started from an identical initial state corresponding to the situation in a forest gap of 1998 year, when the average age of the forest was 40 years. The position of each tree in the forest gap was projected to the diagonal of this gap. The year 1999 as the 41 year of forest age was taken also as the first year of the model time, and we will use this model time in the following text.

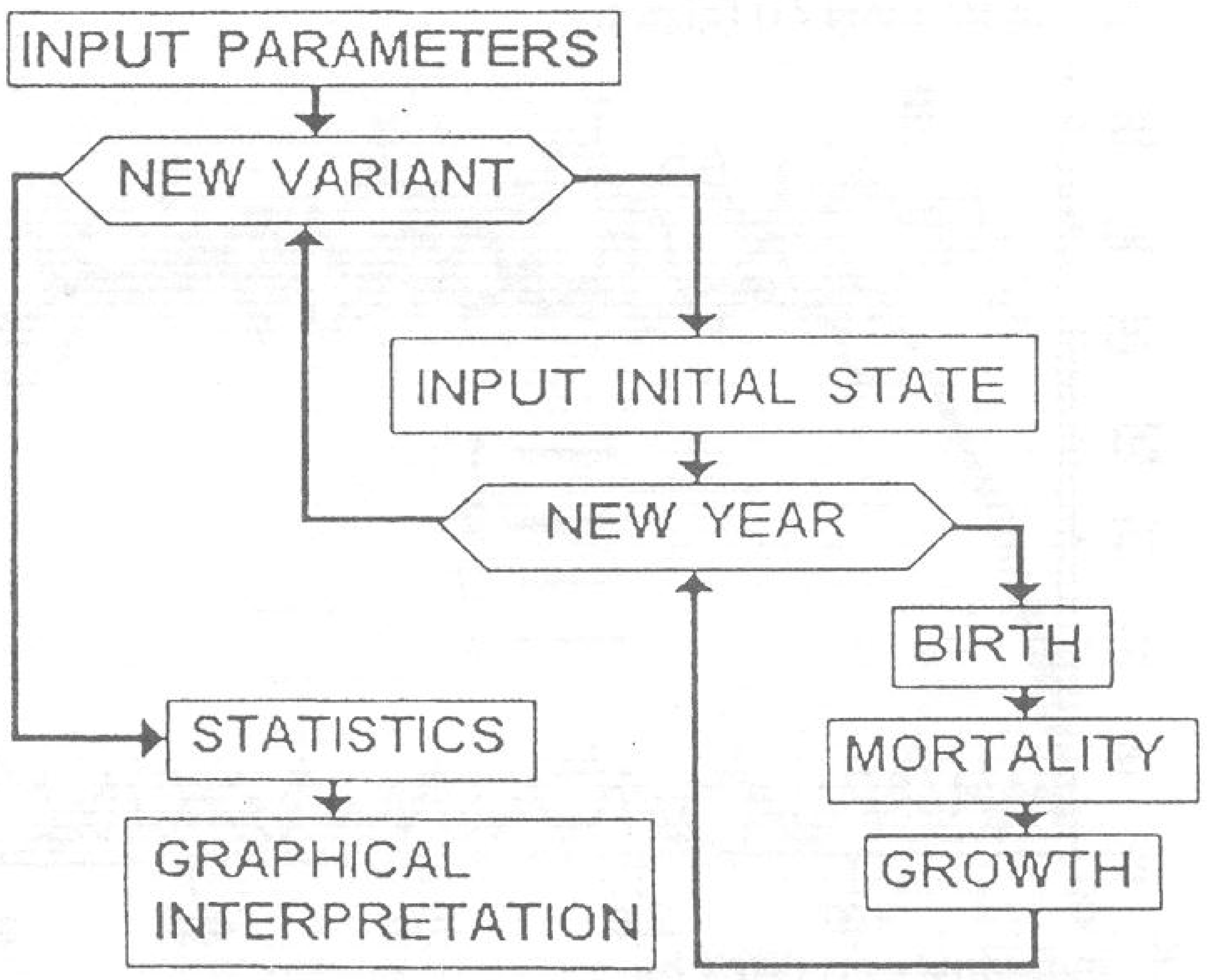

Fig. 1. Diagram of the FORKOME model algorithm.

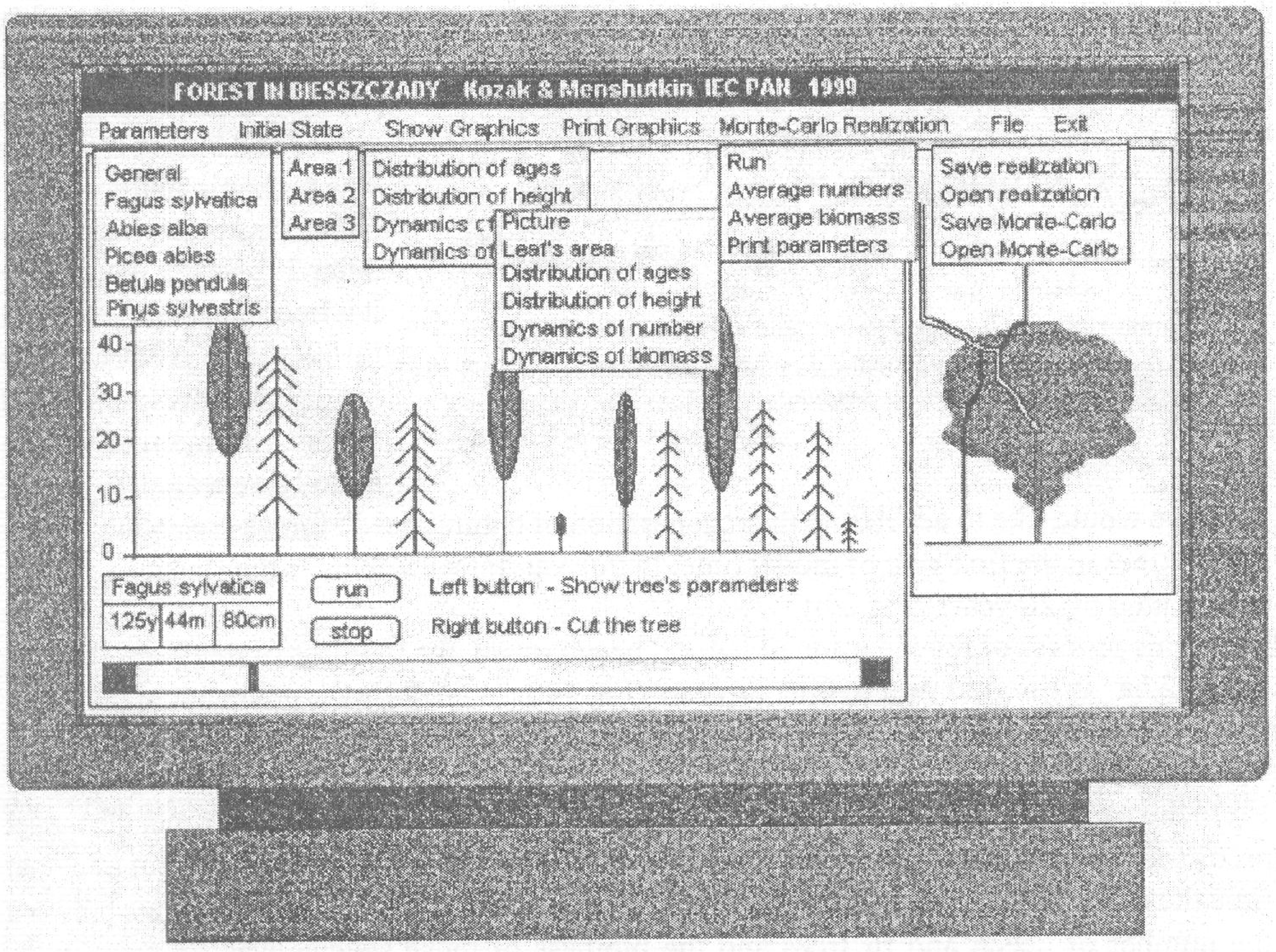

Fig. 2. Interface of FORKOME model.

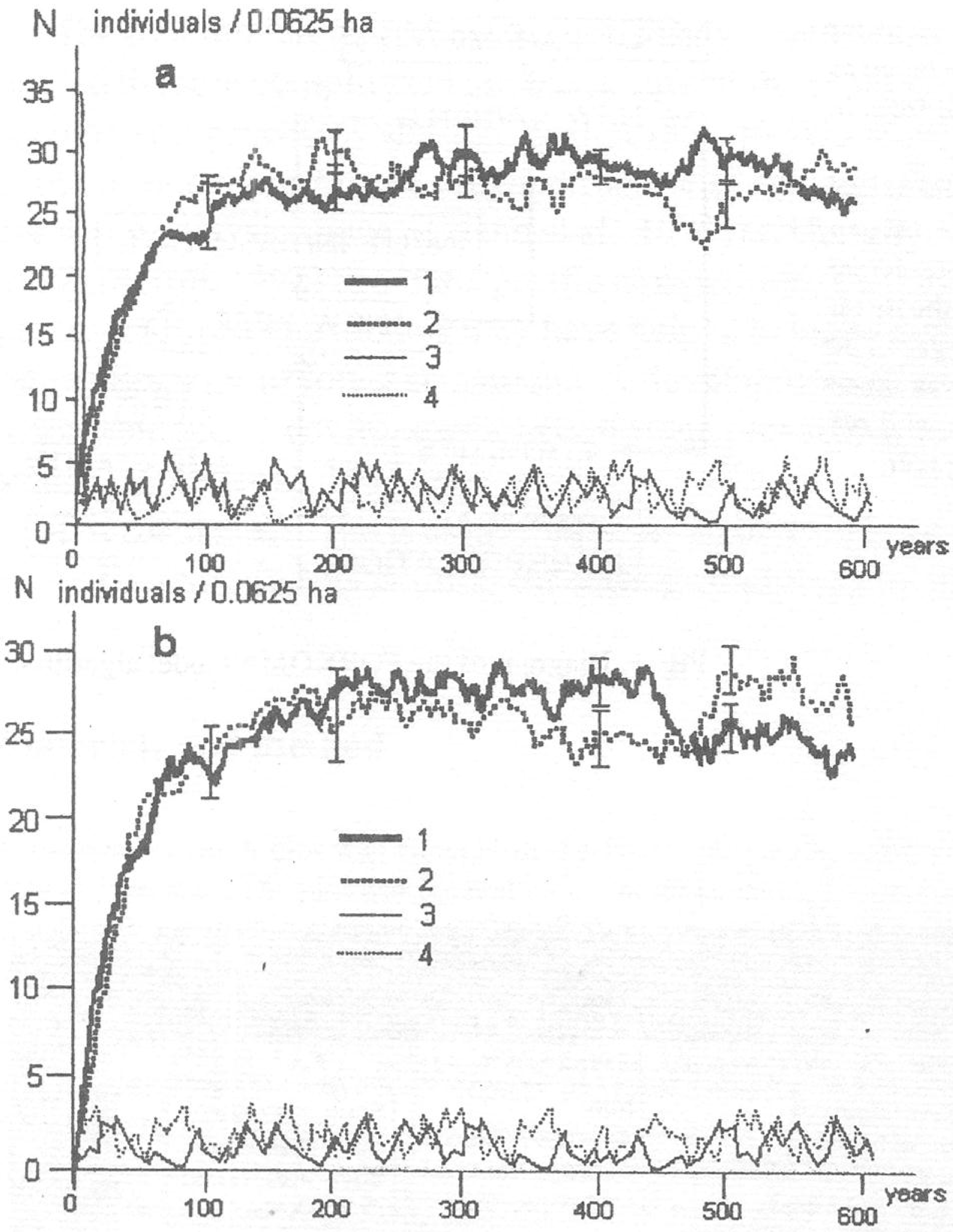

Fig. 3. Number of trees in spruce forest stand a – control, b – cutting in the first year of model time. Legend: 1 – *Fagus sylvatica*, 2 – *Abies alba*, 3 – *Picea abies*, 4 – *Betula pendula*.

Results

Our FORKOME model confirmed the short time of spruce growth. The model predicted in the control conditions a decrease in numbers of spruce trees and regeneration of beech forest. For example, the number of spruce trees decreased from 35 individuals in the model time of first years to 2 individuals in 20 years (Fig. 3a). In the following the number of spruce trees increased only to 5 individuals and decreased to 1 very often. Such pattern is typical also of birch trees (*Betula pendula* L.). An increase in spruce and birch percentage was probable in the periods of beech or fir weakening. After 20 years of model time it is beech that dominated up to 60 years. After that the model predicted cyclic changes between beech and fir to be repeated.

If we would like to accelerate the regeneration of natural beech forest, we should cut all spruce trees in the first year of model time. In this variant we will have dominance of beech accelerated by 20 years (Fig. 3b).

In this process of regeneration of natural beech forest, the biomass of trees was reduced from 82 ha^{-1} in the first year to 0 in 20 years (Fig. 4a). In the following the model predicted the beech dominance up to 100 years. In the subsequent time the cyclical change between beech and fir repeated.

In the variant 2 assuming the cutting of all trees at the first year of model time, the model predicted similar dominance of beech and fir biomass up to 90 years (Fig. 4b), but after that time the cyclical change between beech and fir recurred. This cyclical interchange between the number of beech and fir trees and the biomass of those species was frequent in the statistical elaboration and in one simulation run too.

The FORKOME model predicted the regeneration of beech forest on the place of the secondary spruce forest during 60 years for number of trees and during 90 years for biomass. In the model time of the first year on the spruce plot there were 35 individuals of spruce, 5 of birch, 2 of beech and 1 of pine. The position of each tree in the plot was projected to the diagonal of this plot. In 10, 20 and 40 years spruce numbers decreased and beech and fir increased (Fig. 5).

In the variant of cutting all trees in the first year of model time the model predicted the beech regeneration too.

The distribution of cumulative leaf area, in the years 1, 10, 20, 40 of model time, was less compact in the natural regeneration of beech forest without cutting of all trees than in variant 2 with cutting all trees at the first year of model time.

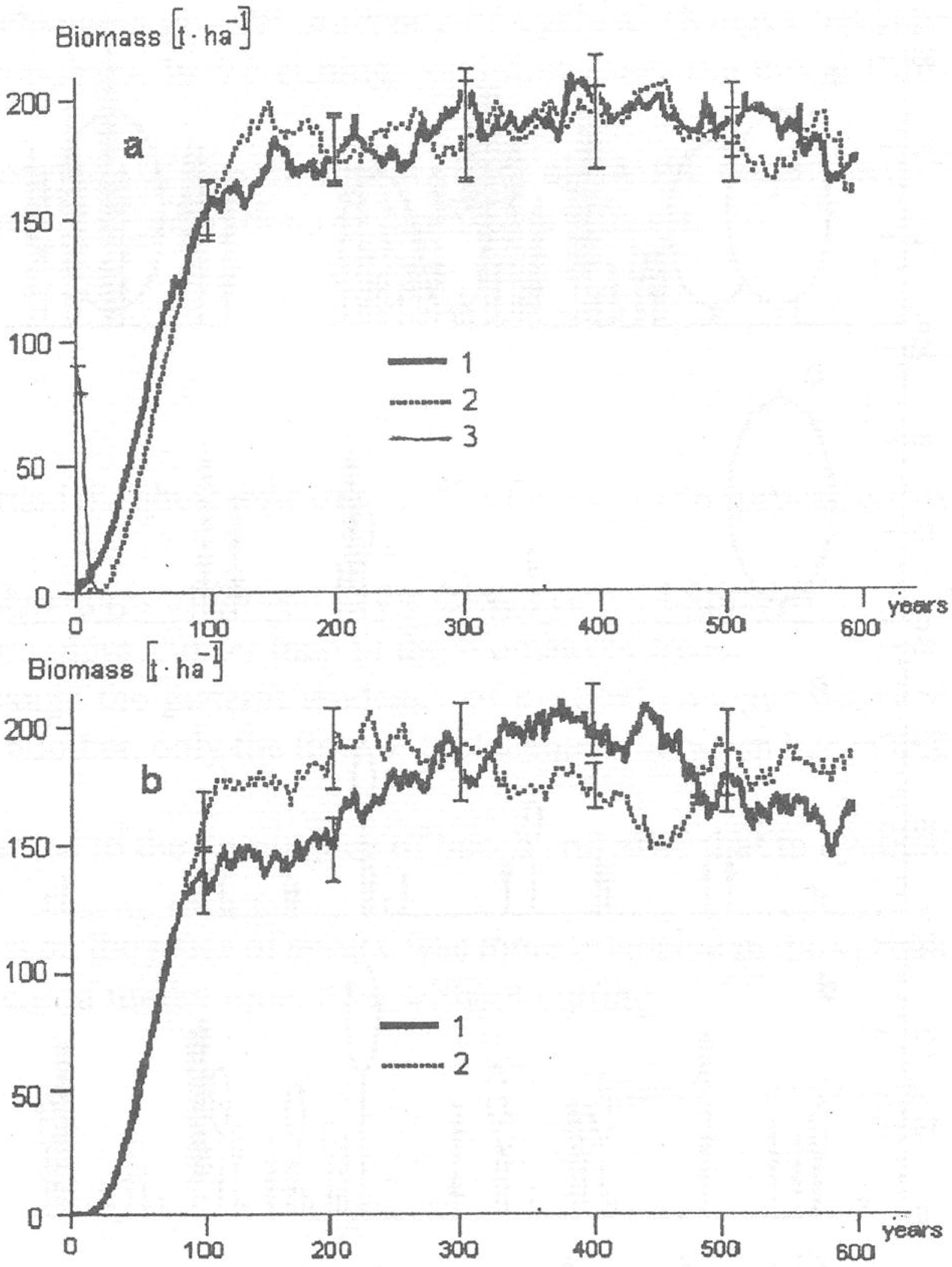

Fig. 4. Biomass of trees in the spruce forest stand a – control, b – cutting in the first year of model time. Legend: 1 – *Fagus sylvatica*, 2 – *Abies alba*, 3 – *Picea abies*.

Discussion

In the literature there are many data about short time growth of secondary spruce forests in the Carpathians. According to the data from Ukrainian Carpathians (Holubets, 1978; Kozak, 1990) secondary spruce forests grow quickly up to 35-40 years and next they are destroyed. The same situation occurs in the Polish Bieszczady Mts (Jaworski, 1997) and in the Slovakian Carpathians (Klimo, 1998; Kodrík, 1998).

Our FORKOME model also confirmed a short time of growth of spruce. The model predicted in the control conditions a decrease of numbers of spruce trees during 20 years

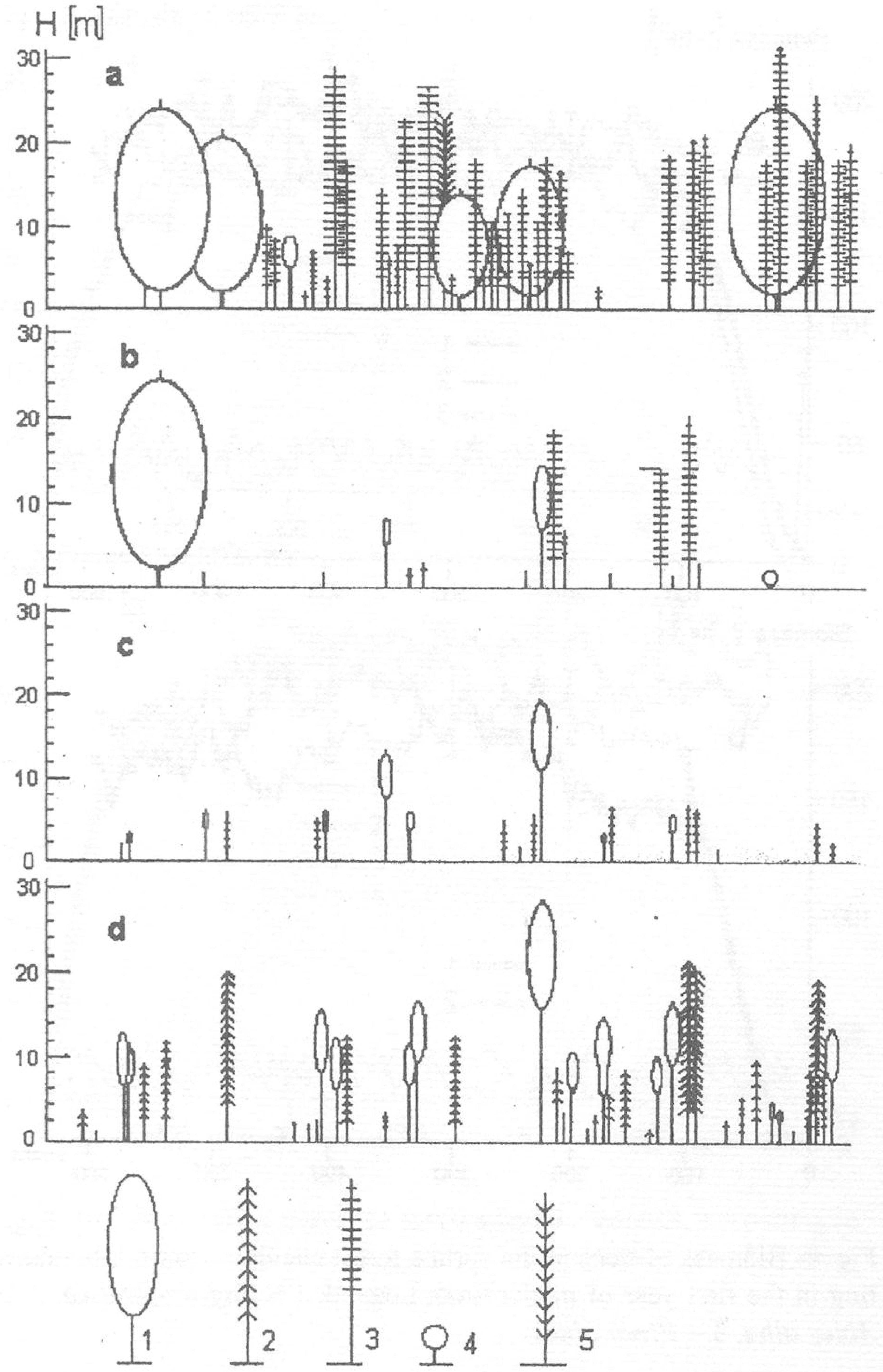

Fig. 5. Regeneration of beech forest on the place of secondary spruce a – in the 1 year, b – in the 10 year, c – in the 20 year, d – in the 40 year of model time. Legend: 1 – *Fagus sylvatica*, 2 – *Abies alba*, 3 – *Picea abies*, 4 – *Betula pendula* 5 – *Pinus sylvestris*.

and restoration of natural beech forest. Subsequently the number of spruce trees increased only to 12 individuals in one simulation run and to 5 in statistical elaboration and decreased to one very often. This was typical of birch trees too. An increase in spruce and birch participation was probable in the periods of beech or fir weakening.

The model confirmed the cycle of community development trends. Such cycles were already described in literature (Shugart, 1984). Our model predicted the cyclical dynamics of species succession between beech and fir after spruce forest was destroyed. The tendency of beech tree number dominance after the decay of spruce forest and later on of fir dominance was also visible. The cycles interchanged more often as for number of trees than in biomass dominance.

One simulation run allowed a more detailed analysis of change inside the simulation. In this case very perspective were investigations of changes of age and height of trees or of the distribution of leaf area indices and light access in the course of succession.

Statistical Monte Carlo realization predicted also cyclical changes. The amplitude of these changes was not so high as for one simulation run, but in the Monte Carlo realization it is possible to analyse the tendency of changes in biomass and tree numbers during succession.

The cutting of trees will not change a general tendency of cyclical changes between beech and fir biomass and tree numbers. In the cutting conditions only the time of this replacement would be variable.

The cutting of trees in the first year of model time will not allow the dominance of spruce forest, but it will accelerate the regeneration of natural beech forest.

Summary

- The FORKOME model confirmed the short time of growth of man- made spruce forests in the Bieszczady Mountains.
- The model predicted cyclical dynamics of forests in the Bieszczady Mountains.
- The cycles in tree numbers were more shorter than in the biomass of trees.
- Cutting of trees would not change the general tendency of cyclical changes between beech and fir biomass and tree number, only the time of replacement between beech and fir would be variable.
- Cutting of trees in the first year led to the dominance of beech and after that to cyclical changes between beech and fir.
- The regeneration of beech forest on the place of spruce was more intensive in the variant of cutting of trees in the first year of model time, than without cutting.

Translated by the author

References

Bonan, G.B., van Cleve, K., 1992: Soil temperature, nitrogen mineralization, and carbon source- sink relationships in boreal forests. Can. J. For. Res., *22,* p. 629-639.

Botkin, D.B., Janak, F. J., Wallis, J. R., 1972: Some ecological consequences of computer model of forest growth. J. Ecol., *60,* p. 649-873.

Brzeziecki, B., 1991: Ecological growth Model of the Forest: some methodical and calibration problems. Sylwan, *9,* p. 5-15.

Friend, A.D., Shugart, H.H., Running, S.W., 1993: A physiology-based gap model of forest dynamics. Ecology, *74,* p. 792-797.

Holubets, M. A., 1978: Spruce forests of the Ukrainian Carpathians (in Ukrainian). Naukova dumka, Kiev, 280 pp.

Horn, H.S., 1975: Forest succession. Sci. Am., *232,* p. 90-98.

Jaworski, A., 1997: Carpathian forests of primeval character and their importance in shaping the pro-ecological model of forest management in mountains (in Polish). Sylwan, *4,* p. 33-47.

Kienast, F., 1987: FORECE – A forest succession model for southern central Europe. Oak Ridge National Laboratory, Oak Ridge , TN, ORNL/TM 10575, 69 pp.

Klimo, E., 1998: Stress conditions of a man-made Norway spruce pure stand established outside its natural range in the region of the Drahanska uplands. Ecologie, *29,* p. 97-300.

Kodrik, M., 1998: Investigation of fine roots of *Picea abies* ecosystem in the Northern Slovakia. Ekológia (Bratislava), *17,* 4, p. 358-363.

Kozak, I., 1990: Anthropogenic transformation of forests in the mountain part of Prut river basin. Lesovedenie, *3,* p. 3-10.

Kozak, I., Menszutkin, V., 1999: Computer simulation of forest Ecosystem Dynamics. Biology Bulletin, *26*, 6, p. 586-592.
Leemans, R., Prentice, I.C., 1989: FORSKA, a general forest succession model. Institute of Ecological Botany, Uppsala, 70 pp.
Martin, Ph., 1992: EXE: A climatically sensitive model to study climate change and CO2 enrichment effects on forests. Aust. J. Bot., *40,* p. 717-735.
Menshutkin, V., Kozak, I. 1997: An investigation of a mixed beech forest dynamics in Ukrainian Carpathians using a computer model. In Perzanowski K., Augustyn M. (eds): Selected ecological problems of Polish-Ukrainian Carpathians. Bieszczady, p. 23-29.
Mitchell, K. J., 1975: Stand description and growth simulation from low-level stereophotos of tree crowns. J. For., *73,* p. 12-16.
Pastor, J., Post, W.M., 1985: Development of a linked forest productivity-soil process model . U.S. Dept. of Energy, ORNL/TM-9519.
Pawłowski, W. J., 1996: Computer simulation of growth of a spruce stand using the PICEAT model. Ekol. Pol., *44,* 3-4, p. 333-349.
Shugart, H. H., 1984: Theory of forest dynamics. Springer Verlag, NY 278 pp.
Shugart, H. H., West, D. C., 1977: Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. J. Environ. Manag., 5, p. 161-179.
Solomon, D.S., 1974: A growth model of natural and silviculturally treated stands of even-aged northern hardwoods. U.S.D.A. Forest Servise Tech. Report. NE.-36, 30 pp.
Sullivan, A. D., Clutter, J. L., 1972: A simultaneous growth and yield model for loblolly pine . For. Sci., *18,* p.76-86.
Suzuki, T., Umemura, T., 1974: Forest transition as a stochastic process. V. J. Jpn. For. Soc., *56,* p. 195-204.
Szwagrzyk, J., 1994: Simulation models of forest dynamics based upon the concept of tree stand regeneration in gaps (in Polish). Wiadomości ekologiczne, *40,* 2, p. 57-95.
Waggoner, P. E., Stephens, G.R., 1970: Transition probabilities for a forest. Nature, *225,* p. 1160 1161.
Mc Cormick, J., 1968: Succession. Via 1, p. 1-16.

Received 1.8.2000

Kozak I., Menshutkin V.: **Štúdium dynamiky smrekových lesov v pohorí Bieszczady pomocou počítačového modelovania.**

V práci predkladáme výsledky štúdia dynamiky smrekových lesov v pohorí Bieszczady v Poľsku použitím modelu FORKOME. Model sme overovali terénnym výskumom uskutočneným v rokoch 1998-1999 v smrekovom lese v oblasti Procisne. Výskum lepšie potvrdil model FORKOM, že človekom založený smrekový les v pohorí Bieszczady rastie rýchlejšie. Prezentovala sa transformácia smrekovej monokultúry na bukový les. Model predpovedal cyklickú dynamiku buka a jedle v pohorí Bieszczady, ďalej potvrdil, že v modelovom čase 1 roka regenerácia bukového lesa na mieste smrekového lesa bola intenzívnejšia vo variante, keď sa vyrúbali všetky stromy, ako keď sa nevyrúbali.