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POSSIBILITIES OF APPLICATION OF COMPUTER MODELLING FOR PREDICTION OF TREE STAND SUCCESSION DYNAMICS ON THE EXAMPLE OF FIR-BEECH TREE STAND IN THE BIESZCZADY MOUNTAINS

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ABSTRACT. This work presents the results of investigation of fir-beech tree stand succession in the Bieszczady Mountains using the FORKOME* model. The model was verified according to field observations in 1998-1999 in a forest with dominating fir (*Abies alba* Mill.) in the forest district Stuposiany. The model predicts that fir-beech stand of an average age 72 years is a stage of forest succession on the way to restoration of beech forest. The model predicts that after 100 year of simulation for numbers, and after 200 years of simulation for biomass this stage changes into the stage of beech forest. In the variant of cutting all trees in the 20 years of model time the model predicted the accelerating of beech stage of succession, comparing to control.

KEY WORDS: fir-beech tree stand, computer model, Bieszczady

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INTRODUCTION

From 1970s the progressive mathematization of the field of ecology developed. As a results different models have been constructed (WAGGONER and STEPHENS 1970, SULLIVAN and CLUTTER 1972, BOTKIN et al. 1972, SUZUKI and UMEMURA 1974, MITCHELL 1975, HORN 1975, SOLOMON 1977, SHUGART and WEST 1977).

Since the early eighties many gap models, especially by Shugart and his collaborators, have been developed for different forest types. The detail analysis of this models is in the publications of SZWAGRZYK (1994) and BRZEZIECKI (1991, 1999).

The first models have been rather simple. The subsequent research has led to more complicated models. Those models include detailed information about different blocks of the forest. The increasing complexity of forest gap models allows to make detailed and presumably more accurate projections of forest succession (PASTOR and POST 1985, KIENAST 1987, LEEMANS and PRENTICE 1989, BONAN and CLEVE 1992, MARTIN 1992, FRIEND et al. 1993, PAWŁOWSKI 1996). The forest gap model approach has proven to be useful in many respects. A development of an ecological model of forest stand applicable under environmental conditions prevailing in Polish forest stands was presented (BRZEZIECKI 1991, 1999).

The main aim of the present study was an investigation of the dynamics of fir-beech tree stands under logging management in the Bieszczady Mountains by means of our FORKOME model.

MATERIALS AND METHOD

Permanent research plots were situated on the North slope of Kosowiec mountain (forest district Stuposiany) with inclination 18° at the altitude of 750-760 m a.s.l. Brown soils over the Carpathian flish were dominating within the plots. Dominating tree species was fir. Average age of the tree stand was 72 years.

In our FORKOME model we investigated the tree stand changes on a small plots within a 28 m $\times$ 28 m (MENSHUTKIN and KOZAK 1997, KOZAK and MENSHUTKIN 1999). In the model different modules are distinguished (Fig. 1).

The block "INPUT PARAMETERS" represents the estimation of tree and forest community parameters, e.g. 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"). Those are

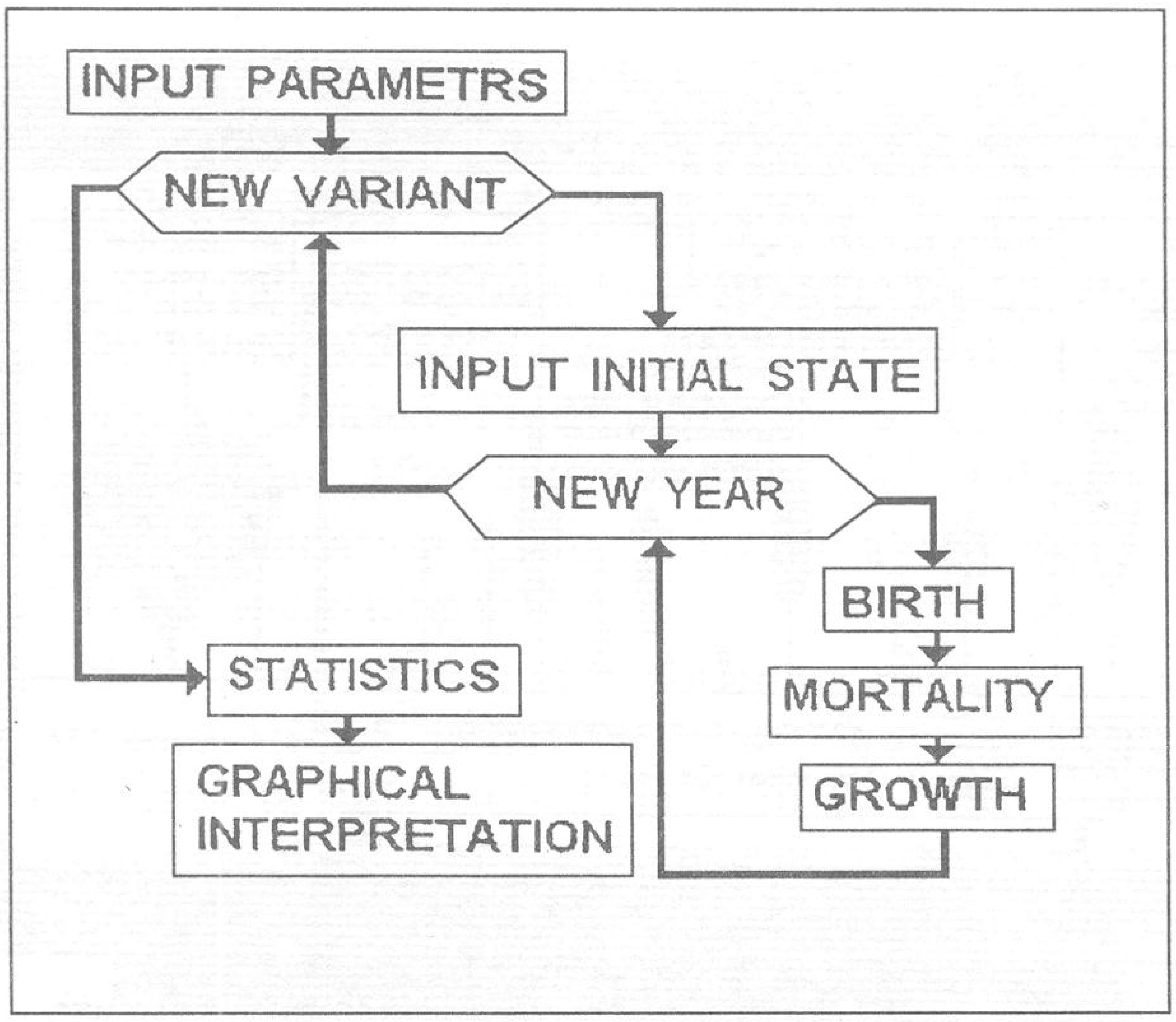

Fig. 1. Diagram of the FORKOME model algorithm

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 trees reproduction (block "BIRTH") is represented in the model as a stochastic process. The growth rate of each tree (block "GROWTH") depends on its dimensions, tree species, and conditions of water and light, temperature, and supply of nutrients. After the realization of all variants of the model, the programme carries out a statistical analysis of the obtained 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 cross-correlation functions are calculated.

The interface of FORKOME model (Fig. 2) has different pictures for ONE REALIZATION: "PARAMETERS", "INITIAL STATE", "SHOW GRAPHICS", "PRINT GRAPHICS". 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 tree. The right button of the mice allows for cutting the tree.

The statistical elaboration "MONTE-CARLO REALIZATION" 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.

The position of each tree in the tree stand was projected to the diagonal of research plot (Fig. 3). The year 1999 as the 73-year of forest life was taken also as the first year of the simulation. In the following text we will use this model time.

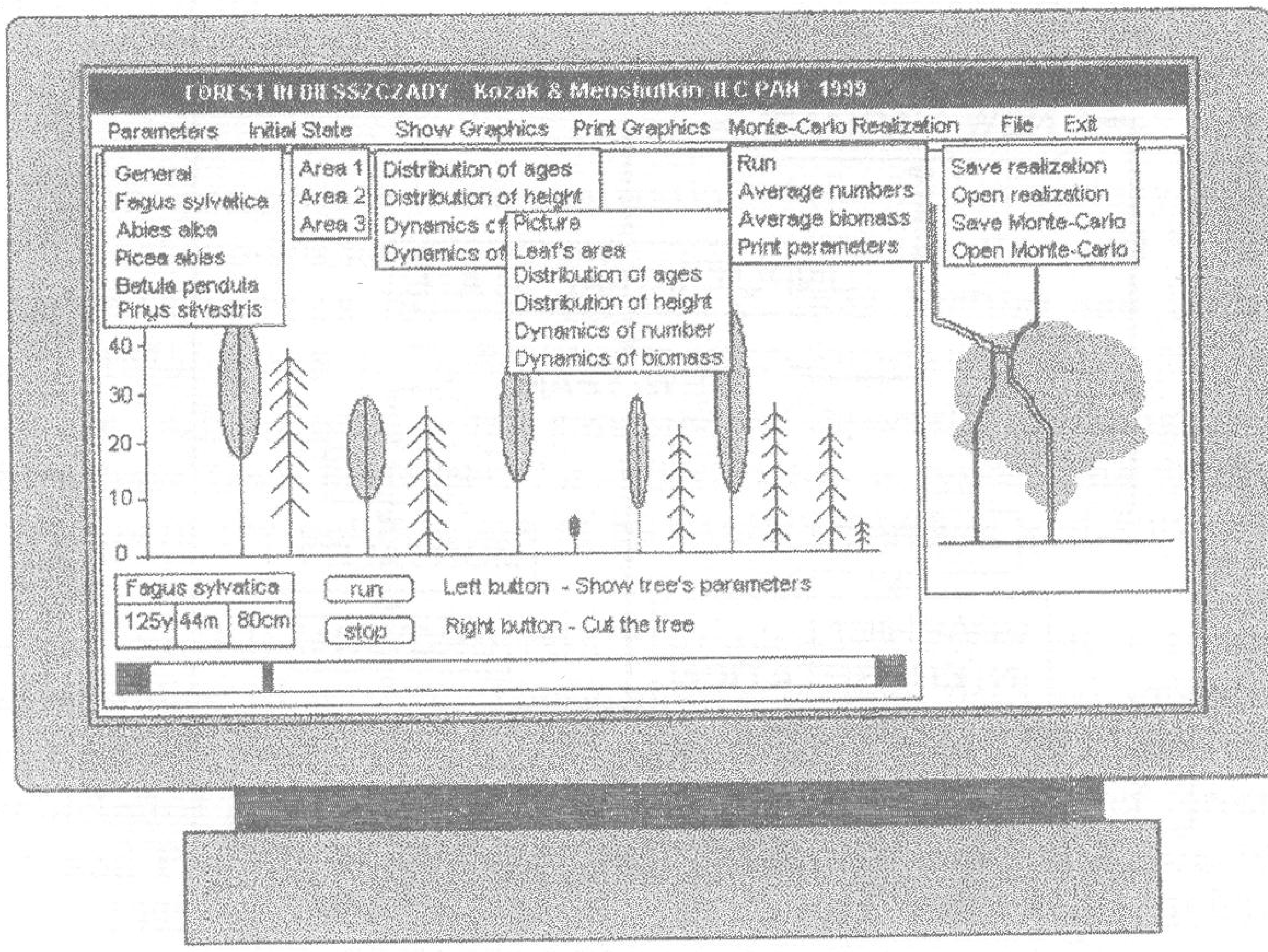

Fig. 2. Interface of FORKOME model

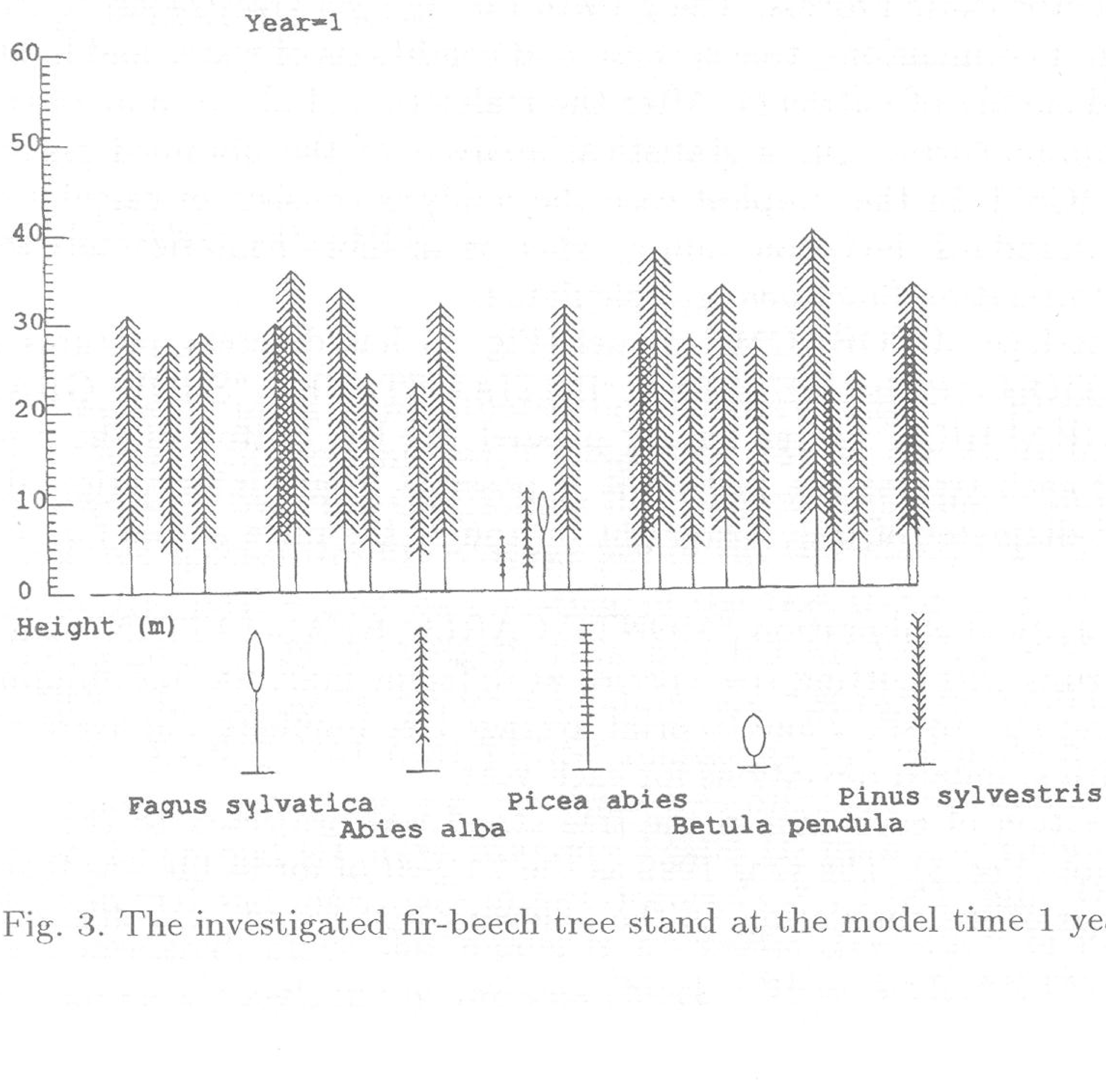

Fig. 3. The investigated fir-beech tree stand at the model time 1 year

RESULTS

In control, the model predicted an increase of tree numbers of fir from 21 individuals in the first year of model time, to 56 individuals in 23rd year (Fig. 4 a). Consecutively fir numbers decreased to 26 individuals in the 96 years. At that time the beech tree numbers increased. From 100 years to 200 years the number of fir and beech trees were similar. After 200 years beech trees dominated. An increase in spruce and birch participation up to 12 individuals was also probable in the periods of fir and beech weakening.

The model predicted an increase of fir biomass from 325 ± 5.6 $T \cdot ha^{-1}$ in the first year of model time to 456 ± 8.1 $T \cdot ha^{-1}$ in 23rd year (Fig. 4 b). Later, the biomass of fir decreased to 185 ± 4.3 $T \cdot ha^{-1}$ in the 96th year. The biomass of fir continued to dominate until 200 year and was at the same level. The biomass of beech increased from 5 ± 0.1 $T \cdot ha^{-1}$ in model time year 1st to the 180 ± 3.1 $T \cdot ha^{-1}$ in 200 year. After that, the biomass of beech trees dominated to 360 years. Later, model predicted some shot dominance of biomass of fir during 50 years with following beech dominance again.

In the statistical elaboration the model predicted also the increase of number of beech trees from 1 tree in the first year to 30 trees in the 400 year. Number of fir trees was at the same level (between 24-30 individuals). From the year 60 to the year 600 the numbers of fir and beech trees was similar. However in the first half of the analysed period of succession dominated fir trees and in the second part beech. The model predicted the decrease of fir biomass from 336 $T \cdot ha^{-1}$ in the year 1 to 180 $T \cdot ha^{-1}$ in 200 year and increase of beech biomass from the model time 1st year to the year 200.

In the variant 1 (cutting all trees at the model time 20 years) the model predicted in a single simulation run for tree numbers, the accelerating of the succession towards the beech stage (Fig. 5). In this variant the biomass of fir and beech up to 96 year were similar. Later, the cyclical changes between beech and fir have repeated.

According to statistical elaboration the cutting of all trees at the model time of 20 years also predicted the increase of beech biomass to 180 $T \cdot ha^{-1}$ in the year 160. Later, the biomass of beech and fir were at similar level. The cyclical changes between the biomass of beech and fir were also visible.

DISCUSSION

The fir stand of an average age of 72 years is a stage of forest succession on the way to restoration of beech forest. The FORKOME model predicts that after the

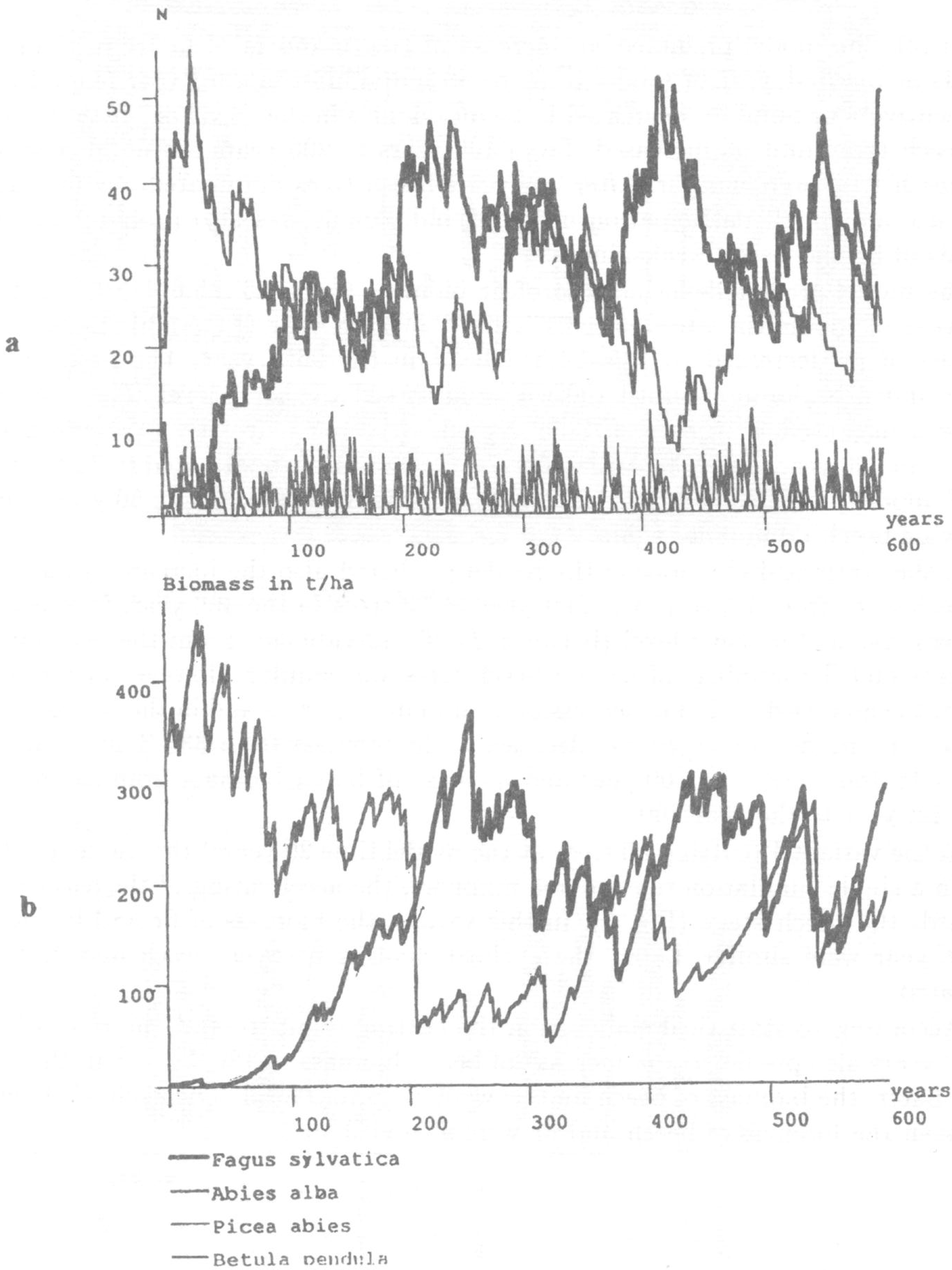

Fig. 4. Number and biomass of trees in the investigated fir-beech tree stand (a single simulation run): a – number of trees, b – biomass of trees

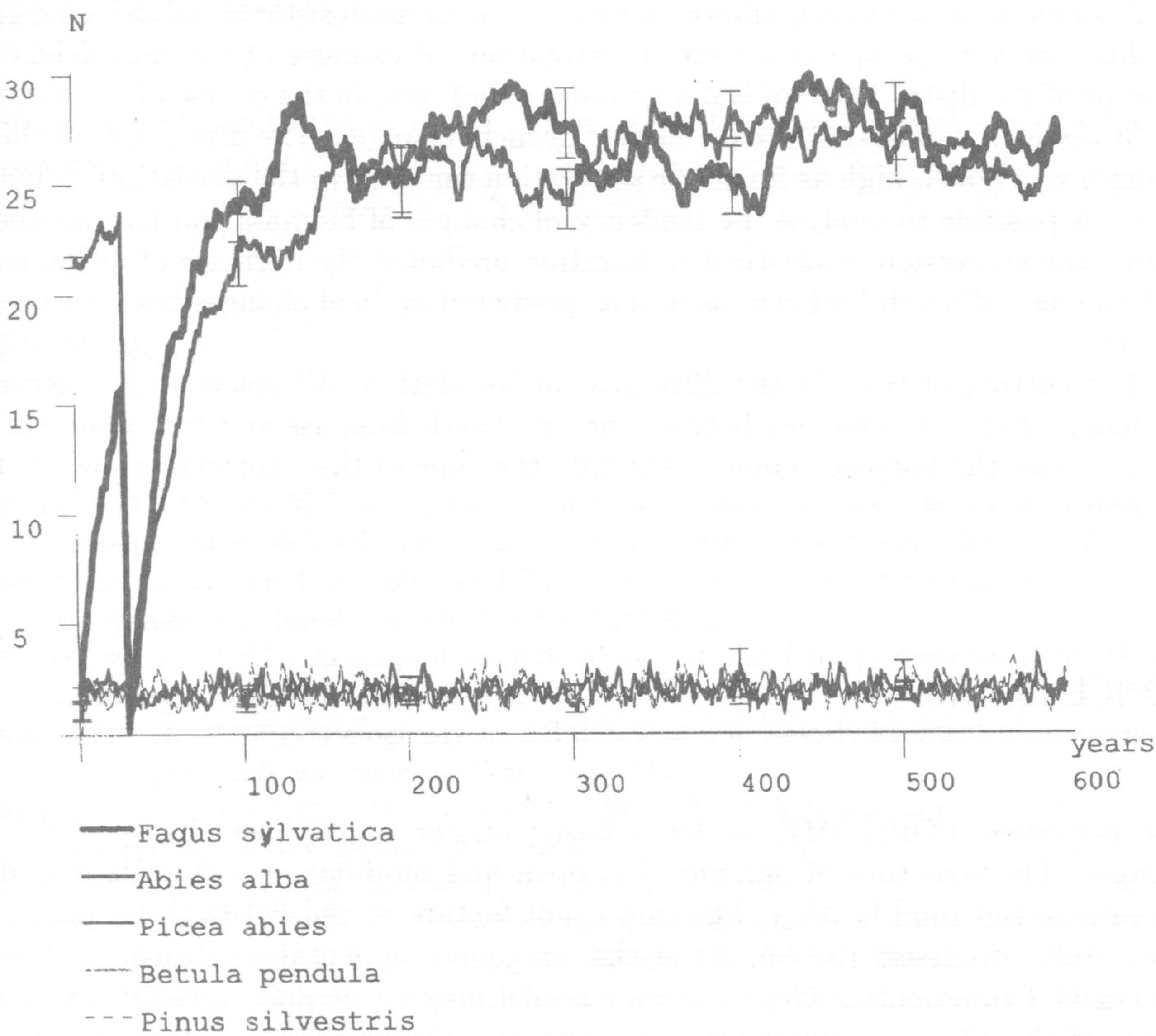

Fig. 5. Number of trees in the investigated fir-beech tree stand (monte-carlo realization)

year 100 of the simulation for numbers and after the year 200 of the simulation for biomass this tree stand changes into the beech stand. In the variant of cutting all trees in the 20th year of the simulation the model predicts the acceleration of succession towards beech comparing to control.

The model confirmed the cycle of community development trends. Such cycles were already described in literature (SHUGART 1984). Our model predicted the cyclical changes of species succession. In variant 1 this tendency of cyclical changes was also confirmed. The cycles were more frequent for numbers of trees than for the biomass.

The tendency of fir tree number dominance at the beginning of modelling time and later on of beech dominance was visible. An increase in spruce and birch participation up to 12 individuals was also probable in the periods of fir and beech weakening. It was in accordance with hypothesis that put forward by MILKINA (1985) in the course of the analysis of plant cover in the Carpathians.

A single simulation run allowed a more detailed analysis of simulated changes. 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 in the course of succession.

Statistical elaboration predicted also cyclical changes. The amplitude of these changes was not so high as for single simulation run. But in the statistical elaboration it is possible to analyse the tendency of changes of biomass and tree numbers during the succession. Statistical elaboration predicted the decrease of fir biomass and increase of beech biomass, as well as predicted cyclical changes between beech and fir.

The cutting of trees in the 20th year of simulation will not change a general tendency of cyclical changes between fir and beech biomass and tree numbers of trees. Under the logging management only the time of this replacement would be variable.

CONCLUSIONS

The presented FORKOME model is based on the gap- phase theory of forest changes. The structure of our model is open and modular, enabling its easy development and modification. The important feature of the FORKOME model is a possibility to assess the impact of changing environmental conditions on forest growth and functioning. Generally, our model may be used for quantitative estimates of the effects of various factors (cutting, climate changes, introductions of new tree species) on succession of forest community.

In this simulation, assuming selected environmental and tree stand factors, the prognosis would be as follows:

1. The fir-beech tree stand is a stage on the way of regeneration of beech tree stand and will change towards the dominance of beech after 100 years of simulation.

2. The model predicted cyclical changes between beech and fir in the Bieszczady Mountains.

3. Cutting of all trees in the year 20, results in the acceleration of the succession towards the beech stage.

4. Cutting of trees would not change the general tendency of cyclical changes between beech and fir biomass and tree numbers, only the time of replacement between beech and fir would be differ.

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