# MODELLING OF BEECH FOREST DYNAMICS IN THE BIESZCZADY MOUNTAINS IN RESPONSE TO CLIMATE CHANGE

IHOR KOZAK[1], VLADIMIR MENSHUTKIN[2], MARCIN JÓŹWINA[1], GRZEGORZ POTACZAŁA[1]

[1] Faculty of Landscape Systems, Catholic University of Lublin, Poland, e-mail: modeliho@kul.lublin.pl
[2] International Centre of Ecology, Polish Academy of Sciences, Warsaw, Poland

Abstract

Kozak I., Menshutkin V., Jóźwina M., Potaczała G.: Modelling of beech forest dynamics in the Bieszczady Mountains in response to climate change. Ekológia (Bratislava), Vol. 22, No. 2, 152–161, 2003.

This work presents results of investigation of beech forest succession in the Bieszczady Mountains using a FORKOME* model in response to climatic changes. The model was verified according to field observations in 1998–2001 in beech forest in the forest district Procisne in the Bieszczady Mts (Poland). Prediction of tree biomass and tree number was aimed at for the next 600 years. Simulation demonstrated beech domination when mean annual temperature increases by 2 °C. However while the decrease in temperature by 2 °C fir becomes dominant in research plot . Both one simulation run and Monte Carlo simulation showed comparable results of statistical analysis. 3. scenario (warm and humidity) illustrated an increase in beech biomass. That trend is also characteristic to 4. scenario with parameters set to cold and humidity. In opposite situation - dry climate (6. scenario – cold and dry, 5. scenario – warm and dry) descending number of beech trees resulted in an increase in fir trees number. Change in trees number is noticeable in 7. scenario where air temperature is fluctuating.

*Key words:* forest, beech, computer model, climate changes, Bieszczady Mountains

## Introduction

To the human eye a forest is a slowly changing ecosystem that looks alike year after year. But in fact there are dynamics at the time and spatial scales in the forest. Most of alterations in succession are caused by climate changes. These changes can result in fluctuation in temperature and rainfalls. Data presented in literature indicate high differences among mean annual air temperatures during last two centuries. Along with an increase in temperature (e.g. mean annual temperature in 1799 was 4.6 °C and in 1989 was 9.8 °C) vegetation period became longer (Kowalski, 1993).

* FORest+KOzak MEnshutkin



The main problem we have to confront with in forthcoming years is the change of climate.

Considering climate warming it is worth to notice that a majority of the currently used general circulation models show that a global temperature increase of the magnitude of 1 °C to 4 °C is conceivable with $CO_2$ doubling (Maxwell, 1992). Global warming is estimated as an increase in the mean annual air temperature (Bednarz et al., 1994; Obrębska et al., 1997) by 2.5 °C until the end of year 2100 (Puhe, Ulrich, 2001). The increase in temperature for Central Europe is forecasted for 2–3 °C (2–5 °C in winter, 1–3 °C in summer).

Many crucial parameters concern forecasting climate influence on forest ecosystems evolution (Krauchi, 1993). Common demand extorts tools development for use in prediction potential effect of climate change on ecosystems. Many scientists deal with that problem in the literature (Krauchi, 1995; Hong et al., 1999; Brzeziecki, 1999).

Little is known about possible alterations in beech forests dominating in the Bieszczady Mts from 400 to 900 m a. s. l. in different climatic conditions. That is why we run investigation into computer simulation of beech forest succession in examined area with various scenarios of climate changes using the FORKOME model.

## Materials and method

We used data concerning the distribution of beech (*Fagus sylvatica* L.) forest communities in the Bieszczady Mts (Zarzycki, 1963). After having analysed results presented in literature stationary area was selected. Research plot is situated on the north slope of the Kosowiec mountain (forest district Procisne) in the Bieszczady Mts (Poland) along the transect on the slope. The plot is located on the top of the mountain (inclination 10°) at the altitude of 880-890 m a. s. l. Brown soils over the Carpathian flish are characteristic of the plot. Dominating tree species was beech. The average age of the beech stand is 93 years.

Different types of scenario were simulated:

- Control – at the actual conditions: annual temperature 6.1 °C, precipitation 800 mm
- Scenario 1 – in increased by 2 °C temperature
- Scenario 2 – in conditions of temperature decrease by 2 °C
- Scenario 3 – increased by 2 °C temperature and increased by 200 mm precipitation (warm and humidity)
- Scenario 4 – decreased by 2 °C temperature and increased by 200 mm precipitation (cold and humidity)
- Scenario 5 – increased by 2 °C temperature and decreased by 200 mm precipitation (warm and dry)
- Scenario 6 – decreased by 2 °C temperature and decreased by 200 mm precipitation (cold and dry )
- Scenario 7 – alternate air temperature changes.

Description of the FORKOME model was presented in detail in our former articles (Menshutkin, Kozak, 1997; Kozak, Menshutkin, 2000, 2001). Here only new, additional functions, added to the model recently will by illustrated.

First important feature is possibility of computing climate changes while simulation runs. Four new parameters concerning temperature fluctuation were added: $K_0$, $K_1$, $K_2$, $K_3$.

As far as degree-days are concerned (sum of temperatures higher than 5 °C) new formula is proposed:

$$K = K_0(1 + K_1 t) + K_2 \sin\left(\frac{2*3.14}{K_3} t\right),$$

where $K$ – sum of effective temperatures (higher than 5 °C)

$K_0$ – constant coefficient

$K_1$ – direction of sum of mean effective temperatures change

$K_2$ – alternation amplitude of the sum of mean effective temperatures

$K_3$ – alternation period of the sum of mean effective temperatures

$t$ – time period (years).

In our model we took into consideration leaf transpiration depending not only from meteorological parameters, as implemented in other gap models (Shugart, 1984; Brzeziecki, 1999), but also from the tree species. In our FORKOME model transpiration depends on biomass and species set of the stand.

Model includes dependences of various tree species on ground water level and dependences of trees growth on amount of available water. The core of this block is following formula concerning water balance:

$$W(t+1) = W(t) + \mathrm{prec}(t) - \mathrm{trans}(t) - \mathrm{evapor}(t),$$

where $W(t)$ – amount of water in the ground in time $t$

$\mathrm{prec}(t)$ – precipitation

$\mathrm{trans}(t)$ – trees transpiration

$\mathrm{evapor}(t)$ – water evaporation from the ground surface.

Comparing former articles, here more detailed illustration of algorithm used in the model is presented (Fig. 1). Algorithm is divided into several blocks. The block "PARAMETERS" represents the estimation of temperature, precipitation, influence of animals and felling on the research plot. It is possible to simulate forest dynamic in different scenario condition and different initial states.

Since this model is stochastic, the study of its dynamic requires running through many variants (block "VARIANT"). In the case of investigations and for prediction purposes it may simulate the period of 600 years. These processes are controlled by the block entitled "YEAR". There are tree and forest community parameters such as a real diameter (DBH) of each tree on the research plot and maximum tree diameter ($DBH_{max}$) at standard height at 130 cm above the ground level, real height (H) and maximum height ($H_{max}$), real age (AGE) and maximum age ($AGE_{max}$), minimal and maximal of degree-days ($DEGDAY_{min}$, $DEGDAY_{max}$), light intensity, nitrogen and water contents.

The model regards processes of the natural death, seedlings, vegetative distribution, vegetative reproduction, water balance and growth for any year of the run. The growth rate of each tree depended on its dimensions, tree species, and conditions of light, temperature, and supply of nutrients and water.

After the realisation of all variants of the model, the program carries out a statistical analysis of the obtained results (block "STATISTICALS PROCEDURES"). Different scenarios were simulated for beech permanent plots (TEMPERATURE, PRECIPITATIONS, ANIMALS, FELLING).

As it is showed in the interface of FORKOME model (Fig. 2) the position of each tree in the forest is projected along a diagonal of research plot (28x28 m). The year 2000 was regarded as the first year of the model time. The study time is used as the model time.

## Results and discussion

At the control situation the FORKOME model predicted decrease of beech biomass from 400 ± 12.1 t/ha to 136.0 ± 10.2 t/ha in 65 years (Fig. 3a). Then with age the biomass of beech increased to 210 ± 7.3 t/ha in 400 years and to 196.0 ± 4.1 t/ha in 600 years. The biomass of fir gradually increased to 60.0 ± 1.1 t/ha in 35, 120.1 ± 4.0 t/ha in 190 and 165.1 ± 14.1 t/ha over 600 years.

As shown in Fig. 3 (Fig. 3b), 30-run Monte Carlo simulation forecasts beech domination when the mean monthly temperature increased by 2 °C. While air temperature is decreasing fir domination is simulated by the model (Fig. 3c).



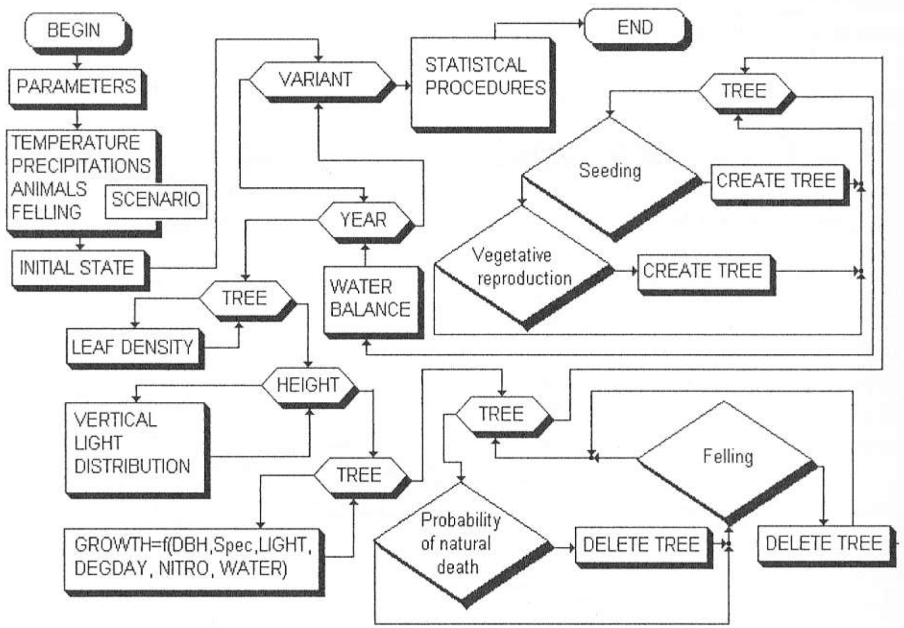


Fig 1. FORKOME model algorithm.

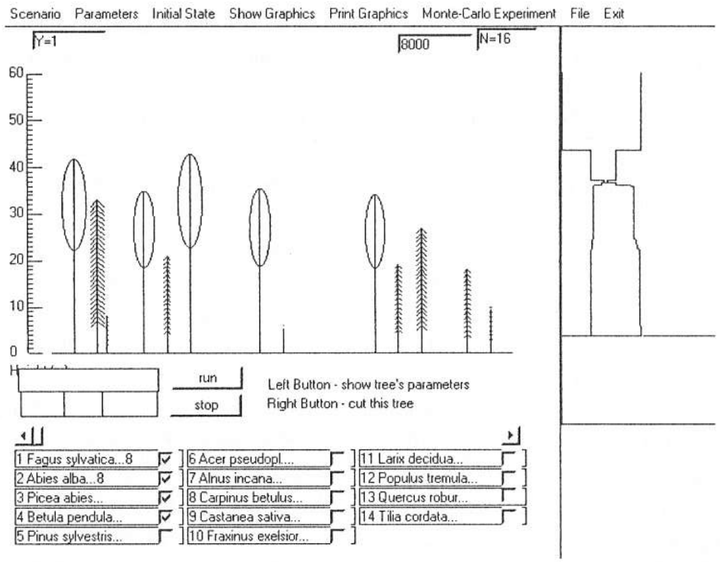


Fig. 2. Interface of the FORKOME model.

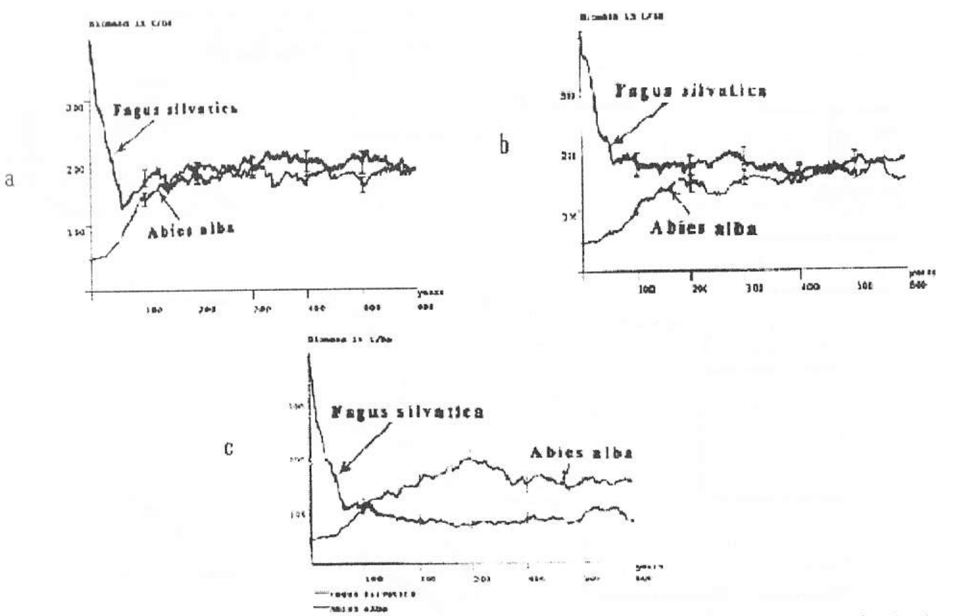


Fig. 3. Monte Carlo biomass simulation: a – control, contemporary climate conditions, b – scenario No. 1 – warming, c – scenario No. 2 – cooling .

The dependences of tree species on air temperature are also visible in one simulation run. One of the simulations will be presented as an example. The example illustrates differences between control situation results (Fig. 4a), warming – 1. scenario (Fig. 4b) and cooling – scenario 2 (Fig. 4c).

In control situation model predicts decrease in beech biomass to 500 t/ha in the first year and to 105 t/ha in 52. year of the simulation (Fig. 4a). Subsequently periodic exchanges in beech and fir biomass are forecasted. However after 400. year of the simulation beech domination is clearly visible.

First scenario predicts beech domination in biomass for all simulation run (Fig. 4b). Yet from 135. to 150. year model predicts small fir biomass superiority. Then short-term fir domination is presented from 280. to 300. year and subsequently from 440. to 460. year of simulation. These short-term dominations in fir biomass coincide with its highest values in control variant. Furthermore, in climate warming scenario, after beech vanishing at the beginning of simulation, its highest biomass appears sooner than in control scenario.

In 2. scenario (climate cooling), after decrease in beech biomass, model predicts fir domination (Fig. 4c). Just after 150. simulation year fir predominate over beech in biomass. Fir dominates in biomass until the 450. year. Through a hundred years (450.-550.) beech and fir keep their biomasses in balance in order to take by fir domination after 550. year.

Air temperature alternations very often coincide with precipitations changes. Considering this situation we attempted to simulate examined plot according to conditions from 3., 4., 5., 6. scenario concerning precipitations changes in terms of warming and cooling.



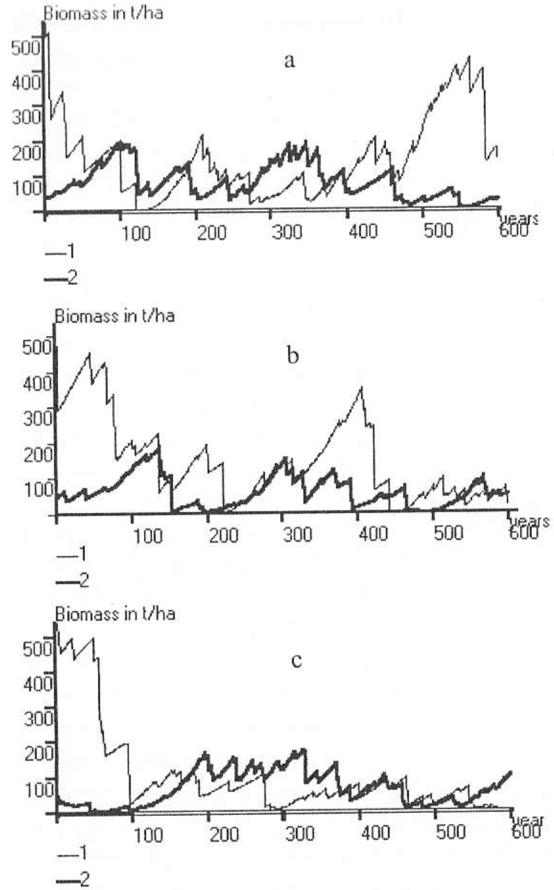


Fig. 4. One simulation run: a – control, b – 1. scenario, c – 2. scenario; 1 – *Fagus sylvatica*, 2 – *Abies alba*.

An increase in beech biomass was determined in 3. scenario where climate was warm and humid (Fig. 5a). That tendency appears also in first half and last 150 years of 4. scenario (Fig. 5b).

No statistically adequate differences were found in trees biomass while simulating both warm (5. scenario) and cold (6. scenario) dry climate. Only beech trees number was decreasing insignificantly with simultaneous increase in fir trees number in comparison to control situation.

It is noticeable that all simulation results are consistent with Sprugell's theory (1991). Sprugell claims that relatively small alterations of temperature and rainfalls can result in significant and long-lasting plants changes.

That Sprungell thesis was the inspiration for us to attempt modelling of beech forests changes not only influenced by temperature but also precipitation change. Similar simulations were run by Brzeziecki (1999) and resulted in the conclusion that *Fagus sylvatica* is dominant species, but when climate is dry then *Fagus sylvatica* does not appear. Alike results appear in other literatures (Krauchi, 1995), where mixture of long-lasting processes of succession and short-lasting processes of hydrology were used for more realistic ecosystem simulation.

Scenario No. 7 (alternate changes of air temperature) was used to simulate biomass and trees number changes while changing coefficient of amplitude and alternation period of sum of effective temperatures (sum of temperatures higher than 5 °C).

We based on presumption that period of warming lasts circa 200 years. We deduced it from IPCC's data – "business-as-usual", where appeared information about presumed increase in mean annual temperature by 0.3 °C for every decade by the year 2100 (IPCC, 1992) and other sources, which indicate rise of mean annual temperature by 2–5° in the next

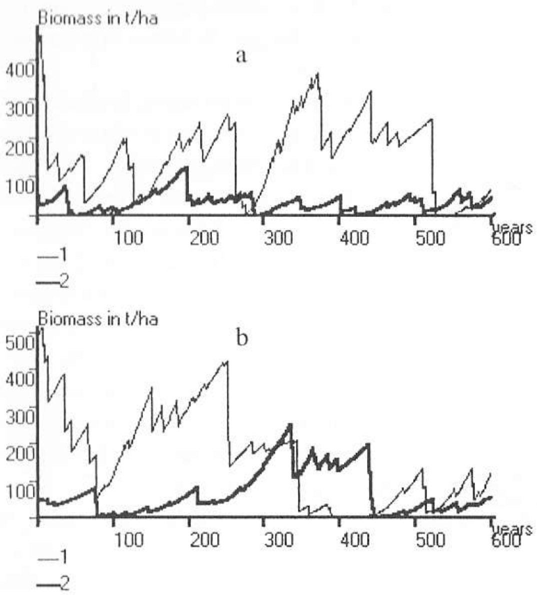


Fig. 5. Change in biomass in one simulation run: a - at 3. scenario, b - at 4. scenario.

100 years (Carter et al., 1995). On the other hand an increase in air temperature was visible during last hundred years for south Poland and the Carpathian Mountains (Bednarz et al., 1994; Obrebska et al., 1997). Analysing collected information 200-year alternation period for changes in temperature was constructed to represent future situation (Fig. 6).

The FORKOM model predicts a decrease in trees number during both highest and lowest temperatures in second half of simulation (Fig. 7b). After 270. year quite permanent, in comparison with control situation (Fig. 7a), reduction in trees number takes place. Further decrease in individual number can coincide with the next alternation height in 500. year.

Obtained results suggest that even smallest climate changes, especially in air temperature and rainfalls, can cause high fluctuation of sequel in succession. It is consistent with data presented in literature. For example, in Germany on plot Solling simulation of FORSUM model was performed with use of IPCC – "business-as-usual" climatic scenario which presumes raise of mean annual temperature by 0.3 °C for every decade by the end of XXI century (Krauchi, 1995). Simulation presumed, like our model, an increase in beech trees number. It was illustrated that *Picea abies* will definitely vanish from Solling site and will be replaced by *Luzulo-Fagetum* forest type including *Acer platanoides*, *Quercus petraea* and *Fagus sylvatica* (Krauchi, 1995). In view of the simulation it was noticed that decreasing number of *Picea abies* was caused by decreasing competitiveness. At the end of the century various species can afford an "attack" and successful establishment in the Solling area. Along with new species such as *Sorbus aucuparia*, *Salix alba* and *Betula pendula*, European beech is establishes easily .

## Conclusions

The FORKOME model predicts beech domination while mean annual air temperature increases by 2 °C and fir domination while temperature decreases by 2 °C.

The model also forecasts increase in beech biomass while precipitation increases. This tendency is also characteristic while climate is warming or cooling.



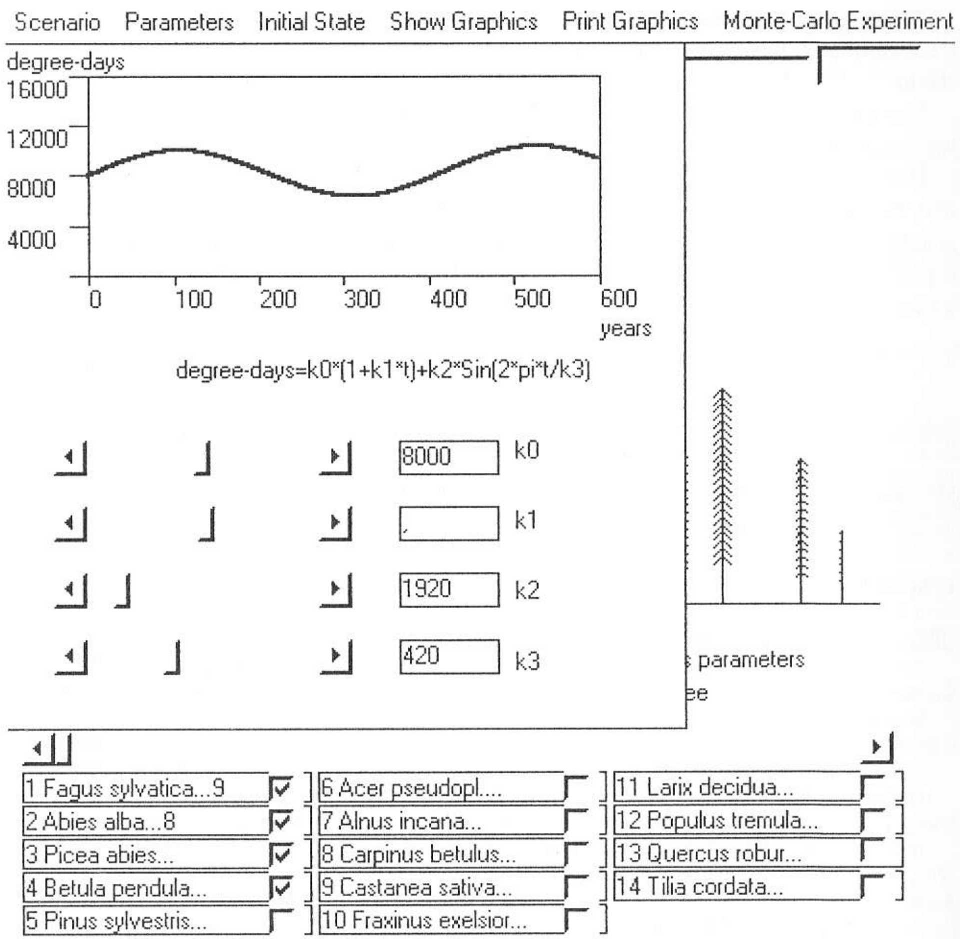


Fig. 6. Parameters of alternative air temperature changes at 7. scenario.

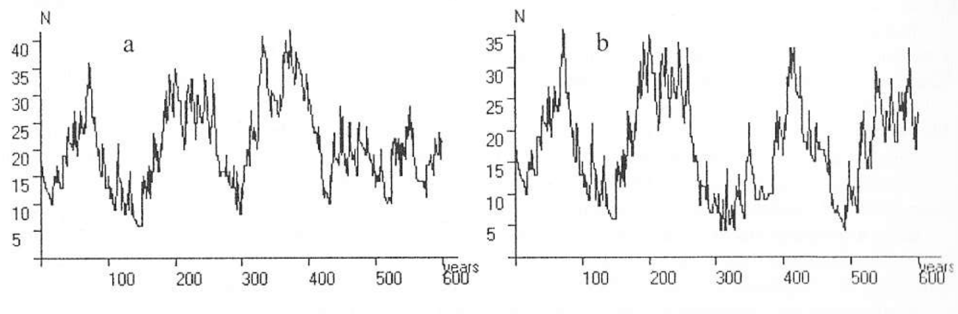


Fig. 7. Simulation of trees number. a - control, b - at 7. scenario.

An increase in dryness of climate while warming or cooling results in decrease in beech trees number with simultaneous increase in fir trees number in comparison to control situation.

Simulations performed by FORKOME model indicate high need to include alternate air temperature changes.

Results of FORKOME model simulations enable to set a thesis that forest succession may be used for evaluating a level of climate change impacts on forest ecosystems. Presented results indicate high usefulness of the model while investigating various subjects, especially concerning climate changes, which have both theoretical and practical importance

*Translated by the authors.*

*Acknowledgement*

The authors are grateful to the Polish Committee for Scientific Research (Grant No. 6 P06L 042 21) for supporting this work.

**References**

Bednarz, Z., Niedźwiedz,T., Obrębska-Starkel, B., Olecki, Z., Trepińska, J., 1994: Natural and antrophogenic fluctuations and trends of climate change in Southern Poland. Geogr. Polonica, *62*, p. 7-22.

Brzeziecki, B., 1999: Ecological model of forest stand: development, calibration and application (in Polish). Warszawa, 115 pp.

Carter,T., Posch, M., Tuomenvirta, H., 1995: SilmuScen and CLIGEN. User s Guide. Guidelines for the construction of climatic scenarios and use of a stochastic weather generator in Finnish Research Programme on Climate Change (Silmu).Publication of the Academy of Finland, 5, 95, p. 1-62.

Hong, S.He., David, J., Mladenoff, T., Crow R., 1999: Linking an ecosystem model and a landscape model to study forest species response to climate warming. Ecological Modelling, *114*, p. 213-233.

IPCC, 1992: 1992 IPCC Supplement. WMO/UNEP, 70 pp.

Kozak, I., Menshutkin, V., 2000: 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. Forestry, 3, p. 113-122.

Kozak, I., Menshutkin, V., 2001: Prediction of beech forest succession in Bieszczady Mountains using a computer model. Journal of Forest Science, *47*, 8, p. 333-339.

Kowalski, M., 1993: Changes in forest species composition as related to climate change during the last two centuries, In V$^{th}$ Symposium on the Protection of forest Ecosystems. Forest ecosystems versus climate change, Białowieża, p. 12-22.

Krauchi, N., 1993: Potential impact of a climate changes on forest ecosystems. Eur. J. For. Pathol., *23*, p. 28-50.

Krauchi, N., 1995: Application of the model FORSUM to the Solling spruce site. Ecological Modelling, *83*, p. 219-228.

Maxwell, B., 1992: Arctic climate. Potential for change under global warming. In F. S. Chapin III, R. L. Jefferies, J.F. Reynolds, G.R. Shaver and J. Svoboda (eds): Arctic Ecosystems in a Changing Climate, An Ecophysiological Perspective. Academic Press, San Diego, p. 11-34.

Menshutkin, V., Kozak, I., 1997: An Investigation of a mixed beech forest dynamics in Ukrainian Carpathians using a computer model. In Selected ecological problems of Polish-Ukrainian Carpathians (K. Perzanowski and M. Augustyn eds). Bieszczady, p. 23-29.

Obrębska, B., Trepińska, J., Rauczyńska- Olecka, D., Piotrowich, K., 1997: Changes in air temperature on a local scale in the Carpathian Foothills in relation to the global warming of climate at the end of 20$^{th}$ C. Acta Universitatis Wratislaviensis No. 1950. Prace Instytutu Geograficznego. Seria C. Meteorologia i Klimatologia, *4*, p. 23-26.

Puhe, J., Ulrich, B., 2001: Global climate change and human impacts on forest ecosystems. Postglacial Development, Present Situation, and Future Trends in Central Europe. Springer.

Shugart, H.H., 1984: Theory of forest Dynamics. Springer Verlag, NY, 278 pp.

Sprugell, D.G., 1991: Disturbance, equilibrium, and environmental variability: what is natural vegetation in a changing environment? Biol. Conserv., *58*, p. 1-18.

Zarzycki, K., 1963: Forests in West Bieszczady (in Polish). Acta Agr. Et Silv., ser. Leśna, *3*, p. 3-132.

*Received 12.7.2002*

Kozak I., Menshutkin V., Jóźwina M., Potaczała G.: **Modelovanie dynamiky bukového lesa v Bieszczady vo vzťahu ku klimatickým zmenám.**

V práci prezentujeme výsledky výskumu sukcesií bukového lesa v pohorí Bieszczady pri použití modelu FORKOME vo vzťahu ku klimatickým zmenám. Model sme verifikovali podľa terénnych výskumov v rokoch 1998-2001 v bukovom lese v oblasti Procisne v pohorí Bieszczady (Poľsko). Predpoveď stromovej biomasy a počtu stromov sme zamerali na nasledujúcich 600 rokov. Simulácia demonštrovala dominanciu, keď stredná ročná teplota sa zvýšila o 2 °C. Avšak so znížením teploty o 2 °C sa jedľa stala dominantnou na výskumnej ploche. Simulácie poukázali na porovnateľné výsledky štatistickej analýzy. 3. scenár (teplo a vlhkosť) ilustroval nárast bukovej biomasy. Tento trend je takisto charakteristický pre 4. scenár s parametrami pre chlad a vlhkosť. V opačnej situácii - suchá klíma (6. scenár – zima a sucho, 5. scenár – teplo a sucho), ktorá znižuje počet bukových stromov, v podstate zvyšuje počet jedlí. Zmena počtu stromov je významná v 7. scenári, kde teplota vzduchu kolíše.