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PROGNOSIS OF BEECH STAND DYNAMICS IN CLIMATE CHANGE CONDITIONS IN POLISH BIESZADY AND UKRAINIAN BESKYDY

Abstract. The study concerned forecasts for the dynamics of beech (*Fagus sylvatica* L.) stands in the Polish Bieszczady and Ukrainian Beskydy with the use of FORKOME model in different scenarios of climate changes. Simulation conducted in FORKOME model confirms that beech will exist in the Polish Bieszczady and Ukrainian Beskydy regions on the east boundary of beech areal. The changes in the Polish Bieszczady and Ukrainian Beskydy can be estimate as a positive for forest productivity and biomass accumulations. They were confirmed by fieldwork and events documented in the literature, which shows the reliability of the forecasts used FORKOME computer model. Work and study of this kind are necessary for rational forest management and to take appropriate development strategies.

Key words: *simulation, computer, modeling, forest, temperature, precipitation.*

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ПРОГНОЗ ДИНАМІКИ БУКОВИХ ДЕРЕВОСТАНІВ ЗА УМОВИ ЗМІНИ КЛІМАТУ В ПОЛЬСЬКИХ БЕЩАДАХ І УКРАЇНСЬКИХ БЕСКИДАХ

Анотація. Застосування на сьогоднішній день комп'ютерних моделей в екології дозволяє прогнозувати поведінку складних систем, до яких відносяться лісові екосистеми. Беручи до

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уваги специфічні умови лісів, аналіз їх динаміки вимагає використання імітаційних комп'ютерних моделей. Існують чисто лісові (growth-yield) моделі та екологічні (gap) моделі, які розвивались незалежно протягом тривалого періоду і взаємодоповнювались.

Лісові моделі зосереджувались на аналізі деревної продукції і не брали до уваги аспектів змін лісового середовища. Інші екологічні моделі, які також часто називають моделями процесів, враховують зміни лісового середовища у прогностичних імітаціях. Застосована у статті модель FORKOME (Kozak et al., 2012) містить елементи лісових і екологічних підходів і була спеціально розроблена для умов Польщі та України.

Метою дослідження було прогнозування можливих змін букових деревостанів у польських Бещадах та українських Бескидах протягом наступних 500 років із використанням моделі FORKOME у різних сценаріях зміни клімату.

Дослідження базувалось на зібраних матеріалах, отриманих у ході польових робіт у Польщі та в Україні. Бук у Бещадах і Бескидах активно експлуатувався в останні кілька століть. Після Другої світової війни експлуатація деревостанів у польських Бещадах послабилась у результаті депортації етнічних українців у 1944–1947 роках, проте, у букових лісах українських Бескид вона активно проводилась за часів Радянського Союзу. Усе це вплинуло не лише на структуру букових деревостанів, а також на накопичення біомаси у них і відображається у проведених комп'ютерних імітаційних прогнозах.

Дослідження стосувалось прогнозу динаміки букових (*Fagus sylvatica* L.) деревостанів у польських Бещадах і в українських Бескидах. Пробні площі були закладені у лісовому виділі № 13а у лісництві Процісне, надлісництві Ступосяни (49º11'23"N, 22º38'39"E) у Польщі і у лісовому виділі № 3 в Яблунецькому лісництві Надсянського ландшафтного парку (49º09 "47"N, 22º45'15"E) в Україні.

Прогнози показали, що у польських Бещадах і в українських Бескидах бук буде домінувати відносно біомаси у контрольному (1) сценарії, а також у кліматичних сценаріях тепло-волого (2), тепло-сухо (3). Деякі циклічні зміни між буком та ялицею помітні у контрольному сценарії. У 2 і 3 сценаріях модель FORKOME прогнозує можливе послаблення циклічних змін між біомасою бука та ялиці і підвищення біомаси бука. У 4 сценарії можливе збільшення біомаси ялиці до 500 т/га, а також у польських Бещадах і в українських Бескидах можливе збільшення біомаси ялини. У 5 сценарії біомаса бука може знизитись до 100 т/га.

Прогнозування, проведене у моделі FORKOME, підтверджує, що бук буде зростати у регіонах польських Бещад і українських Бескидів на східному рубежі його ареалу. Зміни у цих регіонах можуть бути оцінені як позитивні для продуктивності та біомаси лісів. Усі вони були підтверджені польовими дослідженнями та літературними даними, відображаючи надійність прогнозів із застосуванням комп'ютерної моделі FORKOME. Такі дослідження необхідні для раціонального ведення лісового господарства і прийняття відповідних стратегій розвитку лісів.

Ключові слова: *імітації, комп'ютерне моделювання, ліс, температура, опади.*

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ПРОГНОЗ ДИНАМИКИ БУКОВЫХ ДРЕВОСТОЕВ В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА В ПОЛЬСКИХ БЕЩАДАХ И УКРАИНСКИХ БЕСКИДАХ

Аннотация. В статье представлены результаты прогноза динамики биомасы бука в польских Бещадах и в украинских Бескидах с использованием модели FORKOME в различных сценариях возможного изменения климата. Прогнозирование, выполненное с помощью модели FORKOME, подтверждает, что бук будет произрастать в регионах польских Бещад и украинских Бескид на восточной границе его ареала. Изменения в этих регионах могут быть оценены как позитивные для продуктивности и биомассы лесов. Все они были подтверждены

полевыми исследованиями и литературными данными, что отображает надежность прогнозов, полученным при использовании компьютерной модели FORKOME. Такие исследования необходимы для рационального ведения лесного хозяйства и принятия соответствующих стратегий развития леса.

Ключевые слова: *имитации, компьютерное моделирование, лес, температура, осадки.*

INTRODUCTION

Computer models application in ecology allows the prediction of the behavior of complex systems to which forest ecosystems belong (Scheller, Mladendoff, 2007). However, taking into account the specific condition and arrangement of forests, the examination of their dynamics requires the use of particular tools (Bugmann, 2001). This role may be fulfilled by – adequately constructed – models of forest dynamics. The two existing methods of forest modeling, growth-yield modeling (Marszałek, 2011; Pretzsch et al., 2002) and ecological modeling (Bugmann, 2001; Botkin, 1993; Shugart, 1984) evolved independently over a long period, both competing complementing each other.

Most empirical growth-yield models based on permanent plot data implicitly assume that the future will be like the past, in terms of most environmental factors (Vanclay, 1994). This models are widely used in forestry, while the formerly widespread tabular statement of their results is now replaced by the corresponding regression models or integrated computer models of trees, such as SILVA (Pretzsch et al., 2002) or BWINPro (Nagel, Schmidt 2006).

Ecological (process) models provide reasonable results reflecting the projected state of the environment. Among the earliest computer models of the forest landscape were JABOWA (Botkin et al., 1972) and FORET (Shugart, West, 1977). Among the later constructions of patch models of the forest, based on those archetypes, include FORSKA (Prentice, Leemans, 1990), ZELIG (Urban, 1990) and SORTIE (Pacala et al., 1993). Descriptions of the theoretical and review of process models can be found in literature (Porte, Bartelink, 2002). Bugmann has presented an excellent overview on the gap model approach and the potential of ecosystem models to address the issue of climate change (Bugmann, 2001; Bugmann 2003).

A pursuant of above-mentioned trend in modeling the evolution of forest ecosystems is the patch model FORKOME (Kozak, Menshutkin, 2001; Kozak et al., 2012). The FORKOME model that contains elements of both ecological and growth yield strategy has been specially designed for the conditions of Poland and Ukraine.

The aim of the study was to carry out prognosis of possible dynamics of beech stands in Polish Bieszczady and Ukrainian Beskydy during the next 500 years with the use of FORKOME model in different scenarios of climate changes.

MATERIAL AND METHODS

The study plot «Beech 1» is located in Polish Bieszczady in the department No 13a at forestry Procisne of Stuposiany Forest District (49º11'23''N, 22º38'39''E) in Poland and «Beech 2» in Ukrainian Beskydy in the department No. 3 at Jabloneckie forestry of Nadsiansky Landscape Park (49º09'47''N, 22º45'15''E) in Ukraine.

Beech (*Fagus sylvatica* L.) dominated, and fir (*Abies alba* Mill.) as well as Norway spruce (*Picea abies* L. Karst.) codominated in all the areas. The mean DBH (diameter at breast height) for the plot «Beech 1» – 48,8 cm (max 120, min 6, standard deviation 38,2), for «Beech 2» – 27,1 cm (max 103, min 4, standard deviation 27,8). All the research areas were facing east and the ground slope was 6–9°. Statistical analyses of measurement of trees on the plots were performed using STATISTICA software. In all areas, DBH values are coming to form a normal, right-skewed distribution (Shapiro-Wilk test). Study plots were a 50×50 m rectangle. Each research area was constructed using standard measuring tape to establish a rectangular coordinate system (X axis along E–W and Y axis along

N–S line). The age was established with the help of Pressler drill. The diameter at breast height was measured using a dedicated meter at 1,3 m over the ground level. The tree height was measured with Leiss BL8 height-meter. In order to verify leaf area index (LAI) calculations, 9 hemispherical photographs were taken per research plot (camera Canon EOS 5D 12MP, Sigma 8mm f/3,5 DG FISH EYE lens with 180° viewing angle). The hemispherical photographs were analyzed with the help of the Gap Light Analyzer software (Frazer et al., 2000). Selected data were stored in csv. format and supplied to the FORKOME model.

The influence of climate changes (total effective temperatures and total annual precipitation) on the rate of beech replacement by other species was also the subject of this study. To this end, «temperature changes scenario» and «precipitation changes scenario» tools were used. No climate change scenario was used as 1 – control (1425 degree days on «Beech 1»; 1420 degree days on «Beech 2»; 718 mm on «Beech 1», 700 mm on «Beech 2»). Next, the following climate change scenarios are defined: 2 – temperature increase by 200 degree days and increase in precipitation by 100 mm; 3 – temperature increase by 200 degree days and decrease in precipitation by 100 mm; 4 – temperature decrease by 200 degree days and increase in precipitation by 100 mm; 5 – temperature decrease by 200 degree days and decrease in precipitation by 100 mm.

Model FORKOME (Kozak et al., 2012) was constructed with an aim to simulate the dynamics in forest stands considering the fate of single trees (fig. 1).

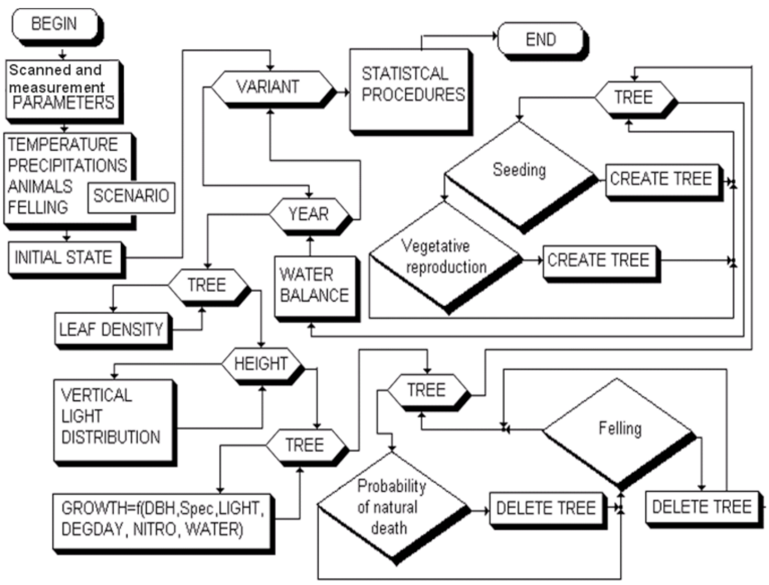


Fig. 1. **The algorithm of the FORKOME model**

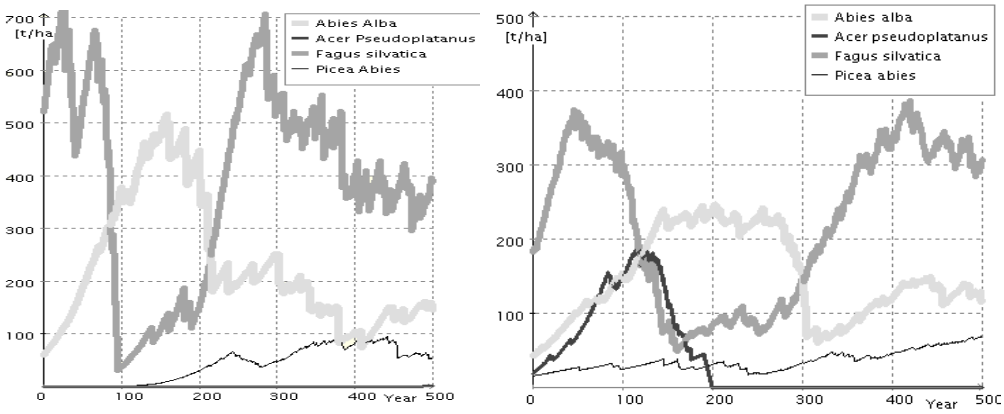
The model conducts simulation of reproductive processes (block BIRTH), growth (block GROWTH) and mortality (block DEATH) of trees during every year, as well as the influence of additional environmental and ecological factors upon the tree stand. Among the factors considered are annual sum of precipitation (block PRECIP), annual sum of temperatures effective DGD (degree days) for vegetation (block TEMP), nitrogen contents in the soil (block NUTRIENT), degree of shading of the area (block LIGHT) by tree crowns (Kozak et al., 2012). All forested areas in the model are analyzed on the basis of the above-mentioned blocks, considering the actual increase of DBH in Monte Carlo (200 runs) simulations. This model was already used in scientific projects in various regions of Poland, Ukraine and Sweden and contains continuously developed presentation layer, which allows for 3D visualization of trees.

RESULTS AND DISCUSSION

In both compared parts of the region, due to present management measures and spontaneous secondary succession, the foreseen change of tree stands at studied plots aims towards typical for this eco-region, climax forest associations, dominated by beech with an admixture of fir, sycamore and spruce. Only the character of those changes will be different in Polish and Ukrainian parts, which is connected with different present state of tree stands, reflecting different management measures in the past. Beech in the Bieszczady Mountains and the Beskydy Mountains actively managed up to World War II. After World War II Polish Bieszczady stands were less used due to deportation of Ukrainians (Gil, 2004) in 1944–1947, however, in the Beskydy Mountains beech forests were actively managed in the times of the Soviet Union. All this affected not only the structure of the beech stands, as well as biomass accumulation in them and reflected in conducting computer simulations. Depopulation of Polish Bieszczady has changed the character of this landscape, and caused a decrease of anthropogenic influence upon forests of this region. Effects of spontaneous secondary succession were reinforced by reforestation of former agricultural land at the area of abandoned villages, fields and pastures. Such was an origin of a considerable part of present forest cover: 45 % in Lutowiska Forestry, 32 % in Stuposiany Forestry, and 41 % in Ustrzyki Dolne Forestry (Marszałek, 2001). However in the part of Ukrainian Beskydy the anthropogenic influence upon forests had increased (Tretiak et al., 2001). In an effect, visible now is not only a difference in the proportion of forest cover between those neighboring regions, having very similar ecological conditions (present maximal percentage of forests in Polish forest districts reaches 80 %, while in Ukrainian forest districts only 47 %), but also a difference in medium age of tree stands (78 years in Polish part and 56 in Ukraine part), as well as the accumulation of biomass (on average over 300 m^3/ha and about 200 m^3/ha in Polish and Ukrainian parts respectively).

We considered above mentioned parameters during the selection of our study plots, to assure their representativeness. Forest taxation parameters of selected plots confirm this visible tendency being a result of former changes in forest management. Standing crop of biomass in the zero year of the prognosis at plots «Beech 1» in the Polish part is higher comparing to values at plots «Beech 2» in Ukrainian part.

Analyses of the diagrams indicate that under the control (1) scenario in the first year of simulation beech dominated in all plots. Beech biomass will dominate during the period predicated at 90 years on the plot 1 (fig. 2, *a*), 110 years on the plot 2 (fig. 2, *b*). In the next time fir will dominate for 100 years on the plot 1, for 200 year on the plot 2, than beech dominate again. In the control scenario cyclical changes between beech and fir are visible

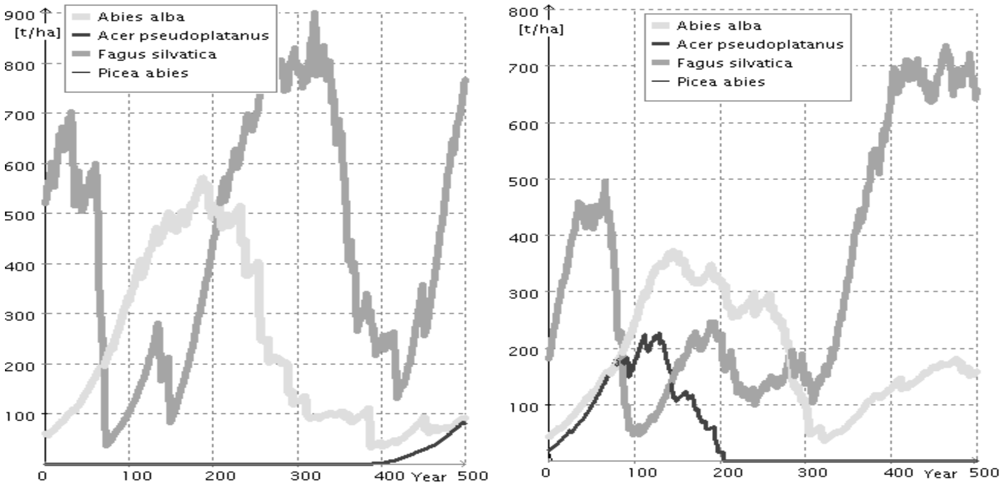


a *b*

Fig. 2. **Prediction of beech stands biomass in 1 scenario:**
a – Beech 1; *b* – Beech 2

in the Polish Bieszczady and Ukrainian Beskydy. In plots 1 beech biomass increase to 700 t/ha, and in the plot 2 beech biomass will increase to 400 t/ha. However, inconsiderable domination of beech biomass occurs at the end of prognosis time (fig. 2, *a*; fig. 2, *b*). Other species as maple up to 180 t/ha (fig. 2, *b*), spruce up to 90 t/ha of biomass (fig. 2, *a*; fig. 2, *b*) fragmentary presented.

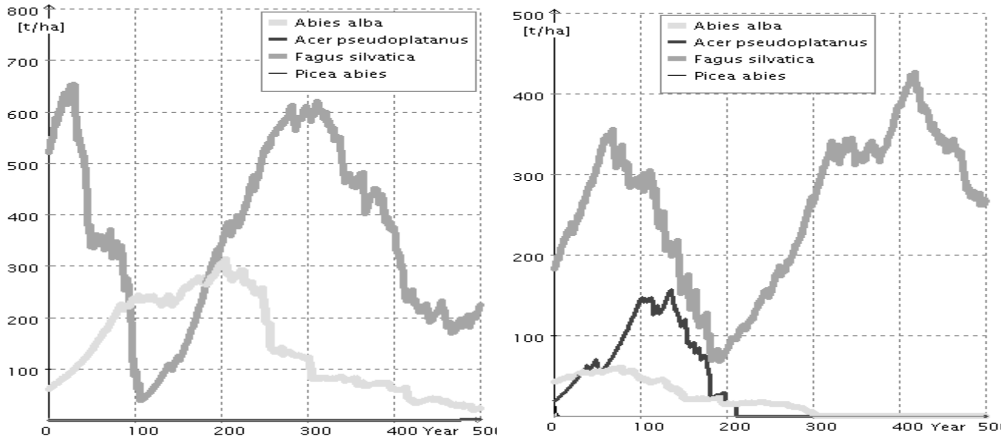
In 2 scenario beech biomass increase up to 900 t/ha on the plot 1, to 740 t/ha on the plot 2 (fig. 3) and FORKOME model predict possible facilitating of cyclical changes between beech and fir biomass dynamic.



a *b*

Fig. 3. **Prediction of beech stands biomass in 2 scenario:**
a – Beech 1; *b* – Beech 2

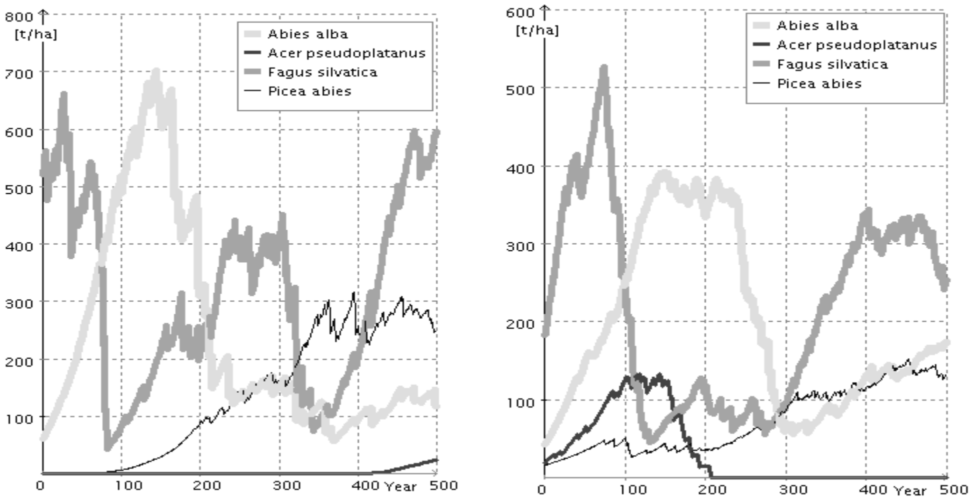
In 3 scenarios beech will dominated, but biomass decreased (fig. 4) and model predict also possible lack of cyclical changes between beech and fir biomass dynamic.



a *b*

Fig. 4. **Prediction of beech stands biomass in 3 scenario:**
a – Beech 1; *b* – Beech 2

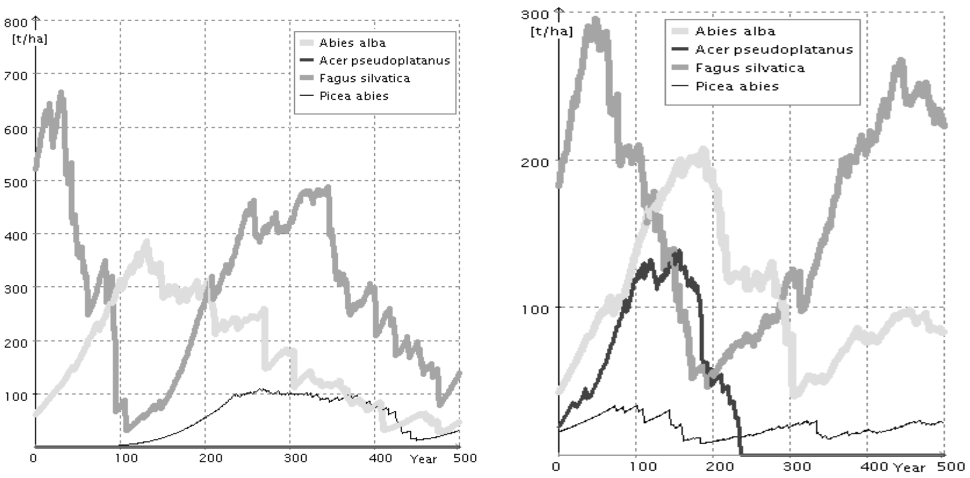
In 4 scenario (fig. 5) fir biomass increase up to 700 t/ha (fig. 5, *a*). In the Polish Bieszczady and Ukrainian Beskydy occurs possible increase of spruce biomass (fig. 5, *a*; fig. 5, *b*).



a *b*

Fig. 5. **Prediction of beech stands biomass in 4 scenario:**
a – Beech 1; *b* – Beech 2

In 5 scenario (fig. 6) the beech biomass decreased up to 100 t/ha on the Beech1 and Beech 2 research plots. On the plot Beech 2 biomass of beech increase for the sycamore costs.



a *b*

Fig. 6. **Prediction of beech stands biomass in 5 scenario:**
a – Beech 1; *b* – Beech 2

The FORKOME model is a good enabler to obtain results that prove the thesis assumed in our paper. Diagrams presenting results of prognosis of plots 1 – «Beech 1», 2 – «Beech 2» are placed in the paper under the control (1) scenario, as well as in 4 climate changes scenarios. We carried out simulations with the FORKOME model in research areas of 50×50 m (1/4 ha). Therefore, within of the 2500 m^2 of the area, 200 used simulation sequences correspond with equilibrium landscape of 50 ha. In other types of models, for instance the JABOWA model (Botkin et al., 1972), 10×10 m areas were used with 100 simulations. The smallest area was 0,5 ha and was used in the FORSKA model (Prentice, Leemans, 1990).

Results obtained from the prediction research correspond to results obtained from field works (Jaworski, Podlaski, 2006; Kozak, Menshutkin, 2001). The FORKOME model proved to be efficient tools adjusted to the research regarding dependences and changes in species structure of forest stands and species biomass. It is possible to devise methods in the model to analyze many parameters of forest stands conditions at the same time what allows obtaining precise results. The FORKOME model enables analyzing the dynamics of forest stands in regard to climate change conditions during any period of time, chosen by the user of the model. Obtained simulation results concerning increased beech biomass can influence to the species composition of tree stands and also to decreased the regeneration and growth of other species (Gessler et al., 2007).

Simulation conducted in FORKOME model confirms that beech will exist in the Polish Bieszczady and Ukrainian Beskydy regions on the east boundary of beech areal. Using computer models for such type of analysis are on the table (Brooker et al., 2007). Important is analysis of temperature and precipitation influence on beech stands. Beech biomass is more sensitive to the precipitation than to the temperature. Precipitation growth rate can decrease up to 0,82. Calculated in FORKOME model cross correlation showed negative influence of precipitation on beech biomass (correlation coefficient – 0,95). Climate changes in the Polish Bieszczady and Ukrainian Beskydy can be estimated as a positive for forest productivity and biomass accumulations. Similar results obtained for north and west Europe (Lindner et al., 2010). Beech stands in Polish Bieszczady and Ukrainian Beskydy regions have plausibility of species composition changes due to climate changes (Dale et al., 2010).

Longer (500 years) time of simulation was used to shown the cycle of biomass changes that were demonstrate in the literature (Shugart, 1984). In the other regions simulation time was 500 and 600 years (Kozak, Menshutkin, 2001). The changes of biomass in computer simulations of beech stands with use of FORKOME model defining their directions regarding possible climate change conditions in Polish Bieszczady and Ukrainian Beskydy and are important issues in forest management, both from the theoretical and practical point of view.

CONCLUSIONS

After World War II the beech forests in the Bieszczady Mountains were less used but in the Beskydy Mountains beech forests were actively managed. All this affected not only the structure of the beech stands, as well as biomass accumulation in them and reflected in conducting computer simulations. Standing crop of biomass in the zero year of the prognosis at plots «Beech 1» in the Polish Bieszczady is higher comparing to values at plots «Beech 2» in Ukrainian Beskydy. In Polish and Ukrainian parts beech will maintain its domination regarding biomass in the control (1), warm humid (2), warm dry (3), cold humid (4) and cold dry (5) climate scenario. Same cyclical changes between beech and fir show in the control scenario. In 2 and 3 scenario FORKOME model predict possible facilitating of cyclical changes between beech and fir biomass dynamic and increasing of beech biomass. In 4 scenario fir biomass increase up to 500 t/ha. In the Polish Bieszczady and Ukrainian Beskydy possible increase of spruce biomass. In 5 scenario the beech biomass decreased up to 100 t/ha.

Simulation conducted in FORKOME model confirms that beech will existence in the Polish Bieszczady and Ukrainian Beskydy regions on the east boundary of beech areal. The changes in the Polish and Ukrainian Carpathians can be estimate as a positive for forest productivity and biomass accumulations. They were confirmed by fieldwork and events documented in the literature, which shows the reliability of the forecasts used FORKOME computer model. Work and study of this kind are necessary for rational forest management and to take appropriate development strategies.

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