

A prognosis for the impact of climate change on beech stand dynamics in the Polish and Ukrainian Roztoche region

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Abstract. This study has been carried out in the Polish Roztoczański National Park and the Ukrainian Ravs'ke Roztochia Regional Landscape Park, both of which are part of the Roztoche region. In each of these two locations, representative study plots were established in beech (*Fagus sylvatica* L.) stands occupying sites with similar environmental conditions. A longterm prognosis for the dynamics of the chosen beech stands were generated using the computer model FORKOME. The model was used to forecast stand developments for four climatic scenarios (warm-humid, warm-dry, cold-humid, cold-dry) covering a time span of 500 years. Our simulation results indicate that in the control scenario, beech stands were dominating and cyclical changes between beech and Silver fir (*Abies alba* Mill.) may occur. In the scenarios with assumed climate warming, a decline of fir biomass and an increase of beech biomass, as compared to the control conditions, was noticed. In the scenario with assumed climate cooling, fir biomass increased for the duration of the investigated time span. To conclude, the application of the FORKOME model was found to be a useful tool for analyzing potential scenarios of long-term dynamics of beech stands in the Roztoche region in Poland and Ukraine.

Keywords: climate change, FORKOME model, tree competition, simulation, Roztoche

1. Introduction

Climate is changing. Over the past 100 years, the average global temperature has increased by approximately 0.7°C (IPCC 2007). During the same period, the average temperature in Europe increased even more – by 0.95°C. According to the forecasts formulated by the Intergovernmental Panel on Climate Change (IPCC), a further, significant increase in the average annual temperature in Europe is expected by the end of the 21st century. It is estimated that over the next 100 years, temperatures in Europe will increase from 2.0°C to 6.3°C (IPCC 2007). The sum of precipitation and the frequency of extreme weather events are also expected to increase (Lindner et al. 2010).

Diverse responses of different tree species to environmental changes are the main determinants of the structural transformations of stands and entire natural systems (Milada et al. 2011), and therefore, climate change should be taken into account in the current and future forest management strategies.

The above postulate especially concerns the areas situated close to the natural limits of tree species ranges. The Roztoche (Roztocze) region is one of such areas. There occurs the natural boundary of common beech (*Fagus sylvatica* L.), one of the main forest forming species in Poland (Maciejewski 2011). Predicting the dynamics of beech stands within the north-eastern limit of beech occurrence in consideration of climate changes, is of much importance – both from scientific and practical standpoints. High dynamics of beech stands has been indicated in many studies carried out in the Polish (Maciejewski 2011, Maciejewski, Szwagrzyk 2011) as well as the Ukrainian (Stojko 2000, Cherniavskiy, Savka 2004) parts of the Roztoche region. The observed transformations in the construction of beech forests can be, among others, due to the current climate change, as beech forest communities in Europe are susceptible to climate variations (Dale et al. 2010).

The forecasting of multi-annual dynamics of forest stands requires the use of special tools, that is, properly designed

Submitted: 5.12.2016, reviewed: 14.01.2017, accepted after revision: 30.01.2017

computer models. One of them is the model of forest growth JABOWA (Botkin et al. 1972), from which originates a large group of the so-called gap models of forest stand dynamics, and among others – FORET (Shugart, West 1977) designed to forecast the forest dynamics in the southern United States. Based on JABOWA, a number of models have been used to simulate and forecast forest dynamics in Europe: FORSKA (Leemans, Prentice 1989), FORCLIM (Bugmann 1997, 2001), FORECE (Kienast 1987) and FORSUM (Kraeuchi 1995). The models of this type were also constructed in Poland: FORKOME (Kozak et al. 2003, 2005, 2012, 2014), FORBIG (Kozak, Brzeziecki 2007) and FORLAS (Zajączkowski et al. 2013)

The assumptions concerning the use of gap models in the Polish forests were initially presented by Brzeziecki (1991, 1999). A contribution to this field was also made by Szwarzgryk (1994), as well as the model PICEAT that simulates the growth of spruce monocultures in the Sudety Mts. (Pawłowski 1996). The gap models give a great opportunity to meet the needs and challenges associated with the rising popularity of cultivating semi-natural forests and a tendency to replace monoculture forestry with ecosystem forestry (Brzeziecki 1999). The model FORKOME has already been used to simulate tree dynamics in the Kampinoski National Park (Kozak et al. 2005), the Bieszczady National Park (Kozak, Menshutkin 2001, Kozak et al., 2003, 2014), the Helgedomen Reserve in Sweden (Kozak et al. 2012) as well as in Ukraine (Kozak, Menshutkin 2002).

The main aim of the present study was to perform the forecasts of changes in beech stands in the Polish and Ukrainian parts of the Roztoche (Roztocze) region, with the use of the model FORKOME, assuming different scenarios of climate change (unchanged – control conditions, warm-dry, warm-humid, cold-dry and cold-humid). The scope of the research also included checking competition relations between beech and fir (cross-correlation analysis) and investigating the effects of changes in the sum of effective temperatures and precipitation on these relations.

2. Materials and Methods

Field trials were conducted in the years 2013–2015, in the Roztochanski National Park (Roztoczański Park Narodowy) (N: 50°35'29, E: 22°57'35) in Poland and the Ravens'ke Roztochia Regional Landscape Park (Rehionalnyj Landshafnyj Park Ravens'ke Roztochia) in Ukraine (N: 50°13'23, E: 23°31'27). In each park, 3 study areas with similar habitat conditions were established. From these, in each park, 1 representative study plot was chosen. Common beech dominated in the stands of all the study areas, and a greater share of Silver fir (*Abies alba* Mill.) was observed in Poland's part. The studied stands grew on brown soils (Tittenbrun 2013), on which there have developed humid and nutrients rich forest sites. In the study plot no. 1 – Beech 1, average DBH of beech was 41.2 cm and in the plot no. 2 – Beech 2 – 34.3 cm (Table 1). The study areas established were representative for the Roztoche region (Roztocze).

All the study areas had western exposure and 10°–11° slope. Each of them had a square shape with a side of 25 m (625 m²). Such size is often used in gap models (Bugmann 2001). After conducting 200 test simulations for each study plot, it was found that the area observed corresponded to the district with the area of $200 \times 0.0625 = 12.5$ ha. Statistical analysis of the data obtained (the Shapiro-Wilk test performed with the use of STATISTICA) showed that DBH of the examined trees had normal distribution with marked right-sided asymmetry.

The trees observed on the study plots were numbered and their DBH, height, crown radius, age, as well as X and Y co-ordinates were recorded. Hemispherical photographs (9/plot) were taken as required for verifying the leaf area index (LAI) calculations performed by FORKOME. A digital SLR camera – Canon EOS 5D with Sigma 8mm f/3.5 DG EX FISH EYE with 180° viewing angle— was used. Gap Light Analyzer software (Frazer et al. 2000) was used for hemispherical analyses. All data collected on the study plots were entered into the model FORKOME (Kozak et al. 2012) and

Table 1. Basic characteristics of the trees that are present on research plots

| Plot | Species | D (cm) | | | H (m) | | | Age (years) | | | N |
|------|------------------------|--------|------|------|-------|-----|------|-------------|-----|-----|------|
| | | mean | min | max | mean | min | max | mean | min | max | |
| 1 | <i>Abies alba</i> | 15.8 | 5.0 | 24.0 | 14.6 | 5.0 | 21.0 | 35 | 10 | 70 | 11.0 |
| 1 | <i>Fagus sylvatica</i> | 41.2 | 11.0 | 98.0 | 21.4 | 8.0 | 39.0 | 78 | 22 | 185 | 29.0 |
| 2 | <i>Abies alba</i> | 5.1 | 4.0 | 8.0 | 3.2 | 2.0 | 5.0 | 11 | 8 | 17 | 5.0 |
| 2 | <i>Fagus sylvatica</i> | 34.3 | 8.0 | 79.0 | 18.4 | 6.0 | 37.0 | 65 | 21 | 156 | 24.0 |

D – d.b.h., H – height, N – number of trees

simulations of stand development over a period of 500 years were carried out (such a long simulation period was needed for stabilizing beech and fir relationships in the stands in the Polish and the Ukrainian parts of the Roztoche region).

The model FORKOME belongs to the group of gap models that simulate the long-term dynamics (succession) of forest complexes, taking directly into account the influence of the most important environmental factors, such as: temperature, precipitation, light, soil nutrient content, on the main processes taking place in the stands: regeneration, growth and decline of individual trees.

The design and structure of FORKOME were described in detail in earlier publications (Kozak, Menshutkin 2001; Kozak et al. 2003, 2012, 2014). This model is largely similar to the model FORET (Shugart, West 1977) and – in the case of some solutions including calculations of light quantities – to the model JABOWA 3 (Botkin 1993). FORKOME also contains a number of original solutions and elements, such as, among others: the method of simulation of fluctuations in thermal conditions, elements of the water balance within a given site and an extent of tree transpiration.

From the programming point of view, the concept of the so-called object is of major importance in model construction. The crucial objects in FORKOME are: 'Area'— representing the surveyed stand and 'Tree'— representing an individual tree. Simulation of growth and development of individual trees is based on environmental conditions (climate, soil, light) that prevail in a given stand (defined in the object 'Area'). Each tree species has specific, quantified habitat requirements. If the site conditions meet the minimum species requirements, then the species is allowed to develop. The final status of the simulation in one year constitutes the input status for the simulation in the following year.

The model FORKOME is divided into modules (blocks) (Fig. 1). The block 'Parameters' contains parameters describing each tree species and the entire forest community. These parameters include: the maximum tree diameter at the standard height of 130 cm from the ground (D_{max}), the maximum height (H_{max}), the maximum age (AGE_{max}) and the minimum and maximum sums of air temperature (DGD_{min} , DGD_{max}). Other parameters related to different development scenarios were added to the model. Because

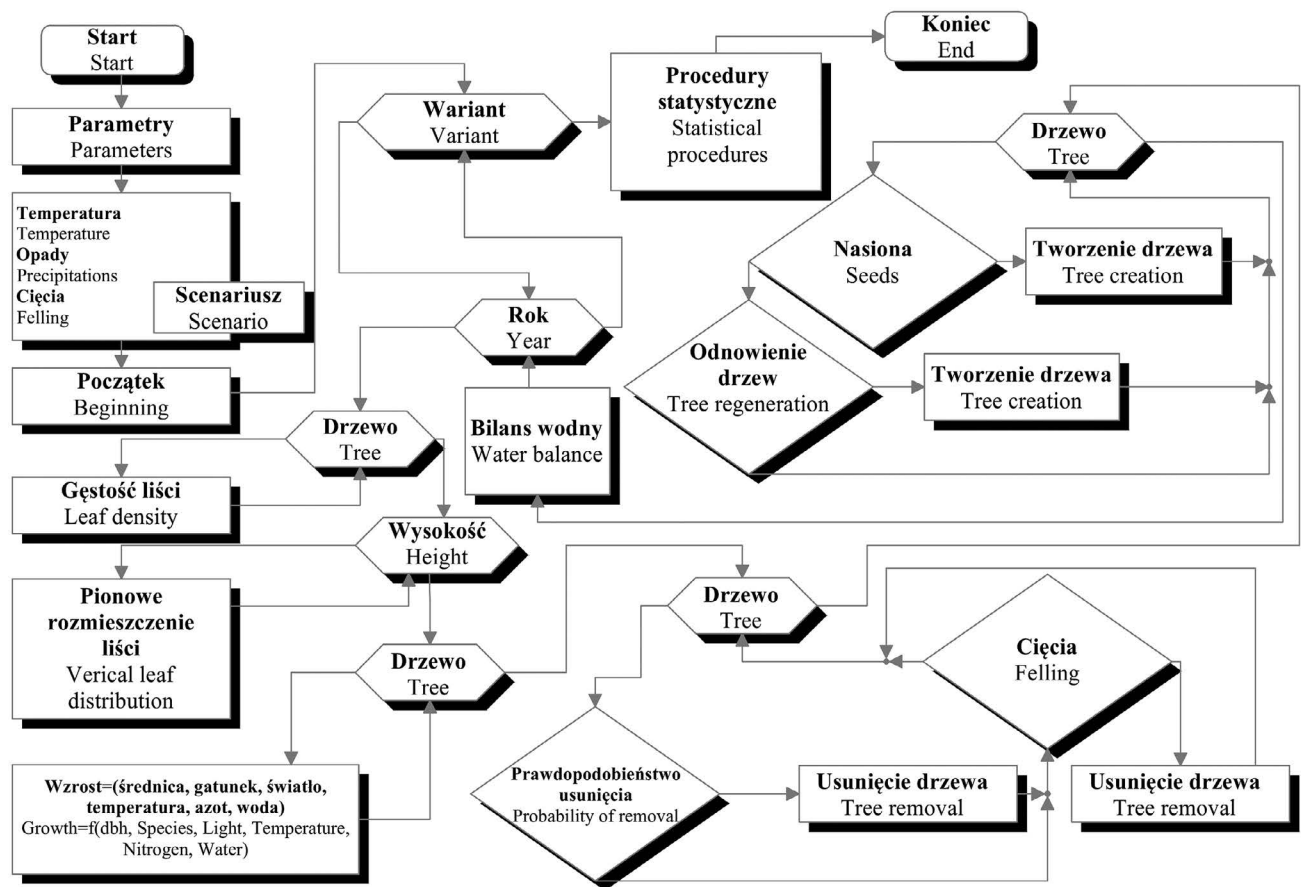


Figure 1. The block diagram of FORKOME model

se the model is stochastic, its dynamics need to include several variants (the ‘Variant’ block). These are controlled by the ‘Year’ block. The model time step is one year. The block diagram shown in figure 1 was expanded with additional blocks and options, including cutting trees, changing air temperatures, and increasing and decreasing precipitation (‘Scenario’ block). The model uses the Monte-Carlo statistical method to simulate 200 variants of forest development in each scenario. After carrying out the Monte Carlo analysis, the program allows to present and print the results on the average tree number and biomass along with standard deviations for each simulation year. In the ‘Statistical Procedures’ block, the option to calculate autocorrelation and cross-correlation functions was added.

One of the most important modules of the model is the ‘Growth’ block. This block calculates the annual increment of each tree occurring in the simulated area (stand patch with defined environmental conditions). The basic calculated factor is DBH increment. The annual tree increment can be from 0 to the value of possible increment in the ideal environmental conditions (optimal in terms of a given tree species requirements) and is calculated according to the formula:

$$\delta(D^2H) = rLa \left(1 - \frac{DH}{D_{\max} H_{\max}} \right)$$

where:

r – constant for species, delineating the photosynthetic productivity of the assimilation apparatus ($\text{cm}^3/(\text{cm}^2 \text{ year})$),

La – leaf area of a given tree (m^2),

D – tree DBH (cm),

H – tree height (cm),

D_{\max} – maximum DBH of a given tree species (cm),

H_{\max} – maximum height of a given tree species (cm),

$\delta(D^2H)$ – increase in tree volume (cm^3).

Based on DBH, using a variety of allometric relationships, a number of other parameters of the simulated tree are calculated, for example – tree height. The influence of external conditions is also taken into account in the annual growth of trees. In the model FORKOME, the actual increment of a real tree $_{real}$ is calculated as the product of the optimal tree increment $_{opt}$ and tree growth limiting factors (f_1, f_2, f_3, \dots), each of which has a value in the range [0,1]:

$$\delta(D^2H)_{real} = \delta(D^2H)_{opt} \cdot f_1 \cdot f_2 \cdot \dots \cdot f_j$$

where:

$\delta(D^2H)_{real}$ – current tree volume increase, after taking into account the effects of external factors (ecological),

$\delta(D^2H)_{opt}$ – tree growth under optimal conditions,

f_1, f_2, f_3, \dots – coefficients determining the influence of the current system of external factors (ecological) expressed on a scale from 0 to 1.

On a regular basis, light availability is the main external factor limiting tree growth. In the model FORKOME, when calculating the amount of light that reaches a particular tree, the loss of solar radiation due to overall shading is taken into account, which is caused by the leaf area of higher trees within the simulated stand area. The mean light intensities are determined at different distances from the ground, comparable to individual tree heights. In terms of light requirements, the tree species observed were divided into three main types: photophilous, intermediate and shade tolerant.

The thermal conditions in the model are determined by the annual sum of effective temperatures (the sum of daily temperatures calculated for the period in which the average temperature exceeds 5 °C). The coefficient expressing the temperature effect on tree growth is calculated from the formula (Botkin 1993):

$$T = \frac{4(DGD - DGD_{\min})(DGD_{\max} - DGD)}{(DGD_{\max} - DGD_{\min})^2}$$

where:

T – growth limiting indicator,

DGD – the sum of effective temperatures characteristic for a given site,

DGD_{\min} – minimum sum of effective temperatures necessary for species existence,

DGD_{\max} – maximum sum of effective temperatures necessary for species occurrence.

The model FORKOME included transpiration dependent not only on general meteorological parameters, as in other gap models, but also on tree species specificity. Furthermore, the effect of groundwater levels (changing) on the occurrence of trees of different species was taken into account, as along with the relationship between tree growth and soil water content, as it was originally built in this very model (Kozak et al. 2003). Another built-in factor limiting tree growth is the so-called site index. The index is determined on the basis of the ratio of current total DBH cross sectional area of the trees in the simulated stand to the maximum area achievable under the conditions of a given site (Botkin 1993).

Tree declining was simulated in the block ‘Death’. The death of a tree occurs in two cases: 1) when a certain minimum increment has not been achieved, and 2) inadvertently, that is, irrespective of tree growth. In the first case, the model is based on the assumption that if a tree does not reach the minimum increment for 10 consecutive years, the probability of its survival in this period of time is 1%. In the second case, the assumption is made that only a small proportion of healthy trees of a given species reaches the maximum age achievable. The model assumes that only 2% of healthy trees reach the maximum age, as shown by the inequality below (Botkin 1993):

$$RND < \frac{4,0}{AGE_{max}}$$

where:

RND – random number in the range $[0,1]$,

AGE_{max} – maximum age of trees of a given species.

In the block ‘Tree Regeneration’, the appearance of young trees is simulated as a stochastic process (Botkin 1993). For each species, the empirically determined maximum number of new trees are considered that can occur within 1 year in a stand of a given size. The maximum number of new trees of a given species is reduced to the extent reliant upon fortuitous events and the amount of light entering the forest floor. For each of the three types of light tolerance, different seedling values are generated.

Further options included in the model allow the user to set basic simulation parameters, as well as those of the analysed area and tree species (Fig. 2), and also – to select a scenario for possible climate change by defining the scope and nature of changes in the sum of effective temperatures DGD and precipitation.

In the analysis of climate processes in the model FORKOME, aggregation of climate factors approach was used (Kahn. 1994). The main environmental factors related to climate (annual temperature amplitude, mean temperature of the vegetation season, sum of precipitation in the vegetation season) were taken into account. Climate scenarios were developed to verify a hypothesis of beech survival on the surveyed areas in Roztoche, under the conditions of different climate change variants.

Additionally, the tool ‘Temperature change scenario’ was used to include in the model adding/subtracting temperature changes to the control temperature value (1425 ‘degree-days’ and 1435 ‘degree-days’ for the first and second study area, respectively): plus 200 ‘degree-days’ for the scenarios warm-dry and warm-humid, and minus 200 ‘degree-days’ for those cold-dry and cold-humid. The tool ‘Scenario of Precipitation Change’ was used to simulate 100 mm increase/decrease in the mean annual precipitation. Precipitation control value for the first study area Beech 1 was 718 mm (data from the meteorological station Zwierzyniec, Poland), and 713 mm for the second study area Beech 2 (data from the meteorological station Rawa Ruska, Ukraine). The presented scenarios assume that the forest is left alone, that is, forest management, including different types of cutting, is not taken into account.

3. Results

The results of the multi-year forecasts with regard to the development of tree stands occurring on the analysed study

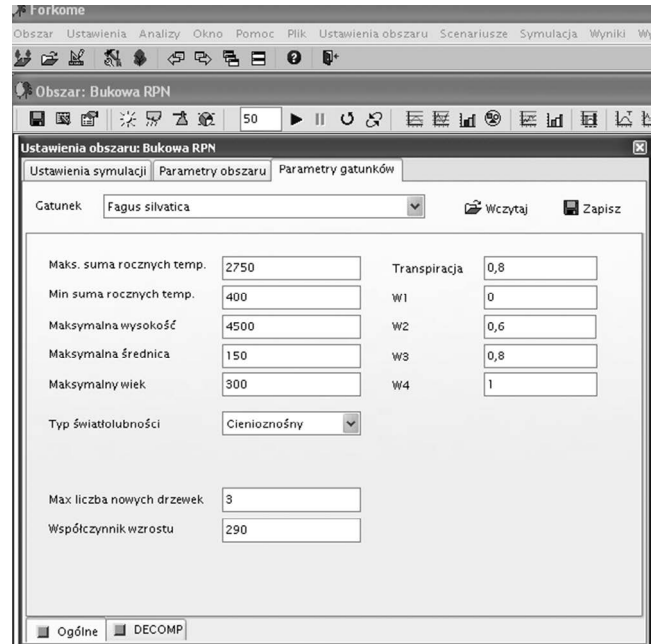


Figure 2. View of the interface on general parameters of trees in the FORKOME model

Area, Settings, Analysis, Window, Help, File, Area settings, Scenarios, Simulation, Results, Beech RPN (Roztochanski National Park), Simulation settings, Area parameters, Species parameters, Species, Load, Save, DGD-max, DGDmin, Maximum height, Maximum DBH, Maximum Age, Shade tolerance type, Maximum saplings amount, Growth coefficient, Transpiration, General, Decomposition

areas – Beech 1 and Beech 2, performed using the model FORKOME, are presented in figures 3–7.

In all the analysed scenarios, within the study area Beech 1, beech (260 t/ha, 76.5% of total stand biomass) was dominant in the first simulation year. Fir trees (23.5%) constituted the remaining part of the Beech 1 stand. The study area Beech 2 was also dominated by beech (201 t/ha, 98.4% of the total stand biomass), whereas the share of fir was negligible (1.6%). The graphical comparison of the Monte Carlo simulation results obtained for the control scenario (no climate change) suggests cyclic replacement of beech by fir and vice versa (Fig. 3). The greatest increase in the role of beech at the expense of fir is visible on Beech 2, during the 220 years – starting from the beginning of the simulation. After this period, beech biomass drops and that of fir grows. However, this does not take long because after the next 140 years, the beech share starts to increase again. In the last period of the simulation, there also appeared admixtures of common hornbeam, pedunculate oak and sycamore maple in the simulated stands (larger on Beech 2). The results of FORKOME forecasting show that in view of forest silviculture, forest succession is relatively slow in the

studied areas. Beech and fir by turn maintain their dominance in terms of biomass and the number of trees. The comparison of these species parameters, as developed by Kahn (1994), with data from the FORKOME simulation using conditions in the Roztoche region, show that beech and fir are not sensitive to changes in the average temperature of the growing season, as well as to the changes in the mean value of temperature amplitude; however, they are somewhat vulnerable to precipitation volume in the growing season. Beech growth rates may slightly decrease (average value of growth factor = 0.82) in the case of decreasing rainfall.

In the scenario 1 – warm-humid (WH), the model FORKOME predicts a possible weakening of cyclic changes between beech and fir. On Beech 1 (Fig. 4a), beech dominates

over fir during the whole simulation period. Similar, and even greater, beech dominance occurred on Beech 2 (Ukrainian part) (Fig. 4b).

In the scenario 2 (warm-dry, WD, Fig. 5), assuming a climate change towards warmer and drier conditions than those existing now, the model predicts a decline in cyclical changes beech and fir shares. Beech biomass significantly decreased on both study areas (from 300 t/ha in the first half of the forecast to 150 t/ha in the second). The admixture species that occurred were hornbeam (for most of the simulation period), maple sycamore and pedunculate oak. The latter increased its share to 120 t/ha at the end of the forecast period (Fig. 5a).

In the scenario 3 (cold-humid, CH, Fig. 6), fir reached the largest biomass share in 270 simulation years on Beech 1,

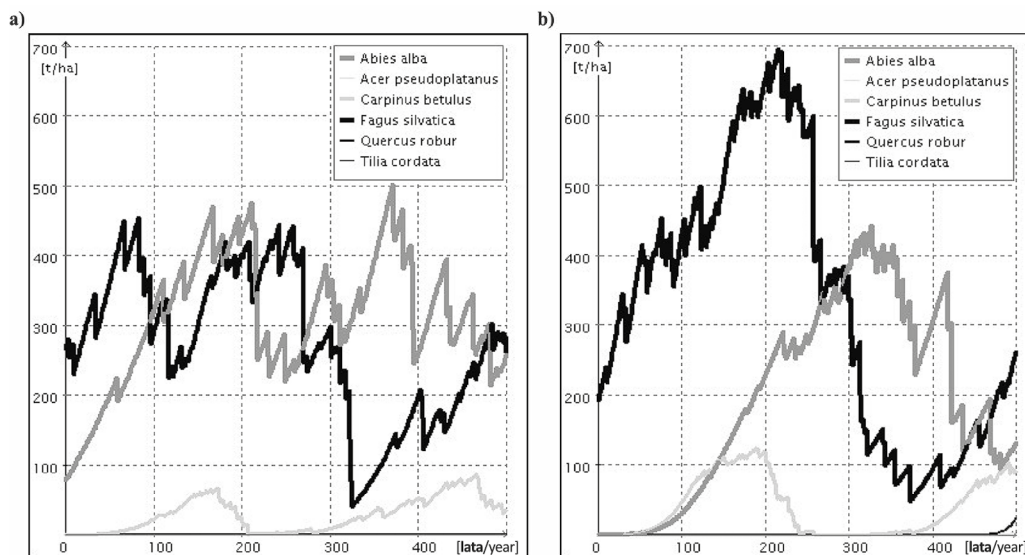


Figure 3. Prognosed changes of tree biomass of particular species in the control scenario on plots: a) 1, b) 2

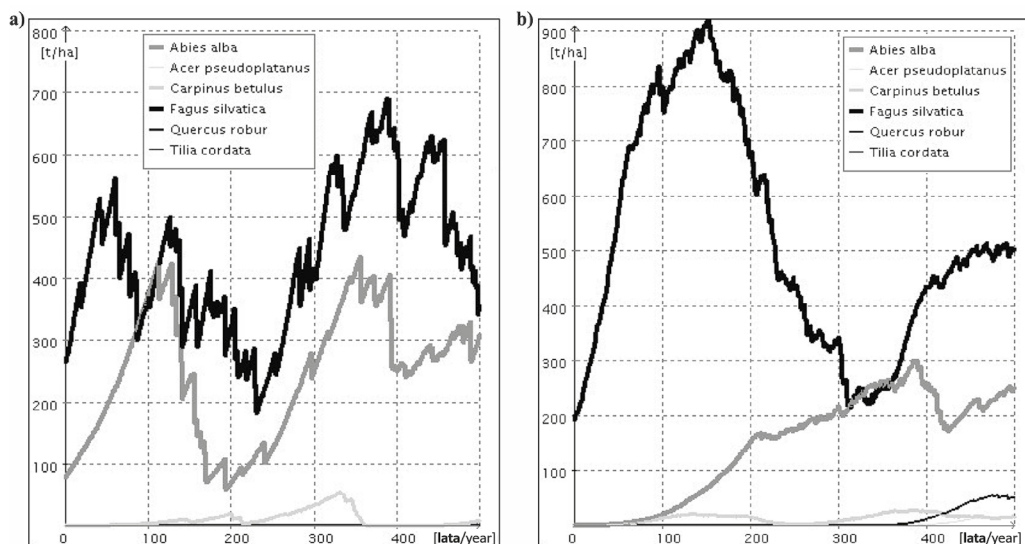


Figure 4. Prognosed changes of tree biomass of particular species in the warm-humid scenario on plots: a) 1, b) 2

and on Beech 2 – in the 360th simulation year. This indicates the cold-humid scenario conditions as most favourable for fir, and at the same time – significantly weakening the competitive ability of beech.

In the scenario 4, that is, cold-dry climate (CD) as compared to the present climate (Fig. 7), in the second half of the simulation period, beech biomass oscillated around the lowest value (100 t/ha and 30 t/ha on Beech 1 and Beech 2, respectively). As in the previous forecast, the beech status of is weakened when compared to that of fir.

As a general rule, the simulation of beech dynamics in the Roztoche region in various climate change scenarios showed a weak cross-correlation between fir and beech. The high absolute values of the cross-correlation coefficient (up

to -0.98) were obtained only in the warm-dry climate scenario (Fig. 8a). This scenario also showed strong positive influence of temperature (Fig. 8b) on beech biomass (cross-correlation between air temperature and beech biomass – greater than 0.80).

4. Discussion

The results obtained on predicted dynamics of beech stands in the Polish and Ukrainian parts of the Roztoche region confirm vulnerability of beech to climate change, as reported earlier (Dale et al. 2010). The results of the simulations carried out using the model FORKOME suggest that the eastern limit of natural beech range is the most sensitive

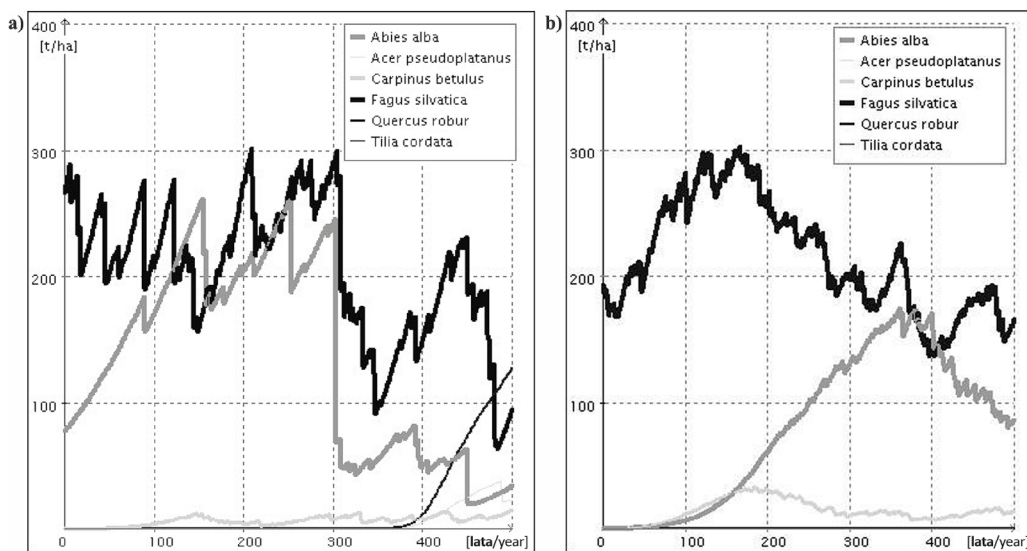


Figure 5. Prognosed changes of tree biomass of particular species in the warm-dry scenario on plots: a) 1, b) 2

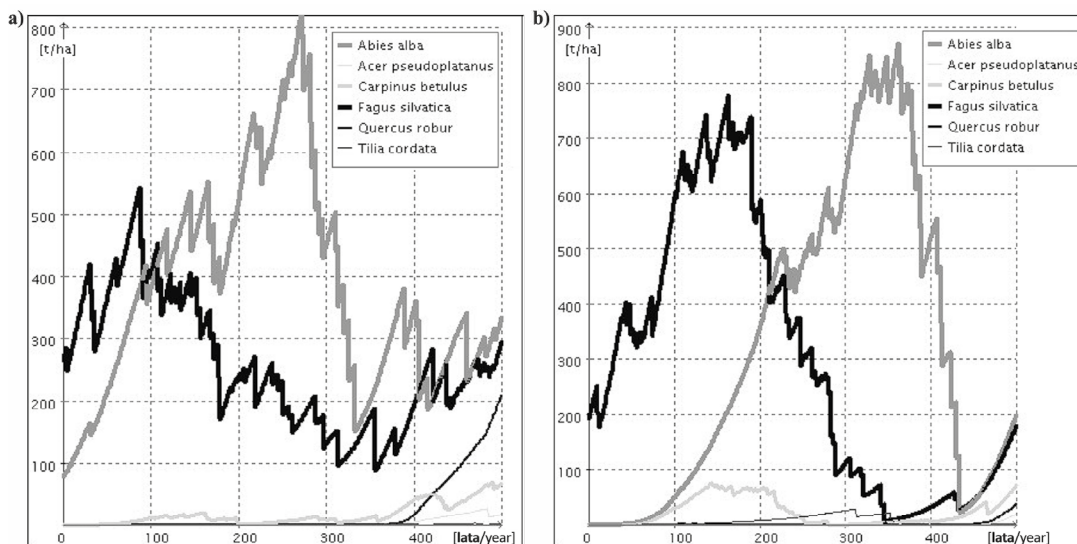


Figure 6. Prognosed changes of tree biomass of particular species in the cold-humid scenario on plots: a) 1, b) 2

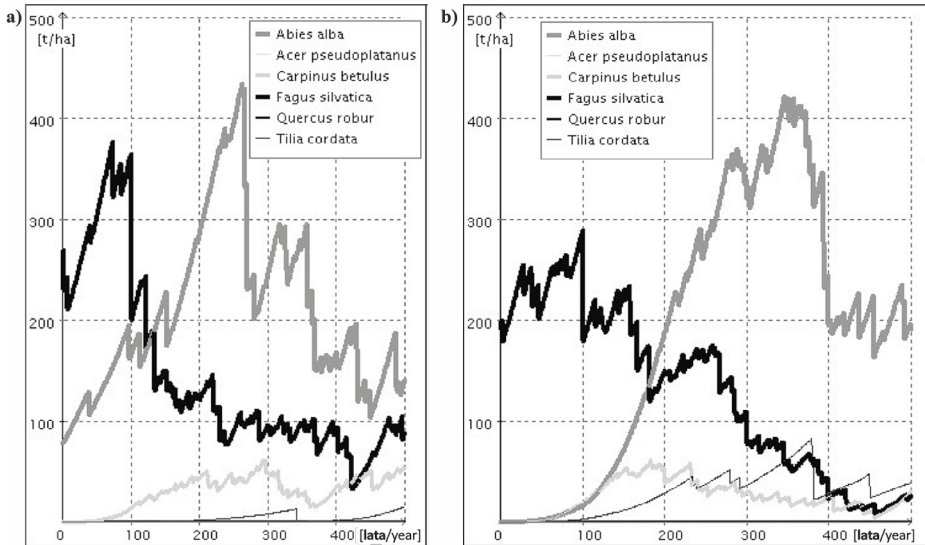


Figure 7. Prognosed changes of tree biomass of particular species in the cold-dry scenario on plots: a) 1, b) 2

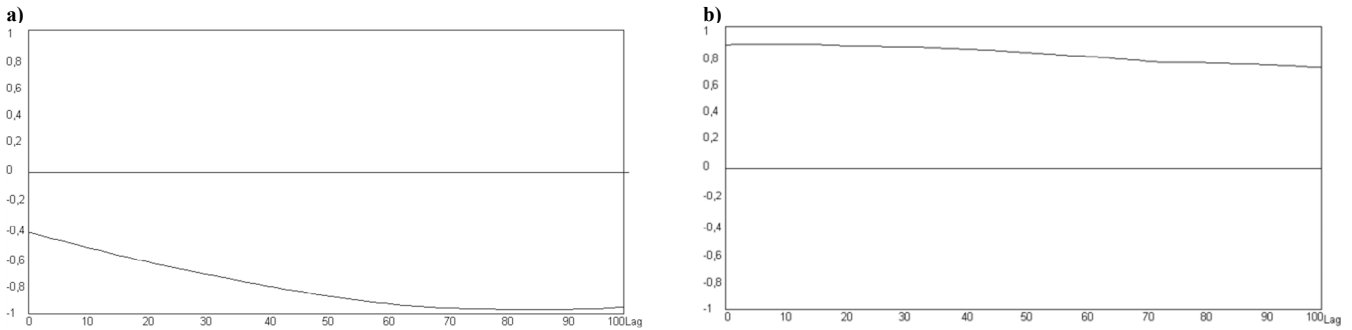


Figure 8. Value of cross correlation parameter on the plot 2 in the warm-dry scenario: a) between beech and fir biomass, b) between temperature and beech biomass

to the decrease in the sum of precipitation. The high sensitivity of beech to fluctuations in rainfall was also observed by other authors (Mátyás et al. 2010).

Beech forests occurring in the Roztoche region are characterized by high flexibility, and the study results show that the transformation of stand species composition is delayed (due to the longevity of trees) as compared to the time of occurrence of climate change resulting in stand alterations. The period of the greatest structural changes can last the shorter, the greater is the initial structural complexity of the stand – expressed by its age diversity, and this was pointed out also by other authors (Dale et al. 2010).

The results of the simulations confirmed that changes in the availability of warmth and water could cause varied reactions of tree species in the Roztoche region. In addition to the weakening of cyclical changes between beech and fir – as demonstrated in the control scenario – in some of the experimental scenarios, the overall tree stock is reduced,

which can further encourage stand structural transformations. The comparable predicted reduction of beech biomass was observed in Germany (Rötzer et al. 2013). FORKOME predicts a higher share of fir in the Polish part of Roztoche when compared to the Ukrainian part, where fir has a lower share of biomass due to past economic activities (Stojko 2000). The model also suggests a smaller proportion of fir on Beech 2 in the first half of the simulation period.

It should be emphasized that in the future also, beech will remain an important forest species on the north-eastern limit of its range. In the present study, the predicted effects of climate change in the Roztoche region were judged as positive for beech. Similar results were obtained for Northern and Western Europe (Lindner et al. 2010).

The model FORKOME allows for considering the current situation, performing forecasts of beech dynamics in Polish and Ukrainian Roztoche, as well as analysing interactions of various environmental factors and demographic processes in

forest stands. The design of the model makes its results easy to compare with the results of other prognostic models, such as FORLAS (Zajączkowski et al. 2013). This is consistent with literature suggestions to conclude on the future species composition based on the comparison of several models, as well as to focus on the assessment of resistance of current stands to changes in the environment (Bugmann 1997). The growth indices used in FORKOME and FORLAS models (Kozak et al. 2012; Zajączkowski et al. 2013) have proven to be a good and simple tool for the direct assessment of the effect of selected environmental factors on growth and competitive relations of tree species, especially beech and fir as the dominant species in the studied stands in the Roztoche region.

In the model FORKOME, in order to fully show the many years of beech stand dynamics, the length of the forecast period was increased to 500 years. Such a long time of simulation was chosen after analysing endurance of the major analysed tree species (beech and fir). A similar forecast period was also applied in beech and fir-beech stand trials in the Bieszczady Mountains (Kozak et al. 2003) and works by Brzeziecki (1999), whose results for the 500-year forecast period suggest a cyclic replacement between beech and fir, with a fixed character. These results are supported by many field studies – well documented in literature on neighbouring regions such as the Świętokrzyski National Park (Jaworski, Podlaski 2006) and the Bieszczady Mts. (Kozak et al. 2003). The trend of replacing fir by beech as well as large expansion of the latter species have been observed throughout Europe. Among others, it was reported from the Eastern Carpathians (in the lower parts).

The use of FORKOME made it possible to visualize the multi-year cycle of beech stand transformation under the conditions of different variants of climate change. Conducting studies on forests, and forecasting the course of their transformation is of great importance for forestry, with particular regard to forest management planning. With this type of research, it is possible to control succession by referring to analogous changes and predicting their direction. Long-term forecasts allow for proper strategies on the subject of reacting, managing and protecting the forest.

6. Conclusion

In the simulations carried out using the model FORKOME, in the control scenario, beech remains the main species of forest stands in the Polish and Ukrainian parts of the Roztoche region – on its north-eastern limit of its range. In the scenario assuming no climate change, the characteristic feature of stand development is the cyclic replacement of beech by fir and vice versa. Other forecasts show that, in all the analysed scenarios of possible climate change, there occurs the abating of cyclical changes between beech and fir. In the scenario with

warmer and more humid climate conditions when compared to present climate, in the forecasted period, beech still holds the dominant position in terms of biomass share. In the scenario of warmer and drier climate, the total biomass of beech is almost half the volume observed in warmer and humid scenario. In the scenarios assuming climate cooling in the second half of the forecast period, fir takes over the role of the dominant species. There was found a strong negative cross-correlation (up to -0.98) between fir and beech.

On account of appropriate solutions (climate change scenarios, correlation analysis block), the model FORKOME, is a useful tool for conducting forest prognostics (up to 200 simulations over a 500-year period), enabling the verification of many hypotheses for the future development of various types of forest. In particular, the results obtained from FORKOME prognostic tests confirmed the model usefulness in simulating the dynamics of beech stands in the Polish and Ukrainian parts of the Roztoche region.

Conflict of interest

Authors declare no potential conflicts.

Acknowledgements and source of funding

The authors thank the employees of the Roztocze National Park in Poland and the employees of ‘Rehionalnyj Landsofnoyj Park Ravs’ke Roztochia’ in Ukraine for their help in providing descriptive materials.

The study was conducted under the NCN N N309 014638 grant.

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Authors' contribution

I.K. – article concept, literature review, data analysis, FORKOME simulations; B.T. – field work, preparation of the manuscript; T.P. – data analysis and field work; H.K. – field work and text revision.