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SELECTIVE FOREST CUTTING USING THE FORKOME COMPUTER MODEL

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Abstract

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This paper presents the results of the investigation into selective forest cutting using the FORKOME computer model. The verification of this model was achieved with field data from beech-dominated mixed forests (*Dentario glandulosae-Fagetum*) in Bieszczady, Poland. A selective felling was selected with chosen shade-generating trees for prognosis after the 1st, 15th and 25th years, and implemented into this model. A fast alteration in the biomass value and increased tree number was observed after cutting. These changes were due to increased light availability to the brushwood. The fifty year prognosis suggests that this tree stand composition will become increasingly multi-species and age-diverse.

Key words: computer modelling, FORKOME, cutting, Bieszczady

Introduction

Foresters currently need more effective tools to provide the results expected from their interventions. They will benefit from the implementation of computer modelling, which is an extremely rapidly developing new method in data analysis.

The existing two ways of forest modelling: growth-yield modelling (Mochren, Kienast, 1991; Pretzsch et al., 2002; Nagel, Schmidt, 2006) and ecological modelling (Shugart, 1984; Bossel, 1991; Botkin, 1993; Brzeziecki, 1999; Bugmann, 2001) evolved independently over a long period, with both competing with, and complementing each other, simultaneously. The application of the FORKOME model in Polish Bieszczady conditions has elucidated the effectiveness of uniting these growth-yield and ecological strategies in forest modelling. Furthermore, the FORKOME model application indicates the necessity of utilizing future hybrid models which contain elements of both growth-yield and ecological factors.

Selective forest cutting was instituted in mountainous multi-storey mixed beech-fir-spruce stands. It was noted that 1 or 2 cuts exerted continuing effects for up to 10 years dependent on the nature of the trees and the extent of deep winter snow.

Foresters shape the structure and condition of a tree stand and trees by removing single trees, so that removal of a certain species leads to the creation of species structure with the desired composition. This action therefore supports one species at the cost of others. This situation is prevalent in the Polish Bieszczady, where the majority of the forest maintainance efforts are directed at supporting natural beech and fir tree establishment.

The main aims of felling include removal of some of the upper-floor trees previously considered useful, and limiting the number of well grown ones. Actions such as this prepare the tree stand for quicker natural establishment by successive removal of older trees to enable growth of the next generation.

Each stage of forest growth can be aided by management such as early and late thinning and felling, so the FORKOME model enable forest development prognosis and decisions about future anthropogenic interventions.

The main aim of this work is to present the results of investigation into selective forest cutting using the FORKOME computer model, and to indicate the tree stand composition in beech-dominated mixed forests in Bieszczady, together with the number of trees and biomass dynamics in a fifty-year prognosis.

Material and methods

Specificity of selective cutting is shown in a 100x100 m research plot situated in the Polish Bieszczady Stuposiany Forestry in the Krosno Forest Province. This plot was located on the northern slope of the mountain at an inclination of 8° and altitude of 700 m a.s.l. The brown soil covering the Carpathian flysh is characteristic for this plot, which has equal beech (*Fagus sylvatica* L.) and fir (*Abies alba* Mill.) trees, with the diameters ($\mathrm{DBH}_{1,3}$) and heights (H) illustrated in Figs 1a and 1b.

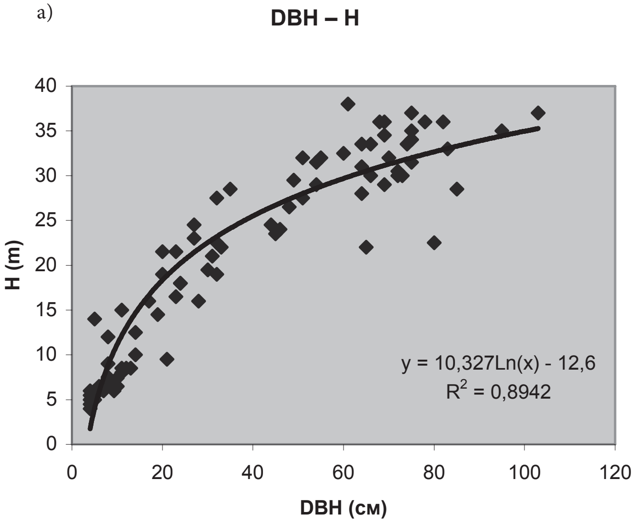
There are many canopy gaps due to the death of upper-floor tree death here, and this improves multi age forest structure dynamics. There is a characteristic group distribution of trees, with a few old and well grown beech and/or fir in the central area, while beech and fir saplings dominate closer to the group's edges.

The one hectare research plot was divided into 16 25x25 m patches. Of these, patch No. 12 was considered the most representative because of species and biomass composition. The FORKOME model was utilized here to enable prognosis of selective cutting.

Since this model has been analyzed in detail in previous publications (Kozak, Menshutkin, 2002; Kozak et al., 2003), only the model basics are required herein.

FORKOME represents a patch-model family, which simulates the forest stands dynamic, allowing single tree research, and herein it is divided into blocks (Fig. 2). The following two kinds of analysis are possible with FORKOME. (1) Statistical analysis with mean value and standard variation, and (2) Sensitivity analysis in a series of auto- and cross-correlation-function calculations. This model sets site, species, climate and felling parameters, and result-saving and additional analysis by other computer methodology and programmers is also possible.

The options of selecting tree felling modes and temperature and humidity conditions is available in certain scenarios (Kozak, Menshutkin, 2002; Kozak et al., 2003). The Monte Carlo statistical method allows simulation of up to 200 variants for each scenario. The model delivers the average number and average biomass of trees with the standard variation in each year. Auto- and cross-correlation functions are included to improve sensitivity analysis of the forest ecosystems. The number of trees and their biomass are important parameters in these calculations, a)



b)

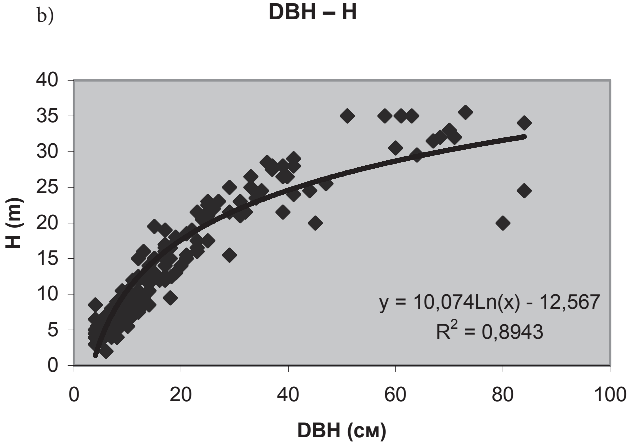


Fig. 1. $DBH_{1,3}$, – H relationship in beech forest 1 ha research area: a) fir, b) beech.

and available charts present the relationships between these parameters and temperature and humidity for each species, and for the entire association.

The FORKOME model is an object system with the following basic components (1) AREA – denotes the current patch (gap) and (2) TREE – gives a single tree. The Area object has characteristic properties defining factors including the dimensions, habitat and climate conditions. Here, the user interface simplifies patch property modification. The Area object contains an almost unlimited number of Tree objects, representing currently existing trees.

This Area object is formed in the system so that it imitates actual world conditions of climate settings and tree felling, and it influences the tree objects by transmitting information concerning current conditions, such as tree light availability. This parameter is calculated for individual height values within the patch, and tree growth

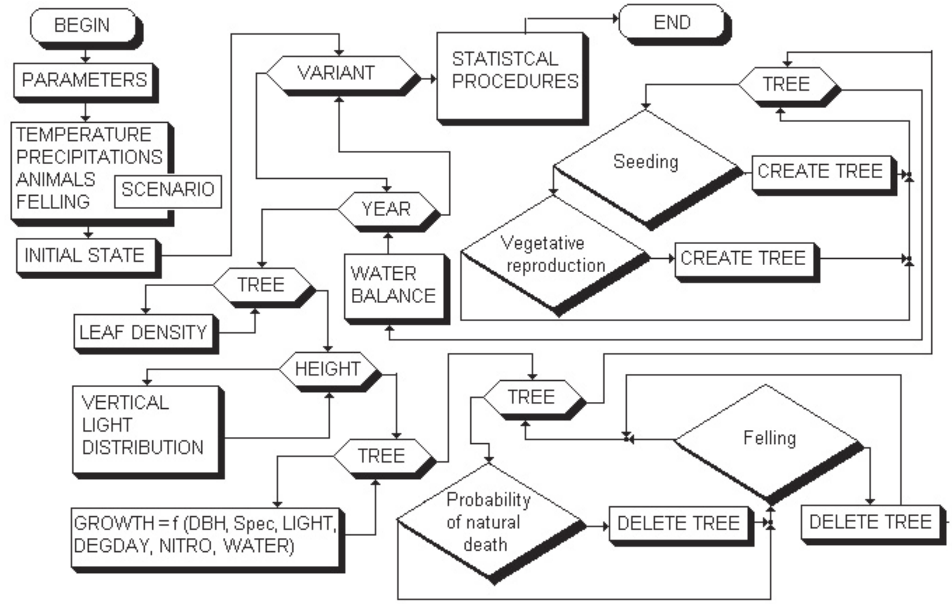


Fig. 2. FORKOME new algorithm.

simulation proceeds with annual spacing. Within each annual simulation, the area object exercises the following calculations for existing trees: the input parameters calculation of leaf area and water conditions; birth; growth; death and felling. The previous year's final state is the input state for the following year.

In the FORKOME model, the "growth bloc" simulates the actual annual tree growth on the studied area. Although each tree has its own genetically coded method of growth, its growth process is also influenced by its environment. The FORKOME model's trees are also described by species-specific growth function; with the main parameters of Diameter Breast Height (DBH), Height (H) and Age, together with the external conditions of the individual patch area. This approach simplifies growth simulation and allows growth-function activation and implementation in current conditions. The basic simulation consists of the tree diameter calculation, where the annual diameter increase ranges from the minimal value of 0 to the maximum value for each species under ideal conditions. Here, the following equation is used:

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

where

r – species constant, describing assimilation apparatus' photosynthetic productivity,
La – relative tree leaf area in m^2/m^2,
D – tree diameter measured in cm 1.30 m above ground level,
H – tree height in cm,
D_{max} – species maximum diameter in cm,
H_{max} – species maximum height in cm,
$\delta(D^2H)_{opt}$ – tree volume increase in cm^3.

The influence of external conditions is factored into the annual tree volume increase process. The actual tree increase $\delta(D^2H)_{real}$ results from the optimal increase $\delta(D^2H)_{opt}$ and tree growth inhibiting conditions $f_1, f_{2,\ldots}\ f_{j.}$ where the value of each tree growth-inhibiting factor ranges from 0 to 1.

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

where
$\delta(D^2H)_{real}$ – actual tree volume increase, considering influences from external conditions,
$\delta(D^2H)_{opt}$ – tree growth optimum conditions,
$f_1 \cdot f_2 \cdot \ldots \cdot f_j$ – external conditions, in the range of 0 to 1.

These equations form the components of this multiplicative approach method.

Light availability is the most important external factor inhibiting tree growth, and in FORKOME this is calculated with consideration of light radiation loss. This loss is caused by the total shading by the leaf area of higher trees. The available light function describes the amount of light available for specific tree leaves, and it is calculated according to the equation:

$$Q(h) = Q_{\max} E^{-k \cdot LA(h)},$$

where
LA(h) – (*leaf-area*) – total tree-leaf area in the patch, above height *h*,
Q_{max} – solar radiation measured on the tree-tops,
Q(h) – height, *h,* measured radiation,
k – constant value – 0.25.

Trees are divided into the following 3 types, dependent on their light tolerance index: sun tolerant, medium and shade tolerant.

The tree-growth inhibiting light index is called the light reaction function, and this is calculated in two different ways, depending on tree-light toleration index. Light-demanding and medium species have the same equation:

$$\mathbf{r} = 2{,}24\ (1 - e^{-1.136[Q(h)-0.08]})$$

while shade-tolerant trees have:

$$\mathbf{r} = 1 - e^{-4.64[Q(h)-0.05]}),$$

where
r – the light reaction function – growth light reduction,
Q(h) – individual height radiation.

This model's thermal conditions are described by the addition of annual effective temperatures above 5°, and the temperature index inhibiting tree growth can be calculated by the following equation (Botkin, 1993).

$$t = \frac{4(DGD - DGD_{min})(DGD_{max} - DGD)}{(\mathrm{DGD}_{\mathrm{max}} - \mathrm{DGD}_{\mathrm{min}})^2},$$

where
t – growth inhibiting index,
DGD – sum of effective temperatures for an individual site,
DGD_{min} – minimal sum of effective temperatures needed for species occurrence,
DGD_{max} – maximal sum of effective temperatures for species occurrence.

The FORKOME model also considers leaf transpiration, and this depends not only on the meteorological conditions but also on the tree species, as in other patch models. There also exist relationships between tree species and ground water level, and tree growth speed and the availability of ground water implemented in the model structure. The bloc is created by the following basic water balance equation:

$$\mathrm{W}(t+1) = \mathrm{W}(t) + \mathrm{Prec}(t) - \mathrm{Trans}(t) - \mathrm{Evapor}(t),$$

where
$\mathrm{W}(t)$ – ground water amount in the time period t,
$\mathrm{Prec}(t)$ – precipitation,
$\mathrm{Trans}(t)$ – transpiration,
$\mathrm{Evapor}(t)$ – soil surface water evaporation.

A further tree-growth inhibiting index is the SITE INDEX which describes the ratio of steam- occupied area to the maximum available area (Botkin, 1993).

$$s = 1 - \frac{BAR}{\mathrm{SOILQ}} \ ,$$

where
s – tree-growth inhibition site index, (dependent on current area occupied by trees),
BAR – total area with stems,
$SOILQ$ – maximum stem area on the patch.

A tree can perish in the following two ways in the FORKOME model. (1) randomly, or (2) if it does not reach minimum diameter increment size.

The Model asserts that if the tree does not increase its diameter every year for ten years, then there is only a 1% chance that the tree will survive that period. The MORTAL statistical probability for annual tree death is 0.386.

The FORKOME model is able to confirm the tree's minimal increase. If the minimum value is not exceeded, then it is assigned its random probability from 0 to 1, and when that value is greater than 0.386, the tree is removed.

Random tree mortality is based on the theory that only some healthy trees live to their maximum age, and the FORKOME assumption states that 2% reach their maximum age. Therefore, the following inequality formula exists (Botkin, 1993):

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

where
RND – random number ranging from 0 to 1,
AGE_{max} – maximum tree-species lifetime.

Several problems are encountered when estimating the number of seeds and samples in some tree species. Precise environmental specifics in the tree-patch surrounds are usually unknown, so that the calculation of seed number becomes an approximation, or at worse, a "guesstimate". This is the main reason for employing a stochastic approach in this model to counteract seed and sapling problems. Research was instituted so that the empirical maximum number of seeds and saplings were collected for each model species in one vegetation season. This amount was restricted by the random and available ground-level light. In addition the sapling number was generated separately for each light-tolerance reading, and the polynomial function was used for nutrient blocks (Weinstein et al., 1982).

The FORKOME model provides ability to define forest-felling scenarios. The interface helps to determine the time and sequence of felling, and also the tree species' diameter. The FORKOME model bloc-construction is adaptable to a wide range of climatic, soil and forest conditions, Model species include forest frame species and admixed ones. Future adaptation of this model for many different scientific simulation experiments is certainly possible.

Results

Detailed analysis of trees distribution in the number 12 area revealed beech and the sugar maple (*Acer pseudoplatanus* L.) group's characteristics (Fig. 3). The western portion of this patch is dominated by beech, with 4 well grown specimens up to 122 years of age (Table 1). Fir and maple trees occupy the eastern part, some up to 162 years old, and the distribution of the trees enforces considerable shade on saplings and brushwood. Beech brushwood and young trees dominate the western part of this patch, while fir, beech and spruce (*Picea abies* (L.) Karsten) are in the eastern portion.

Certain brushwood groups were retained following the removal of well grown and other selected trees. This resulted in a considerable increase in light availability, both from directly above, and from all sides.

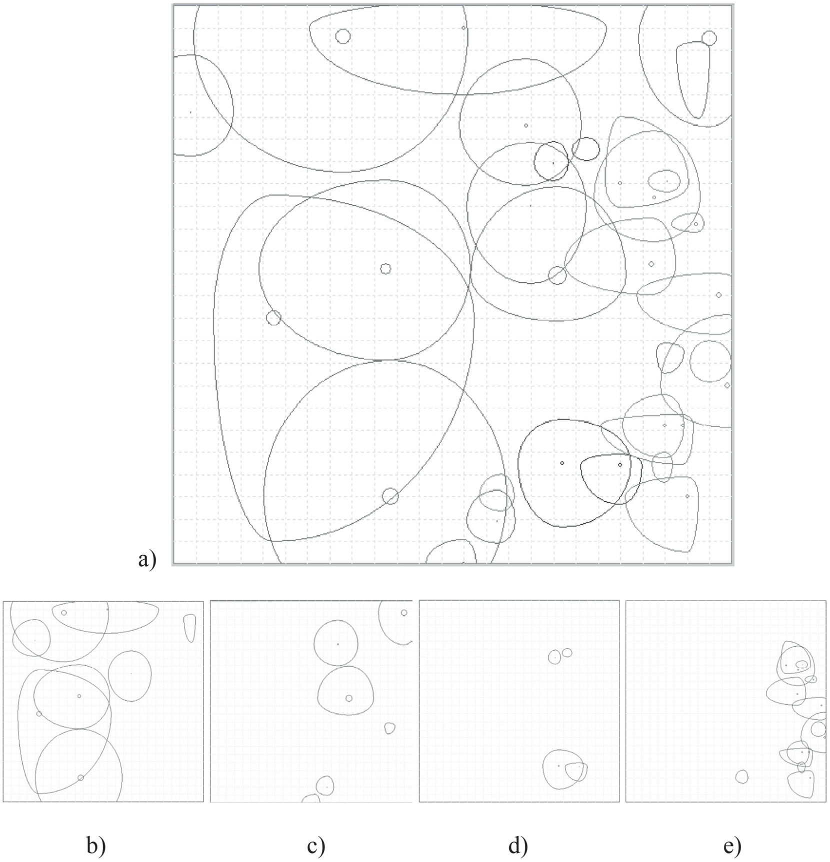


Fig. 3. Canopy projection on 12th research area: a) general view, b) beech, c) fir, d) spruce, e) sugar maple.

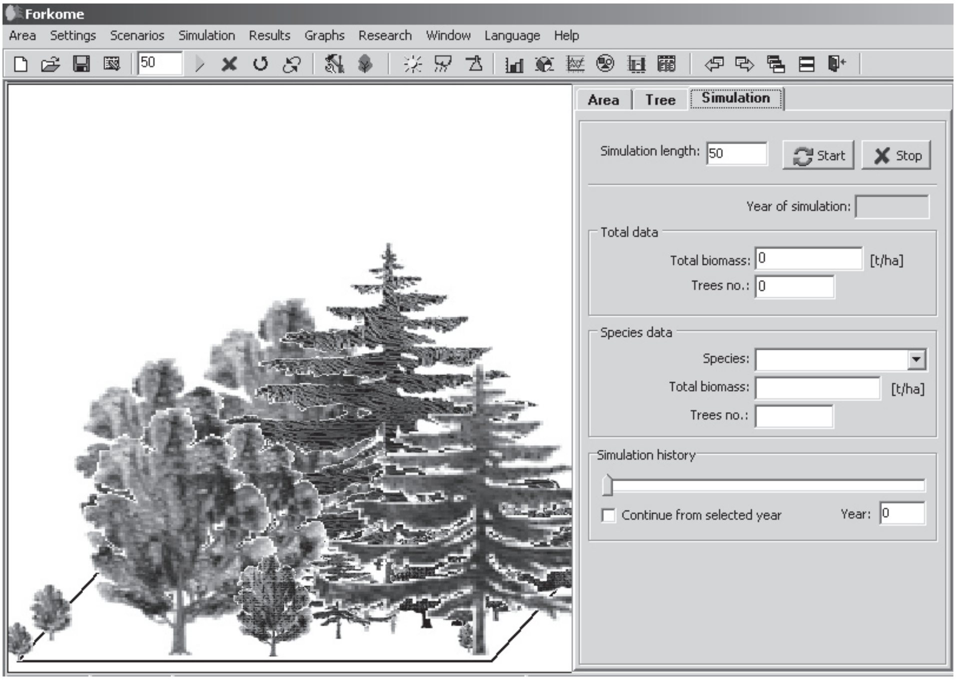
Table 1. Highest trees, shading lower ones.

Species	D_{BH} (cm)	H (m)	Age (years)
Abies alba Mill.	67	31.5	96
Abies alba Mill.	84	34.0	162
Fagus sylvatica L.	65	22.0	102
Fagus sylvatica L.	45	23.5	69
Fagus sylvatica L.	64	33.5	100
Fagus sylvatica L.	75	35.0	122

Implementation of the FORKOME model data afforded a general view of the area in a bitmap (Fig. 4), and also diagonal projection on this area (Fig. 5).

To achieve our prognosis, the highest beech and fir specimens were removed in the scenario's initial felling stage. This action imitated cutting the highest trees shading the area. This resulted in increased light availability to the brushwood, and it's very noticeable dynamic growth. This was clearly distinguished after 14 years of prognosis (Fig. 6).

The second stage in this felling scenario in the 15th year of prognosis consisted of eliminating the 111 year old highest fir from the eastern part, and the two 115 and 117 year old



Simulation length: 50

Year of simulation:

Total data

Total biomass: 0 [t/ha]

Trees no.: 0

Species data

Species:

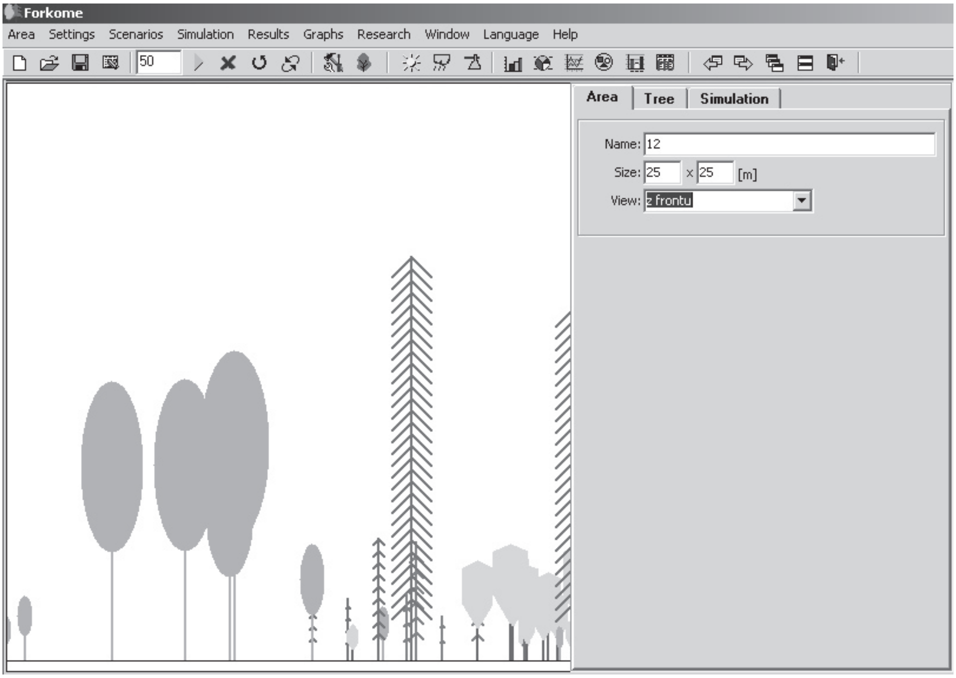
Total biomass: [t/ha]

Trees no.:

Simulation history

☐ Continue from selected year Year: 0

Fig. 4. Research area in bitmap.



Name: 12

Size: 25 x 25 [m]

View: z frontu

Fig. 5. Research area: projection on area's diagonal.

Fig. 6. Trees location on area No. 12 diagonal in the 14th year of prognosis.

beech trees. This removal lessened the number and effect of shade generating trees and it encouraged the growth of brushwood (Fig. 7).

The third stage of felling involved the removal of the remaining well grown beech tree which was over 100 years old (Fig. 8).

The first 50 years of prognosis was characterized by even growth and multi-species composition-shaping (Figs 9a, b). The model prognosis results describe the achievement of a high level of biomass at 450 tons per hectare in this very short 50 year time span.

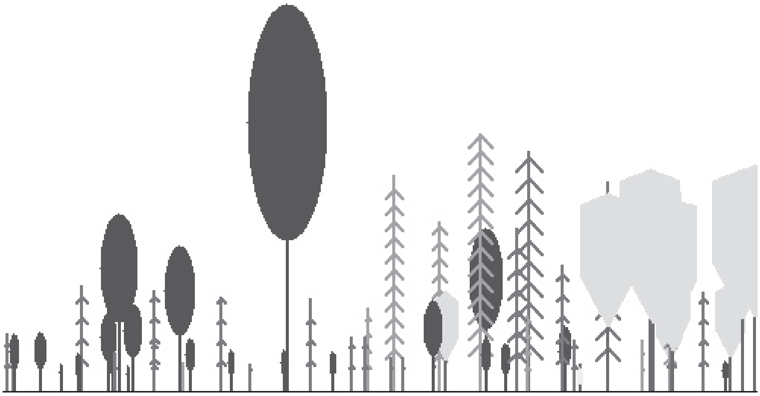


Fig. 7. Trees location on area No. 12 diagonal in the 15th year of prognosis. Situation after second stage of thinning.

Fig. 8. Trees location on area No. 12 diagonal in the 25th year of prognosis. Distribution after third stage of thinning.

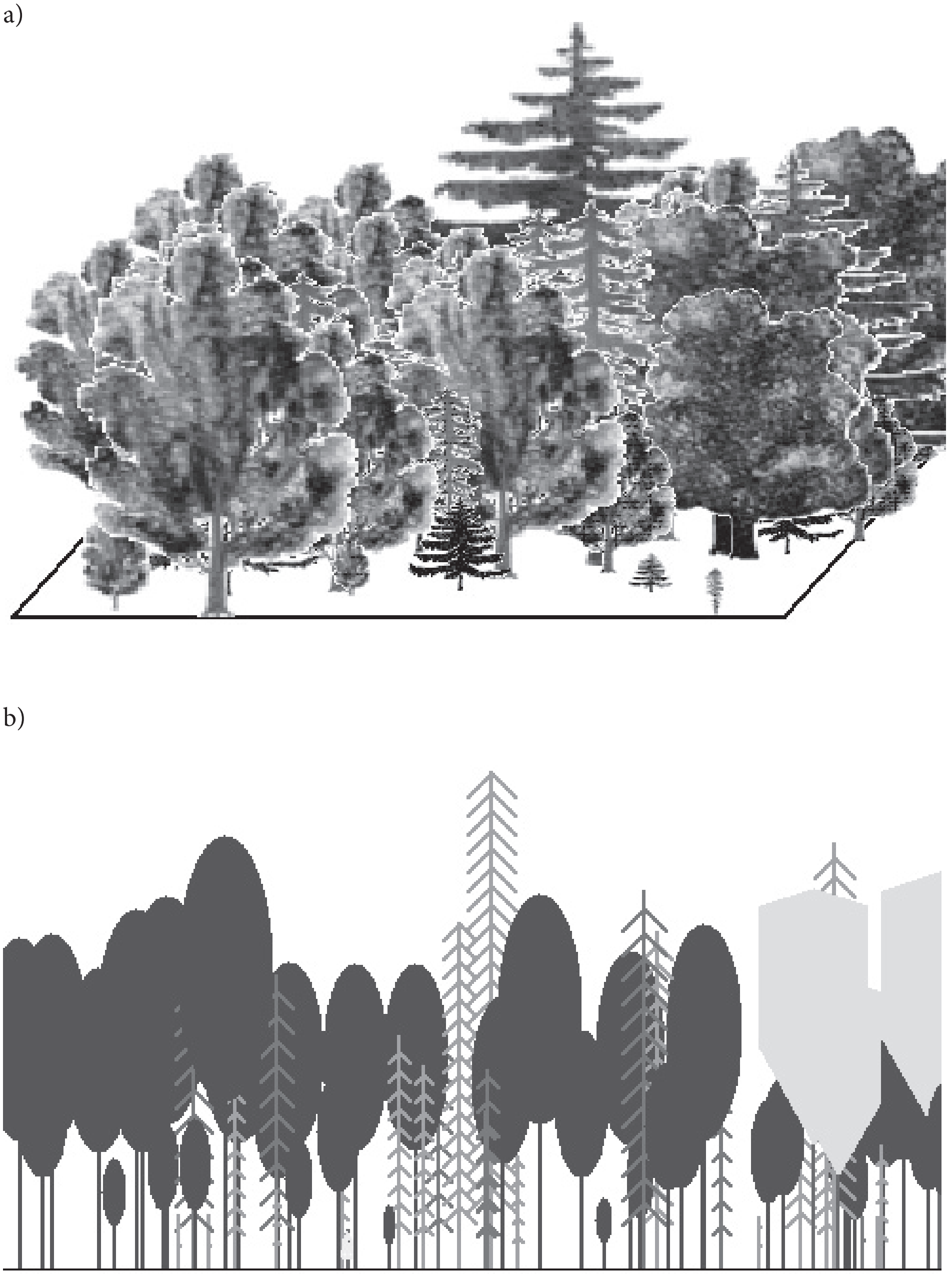


Fig. 9. Research area in the 50th year of prognosis: a – bitmap, b – projection on area's diagonal.

Fig. 10. Biomass change prognosis on area No. 12.

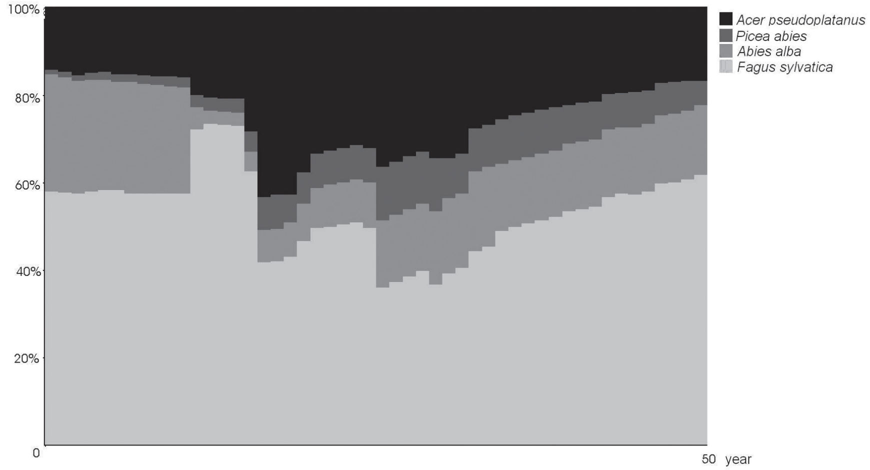


Fig. 11. Trees amount change prognosis on area No. 12.

The prognosis presents production of a multi-species tree stand, with a species biomass percentage of 65% dominant beech, plus 16% fir, 15% spruce and 4% sugar maple (Fig. 10). The number of beech trees tends to increase over time, while fir tree numbers remain stable. The spruce rose at the beginning of this prognosis and it retained its high values until the final prognosticated years. The number of sugar maple trees decreased and maintained that tendency until the end of the prognosis (Fig. 11). Generally speaking, the number of trees on the area increased slowly.

Discussion

The demonstrated FORKOME model proved to be an efficient prognostic tool for biomass and tree number change in this simulated felling management system. The current version of this model enables us to view each tree's coordinates and its properties throughout the entire prognosis. This improves the distribution analysis and mutual shading approaches. Therefore, this selective cutting prognosis is very useful and reliable. It should be noted that the seedling distribution is hardly ever regular, as differences in canopy projections and gaps originating following old trees' death and removal determine the seedling and brushwood distribution mosaic. The seedlings first appear within the gaps, and not on shaded areas. This clearly shows their essential reliance on the forest environment and light availability. Further influential factors include the exclusion of light tolerant grass and minor day/night temperature oscillation in gaps, compared to open spaces (Pogrebniak, 1968). In addition, saplings are better protected against spring ground-frost, and moderate conditions of humidity and warmth support germination. The surrounding tree-roots hamper seedling growth and preclude competition mechanisms. Mixed-beech tree stands with shadow tolerant beech, fir and spruce are perfect for analysis and selective prognosis, because these species are often established in groups with normally created gaps.

The supply of moderate light exposure to well-grown and useful trees by thinning and removal of damaged trees from the tree stand improves the wood's essential properties, and stimulates diameter increment. In addition, felling increases the area available for root system development, and it improves soil and water conditions.

Late felling-management is applied after the tree stand is 40 years of age. This limitation and other felling methods consist only of currently accepted ones, and these depend on many factors including species composition, habitat and tree-stand development stage. Late felling management leads to the final stage of forest development. In this way, a mature tree stand is able to establish itself properly, maintain a dynamically balanced species composition and density and provide high-quality wood. Other crucial functions of mature tree stands include maintaining a high but natural level of biological diversity and intensifying all soil processes. These accommodate light, water and warmth availability requirements, and they ensure the desired landscape conservation and environmental effects.

This selective cutting method has previously been employed in Germany, starting with Karl Gayer (Gayer, 1898). Selective cutting is usually applied to mixed tree-stands with shade tolerant species such as beech, fir and spruce. The tree-stands have multi-level construction through good felling management. Beneficial selective cutting specifies improvement in light availability and maintaining a stable number of established groups. The highest trees in these groups are removed individually in several stages. The most important technical requirement in this cutting is winter tree-removal, so that excessive damage to brushwood is prevented. The prognostic approach, after each stage of felling individual specimens and consequent brushwood growth, presents very promising and prospective mountain forest management.

The main advantage of the cutting technique employed in this model is the brushwood's successive exposure to sufficient light, without causing serious disturbance to overall forest conditions. This described cutting management considers the nature of forest establishment and, most importantly, it closely conforms to the main concepts of the FORKOME model. This selective forest management method delivers support for natural establishment processes which are so very important on these mountain slopes.

Modelling can aid determination of the best timing of species' thinning, and facilitate an accurate estimation of its long-term effects. Therefore, since the prognostication period in the FORKOME model simulation can be extended up to 400 years,, this provides the possibility of tracing the ecosystem's evolution over this prolonged time-period. Although results of the thinning process are most apparent in the first years following its completion, their effects on the development patch continue for a much longer period.

Conclusion

The FORKOME model simulates fast biomass increase (up to 450 t/ha) in selective cutting prognosis.

Multi-species tree stand dominated by beech and general tree number growth are the results of the prognosis.

After completing forest selective cutting prognosis and analyzing the results, the FORKOME model proved a useful and reliable tool for this research. This model is a simple and inexpensive tool used in current forest studies and in forecasting forestry needs. It can be used to simulate the development of actual forest areas and also to answer questions about their appropriate management.

FORKOME model simulations are very useful before cutting is done in forests. Following these simulations, this model is capable of choosing the optimal scenario, together with the optimal tree species and number of individual trees to be cut in the forest stand.

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