Simulation of the effects of different types disturbances on the mixed forest stands dynamics

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Purpose of the work

The simulation and analysis of the effects of different types disturbances (fires, windfalls, insect outbreaks, selective cutting and so on) on the mixed-species stands dynamics.

Tasks

- Construction the individual-based model the spatiotemporal dynamics of woody communities
- Simulation of the spatiotemporal dynamics of mixed forest stands influenced by external factors
- The simulation and analysis of various selective cutting regimes in the Far East forest stands

The proposed individual-based model aimed at solving the following tasks

- The individual-based model describes the dynamics of the stock and provides formation on the spatial distribution, age structure, and species composition of mixed stands as a result of intraspecific and interspecific competition for light.
- The initial data for the simulation are different combinations of species and age of stand structures.
- This model may be used to determine the effect of different types disturbances (fires, windfalls, insect outbreaks, selective cutting, etc.) on stand dynamics and composition.
- The model can also be employed in sustainable forest management to develop and analyze different scenarios of selective cutting.
- Applications of the model are limited to temperate forests where light is the main limiting factor of tree growth.

Individual-based model the dynamics of woody communities

The simulated sample plot is divided into a cell grid with a size of 20×20 cm

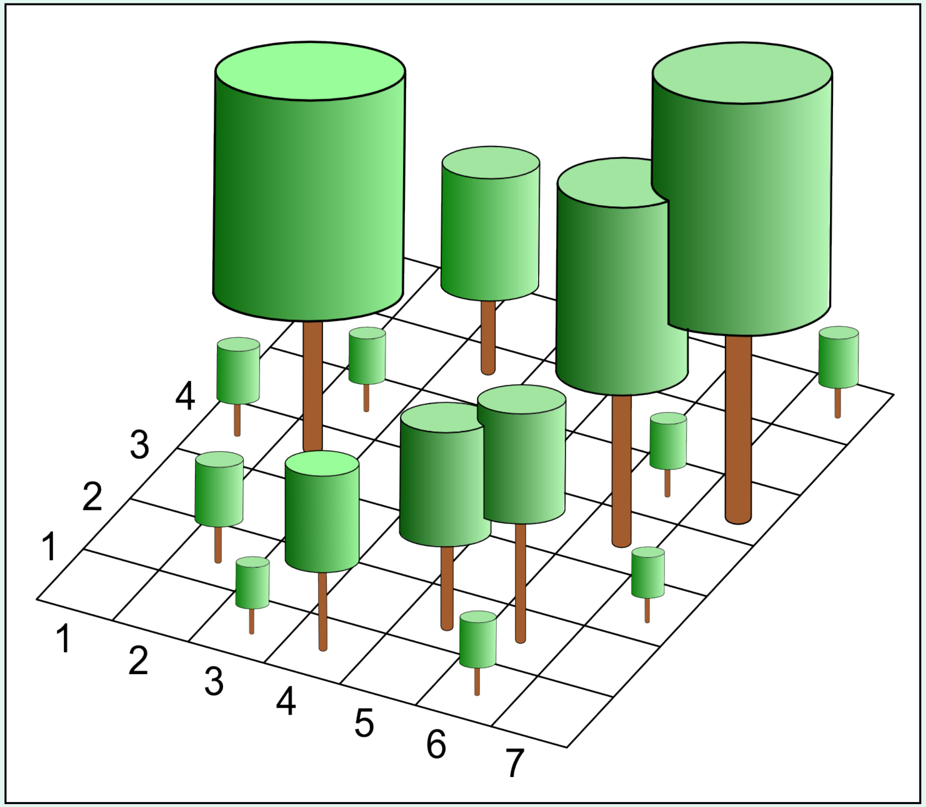
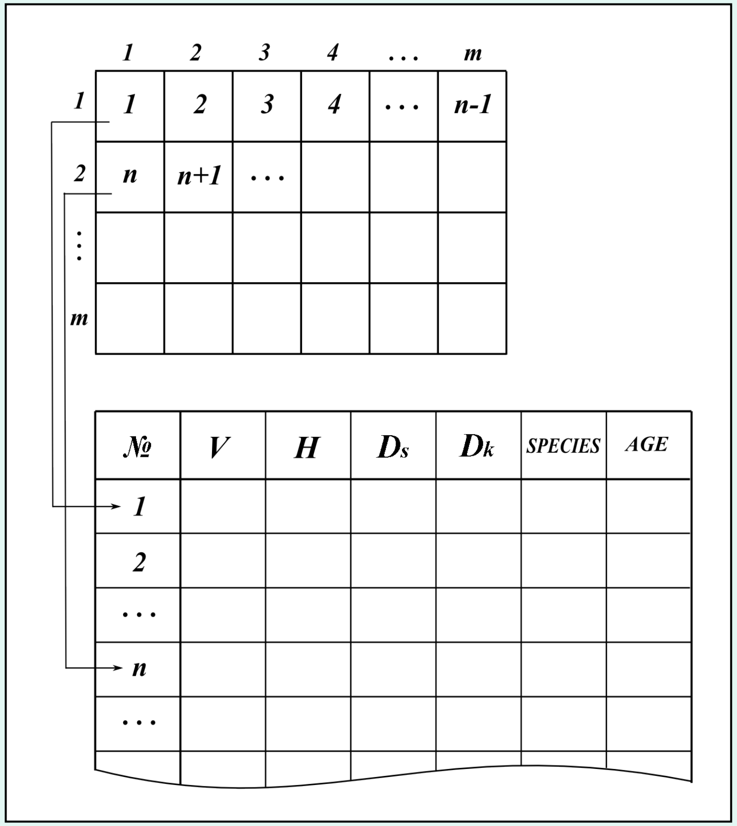
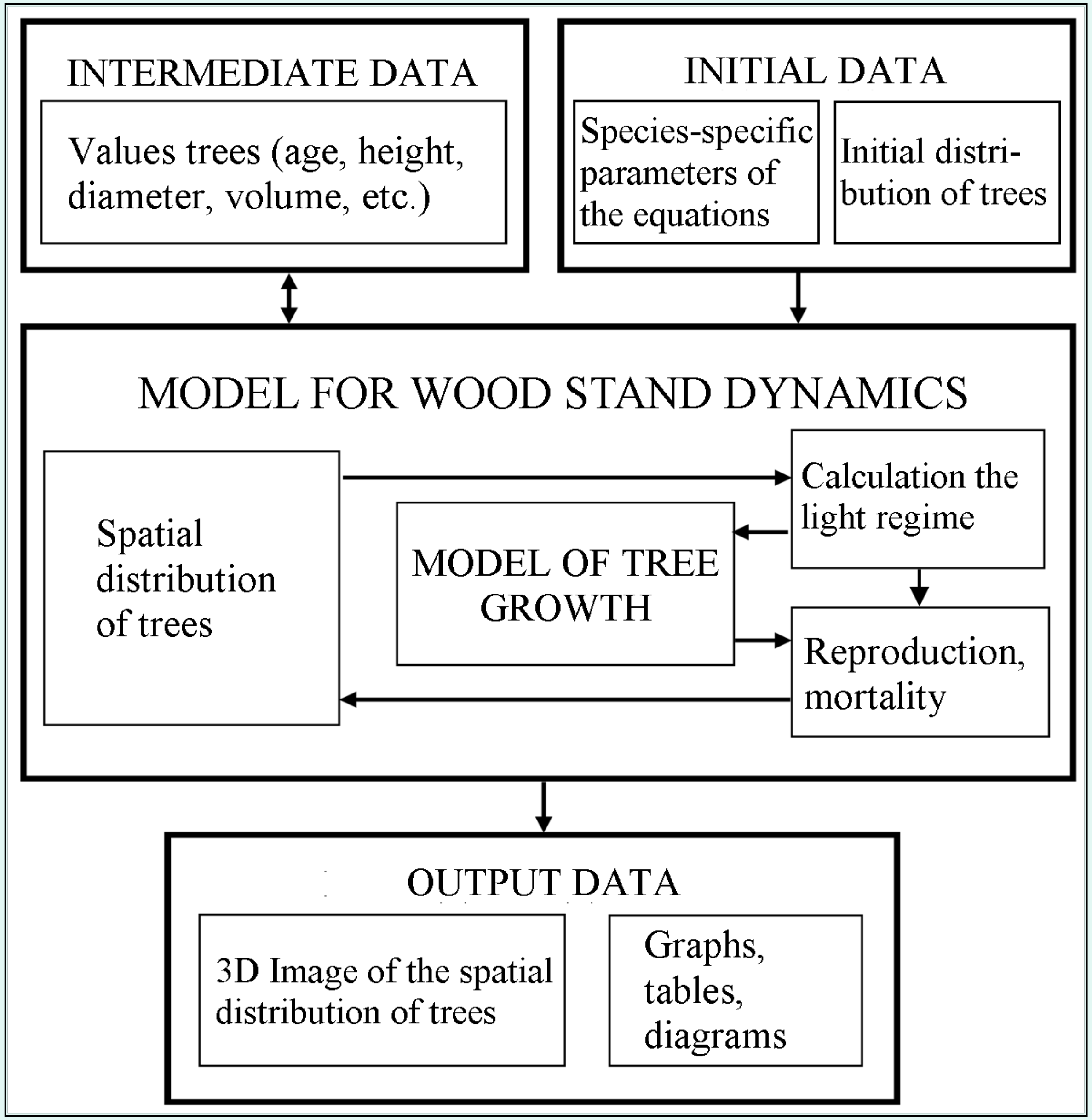


Fig. 1 Tree plotting in spatial grid

Fig. 2 The parameters of each tree (volume, diameter, height, age) are recorded into the array



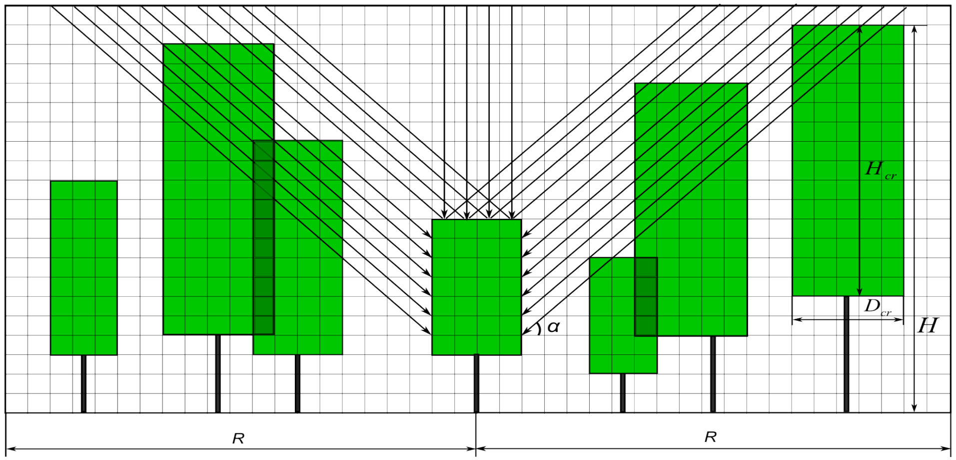
Structural scheme of the tree stand dynamics model

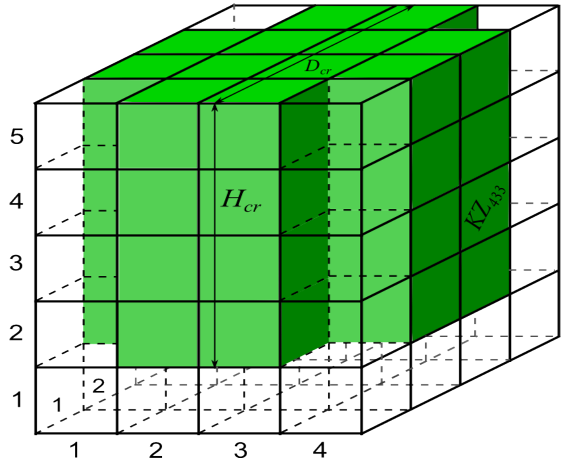


Calculation scheme of a solar radiation of a tree crown in the forest stand

Fig. 1 Sunlight direction is calculated based on the sun angle and solar azimuth angle.

Fig. 2 The stand is discretized into volume cells in which the light transmittance is computed





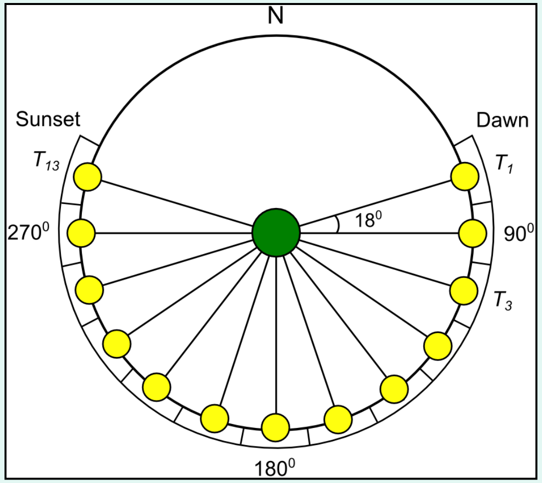


Fig. 3 Fixation points of the sun's position by azimuth

$$Q_{kj} = \prod_{i=1}^{m} KZ_{n_i}^{kj}$$

- portion of solar radiation falling on the k-cell of the crown cover in the *j*-direction

$KZ_{n_i}^{kj}$ - light transmittance rate of an n_i - cell

m – number of cells that transmit the sun beam

The model of tree growth in the forest stand

$$\begin{cases} \dfrac{dV_i}{dt} = \sum\limits_{j=1}^{L} \sum\limits_{k=1}^{N_{ij}} \left(\dfrac{P_{im} \cdot b_i \cdot V_i^{2/3} \cdot \dfrac{1}{N_{ij}}}{p_i} \cdot \ln\left(\dfrac{P_{im} + a_i \cdot Q_{ijk}}{P_{im} + a_i \cdot Q_{ijk} \cdot \exp\left(-p_i V_i^{d_i}\right)} \right) \right) \cdot PT_j - c_i V_i H_i \quad (1) \\ H(t) = c_1 \left(1 - \exp(-c_2 (t - t_0))\right)^{c3} \end{cases}$$

$$D_i = \sqrt{\frac{4V_i}{\pi H_i f(V_i)}} \quad (2)$$

V - tree volume, *H* - height, *D* – diameter, P_m - maximum photosynthesis intensity per one leaf surface unit, *p* - self – shading factor of a tree, *a* - the initial steepness of a light curve, which shows a dependence of photosynthesis on the intensity of illumination, *b* – parameter characterizing the energy influx, *c* –proportionality factor energy consumption for transport of assimilates, *d* – the fractal dimension of the crown, Q_{ijk} - the proportion of solar radiation incident on the *k*-th cell of outer surface of crown in the *j*-th direction ($0 \le Q \le 1$), *L* – number of directions of the solar flux incident on the outer surface of the crown, N_{ij} - number of cells of the outer surface of crown of *i*-th tree on which light is incident in the *j*-th direction, c_1, c_2, c_3 – species-specific parameters of height growth, *f*(*V*) – function characterizing the deviation from the ideal cylinder.

Tree mortality in the model

In the model, a tree dies out when the following conditions are met:

1) if a tree's age has reached the maximum lifespan

2) $\frac{dV_i}{dt} < 0$ if as a result of competition for light, the energy spent to sustain tree life activities, exceeds the received energy

3) $\frac{Vs}{V} > n(Vs)$ if the deviations of the volume of a tree stem growing under a shade from its potential sizes (without shading), exceed a specific threshold

Vs – volume of tree trunk growing in full light
V – volume of tree trunk growing in conditions of shading
$n(Vs)$ – threshold value of the deviation from the potential size

Recruitment of seedlings in the model

- The probability that the seeds of *j* – th species will sprout in every vacant cell is determined by the number of age-bearing trees of *j* – th species and the distance between these trees and the vacant cell

$$N_j = \sum_{i=1}^{n_j} \frac{1}{r_{i,j}} \Big/ \sum_{j=1}^{m} \sum_{i=1}^{n_j} \frac{1}{r_{i,j}}, \quad r_{i,j} \le R$$

R – maximum seed dispersion radius

$r_{i,j}$ – distance from the cell to the *i* - th age-bearing tree of a *j* - th species

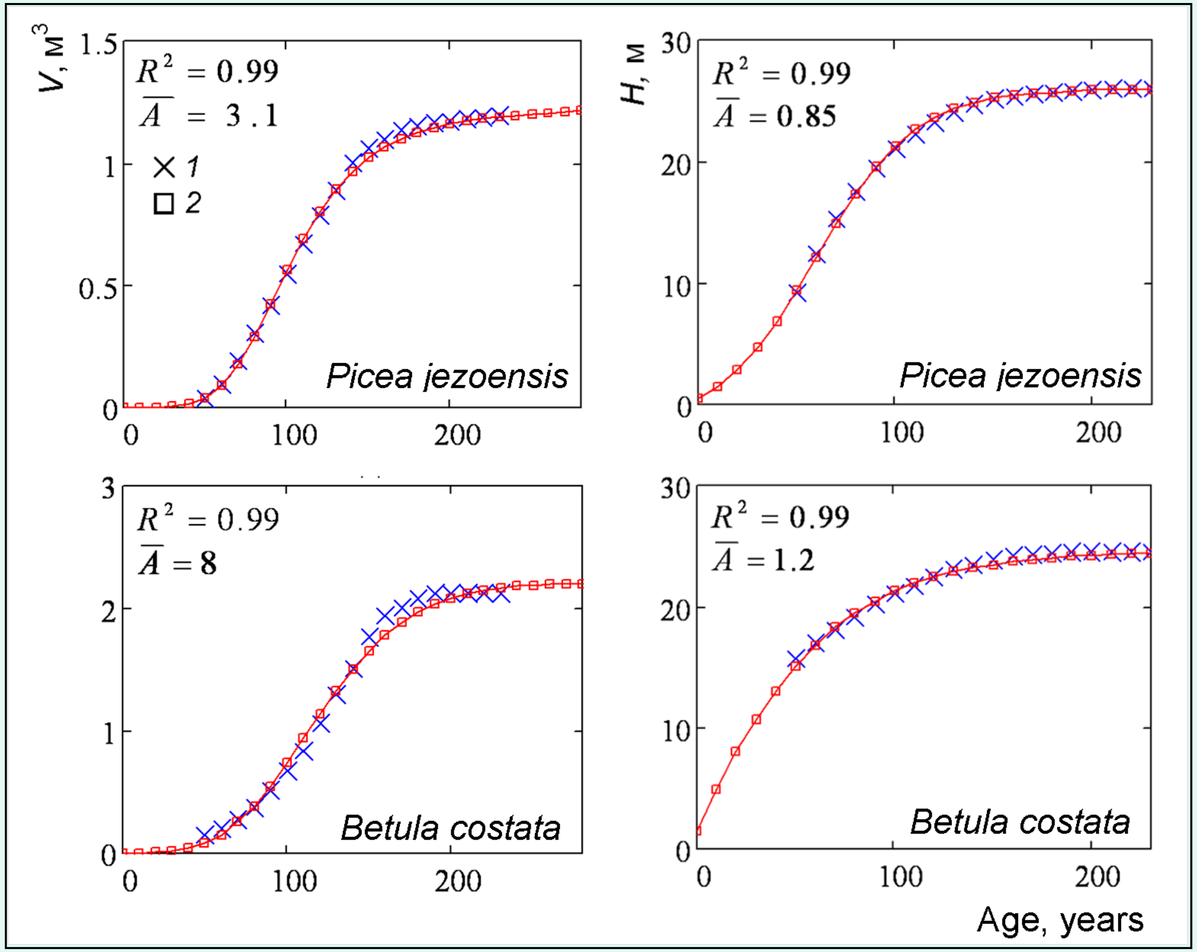
n_j – number of trees of the *j* - th species

m – number of species

- Optimal light conditions in the cell for seedlings are considered, depending on the tree species

- Seed germination probability is also determined when unfavorable conditions are present (high grass, rodents, etc.)

Estimation of parameters of the tree growth model



The growth curves of volume and height of tree trunk for spruce and birch. Crosses are real data, squares are model data. As a result, the coefficient of determination is 0.99, the approximation error is interval of values from 0.8 to 8.

The evaluation of the model was performed based on the data of a standard sample plot in a uneven-aged spruce–fir stand

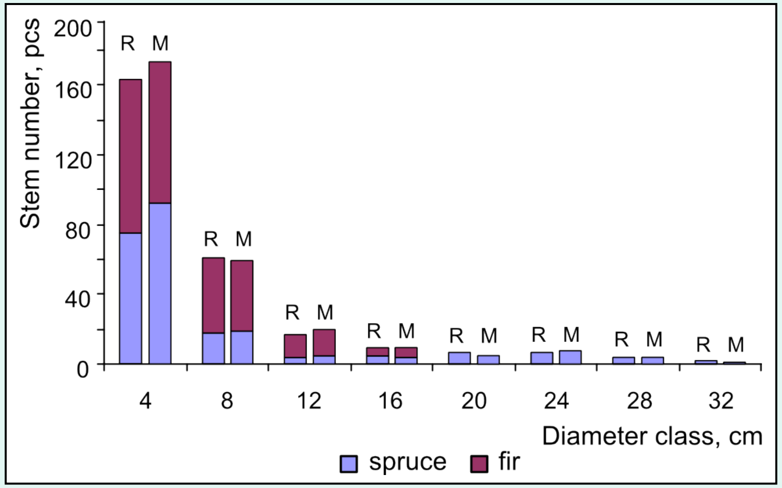


Fig. 1 Tree diameter distribution for the model and the actual plot

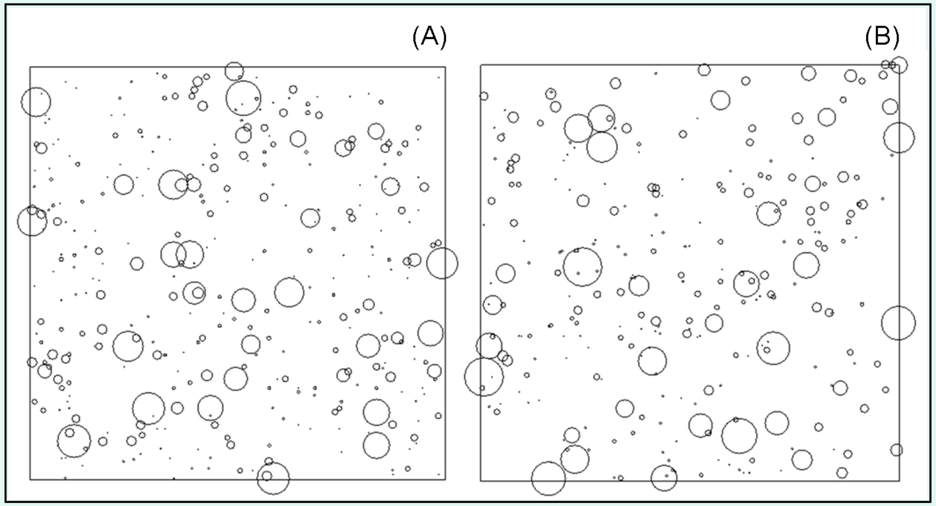
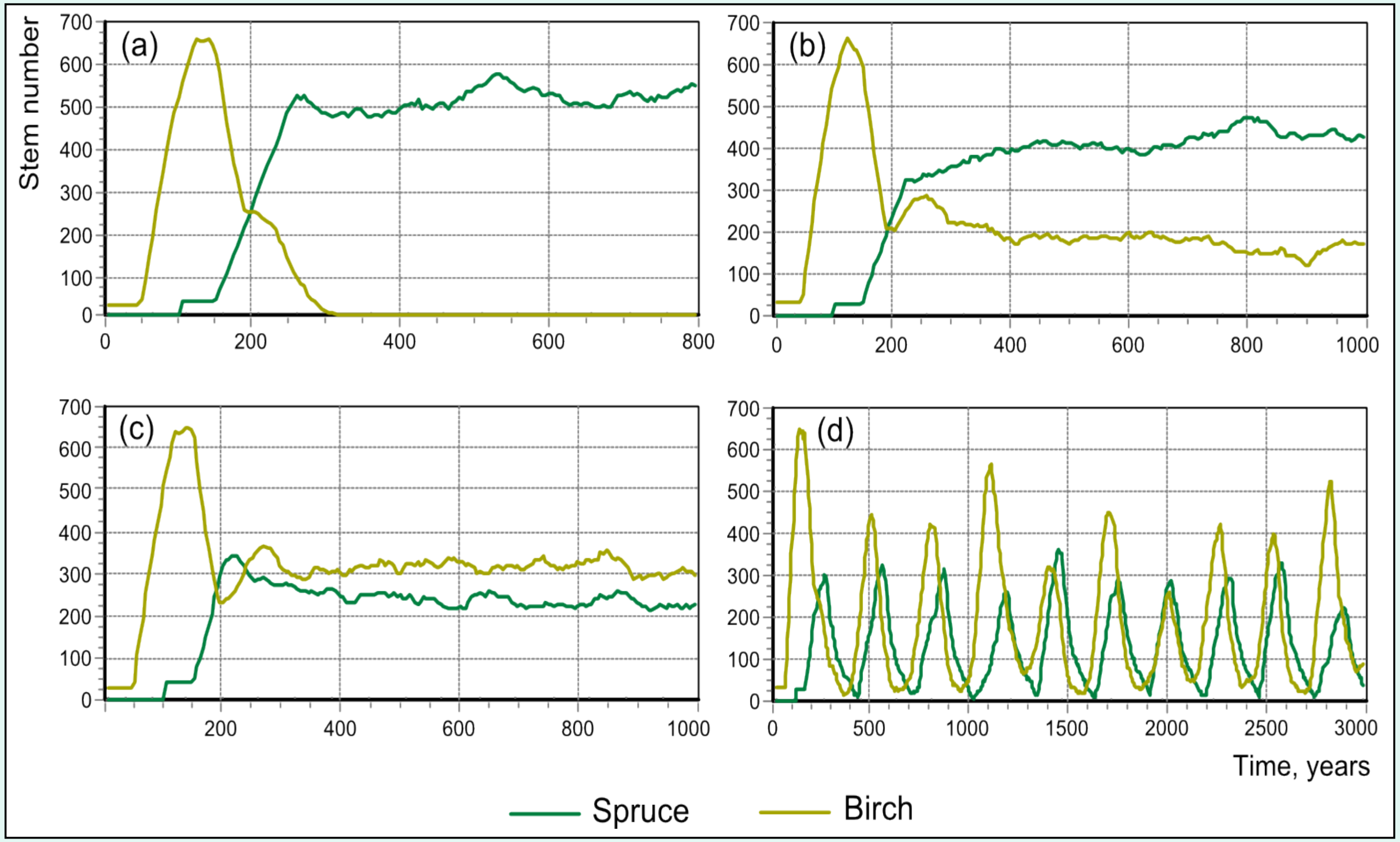


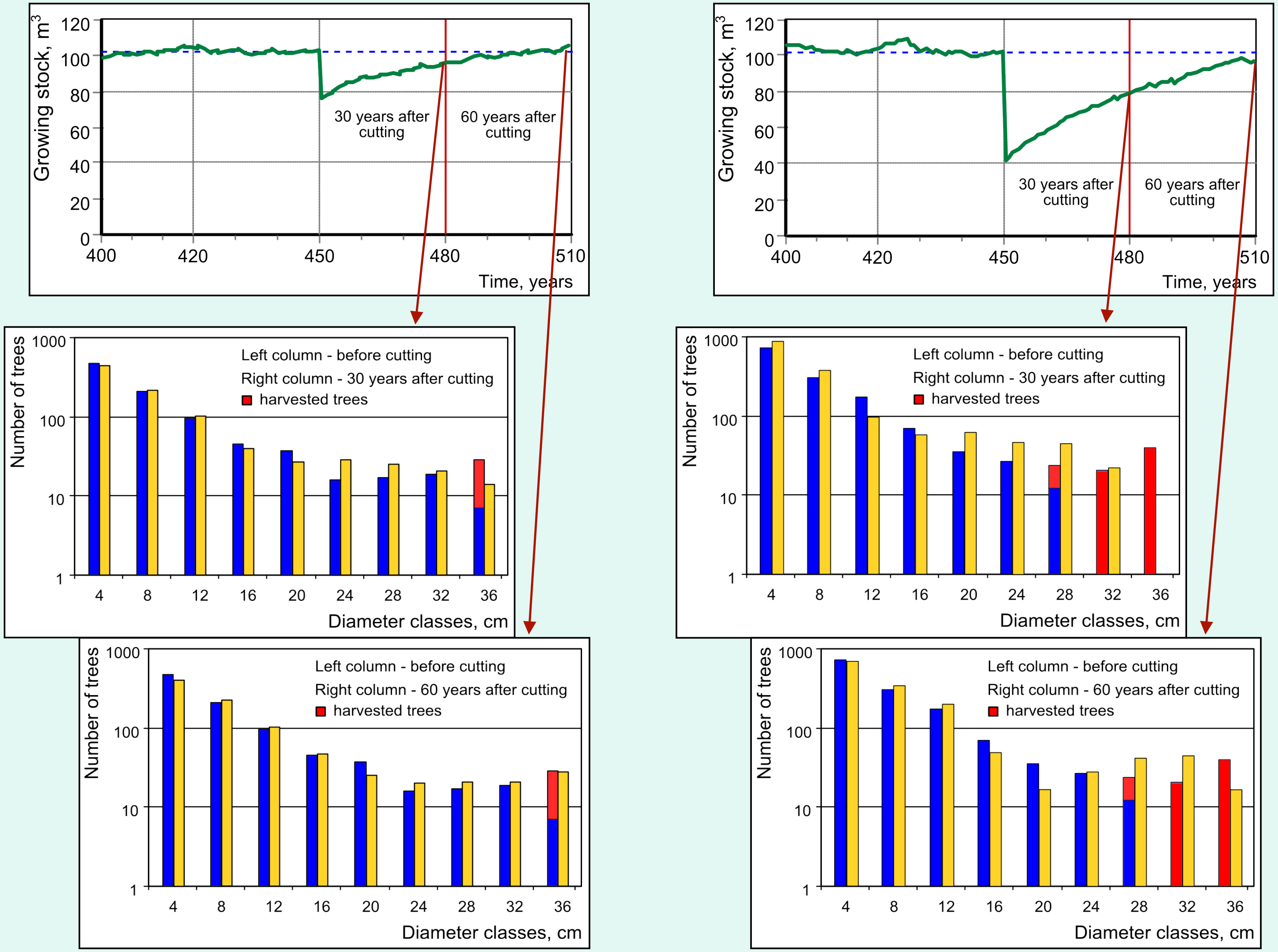
Fig. 2 Spatial distribution of trees in the spruce–fir stand:
A) Model plot, B) Actual plot

Scenarios of a spruce–birch tree stand dynamics with removal of a portion of spruce species



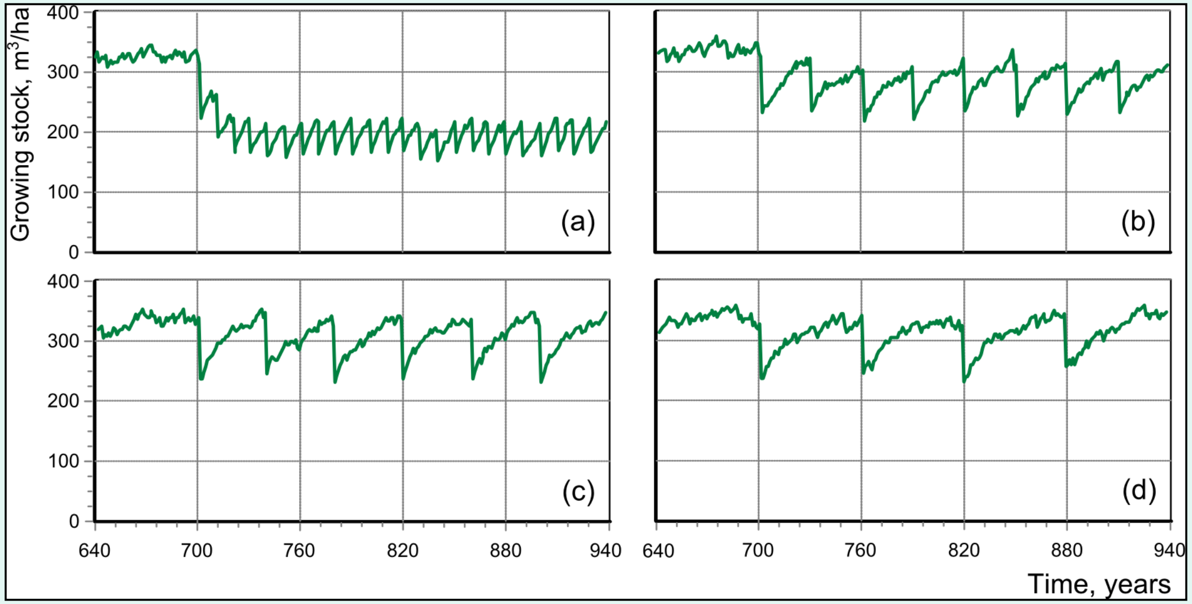
The graph shows that in the case of natural development of the mixed forest stand, without an external influence, the spruce completely crowd out the birch (Fig. a). However, removing a portion of mature trees spruce leads to the coexistence of these species. (Fig. b, c). In the case of removing a portion of spruce saplings it is observed oscillations. The number of dominant of birch gives way to spruce, and the reverse (Fig. d).

Modelling of selective cutting in uneven-aged spruce stands



Increase growing stock of spruce stand and tree diameter distribution in the stand 30 and 60 years after cutting
Figures left – harvested volume 30%, Figures right – harvested volume 60%

Modelling of selective cutting in uneven-aged spruce stands



Scenarios dynamics of spruce stands at different selective cutting regime:
a) period cutting 10 years;
b) 30 years; c) 40 years;
d) 60 years, harvested volume 30% for all cases

Characteristics of different scenarios of selective cutting

Selective cutting regime	Average harvested volume at a time, m^3	Total harvested volume for 240 years, m^3	The maximum diameter of harvested trees, cm	The minimum diameter of harvested trees, cm
10 years, 30%	64	1600	22	17
30 years, 30%	92	738	29	24
40 years, 30%	101	611	29	26
60 years, 30%	104	403	30	26

Conclusion

- The analysis of the dynamics scenarios confirmed the basic hypothesis that, in the long-term perspective and without any external influence, the shade-tolerant species completely crowd out the light-loving species.

- However, removing a portion of shade-tolerant mature trees leads to the coexistence of these species. These dynamics regimes occur with the mortality of mature trees as a result of a windfall, or the damage of stems from phytophages.

- In the case of removing a portion of shade-tolerant saplings it is observed oscillations where a number of dominant light-loving species gives way to shade-tolerant species, and the reverse. For example, these regimes may emerge when some saplings are eaten by ungulates or when samplings die because of ground fires.

Conclusion

- When harvesting volume the thirty and sixty percent, sixty years after cutting, growing stock reaches the value, it was before cutting in both cases. But in the first case, of forest stands structure corresponds to the state, it was before cutting, in the second case does not correspond.
- Selective cutting regime at intervals of cutting thirty years is a compromise between quality and quantity of harvested timber.

Thank you for your attention !