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ANALYSIS OF THE GROWTH CHARACTERISTICS OF A 450-YEAR-OLD SILVER FIR TREE

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Abstract - The growth characteristics of silver fir are of high importance for selection forest management, and for the current aims laid out in Serbia's forest management focused on increasing the share of silver firs in Serbia's growing stock. With the objective of increasing the understanding of the growth characteristics of silver fir, the growth of two silver fir trees felled during forest site production research on Mt. Goč, located in Central Serbia, have been analyzed. Both trees showed significant differences in their growth dynamics over long periods as results of micro-site and micro-stand effects (primarily ambient light regime). The common growth characteristic of the two trees, a 450-year-old tree as the main study object (labeled Tree A) and a 270-year-old Tree B is a long stagnation stage. For Tree A the latent phase, with small interruptions, lasted 410 years; one phase lasted 330 years in continuity, which is the longest period of silver fir stagnation recorded in Europe. Tree B showed a long-lasting stagnation stage that lasted 170 years. The long stagnation stage of Tree A, characterized by an average diameter increment of 1.4 mm/year (average growth ring width of 0.7 mm) and an average height increment of 0.08 m/year, shows the extraordinary silver fir capacity for physiological survival in complete shade. This study adds to the existing knowledge of the shade tolerance of the silver fir. Therefore, the silver fir belongs to the group of extremely shade-tolerant tree species. This characteristic makes silver fir an irreplaceable tree species in the selection forest structure. It offers a wide range of silvicultural flexibility in the management of these forests, and is applicable to silver fir selection Serbia's forests.

Key words: silver fir; selection forests; growth dynamics; stagnation stage

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INTRODUCTION

Silver fir (*Abies alba* Mill) is an autochthonous tree species in Serbia, occurring in large forest complexes in western and southwestern (Tara, Povlen, Maljen, Suvobor, Golija and Prokletije), central (Goč, Veliki Jastrebac and Kopaonik) and eastern (Stara Planina, Rtanj, Suva Planina, Beljanica and Malinik) parts of the country. Most often, it grows at altitudes from 800 to 1600 m in mixed forests with beech, or with beech and spruce (Jovanović, 2007). They are mainly selection forests in which silver fir is the carrier of a specific structure and a tree species without which this silvicultural form could not be developed (Schütz, 2001; Banković et al., 2009b; Pantić et al., 2011). From the aspect of the multifunctional role of forests in human society and the need to ensure numerous protection, social and economic functions, selection forests are nowadays a desirable silvicultural form in forest management. Consistent with these tendencies and the importance of silver fir for forest structure and survival, it is logical that the research of ecological, biological and dynamic characteristics of this tree species is more than significant (Banković, 1981; Bagnaresi et al., 2002).

Silver fir forests occupy 1.1% (25 600 ha) of the area, 2.7% (9 838 863 m^3) of the volume and 2.5% (225 515 m^3) of the current volume increment of the growing stock in Serbia (Banković et al., 2009a). They are the most productive forests in Serbia, with an average volume of 385 $m^3 \cdot ha^{-1}$ and current volume increment of 8.8 $m^3 \cdot ha^{-1}$. The insufficient percentage of silver fir forests, very much unharmonized with site potentials, makes it necessary to introduce this tree species to the regions wherever possible, especially in the belt of beech forests and where the spontaneous extension of forest vertical amplitude is already underway. In addition to a series of economic, technical and biological hypotheses for the solution of this strategic task in the field of forestry in Serbia, great significance is assigned to the research and improvement of the knowledge regarding silver fir growth dynamics and its dependence on site and stand conditions and also on human-induced impacts.

In addition to the above, a specific motive for undertaking the research was the fact that the described 450-year-old silver fir and the tree selected for comparison by its dendrometric characteristics (size, age, length of the latent state) are extreme rarities at the local, and to some extent regional levels, and is of unique value for scientific analysis, even if the rarity of trees of such dimension makes a study of a large number of trees unfeasible.

MATERIALS AND METHODS

Study area

Mt. Goč forests are located between latitudes 43°30' and 43°35'N and longitudes 18°15' and 18°30'E. The parent rock consists of old Paleozoic schists with a low degree of metamorphism, contact metamorphic rocks, marble, granodiorites, andesites, dacites, and serpentinized dunites. The soils are classified as syrozem, black soils, brown soils, leached brown soils and podzols. A humid climate prevails in the region. The average annual air temperature is 7.3°C, relative air humidity is 81%, precipitation is 1 010 mm, and duration of sunny periods is 1 938 h (Banković, 1981; Jović et al., 1999; Medarević et al., 2009).

The study trees were felled in Section b, Compartment 36, Management Unit "Goč Gvozdac-A". The stand is classified as a mixed singletree selection stand of good health, forest type silver fir and beech (*Abieti-Fagetum typicum*) on medium deep acid brown soils over granodiorites and quartz diorites. The stand grows at the altitude of 1 180-1 220 m, on steep to very steep slopes 21°-25°, west-northwest aspect. At present, its main function is forest research (Medarević et al., 2009).

Data collection and processing

The study silver fir was felled during the measurement of research plots and tree cutting in the framework of a production phase of forest site typological description on Mt. Goč. Its dimensions, preliminarily estimated age and the duration of the stagnation stage were some of the motives for undertaking its in-depth dendrometric processing and analysis (Tree A). For the purpose of comparison, another tree was selected from the adjacent trees and was subjected to the same analysis procedure (Tree B). Such impressive silver fir trees are a rarity today on Mt. Goč, and in the forest resources of Serbia in general, which made it impossible to provide a large sample for this research. Only such singular and rare trees offer the opportunity for the specific observations made by this study

The felled trees were cut into disks: on the stump (0.3 m), at breast height (1.3 m), and then at intervals of 2 m (3.3 m, 5.3 m, 7.3 m, etc.). The stem disks were analyzed using LINTAB 4 tree-ring measuring, with TSAP software (RINNTECH e.K., Germany). Tree age was calculated by counting growth rings on the disk taken at the stump. Based on the diameters at the end of the ten-year periods which were marked on each disk from the periphery towards the center, on the height (length) at which the disks were taken and on the number of growth rings, the calculated data made it possible to draw the lines of development and diameter and height increments of Tree A and Tree B, using Tree Analysis Software (Banković and Pantić, 2006). The stagnation stage was differentiated from the post-stagnation period. The criteria for the differentiation of these two phases in silver fir development were growth ring width on disks at breast height, i.e. current diameter increment (Ferlin, 2002), and current height increment (Banković, 1981). Growth ring width above 1 mm, i.e., current diameter increment above 2 mm, and current height increment above 0.125 m, were the indicators that the tree was out of the stagnation stage.

RESULTS

According to early researches by Bioley (1920) and Badoux (1949), in selection forests each tree has its characteristic (individual) growth, i.e. dynamics. This particularity results from the different light tolerance of tree species in selection forests, and from the heterogeneous tree distribution (especially vertical), and consequently very different micro-site and micro-stand conditions. The above statement refers especially to the singletree selection structure (random distribution of trees) that characterizes the stand in which the study silver fir trees were felled.

As the consequence of larger growth space and improved light regime in its surroundings, Tree A increased its diameter increment and within a period of between 50-70 years terminated its stagnation stage (Figs. 1 and 2). However, the surrounding trees, first of all beech trees, reacted quickly to the new conditions by intensive crown spreading, which resulted in a worsened light regime, shading of the silver fir tree and its re-entering the latent state. The second, also very short reaction to improved living conditions is observed as late as the period between 370 and 390 years. With the exception of the above

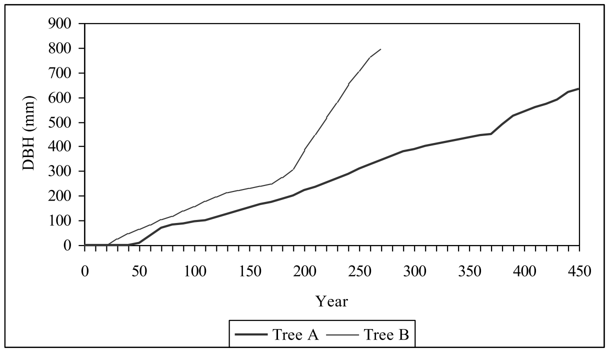

Fig. 1. Growth of tree diameters.

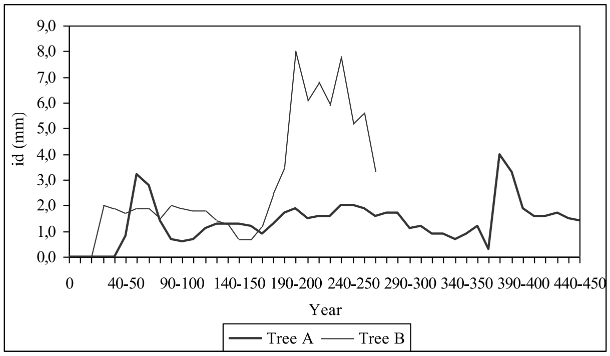

Fig. 2. Increments of tree diameters.

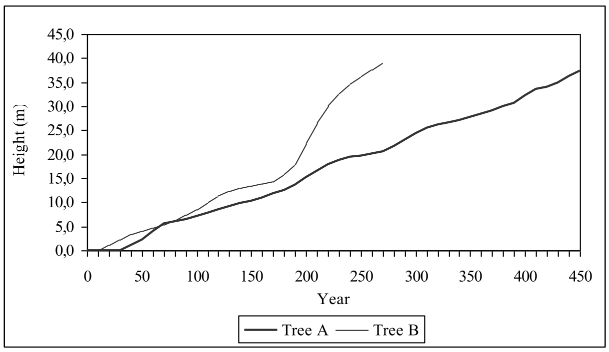

Fig. 3. Tree growth in height.

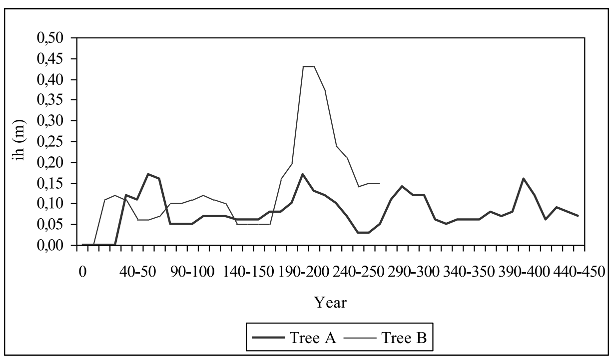

Fig. 4. Tree increments in height.

Table 1. Principal dendrometric values of the studied trees.

Tree	t (year)	DBH (mm)	Height (m)	ipd (mm)	iph (m)	t_1 (year)
A	450	635	37.4	1.4	0.08	330 (410)
B	270	798	39.2	3.0	0.15	170
Difference	180	- 163 (- 25.7%)	- 1.8 (- 4.8%)	- 1.6 (- 114.3%)	- 0.07 (- 87.5%)	160 (240)

t – tree age; DBH – diameter at breast height; ipd – average diameter increment; iph – average height increment; t_1 – period (years) spent in the stagnation stage

periods of normal growth (only 40 years), it can be concluded that this silver fir tree stagnated for altogether 410 years, or in continuity for 330 years. Its height growth (Figs. 3 and 4) was somewhat more dynamic, with a greater number of short-time reactions to the change (improvement) in living conditions. This is understandable, since height increment is faster compared to diameter increment, and the reaction to better light conditions is more intensive, as the consequence of an attempt to reach a more favorable position for light from above. Average diameter increment amounted to 1.4 mm/year (average growth ring width only 0.7 mm), and height 0.08 m/year (Table 1). Despite the exceptionally long period of slow growth (stagnation), this tree attained considerable size. Diameter at breast height was 635 mm, and height 37.4 m, which is the consequence of both the age of 450 years, and the good site potential.

The growth dynamics of Tree B differed significantly from Tree A. Its stagnation stage lasted continuously for 170 years. After this period, its growth space increased and as a result, the light regime in its surroundings improved. The tree reacted by rapid growth acceleration, increase in current diameter increment and by the termination of the latent state (Figs. 1 and 2). The culmination of current diameter increment occurred between the ages of 190 and 200 years, with a rather high value of 8 mm. The moment of culmination represented the growth curve inflection point, i.e. the curve changed from a convex to a concave form toward the abscissa axis. The increment oscillated after the culmination; it regained a significant value of 7.8 mm at the age of 230-240 years and then dropped sharply toward the final age (tree cutting). The course of height growth was similar to diameter growth, with somewhat more marked dynamics (Figs. 3 and 4). The curve of current height increment also shows the termination of the latent state about the age of 170 years. After that, this increment increased sharply and culminated at the age of about 190, retaining the attained value of 0.43 m until the age of 230 years, after which it dropped abruptly to the final age. Average diameter increment amounted to 3 mm/year (average growth ring width 1.5 mm), and height increment 0.15 m/year (Table 1). Tree B reached imposing dimensions – diameter at breast height was 798 mm, height 39.2 m.

Although Tree A was 180 years older than Tree B, it attained lower dimensions. Its diameter at breast height was lower by 163 mm (-25.7%), height by 1.8 m (-4.8%). The differences were especially high in average increment and in diameter increment and accounted for -114.3%, i.e. -87.5% in height increment (Table 1). Tree A spent 73% of its lifetime in continuity in the stagnation stage, i.e. 91% if total duration of the latent phase is taken into account. This phase accounted for 63% of Tree B's life span.

DISCUSSION

The analyzed Tree A and Tree B are characterized by significantly different growth curves, as the consequence of the effects of different micro-site, and primarily micro-stand conditions, the most important of which is the impact of growth space and thus the effect of light regime in their surroundings. The only common characteristic in the growth of Tree A and Tree B is the stagnation stage. The stagnation period of Tree A, with small interruptions, lasted for about 410 years, in continuity 330 years, which is 91%, i.e. 73% of its lifetime. The period of stagnation and slow growth of Tree B was considerably shorter, amounting to 170 years in continuity, which is 63% of its lifetime. According to references, different maximal lengths of silver fir stagnation are reported in selection forests in Europe. Thus Assman (1961) reported the duration of only several decades, Milojković and Mirković (1955), Schütz (1969, 2001, 2002) and Jaworski and Zarzycki (1983) about 100 years, Frančisković (1938) 140 years, Ferlin (2002) 189 years and Šafar (1963) 200 years. Based on the available literature, the duration of a latent state of 330 (410) years is the longest period of silver fir stagnation recorded to date in selection forests and forests in general in Europe. Such a long stagnation, together with the average diameter increment of 1.4 mm/year (average growth ring width only 0.7 mm) and average height increment of 0.08 m/year, which were also significantly lower during the latent phase, point to an extraordinary silver fir capacity for physiological survival in the conditions of complete shade. For that reason, silver fir is classified in the group of extremely shade-tolerant tree species (Kobe et al., 1995; Parent and Messier, 1996; Kobe and Coates, 1997; Stanescu et al., 1997; Stojanović and Krstić, 2008), and as such it is irreplaceable in the formation and preservation of selection forest structures.

Despite a very long stagnation stage, both trees attained considerable dimensions (diameter and height). The reasons are silver fir biological characteristics, good site potentials and the age, especially of Tree A. At the time of felling, Tree A was in good health, so it can be presumed that it would have reached an age even greater than 450 years. In regularly managed forests, European silver fir reaches the age of up to 200 years (Jovanović, 2007), and in virgin forests even over 500 years (Mayer, 1977; Godet, 1999; Moro, 2007). The greatest age of European silver fir of 700 years was recorded in 1955 in Italy, in Malga Boazzo (Valle di Daone). In the context of tree dimensions and length of stagnation stages, it is questionable whether silver fir stagnation is desirable in selection forests. From the economic aspect, a latent state is certainly desirable because under constantly favorable growth conditions (without a stagnation stage), the trees would reach far greater sizes over the same period, i.e. the diameter of felling maturity would be reached in a considerably shorter time. From the aspect of management, this phase is essential for the development and maintenance of selection structure. The length of the stagnation stage can be shortened by selection cuttings and by the effect on growth space and light regime in the stand, tree recruitment can be accelerated and the time of transition can be shortened. However, any acceleration of dynamic processes would certainly lead to the disturbance and gradual loss of selection structure, which is an imperative in modern trends of forest management. In any case, knowledge of the extreme high and long-lasting shade tolerance of silver fir offers, both for long-term selection forest concepts and on the level of single-stand management and development, flexibility of silvicultural measures.

Based on the above, it can be concluded that silver fir trees in forests with singletree selection structure have very different growth dynamics, conditioned by micro-site and micro-stand conditions (primarily light regime), and that the common characteristic of their growth is the stagnation stage, which is necessary from the aspect of development and preservation of selection structure. The above facts should be taken into account in the management of selection forests, and in the efforts of increasing the percentage of silver fir in the growing stock of Serbia.

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