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Growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Region of Yundola Training and Experimental Forest Range, Bulgaria

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Abstract: The aim of the article was to study the growth of Douglas-fir plantations in the region of the Training Experimental Forest Enterprise, Yundola (Central South Bulgaria). The study sites were three Douglas-fir plantations, ranging between 50 and 55 years of age at altitudinal range between 1,400 m and 1,600 m above sea level (masl). The mean height, diameter at breast height, site class, stem volume as well as the mechanical resistance (*H/D* ratio) of Douglas-fir were measured for each plantation. The results showed that Douglas-fir had the best height growth of the studied plantations on slope facing South at altitude 1,600 masl and Douglas-fir with age 55 years old reached a mean height of 32.4 m. The average diameter at breast height of the studied plantations reaches approximately 30 cm, which shows that they are suitable for large scale wood harvesting. The average stem volume of Douglas-fir in the observed plantations up to age of 55 is within the range of 400-600 m^3/ha, with an average annual volume increment from 7 m^3/ha to 12 m^3/ha each year. The high index of mechanical resistance (*H/D* ratio) indicated a risk for abiotic damages, which implicated the need for the immediate implementation of felling.

Key words: Diameter of breast height, Douglas-fir plantations, mean height, *H/D* ratio, stem volume.

1. Introduction

Douglas-fir is one of the fastest growing and highly productive coniferous tree species [1-3]. In its natural range, the species grows from sea level up to 3,000 m on the slopes of the Rocky Mountains [4]. In the regions of cultivation, it is used at different altitudes. In Great Britain, it is widely considered that Douglas-fir is a species for the middle-hill slopes. It is rarely planted in valleys or at high altitude. It has been grown successfully at altitudes of 305 m in Scotland and up to 408 m in Wales, but because of the high risk of top damage in wind-exposed areas, it is grown under 250 m above sea level (masl) [5]. Douglas-fir has gradually become the main species used in reforestation programs in France, used especially at altitudes ranging between 600 m and 1,200 m [6]. In Italy, its optimal vegetation zone ranged in 600-1,000 masl [7].

Douglas-fir is the most widely used as the introduced coniferous tree species for the purposes of reforestation in Bulgaria. The first Douglas-fir plantation was established in 1906. Nowadays, Douglas-fir plantations occupy an area of 7,372 ha, i.e., 0.7% of the whole coniferous forests area. Douglas-fir plantations were established in many places throughout the country, primarily in the foothills and low-mountain, yet some of the plantations are located in the mountainous zone at an altitude of over 1,000 m. In one plantation, located 110 km East of Sofia at an altitude of 1,000 m on brown forest soil (cambisols, FAO), at the age 71 years, Douglas-fir has mean height of 33.0 m, mean diameter of breast height 51.0 cm and mean annual

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volume increment 17.4 m^3/ha [8]. There is evidence of very good growth and productivity of Douglas-fir in Bulgaria also at an altitude of over 1,000 m [9-16]. Petkova [17] studied eight young Douglas-fir plantations (11-21 years old) located on the Northern slopes of Stara Planina Mountain in the middle belt (1,100-1,400 masl), and concluded that the most productive 21-year-old plantation was established of shady exposure and altitude of 1,200 m. In West Rila Mountain (Southwestern Bulgaria) with an altitude of 1,400 m and age of 82 years, Douglas-fir reached a mean height of 38 m, mean diameter of breast height 43 cm and mean annual volume increment 14.19 m^3/ha [18]. Ferezliev [19] studied 12 plantations in Northwestern Rhodope Mountains from 1,100 to 1,450 m and confirmed the excellent growth capabilities of the Douglas-fir in highland conditions. According to the author, the mean height reached 34.8 m and the diameter of breast height 33.2 cm, at 46 years of age [19].

Citied authors have investigated that Douglas-fir plantations are situated at altitudinal range between 1,000 m and 1,450 m. It would be interesting to examine whether Douglas-fir in Bulgaria could grow successfully and even on higher altitudes. To get an answer to this question, the authors turned to study some Douglas-fir plantations in the region of the Training Experimental Forest Enterprise, Yundola. It is situated in central South Bulgaria covering parts of the Rila and Rhodope Mountains. The region is characterized by a typical mountain climate and a maximum altitude of 1,834 m. Douglas-fir plantations were established here at altitudinal range between 1,400 m and 1,600 m.

The aim of the study was to research the growth rate of Douglas-fir plantations situated at a higher altitude in the region of the Training Experimental Forest Enterprise, Yundola, central South Bulgaria.

2. Materials and Methods

The studied region covers parts of Rila and Western Rhodope Mountains (South Bulgaria). The average altitude is 1,479 m (from 1,030 m to 1,834 m).

The climate in the region is mountainous with an average annual temperature of 5.3 °C and average temperature of the growing period 11.2 °C. The average annual precipitation is 697.1 mm, of which more than half (383.5 mm) fall during the growing period. The average relative humidity varies over the year from 69% to 85% and three is no prolonged droughts. The duration of the growing period is approximately four months. Strong winds, more often with erratic direction, are specific for higher and uncovered parts of the region. The soil in the region is mainly brown forest soil (dystric-eutric cambisols, FAO) and umbric cambisols (FAO) over 1,700 masl. The natural vegetation is represented mainly by conifers tree species—Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.) and silver-fir (*Abies alba* Mill.), and fewer deciduous tree species—common beech (*Fagus sylvatica* L.) and sessile oak (*Quercus petraea* Liebl.). Here are established Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), Macedonian pine (*Pinus peuce* Griseb.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations.

Three Douglas-fir plantations aged from 50 to 55 years and situated between 1,400 m to 1,600 m are studied (Table 1). The soils are on brown, mixed sandy loam, medium stony, medium deep, slightly moist to moist. The parent material is granite. The plantations SP 1 and SP 2 are situated on slopes facing South and SP 3 is on slope facing Northeast.

Each plantation was allocated a sample plot, which is defined as average representative for the plantation. The sample plots are correct geometric form (preferably rectangular). The area of each sample plots (F_0) in Table 1 is defined as an orthogonal projection of the sample plots by Eq. (1) [20]:

$$F_0\ (\mathrm{m}^2) = F_t \times \cos i \qquad (1)$$

where, F_t is an area measured on the field (m^2), i is slope inclination in degrees.

Table 1 Habitats of Douglas-fir plantations at the particular sample plots (SP).

No.	Area (F_0) (m^2)	Geographical latitude (North)	Longitude (West)	Altitude (m)	Aspect	Slope inclination (°)	Type of soil	Habitat
SP 1	990	42°04′14″	23°51′42″	1,407	South	8	Cambisols	C_2
SP 2	369	42°04′15″	23°50′00″	1,600	South	10	Cambisols	C_2
SP 3	1,188	42° 05′06″	23°51′59″	1,480	Northeast	18	Cambisols	$C_{2,3}$

The planting scheme was based on several control measurements of the distances between the rows and between the plants in the order.

For each sample plot, stem analysis was applied [21] that includes:

(1) Determination of the average diameter at breast height;

(2) Determination of average height;

(3) Selection of the average model tree—a tree with an average diameter at breast height and average height;

(4) Felling of the average model tree for each sample plot, separating the stem by sections with length of 2 m and extraction of stem discs in the middle of each section;

(5) Measurement of diameter increments of two mutually perpendicular diameters—with bark, without bark and into the center of the discs by five years. Data were entered and processed by software program "STA 98" [22]. The analysis results were presented graphically.

The average diameter at breast height for each sample plot was determined in the following way. The diameters of all trees in each sample plot were measured in diameter classes by 2 cm. The diameter class (with a width of 2 cm) included all tree diameters within 2 cm interval and was even numbered (4, 6, 8, etc.). For example, the diameter class 10 included all trees with diameters from 9.1 cm to 11.0 cm. The average diameter (D) was calculated by Eq. (2) [20]:

$$D\,(\text{cm}) = \sqrt{\frac{4G}{\pi N}} \tag{2}$$

where,

$G = \Sigma(n_i g_i)$, the total basal area of the trees in the sample plot (m^2);

n_i—the number of trees in the respective diameter class (by 2 cm);

g_i—the basal area in the respective diameter class, in m^2;

N—the numbers of trees in the sample plot.

The mean height (H) of Douglas-fir of each sample plot was calculated as the average arithmetic of the heights of 9-19 trees of central and neighboring diameter classes (by 2 cm).

The stem volume (V) was calculated according to Eq. (3):

$$V\,(\text{m}^3) = \frac{G}{g} \times v \tag{3}$$

where,

G—the total basal area of the trees in the sample plot, in m^2;

g—the basal area of the mean model tree, in m^2;

v—the volume of the mean model tree with bark, (m^3).

The determined stem volume was recalculated for 1 ha.

The site class of Douglas-fir of each sample plot was determined by the Bergel's tables [23]. The ratio of height (m) to diameter (cm) at breast height (H/D) —known as the coefficient of mechanical resistance was calculated. According to Lindemann [24], when the ratio $H/D > 0.83$, there is an increased damage risk caused by abiotic factors (wind, snow, ice).

3. Results

Table 2 shows the basic characteristics of the studied plantations.

The comparison of the height growth of the Douglas-fir by SP 1, SP 2 and SP 3 shows (Fig. 1) that

Table 2 Basic characteristics in the particular sample plots (SP).

Characteristics	SP 1	SP 2	SP 3
Age (years)	55	55	50
Mean height (m)	25.9	32.45	25.7
Diameter at breast height (cm)	32	28	20
Site class	II	I	II
Planting scheme (m)	2.0 ÷ 2.2 × 1.5 ÷ 1.8	2.2 × 2.0	1.2 ÷ 2.0 × 0.5 ÷ 1.0
Initial density (numbers/ha)	2,720	2,273	8,333
Current density (numbers/ha)	990	540	1,716
Basal area (m^2/ha)	40.3	42.2	48
Stem volume (m^3/ha)	395.6	587.1	616.6
Mean annual volume increment (m^3/ha)	7.19	10.67	12.33
Coefficient of mechanical resistance (*H/D*)	0.89	1.22	1.3

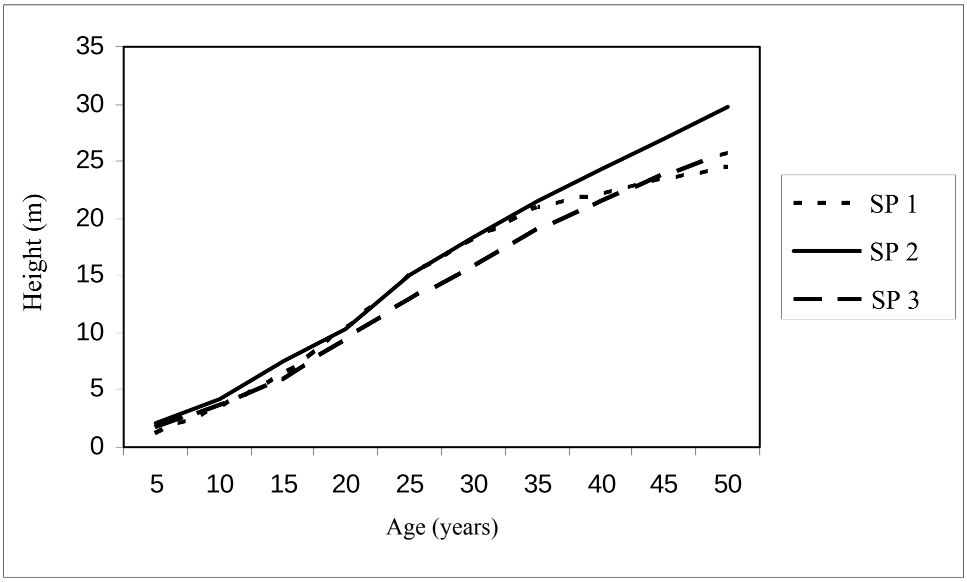

Fig. 1 Height growth of Douglas-fir in SP 1, SP 2 and SP 3.

by 10 years of age, it reaches uniformity in all three plantations. After the age of 10 years, the Douglas-fir that grow more actively in height are the ones from SP 2, which are located at the highest altitude (1,600 m). Between the 25th and 30th years of life, the height growth of Douglas-fir in SP 1 and SP 2 is nearly identical. During the same period, the Douglas-fir in SP 3 shows a slower growth. After the 30th year, the Douglas-fir in SP 3 are characterized with the best height growth.

The tracking of the average height increment (Fig. 2) shows that once again the most intensively growing is Douglas-fir in SP 2. In this plantation, the height increment reaches a maximum value at the age of 30 years of 0.61 m, and then slightly decreased. The same value of the annual height increment at age of 30 years was indicated by Lavender and Hermann [5] for the Douglas-fir in its natural range on medium rich habitat and low altitude. The curves of the height increment of Douglas-fir in SP 1 become the same as in the SP 2 plantation around the age of 20 years, but at the age of 35 years it begins to decline. In SP 3, the Douglas-fir maintains the lower values of average height increment throughout the studied period compared to the other two plantations.

Figs. 3-5 show the current and average annual volume increment of Douglas-fir according to the data from the model trees. The curves of the current and

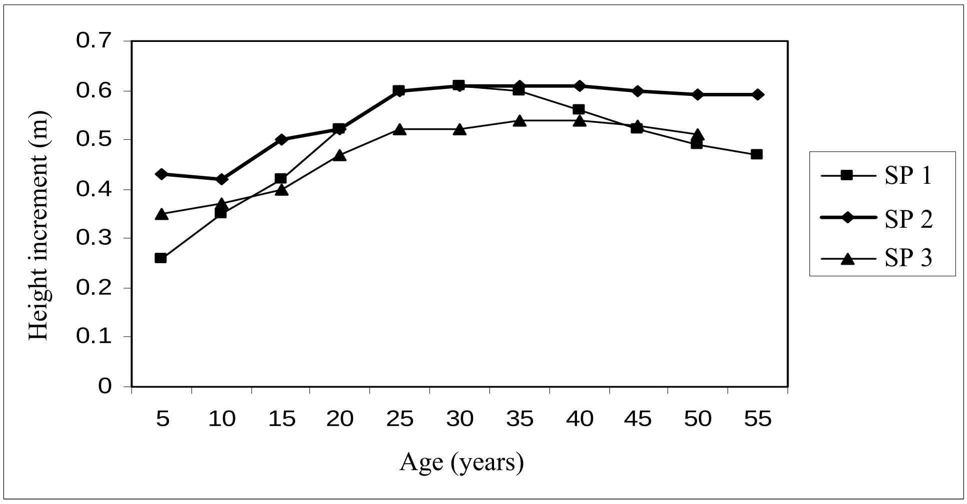

Fig. 2 Average height increment of Douglas-fir in SP 1, SP 2 and SP 3.

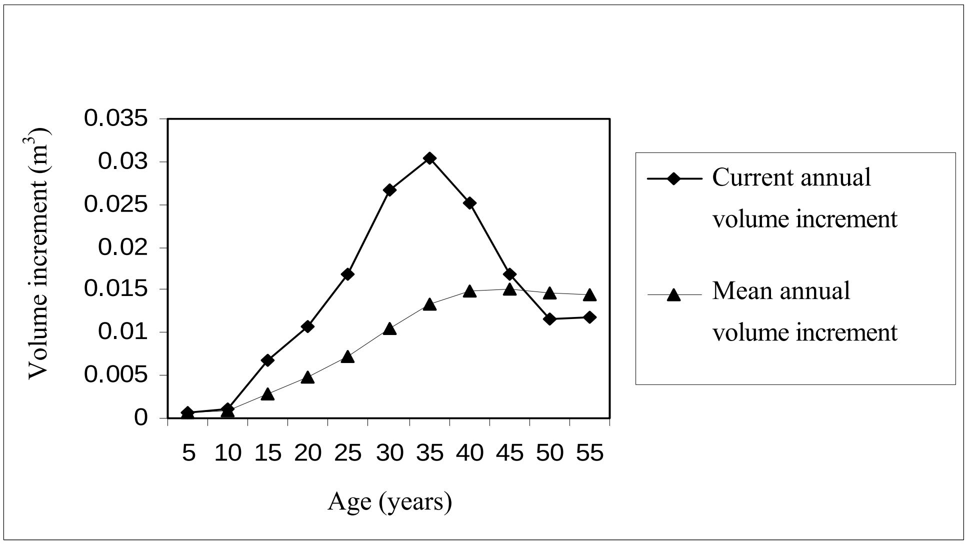

Fig. 3 Volume increment in SP 1.

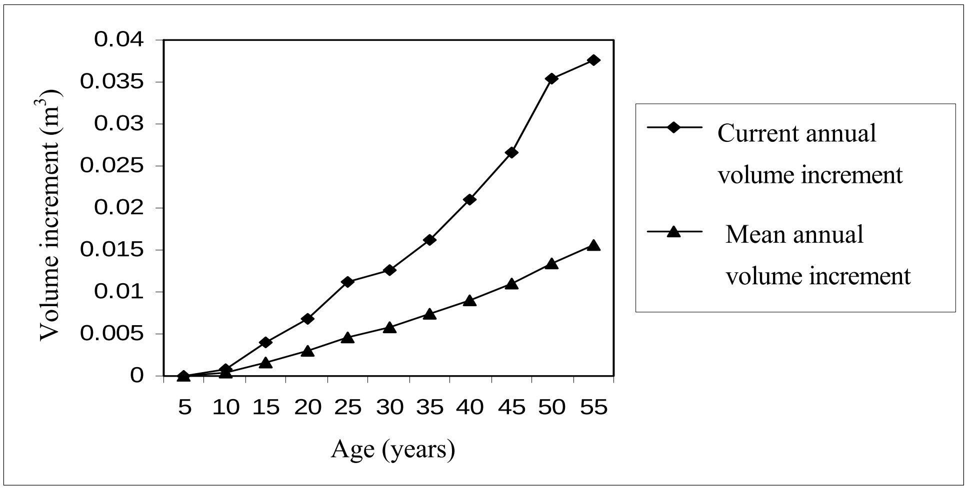

Fig. 4 Volume increment in SP 2.

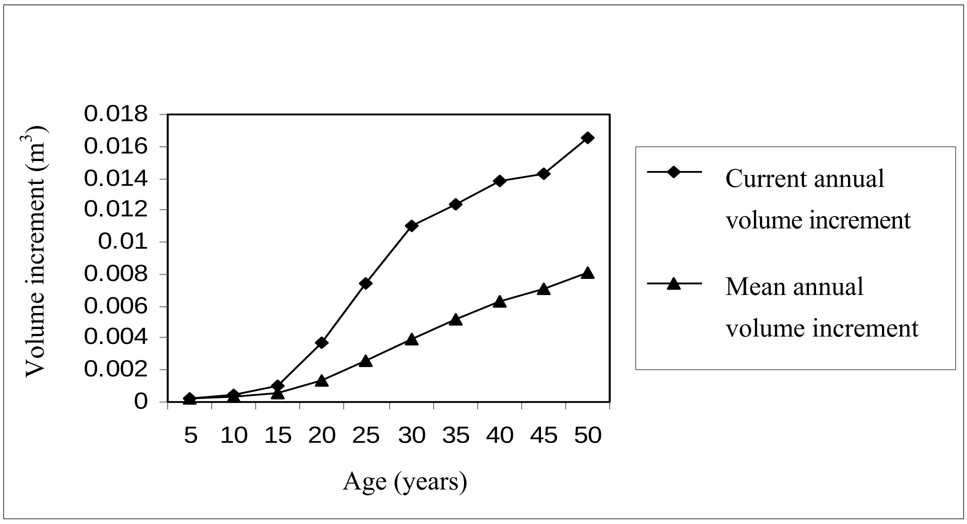

Fig. 5 Volume increment in SP 3.

mean annual volume increment of model trees intersects between 45 and 50 years of age only in SP 1, which indicates the occurrence of quantitative maturity in this plantation.

The stem volume of the Douglas-fir at 50-55 years is within the range of 400 m^3/ha to 600 m^3/ha, with mean annual volume increment from 7 m^3/ha to 12 m^3/ha.

The height (m) to diameter (cm) ratio at breast height (*H/D*) is a good indicator of the risk of stem breakage or windthrow. The estimated ratio (*H/D*) (coefficient of mechanical resistance) of Douglas-fir in all plantations is above the critical value of 0.83, which indicates a risk of such damages (Table 2). The high values of *H/D* ratio are due to the higher initial density and a lack of silvicultural interventions on plantations during the studied time.

In all plantations, the presence of seedlings was found, indicating a sign of the beginning of natural regeneration and naturalization of Douglas-fir in the studied region. Broncano et al. [25] reported about naturalization and begin invasion of Douglas-fir in Spain at altitudes above 1,000 m.

4. Discussion

When comparing the climatic conditions in the studied region with those in Western Washington, from where were imported seeds for the most Douglas-fir plantations in Bulgaria, major differences are found. The average temperature for January (-3.8 °C) and the average temperature for July (14.3 °C) are both lower from those in the natural range (-2.5 °C to 2.5 °C for January and from 20 °C to 27 °C in July) [5]. There is also a significant difference in the duration of the growing period. In the studied region, it is about four months, while in Western Washington it is about six months.

The differences in precipitation patterns show less rainfall in the studied region compared to the area of Western Washington. The annual rainfall in the region was 697.1 mm, and in the natural range of Douglas-fir in some places reached levels of 3,000 mm, the majority of which took place during the winter [5].

Generally, the temperature conditions in the area are less favorable, and the precipitation amounts are significantly lower in comparison to that of the natural range of Douglas-fir.

The conducted studies of the growth indicate that the Douglas-fir in the region adapts very well to those different climate conditions, and the Douglas-fir of age of 30 years has a similar height increment with this as referred by Lavender and Hermann [5] for its natural range. Douglas-fir in SP 2 grows especially actively in height. This plantation is located at the highest studied altitude of 1,600 m, and has the highest site class (class I) (Tables 1 and 2). From the comparison of the height growth of Douglas-fir in SP 1, SP 2 and SP 3 (Fig. 2), it can be concluded that the differences in the intensity of its growth could be attributed to its aspect. Douglas-fir in SP 1 and SP 2 shows better average height increment on slopes facing South, and both plantations have a medium rich and fresh habitat; while the Douglas-fir of SP 3 has significantly weaker growth, average height increment on slope facing Northeasth and medium rich habitat. At a relatively high altitude, the shadowy aspect most likely further deteriorates the disadvantageous temperature conditions, which contributes to slower growth in height. The very good height growth of Douglas-fir in the studied region confirms the conclusion of Petkova [17] that in sub-belts forest of beech, silver-fir and spruce, the Douglas-fir could be successfully cultivated and even up to 1,400 m. The present study demonstrates that in habitats on slopes facing South, the Douglas-fir grew and developed successfully, and that at an altitude of 1,600 m, they showed better height growth than at lower altitudes (1,400 masl).

In this case, the particular conditions of habitat positively affected the growth in height. Bond et al. [26] also pointed out that the growth in height of Douglas-fir was strongly influenced by site conditions. Under these conditions, Douglas-fir showed very good growth, matching the one in its natural range, even at low altitudes [5]. Evidence of its good adaptation in those conditions and habitat is the established natural regeneration by Douglas-fir.

The problem with the sensitivity of Douglas-fir of damage by abiotic factors (wind, snow)—high *H/D* ratio and the suggestions to resolve it by conducting of felling are subject to a number of publications [27-29]. Wilson and Baker [28] emphasized that later thinnings may not be effective in promoting stability, since there was no lower *H/D* values appeared. In the studied Douglas-fir plantations, silvicultural interventions are late and the intervention should be conducted very carefully.

5. Conclusions

(1) In the slope facing South and at an altitude of 1,600 m, Douglas-fir has the best height growth of 32.4 m at age 55 years and the site class is class I. In a similar habitat and a slightly lower altitude (1,480 m), the mean height of Douglas-fir at the same age reaches 25.9 m (site class II).

(2) The average diameter of the Douglas-fir in the surveyed region at the age of 50 years reaches 30 cm and more, which shows that they are suitable for a large size wood harvesting.

(3) The high *H/D* ratio (coefficient of mechanical resistance) indicates a risk from abiotic damages, which makes felling necessary as soon as possible.

(4) In all of plantations, natural regeneration was observed (presence of seedlings), which is an indicator for the successful adaptation of Douglas-fir to the local conditions.

(5) The high growth potential of Douglas-fir to the upper sub-belts of highland forests of beech, silver-fir and spruce (1,600 masl) comparable to that in its natural range is on evidence of its successful cultivation in Bulgaria and at a higher altitude.

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