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# *Comparative Study of the Height and Volume Structure of Douglas-Fir Forest Plantations in North-West Rhodopes, Bulgaria*

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**Abstract.** Comparative study on the variation curves of height and volume distribution in mid-aged Douglas-fir plantations, created after mid-20th century in State Forestry Alabak – Velingrad-North-West Rhodopes was carried out. The plantations are located at different altitudes and various forestry activities were conducted in them. Their mean height curves and the unified height curve of Tyurin are compared. It is concluded that the height curves are roughly the same, and their course does not depend on tree species and environmental conditions. The curves in the tended sample plots are close to each other and, although varying in wide interval, they are closer to the common variation curve than to the variation in the untended plot. Curves and straight lines of the masses are built and they are recommended for use during cubic measurement of middle-aged plantations dominated by Douglas-fir and other similar tree stands, growing at comparable to the studied environmental conditions. The results obtained have theoretical and practical importance. The revealed features of the height and volume structure complement the research carried out so far and can be used to select the correct and appropriate management of the forest plantations with participation of Douglas-fir in third age class, located at relatively high altitudes.

**Key words:** variation curves for height and volume distribution, height and volume structure, forest plantations, *Pseudotsuga menziesii* (Mirb.) Franco.

## Introduction

Increasing the productivity of forest plantations and meeting the growing needs of wood can be achieved by introducing fast-growing tree species and conducting targeted silvicultural activities. The creation of such tree plantations is one of the main tasks of modern forestry (ILIEV, 1980). In a number of European countries, for the creation of special plantations such for intensive wood production, a great deal of attention is paid to a number of fast-growing and high-yielding coniferous trees, such as the *Douglas-fir (Pseudotsuga menziesii* (Mirb) Franco (MIKLOS, 1980; PARDE, 1985; RABSTAJNEK, 1985 BOUCHON, 1984; REUTZ, 2003; ABRAROVA *et al.*, 2010), *Larix spp., Cedrus spp., Pinus strobes* L., *Pinus excelsa* Will, *Pinus pinaster* Ait., *Pinus radiata* D. Don. Among the listed species, important for Bulgaria for accelerating wood

production is the Douglas-fir (ZAHARIEV, 1980; TASHKOV *et al*., 1980; PETKOVA, 1999).

Since 1963, Douglas-fir forest planting with origins mainly from the State of Washington (USA) have been carried out in many different regions of Bulgaria (ZAHARIEV, 1980). Subsequently, however, some of these plantations were not grown purposefully or not even been subjected to silvicultural activities, and thus the original designing concept did not materialize whatever it was (creation of industrial forests, anti-erosion afforestation, afforestation of wetter habitats, etc.).Reaching third grade of age (middle-aged), in these plantation are observed differences in their structure according to dendrometric indexes due to abiotic, biotic and anthropogenic reasons, and there is a need for targeted guidance on their future management in relation to established growth specificity (FEREZLIEV *et al*., 2018).

In this regard, the aim of the present study is to continue the former studies related to growth and increment in height (FEREZLIEV & TSAKOV, 2012) and to volume (FEREZLIEV & DELKOV, 2013) with the height structure, dynamics in height growth and structure of the Douglas-fir plantations (FEREZLIEV *et al*., 2013; FEREZLIEV 2013) in the Northwest Rhodopes and to be made comparative investigations of the curves of heights, the curve and straight line of masses related to the regularities in the structure of height and volume of the middle-aged plantations, created on different altitudes (but - higher than recommended by (ZAHARIEV, 1980) and managed differently within the borders of State Forest Enterprise "Alabak" - Velingrad.

**Materials and Methods**

In middle-aged Douglas-fir plantations, created at different altitudes, three rectangular sample plots are made up (Table 1). After total measuring of diameters and division of trees according to tree species, number and degrees of thickness it was measured the height of 3 trees of Douglas-fir from each degree of thickness (from the central ones-of 5 trees) using ultrasonic altimeter VERTEX IV. The average height was calculated after the formula of Lorey's (Lorey, 1878):

$Hav=(h.g_{1}+h_{2}.g_{2}+.....+h_{n}.g_{n})/(g_{1}+g_{2}+.....g_{n})$ (m)

where $h_{(1,2...n)}$ – is a mean (arithmetic) height of each degree of thickness $_{(1,2...n)}$ (m);

$g_{(1,2...n)}$ – is a basal area for each degree of thickness $_{(1,2...n)}$ ($m^2$).

The stem stock(volume) for each degree of thickness was determined, as well as the total growing stock for each sample plot. Stem volume of the degrees of thickness was calculated by the basic formula for the volume:

$V = g_{1.30}.h.f_{1.30}$ ($m^3$), where:

$g_{1.30}$ - basal area for each degree of thickness ($m^2$);

h – mean (arithmetic) height for each degree of thickness (m);

$f_{1.30}$ – breast (DBH) form factor for the determined mean height (for the determination of $f_{1.30}$, the relevant local table for form factors , as well as the species form heights of the Douglas fir was used, (FEREZLIEV & TSAKOV, 2010).

For studying the regularities in the structure according to height and volume, comparative studies were carried out on the variation distribution curves according to the respective dendrometric indicator.

**Results and Discussion**

On the basis of carried out measurements of Douglas-fir trees in the sample plots the following results were obtained (Table 2). In Fig. 1 are shown the curves of heights obtained for the studied sample plots. To investigate the regularities in the height structure, the so-called method of relative heights was applied. Its essence is that trees heights are determinated as relative according to average height (natural degrees of height-NDH) (DAVIDOV, 1949) and the number of trees in different heights is presented as a percentage of the total number of trees (KRASTANOV, 1969).

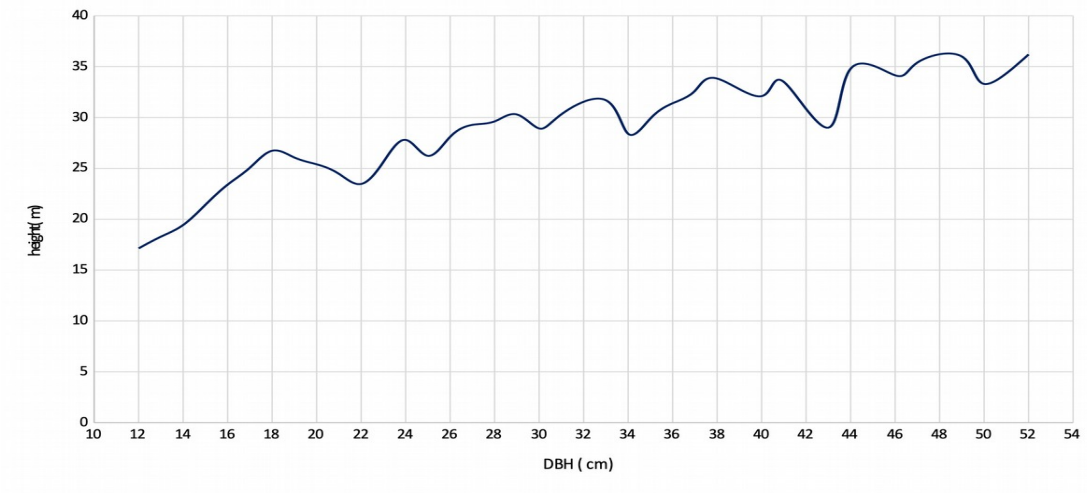
After consecutive summing up percentages of obtained variation rows, the sum rows of distribution are obtained, respectively the curves of sum distribution (Table 3 – 5) and respectively variation curves of percentage distribution of Douglas fir trees according to natural degrees of height in the three sample plots (Fig. 2).

**Table 1.** Location and characteristics of sample plots.

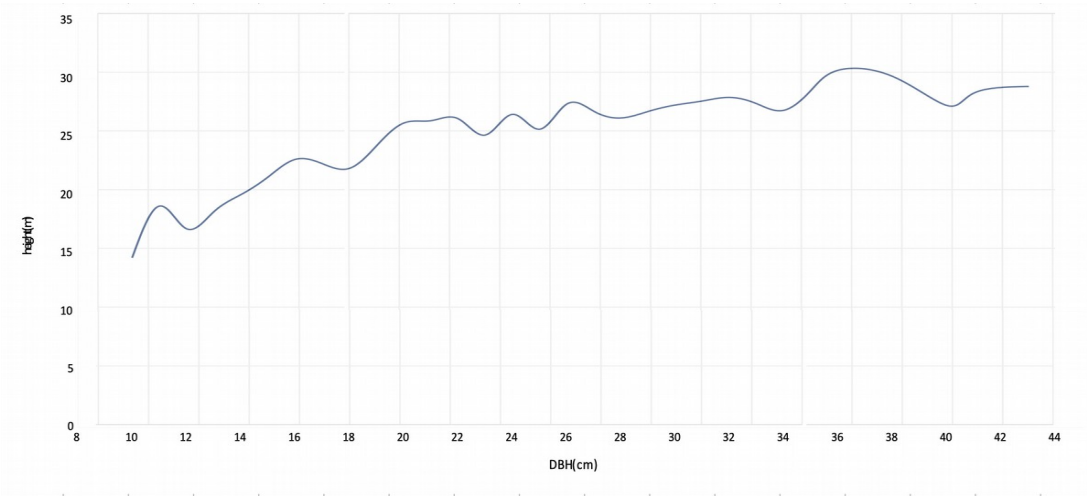
| **№ of sample plot (SP)** | **1** | **2** | **3** |
|---|---|---|---|
| Location | SFE Alabak | SFE Alabak | SFE Alabak |
| Land | Draginovo, Biala voda | Sveta Petka, Varbitsa | Velingrad, Macheshki skali |
| Coordinates | 42.1067753 N<br>23.9696273 E | 42.0458411 N<br>23.9060821 E | 42.0411415 N<br>23.9386711 E |
| Division /subdivision | 474 /v | 366 /r | 385/t |
| Size of SP (m) | 40 x 25 | 40 x 25 | 60 x 30 |
| Area of SP(ha) | 0,1 | 0,1 | 0,18 |
| Altitude (m) | 1450 | 1225 | 1100 |
| Exposition | E, slope upper part | S, slope upper part | NE, slope upper part |
| Slope (°) | 10–15 | 16 | 15 |
| Habitat | T-II-2 C-2,3 | T-II-2 C-2 | T-II-1 C-2 |
| Age | 52 | 49 | 39 |
| Year of creation | 1965 | 1968 | 1978 |
| Type of area prior to afforestation | barren land | barren land | barren land |
| Planting scheme (m) | 1,20 x 0,90 | 1,30 x 0,90 | 1.00 x 1,50 |
| Initial density, N/ha | 9259,<br>8516 (at the age of 14) | 8547 | 6667 |
| Creation method | planting | planting | planting |
| Post-planting cares | Growing up to 3 years and filling | Growing up to 3 years and filling | Growing up to 3 years and filling |
| Conducted silvicultural activities | pre-commercial thinning – 1979;<br>commercial thinning– 1986, 1993 and 1999;<br>10-12% intensity) | – | commercial thinning – 2010;<br>15% intensity |

**Table 2**. Calculation of taxonomic indices of Douglas- fir in studied sample plots.

| **Sample plot (SP)** | **Number of trees in sample plot** | **Average DBH (cm)** | **Average height H (m)** | **Basal area per 1 ha m²/ ha** | **Volume per 1 ha m³/ha** |
|---|---|---|---|---|---|
| 1 | 112 | 28.4 | 30.3 | 70.806 | 966.58 |
| 2 | 159 | 24.2 | 26.7 | 72.898 | 900.77 |
| 3 | 104 | 24.1 | 25.1 | 26.347 | 309.98 |




a

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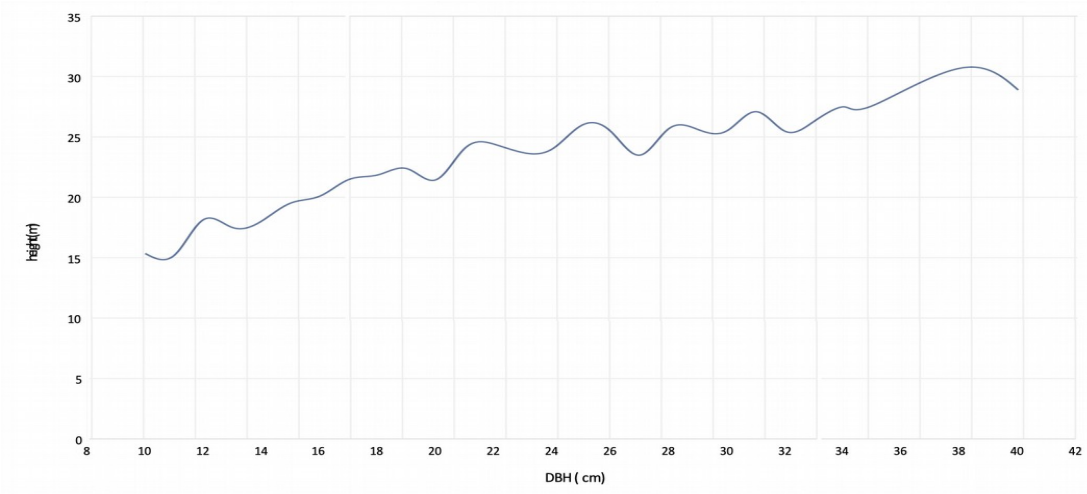



c

**Fig. 1.** Curve of heights in SP1(a), SP2(b) and SP3(c).

**Table 3.** Absolute and percentage distribution of the number of trees by natural degrees of height in SP1.

| Number of trees | Natural degrees of height | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1.1 | |
| Estimated number of trees | 7 | 5 | 4 | 4 | 8 | 1 | 29 |
| Equalized number of trees | 27 | 19 | 15 | 15 | 31 | 4 | 112 |
| Number of trees (percentage) - N(%) | 24.1 | 17.2 | 13.8 | 13.8 | 27.6 | 3.4 | 100 |
| Comulated percentage - N(%) | 24.1 | 41.4 | 55.2 | 69.0 | 96.6 | 100.0 | 100.0 |

**Table 4.** Absolute and percentage distribution of the number of trees by natural degrees of height in SP2.

| Number of trees | Natural degrees of height | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1.1 | |
| Estimated number of trees | 1 | 3 | 8 | 8 | 17 | 2 | 39 |
| Equalized number of trees | 4 | 12 | 33 | 33 | 69 | 8 | 159 |
| Number of trees (percentage) - N(%) | 2.6 | 7.7 | 20.5 | 20.5 | 43.6 | 5.1 | 100 |
| Comulated percentage - N(%) | 2.6 | 10.3 | 30.8 | 51.3 | 94.9 | 100.0 | 100.0 |

**Table 5.** Absolute and percentage distribution of the number of trees by natural degrees of height in SP3.

| Number of trees | Natural degrees of height | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | |
| Estimated number of trees | 1 | 3 | 4 | 7 | 2 | 1 | 18 |
| Equalized number of trees | 6 | 17 | 23 | 40 | 12 | 6 | 104 |
| Number of trees (percentage) - N(%) | 5.6 | 16.7 | 22.2 | 38.9 | 11.1 | 5.6 | 100 |
| Comulated percentage - N(%) | 5.6 | 22.2 | 44.4 | 83.3 | 94.4 | 100.0 | 100.0 |

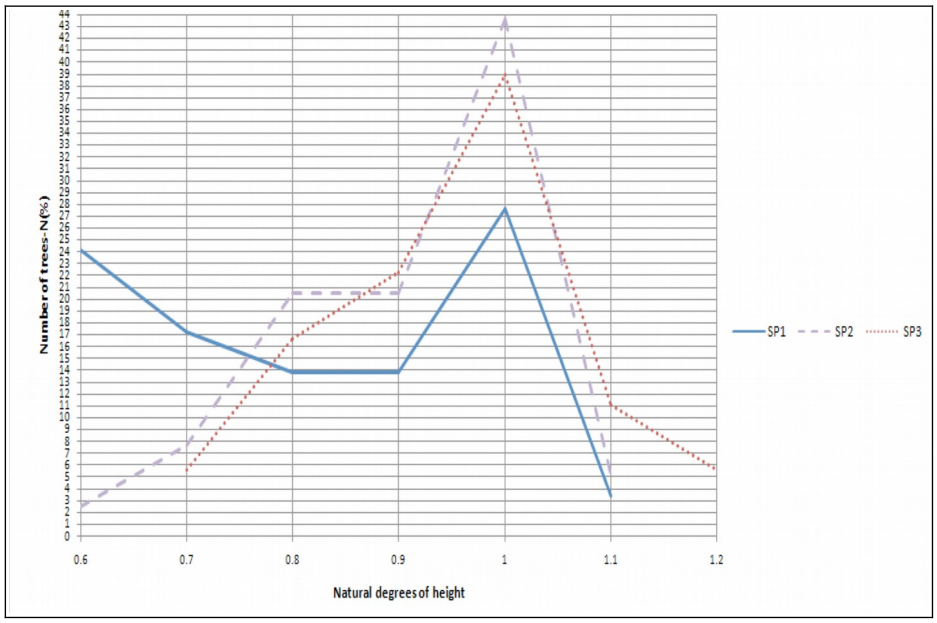



**Fig. 2.** Variation curves of percentage distribution of the number of trees (*Ps. menziesii* (Mirb)Franco) in sample plots by natural degrees of height.

On the bases of determined regularities in the structure of volume-forming factors (from the basic formula for calculation of the volume) the peculiarities of the structure according to volume are determined by calculation and application of the so-called relative volumes. Calculated relative basal areas are used, as well as tree form height in relative numbers (Tables 6–8).

From the current point of view, due to the entering of a large part of the Douglas plantations into the "middle-aged" class in Bulgaria, the conclusions, concerning the structure of height in Douglas plantation for which no care were taken and thinning with different intensity were carried out, can be used as a practical guidance for their differentiated cultivation (FEZERLIEV, 2013). In the height structure the attention is directed mainly to the curves of height and average height and well-known correlation between thickness (diameter) of trees and their height has been applied. The Figure 3 shows the height curves for the three sample plots according to natural degree of height (NDH) and natural degree of thickness (NDT) (in relative numbers) as well as equal curves for each one of them.

The equal curves of heights give an opportunity to compare the height curves for sample plots with the unified height curves of Tyurin (Fig. 6). The conclusion is confirmed that curves of heights of tree stands have almost one and the same form and their course does not depend on the tree species and site conditions. Fig. 6 shows that average curves in all three sample plots within the range of natural degrees of thickness from 0.5 to 1.3 are under the unified heights curve of Tyurin. The curve of SP3 (red curve) crosses this of Tyurin in natural degree of thickness 1.3, and these ones of SP1 and SP2 get near it only at natural degree of thickness 1.6. The range of variation of relative heights according to natural degrees of thickness is approximately equal and is determined from natural degrees of thickness 0.4 to 1.8 for SP1 and SP2 and from natural degrees of thickness 0.4 to 1.7 for SP3. For all three curves of investigated areas the range of natural degrees of thickness is wider than this one at Tyurin's curve (the range of which it covers natural degrees of thickness 0.5 to 1.7). In the same time the varying of relative heights in the mentioned ranges is almost within one and the same limits (from 0.6 at natural degree of thickness 0.4 to 1.2 in SP1 and SP3 and from 0.5 to 1.1 at SP2) and is more considerable than this one of Tyurin (from 0.8 to 1.5), getting mostly close to the variation determined by Shiffel (from 0.68 to 1.14) (MIHOV, 2005a).

The growth in volume are differed from the other dendrometric indexes according to general course of curves (FEREZLIEV & DELKOV, 2013). On the base of calculated relative volumes (Tables. 6–8)and in their entering on the ordinate of co-ordinate systems and on abscissa of NDT is results in so-called curved lines of masses for investigated sample plots (Fig. 4). When entering of the relative volumes on the ordinate and of the natural basal areas on the abscissa of the co-ordinate system the so-called straight lines of masses appear (Fig. 5).

**Table 6.** Relationship between volumes, natural degrees of thickness and relative basal areas in SP1.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 |
| Relative basal areas | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.7 |
| Relative volumes | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 |
| Relative form heights | 0.64 | 0.71 | 0.78 | 0.84 | 0.90 | 0.94 | 0.97 | 0.97 | 0.94 | 0.94 | 0.90 | 0.97 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.3 |
| Relative basal areas | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 |
| Relative volumes | 0.7 | 0.8 | 0.9 | 1.0 | 1.0 | 1.1 | 1.1 | 1.3 | 1.4 | 1.5 | 1.7 | 1.7 |
| Relative form heights | 1.03 | 0.97 | 1.03 | 1.08 | 1.08 | 1.08 | 1.03 | 1.08 | 1.08 | 1.03 | 1.08 | 1.08 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.7 | 1.7 | 1.8 | 1.8 |
| Relative basal areas | 1.7 | 1.8 | 2.0 | 2.1 | 2.3 | 2.4 | 2.6 | 2.8 | 2.9 | 3.1 | 3.4 |
| Relative volumes | 1.9 | 1.9 | 2.1 | 2.3 | 2.3 | 2.6 | 2.9 | 3.0 | 3.2 | 3.4 | 3.7 |
| Relative form heights | 1.08 | 1.08 | 1.08 | 1.08 | 1.03 | 1.08 | 1.08 | 1.08 | 1.08 | 1.08 | 1.08 |

**Table 7.** Relationship between volumes, natural degrees of thickness and relative basal areas in SP2.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 |
| Relative basal areas | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 |
| Relative volumes | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.6 | 0.7 |
| Relative form heights | 0.63 | 0.79 | 0.72 | 0.77 | 0.82 | 0.87 | 0.93 | 0.91 | 0.91 | 0.97 | 1.04 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.3 |
| Relative basal areas | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.6 |
| Relative volumes | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 | 1.2 | 1.3 | 1.3 | 1.5 | 1.6 | 1.7 |
| Relative form heights | 1.04 | 1.04 | 1.00 | 1.06 | 1.02 | 1.08 | 1.07 | 1.04 | 1.07 | 1.08 | 1.09 |

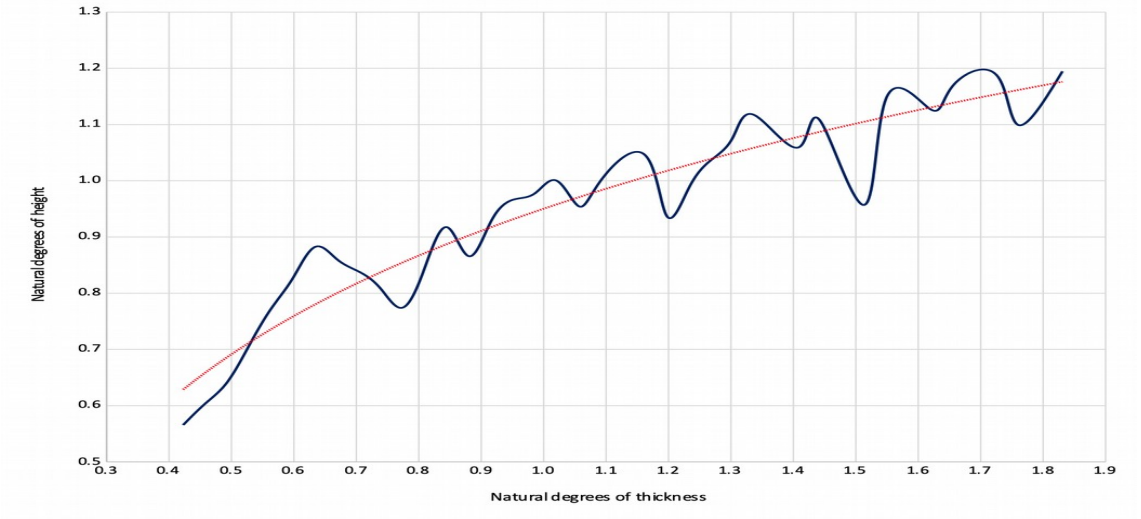
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 1.3 | 1.4 | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 | 1.7 | 1.8 |
| Relative basal areas | 1.6 | 1.8 | 1.9 | 1.9 | 2.0 | 2.3 | 2.5 | 2.7 | 3.0 |
| Relative volumes | 1.8 | 1.9 | 2.0 | 2.2 | 2.4 | 2.7 | 2.7 | 3.0 | 3.4 |
| Relative form heights | 1.11 | 1.09 | 1.07 | 1.12 | 1.17 | 1.16 | 1.08 | 1.11 | 1.14 |

**Table 8**. Relationship between volumes, natural degrees of thickness and relative basal areas in SP3.

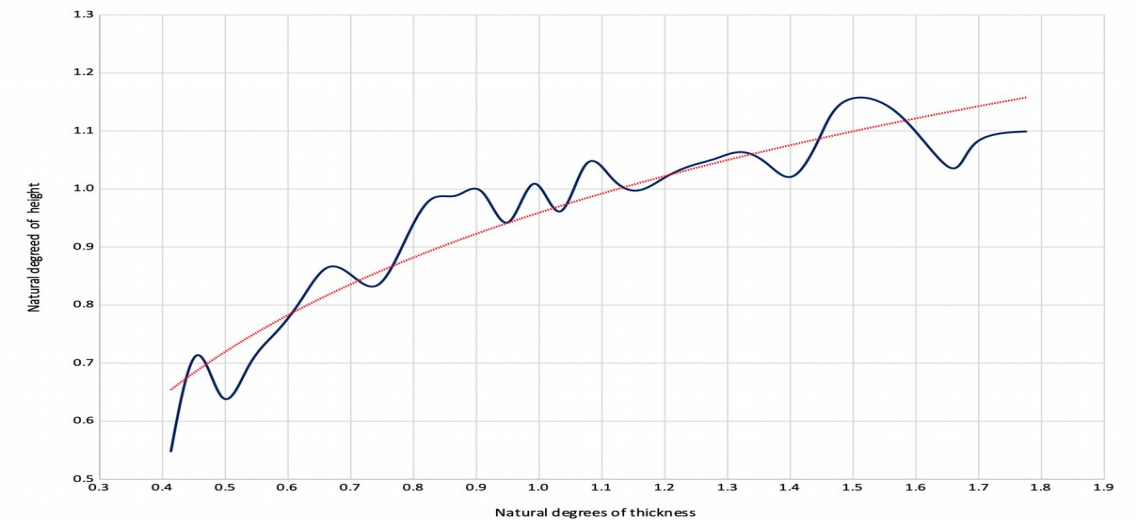
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 |
| Relative basal areas | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 |
| Relative volumes | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 |
| Relative form heights | 0.72 | 0.69 | 0.80 | 0.80 | 0.80 | 0.87 | 0.87 | 0.94 | 0.94 | 0.94 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.2 | 1.2 |
| Relative basal areas | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.2 | 1.3 | 1.5 |
| Relative volumes | 0.6 | 0.8 | 0.8 | 0.9 | 1.0 | 1.2 | 1.3 | 1.2 | 1.5 | 1.6 |
| Relative form heights | 0.94 | 1.02 | 1.05 | 1.02 | 1.02 | 1.09 | 1.09 | 1.02 | 1.09 | 1.09 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Natural degrees of thickness | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 | 1.6 | 1.7 |
| Relative basal areas | 1.5 | 1.7 | 1.8 | 1.8 | 2.0 | 2.0 | 2.4 | 2.7 |
| Relative volumes | 1.7 | 1.9 | 1.9 | 2.0 | 2.3 | 2.4 | 2.9 | 3.3 |
| Relative form heights | 1.09 | 1.15 | 1.09 | 1.09 | 1.15 | 1.15 | 1.22 | 1.22 |




a

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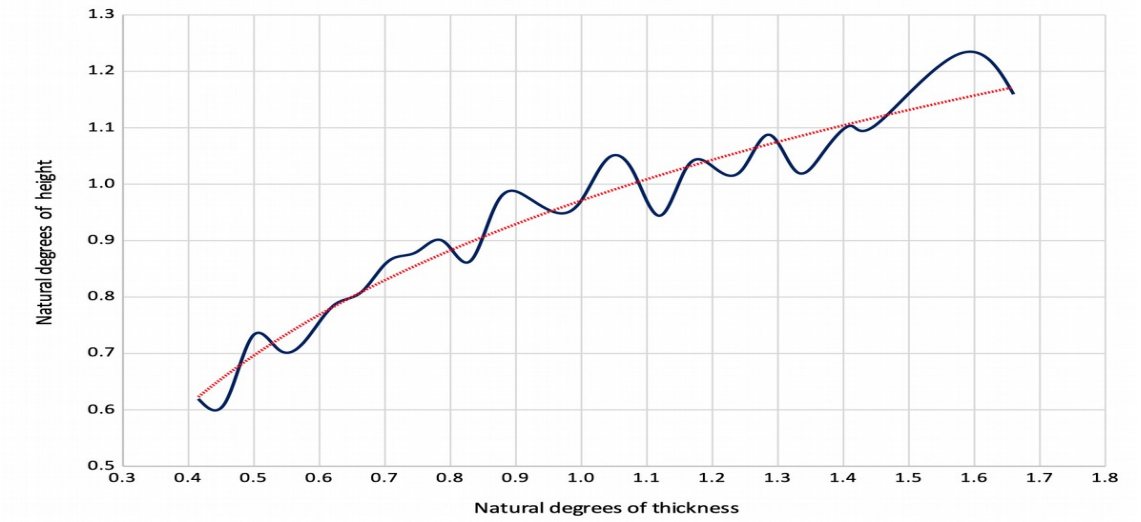
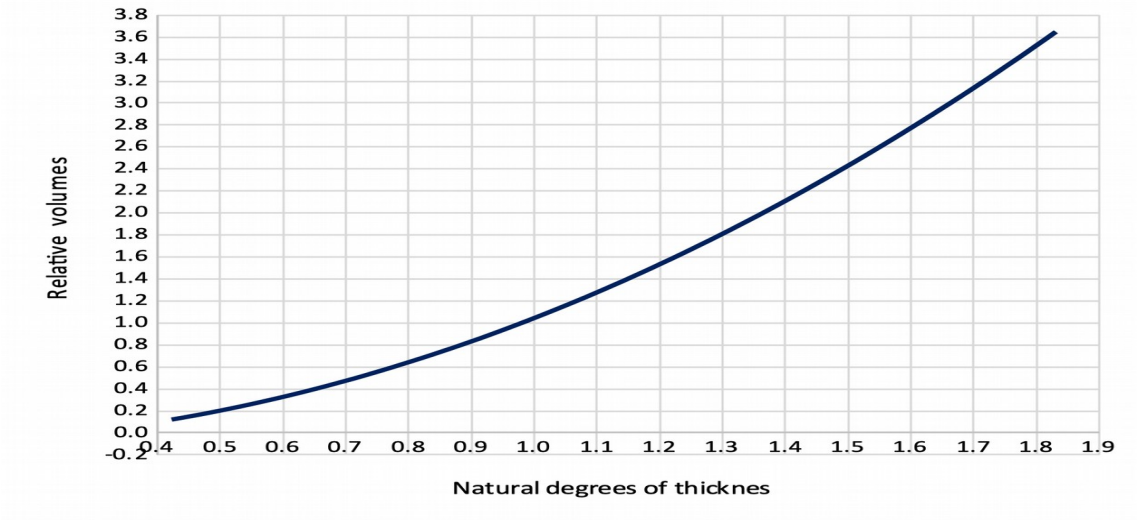



c

**Fig. 3.** Curves of heights in relative numbers for SP1 (a), SP2 (b) and SP3(c).

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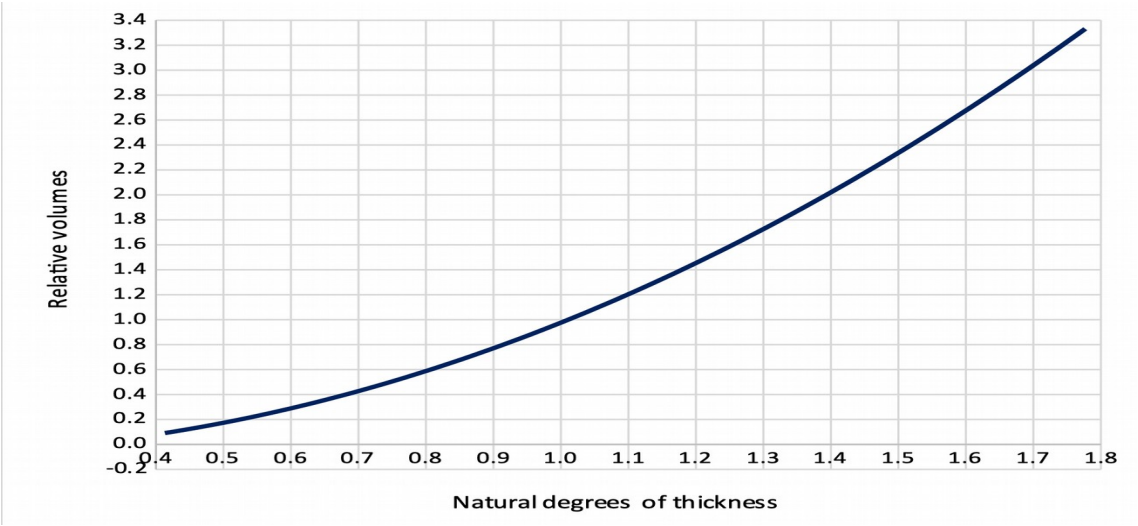


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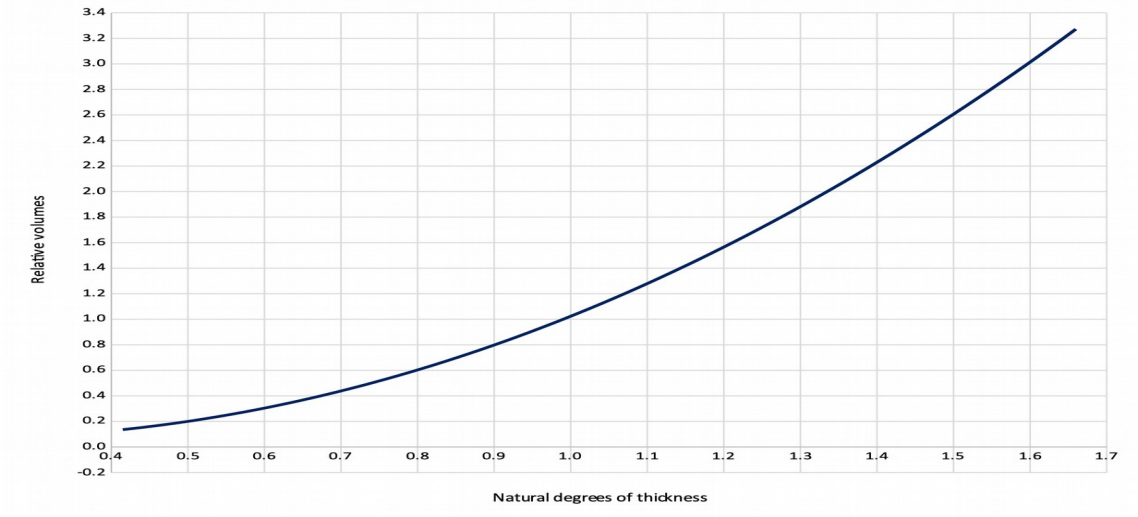
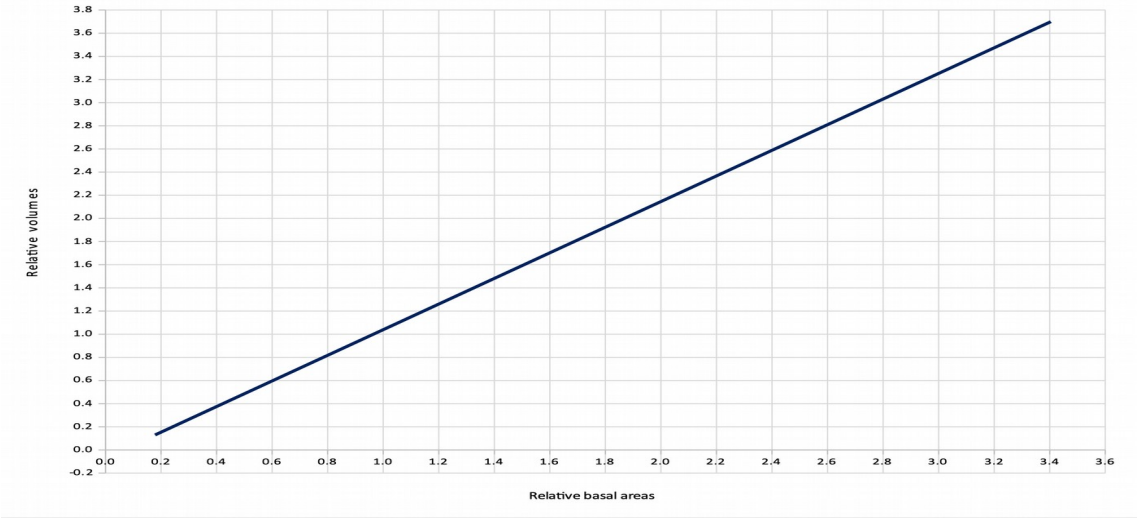



c

**Fig. 4**. Curve lines of volumes for SP1 (a), SP2 (b) and SP3(c).

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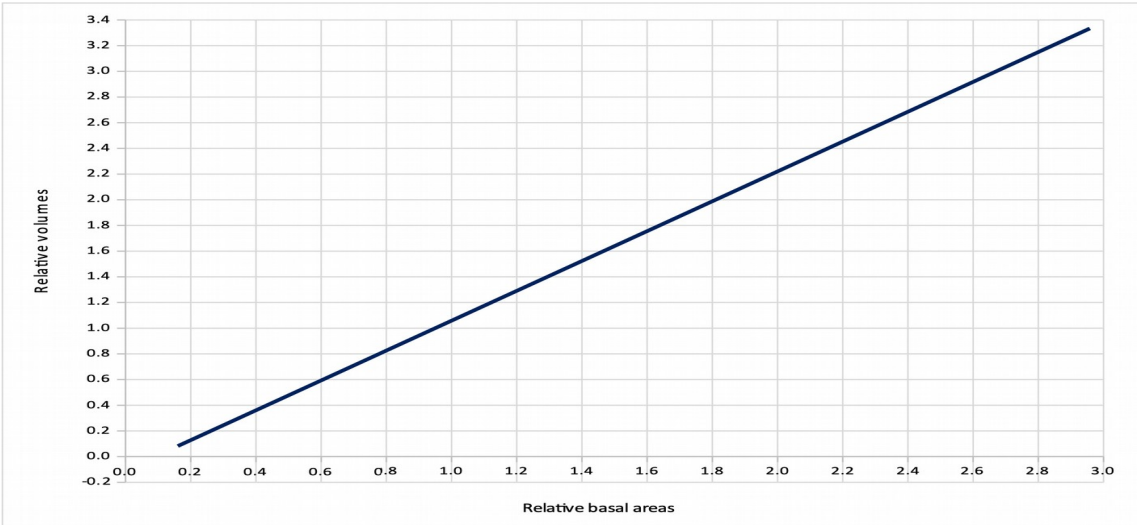


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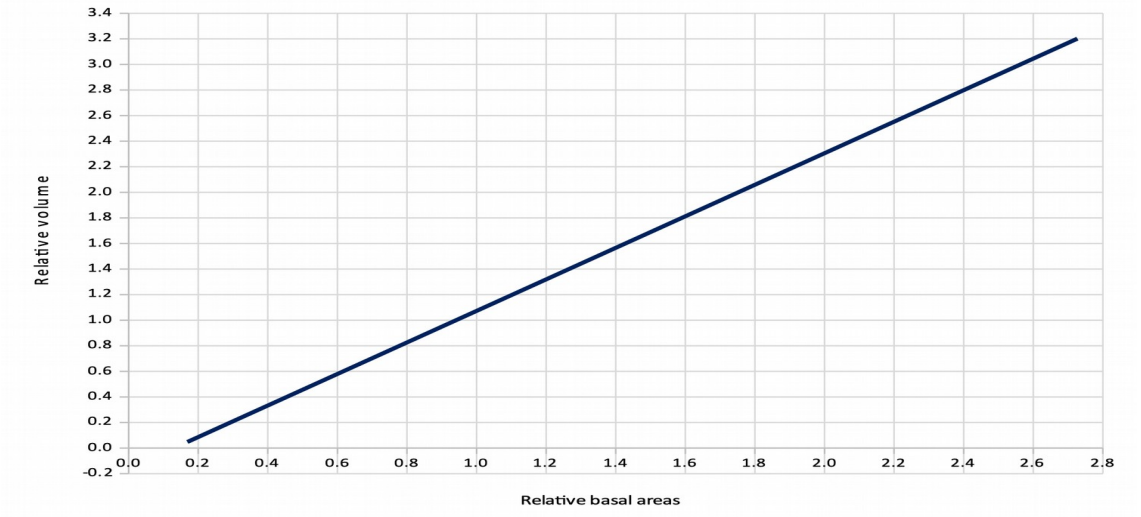


c

**Fig. 5**. Straight lines of volumes for SP1 (a), SP2 (b) and SP3 (c).

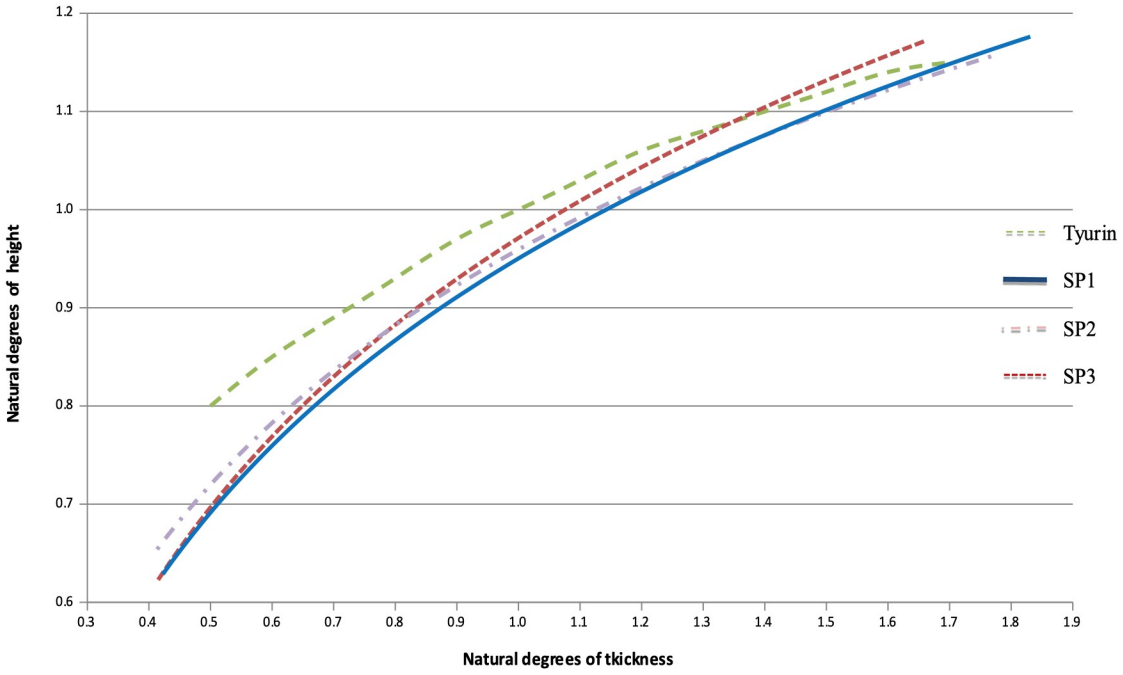


**Fig. 6.** Comparison of the mean curves of the heights in the investigated sample plots with the mean curve of the heights of the A.V. Tyurin.

The curved line of masses, known as well as the curved lines of masses of Spaidel and the straight lines of masses of Kopetcki (MIHOV, 2005b) are the basis for scaling of investigated tree plantations, i.e. through graphics to be able to determine the volume (scale) the studied Douglas fir plantations and the group of relatively equal tree artifical stands.

**Conclusions**

The Douglas fir plantations reach their aim showing good growth and significant wood production opportunities on these sites. At 1100 m a.s.l. and the age of 39 the total growing stock of the plantation is 310 $m^3$/ha at a density of 578 trees/ha. At 1225 m a.s.l. and 49 years of age the total growing stock is 901 $m^3$/ha at a density of 1590 trees/ ha. At 1450 m a.s.l. and 52 years of age the total growing stocke is 967 $m^3$/ha at a density of 1120 trees/ha.

Study on the height structure confirmed what Tyurin has published that the height curves of tree stands have almost one and the same shape and their course does not depend on the tree species and site conditions. Relatively equal variation of average curves of heights is observed in plots managed in different ways and in thinned sample plots the variation of average height curves are close to each other. In all three experiments the intervals of variation are wider than at the unified variation curve of Tyurin.

The curved and straight lines of masses established during the study on volume structure are the basis for scaling of investigated tree stands, due to which it is recommended to use them for scaling of other groups of similar tree stands with predomination of Douglas fir within the range of investigated area. The availability of information on the overall course of the curves, characterizing the course of height increment and volume growth, together with such of thickness, can be used to develop a forest simulation model for choosing an optimal economic approach to the management of Douglas fir plantations in the future.

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