Results of 20 years old Douglas-fir provenance experiment established on the northern slopes of Rila Mountain in Bulgaria

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ABSTRACT: The purpose of this study is to facilitate the detection of provenances relevant to the reforestation practice in Bulgaria. Studies were carried out in a Douglas-fir provenance trial plantation established at an altitude of 800 m a.s.l. on the northern slopes of Rila Mountain. To establish the productivity, assess the stands and rank provenances biometric procedures, methods of descriptive statistics and ANOVA were used. The diameter at breast height, average height, dominant height, total growing stock volume, assortment timber structure and survival of trees were analyzed in the stands of 55 Douglas-fir provenances. The provenances were characterized in terms of productivity of forest stands at 20 years of age and their ability to produce high quality timber was evaluated. Provenances: Newhalem No. 4 (Seed zone 402), Darrington No. 7 (Seed zone 403), Parkdale No. 19 (Seed zone 661) and Idanha No. 29 (Seed zone 452) have been recommended. Among the recommended provenances are those with growing stock volume with branches from 296 to 354 $m^3 \cdot ha^{-1}$, mean annual increment from 14.8 to 17.7 $m^3 \cdot ha^{-1}$ and dominant heights of up to 17.9 m.

Keywords: *Pseudotsuga menziesii*; introduction; plantation forestry; productivity; assortment structure

The productivity of Douglas-fir stands depends on their response to the impact of various factors of natural habitats that finds expression in their growth in height, diameter, growing stock volume, assortment structure, etc. The use of reproductive material from different provenances of the natural habitats of the species in North America is associated with a high degree of variation in these parameters. Thus it is paramount that provenance experiments have to be established all over Europe where long-term and complex research, aimed at the selection of highly productive and adaptable provenances for use in reforestation practices, may be carried out.

Douglas-fir is among the fastest growing conifers and has a clear market positioning of wood. In many countries its cultivation is a priority of forest policy. In France, Douglas-fir has become one of the main species for reforestation practices (Hermann, Lavender 1999). Douglas-fir plantations were created in almost all European countries (Bastien et al. 2013). The number of research studies devoted to the Douglas-fir in the world has constantly been increasing (Lavender, Hermann 2014).

Douglas-fir was introduced into Bulgaria as a tree species for reforestation in 1908 and became relatively widespread in the 1950s and 1960s. The actual area of Douglas-fir plantations in Bulgaria is 7,372 ha, and the total growing stock volume is 2,776,208 m^3. There is no information about the origin of the reproductive materials for that period. Nevertheless, the species has demonstrated good growth capacity and adaptability to local conditions (Ferezliev 2012; Kalmukov 2012). Twenty-five years ago (1989 to 1990) the first set of provenance experiments in Bulgaria was established in five localities in the country with different environmental conditions (Kostenets, Kyustendil, Petrohan, Klisura, and Zlatograd). Both collections and planting sites represent variable climatic and soil conditions.

Well-documented data and early published results are available for the experiments in Kostenets, Kyustendil, and Petrohan: Popov (1990, 2010), Iliev

Presented at the NFZ Summer School 2013: Douglas fir, opportunities and risks for European Forestry. Esthal, 9.–13.9. 2013.

and Petkova (1995), Popov and Petkova (2003) Georgieva (2007), Petkova (2011). These results indicate that some provenances originating from the Western Cascade mountains and the Coastal region in the states of Oregon and Washington have not only outperforming growth parameters such as height and diameter, but also have relatively good resistance to needle cast diseases *Rhabdocline pseudotsugae* and *Phaeocryptopus gaumannii*.

The purpose of this study is to facilitate the detection of provenances relevant to the reforestation practice in Bulgaria, based on the assessment of the potential for overall productivity of the stands of different provenances, as well as their ability to produce high quality timber and to demonstrate the growth capacity of Douglas-fir in Bulgaria at 20 years of age.

MATERIAL AND METHODS

The object of the study is an experimental plantation, which was established in the region of the town of Kostenets (42°16'29.4''N, 23°46'49.6''E) in 1989, on Cambisols, using 2-years-old bareroot seedlings, after clear cutting an area occupied by indigenous vegetation. Climate conditions are represented in Fig. 1, following the methodological approach of Walter (1979).

After the plantation was established, the competition was controlled by hand cultivation of the soil and cutting of the sprouts. The plantation was established using 55 provenances in 3 replicates and square spacing of 2-m intervals between each two seedlings. Most plots measure up to 256 m^2 (16 × 16 m) and each of them contains 49 seedlings (2500 seedlings per hectare). Plot areas measuring up to 676 m^2 (26 × 26 m) with 144 seedlings per plot were also used in the experimental plantation. The plots were separated from each other by a row of Small-leaved Lime (*Tilia cordata*) and Sycamore (*Acer pseudoplatanus*). The experiment is part of the first set of provenance experiments in Bulgaria with an area of 0.63 ha. The methodology for provenance research (Lines 1967) was taken into account when selecting the experimental design. The geographical location of provenances was defined by their latitude, longitude (presented by decimal degrees) and elevation a.s.l. (Popov 1990). Information about the number of trees from which the seeds were collected was unavailable. Seed lots from 20 seed zones of the states of Oregon, Washington, Montana, Arizona and New Mexico were supplied from the National Tree Seed Laboratory of the USA.

Diameters at breast height of all trees equal to or thicker than 4 cm were measured. Smaller trees are out of the scope of the model calculating volumes as they have a near-zero influence on the calculated ones. A total number of 6,568 diameters and 894 heights were measured in the experimental plantation. Diameter measurements were performed to the nearest 1 cm and heights to the nearest 10 cm. The heights of measured trees are representative of 4 different positions of trees in the canopy: dominant, co-dominant, intermediate and suppressed. Heights of twenty trees were measured for each provenance and these values were used for the calculation of their height curves. Using these curves the average heights of the stands in each replication and provenance were determined. The field data were mathematically and statistically processed to reach the summarized results that are suitable for carrying out comparative analysis. Routine methods and formulas of forest taxa-

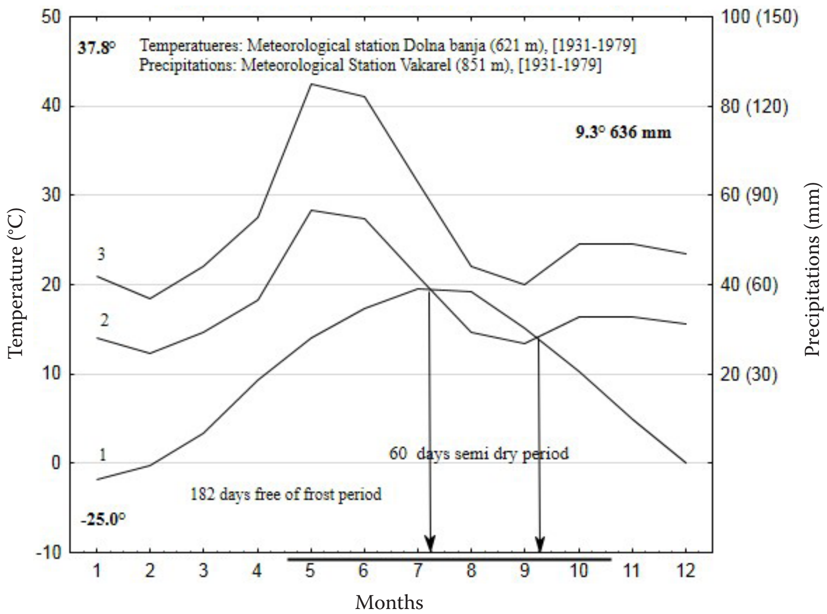

Fig. 1. Climate diagram (Walter 1979)

The climate is semi-continental. The average annual temperature is 9.3°C. The absolute maximum temperature is 37.8°C and the absolute minimum temperature is –25°C. 182 days are free from frost. The annual amount of precipitation is 636 mm – with a maximum in spring and early summer, a semi-dry period with 60-day duration in July, August and September. No dry periods were found tion were used in determining the growth characteristics of forest stands. The average diameter was calculated through the basal area. Methods of descriptive statistics and ANOVA (SPSS, Tulsa, USA) were applied for the evaluation of diameters, heights and volume parameters of provenances. To calculate the volumes of assortments and the total growing stock volume specialized licensed software "SORTN6" Proles Engineering Ltd. (2004), adopted for such calculations in forestry practice, was used.

RESULTS AND DISCUSSION

Height, coefficient of stability of trees, diameter, survival and productivity of stands were analysed and discussed at local conferences. A set of 26 indicators, which completely characterises the growth capacity, survival, volume production capacity, quality and assortment structure of each of the forest stands, has been defined for each provenance and replication, and for the experiment as a whole.

Dominant height H_1 (m), total growing stock volume with branches V ($m^3 \cdot ha^{-1}$), mean diameter of dominant and co-dominant trees $D_{1,2}$, high quality timber V ($m^3 \cdot ha^{-1}$), survival (%), coefficient of stability of dominant and co-dominant trees $H/D_{1,2}$, were chosen as they provide sufficiently comprehensive quantitative and qualitative evaluation information for ranking the provenances. The indicators are listed in a sequence according to their assigned significance for the overall rating.

At the beginning of our study we found that the provenance groups of the continental area east of the Cascade range in the states of Oregon No. 21, 22 and 22 (Bates); No. 35, 36 and 37 (Canyon city), No. 1 (Greenwood) and No. 2 (Keremeos) from Washington as well as the provenances from the states of Montana No. 3 (Whitefish), Arizona No. 54 (Flagstaff) and New Mexico No. 55 (Alamogordo) dropped out of the composition of the experimental plantation as only single trees survived. The surviving trees are in a degraded health condition, in fact they cannot form a canopy and for ten of the cited eleven provenances significant growth retardation has been established. The state of these provenances is due in part to their limited growth capacities and sensitivity to diseases. Similar results of the poor growth of these provenances were obtained in Douglas-fir experimental plantations in DGS Kyustendil (Popov 2010) and DGS Petrohan Popov and Petkova (2003). A strong sensitivity to the pathogen *Rhabdocline pseudotsugae* was detected in the same provenance Georgieva (2007). It is associated with the loss of four, three and even two years old needles, which is in turn associated with the logical in such cases, loss of current increment, and also with tree mortality. As mentioned above, 11 provenances were dropped out of the experiment and in all subsequent analyses, comparisons and rankings were carried out for the remaining 44 provenances. These results clearly demonstrate the negative consequences that may occur if the origin of the reproductive materials is not taken into account and if provenances such as dropouts are used for the reforestation of large areas.

The total growing stock volume with branches ranged from 353.7 $m^3 \cdot ha^{-1}$ in provenance No. 19 to 171.71 $m^3 \cdot ha^{-1}$ in provenance No. 13 (Fig. 2). The largest growing stock volumes with branches in de-

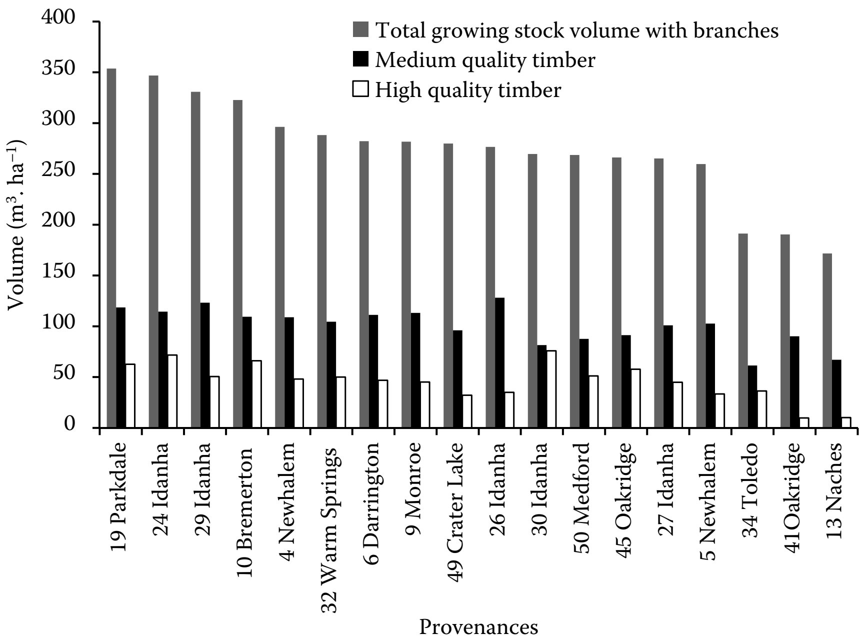

Fig. 2. Main volume and assortment indicators for productivity of stands

To illustrate the amount of variation in parameters total growing stock volume, high quality timber and medium quality timber on the abscissa are plotted for the first 15 provenances with the highest general scores and the three provenances with the worst performance in terms of the parameters

Table 1. Rank of the provenances according to parameters characterising growth. productivity. stability and survival

Rank	Total growing stock volume with branches		Volume of high quality timber		Survival		H_{dom}		Mean diameter of dominant and co-dominant trees $D_{(1),(2)}$		Coefficient of stability of dominant and co-dominant trees $H_{(1),(2)}/D_{(1),(2)}$	
	prov.	($m^3 \cdot ha^{-1}$)	prov.	($m^3 \cdot ha^{-1}$)	prov.	(%)	prov.	(m)	prov.	(cm)	prov.	$H_{(1),(2)}/D_{(1),(2)}$
1	**19**	**353.7**	**30**	**75.91**	**29**	*79.1*	*9*	*18.1*	*30*	*20.9*	*29*	*69*
2	**24**	**346.8**	**24**	**71.76**	**24**	*78.9*	*26*	*18.0*	*52*	*19.8*	*24*	*71*
3	**29**	**330.9**	**53**	**66.25**	**25**	*78.6*	*29*	*17.9*	33	18.8	*25*	*75*
4	**10**	**322.7**	**10**	**66.12**	**40**	**77.6**	*7*	*17.8*	51	18.7	*40*	*76*
5	**4**	**296.3**	**19**	**62.70**	**49**	**76.5**	*30*	*17.7*	50	18.5	*49*	*76*
6	32	*288.3*	**45**	**57.80**	*4*	*70.9*	*15*	*17.7*	19	18.4	4	77
7	6	*282.2*	**7**	**53.16**	*19*	*70.4*	*5*	*17.5*	10	18.3	19	78
8	9	*281.7*	**50**	**51.14**	*26*	*70.4*	4	17.4	24	18.1	26	78
9	49	*279.9*	**29**	**50.50**	*47*	*67.0*	33	17.2	53	17.9	47	79
10	26	*276.6*	**32**	**50.01**	*27*	*66.6*	10	17.2	32	17.9	27	80
11	30	*269.7*	**4**	**48.10**	*12*	*66.3*	11	17.1	7	17.9	12	81
12	50	*268.6*	33	*46.89*	*6*	*66.2*	48	17.1	15	17.9	6	82
13	45	*266.2*	6	*46.87*	*45*	65.9	17	17.1	34	17.8	45	82
14	27	*265.2*	9	*45.21*	*10*	65.0	28	17.0	16	17.8	10	82
15	5	*259.7*	27	*44.93*	48	64.8	24	17.0	43	17.7	48	83
Avg.		*247.1*		*39.5*		60.1		16.6		17.4		84.2
Avg. + 5%								*17.5*				
Avg. + 10%		*271.8*		*43.4*		*66.1*		18.3		*19.2*		*75.7*
Avg. + 20%		**296.5**		**47.4**		72.1		20.0		20.9		67.3
Avg. + 30%		**321.3**		**51.3**		78.1		21.6		22.7		55.6

Avg. – average, prov. – provenance. H_{dom} – dominant height, values at the bottom of the table refer to the general average values (with normal font) for each parameter: total growing stock volume with branches. volume of high quality timber. survival, dominant height, mean diameter of dominant$_{(1)}$ and co-dominant$_{(2)}$ trees, coefficient of stability of dominant$_{(1)}$ and co-dominant$_{(2)}$ trees; values exceeding the average of the whole experiment by 5 and 10% were formatted in italics font, values exceeding the average of the whole experiment by 20% were formatted in bold font and values exceeding the average of the whole experiment by 30% were formatted in bold underlined font; at the top of the table are presented values for the 15 top ranked provenances formatted in the way indicated above

scending order were determined for the following ten provenances: No. 19, 24, 29, 10, 4, 32, 6, 9, 49, 26.

With regard to the production of high quality timber the analogous ranking of forest stands by provenances was as follows: No. 30 (75.9 $m^3 \cdot ha^{-1}$) 24, 53, 10, 19, 45, 7, 50, 29, 32. From these two groups of provenances, No. 10, 19, 24, 29 and 32 are among the top ten for both indicators (Table 1).

These results were compared with those obtained for the same provenances in other experimental plantations in Bulgaria: Kuystendil (Popov 2010) and Petrochan (Petkova 2011), where the provenances Newhalem No. 4, Darrington No. 7, Parkdale No. 19 and Idanha No. 29 were also top ranked.

The table indicates the actual productivity at the time of assessment, which, however, is not the maximum level that could be reached. Due to competition with native vegetation, sometimes in separate single plots, Douglas-fir survival is lower and Douglas coverage is below 75%. The modelling of these losses could probably indicate the potential for the realization of even higher productivity. This, however, goes beyond the scope of the study at hand.

After the first step in the process of selection, 44 provenances remain for analysis. The following approach was adopted as a second step in the selection process and ranking of provenances: selecting provenances which have an average annual growth rate in terms of total growing stock volume with branches above the average and performing well in terms of several indicators related to the productivity and sustainability: dominant height H_1, high quality timber V ($m^3 \cdot ha^{-1}$), mean diameter of dominant and co-dominant trees $D_{1,2}$, survival (%), coefficient of stability of dominant and co-dominant trees $H/D_{1,2}$. Thus, the number of target provenances was reduced from 55 to 15 aiming to select and recommend the best ones for afforestation.

The results here can be summarized as follows: prior to the first elimination, the provenance with the highest productivity exceeded that of the lowest one 25 times. After the elimination of dropout provenances, the provenance with the highest productivity had a total growing stock volume with branches of 353.7 $m^3 \cdot ha^{-1}$, and the provenance with the lowest productivity 148.8 $m^3 \cdot ha^{-1}$, i.e. the most productive outperformed the least productive by more than two times. After the second selection, the difference in the productivity between the provenance in the top of the list and the provenance at the end of this ranking was 94 $m^3 \cdot ha^{-1}$of the total growing stock volume with branches. The concrete numerical values are 353.7 $m^3 \cdot ha^{-1}$ and 259.7 $m^3 \cdot ha^{-1}$. This difference expressed by the average annual growth increment was 4.3 $m^3 \cdot ha^{-1}$per year and/or 17.3 $m^3 \cdot ha^{-1}$ per year for provenance No. 19 and 13.0 $m^3 \cdot ha^{-1}$ per year for provenance No. 5. A rough comparison with the growth rate tables of Hamilton and Christie (1971), Decourt (1973), Bergel (1985), also indicates that the top ranked provenances have shown very good growth performance.

CONCLUSION

Based on this research, other similar studies and the results presented here the following provenances: Newhalem No. 4 (Seed zone 402), Darrington No. 7 (Seed zone 403), Parkdale No. 19 (Seed zone 661) and Idanha No. 29 (Seed zone 452) may be recommended for use in reforestation practice. These provenances outperform others in a set of parameters characterizing their growth and sustainability, total growing stock volume, dominant height, quantity of high quality timber**,** survival and coefficient of stability. These provenances could be used for the establishment of plantations for intensive timber production from the sea level up to 1,400 m a.s.l. Among the recommended provenances are those with growing stock volume with branches from 296 up to 354 $m^3 \cdot ha^{-1}$ at 20 years of age, mean annual increment from 14.8 up to 17.7 $m^3 \cdot ha^{-1}$ and dominant heights up to 17.9 m. All provenances recommended for reforestation produce high quality timber at the age of 20 years. The maximum productivity for that age is not reported for other coniferous species in Bulgaria.

Finally we conclude that Douglas-fir at 20 years of age holds an extremely high productivity including high quality timber. This high productivity can be realized by using the appropriate origins of reproductive materials: provenances recommended above.

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Received for publication January 29, 2014
Accepted after corrections August 18, 2014

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