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Provenance studies of Douglas fir in the locality of »Kontija« (Istria)

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Abstract

Background and Purpose: *One of the most productive and economically important tree species in the USA is Douglas fir (Pseudotsuga menziesii (Mirb.)). Because of its broad natural range, in the horizontal as well as in the vertical sense (from California to British Columbia and from sea level up to an altitude of 1500 m), a variety of its provenances has been differentiated. European foresters, thanks to their insight into Douglas fir productivity and usage in its native country, initiated at the beginning of the 19th century the establishment of provenance tests and research on the success of individual provenances outside their natural distribution. In the framework of the IUFRO programme, numerous European countries, among them Croatia, started provenance tests with the aim of researching the adaptability of this valuable species. In several bioclimatic localities in Croatia (Istria, North-West, Central and Eastern Croatia) different provenances have shown good success. The importance of Douglas fir is becoming increasingly evident in conditions of a changing climate and when the possible application of Douglas fir in the establishment of forest cultures is taken into consideration. Douglas fir can be established on uncovered forest and non-forest areas for wood supply or as a potential renewable energy source. The exploitation of wood and biomass from forest cultures enables the conservation of biodiversity and the survival of our natural forest ecosystems.*

Material and Methods: *This paper is based on research conducted on a Douglas fir provenance trial in the locality of »Kontija« in Istria. The trial, in which ten Douglas fir provenances were included, started in 1969. On the trial plots, dendrometric parameters such as DBH and tree heights were measured on the basis of which wood volume was calculated. Descriptive statistics were made for all analysed variables (DBH, h, V). The differences between the provenances for the investigated variables were tested with an analysis of variance (ANOVA). Provenances which differ between themselves were determined using the Tukey post hoc test. According to data on the survival rate for all provenances, the average survival rate inside the trial was estimated and tested with a test of proportion to determine which provenances differ statistically from the average survival rate. Using a non-hierarchical (k-means) cluster analysis, provenances were grouped according to standardised variables (N, DBH, h, V). In the same way, the species' health condition was determined, as was the resistance of provenances to forest pests.*

Results and Conclusion: *The average survival rate of all provenances in the trial amounts to 64.8% (ranging from 52% for the provenance PE ALL to 77% for the provenance ELMA). The best height growth was identified in the provenance SHELTON which originates from lower altitudes in*

Washington while the provenance SHADE COVE from higher areas of Oregon shows lowest growth. High volume is evidenced in the provenance PE ALL. The results of the analysis of variance (ANOVA) show that there is a statistically significant difference for all analysed variables for the investigated provenances. A k-means cluster analysis grouped ten Douglas fir provenances in four clusters. In cluster 1, only the provenance SHADY COVE is included with a high number of trees with lower heights and smaller DBH and volume. Provenances from cluster 3 (PE ALL and YELM) have, in a small number of trees, higher DBH and volume. The rest of the provenances are grouped in two clusters (cluster 2 and cluster 4) with similar values but with the difference that the provenances SHELTON, CORVALIS, ELMA and HVIDILDE (cluster 2) have higher values than average for the analysed parameters, while the provenances ŠIPKA, BUZET and CASTLE ROCK (cluster 4) have lower than average values. In general, all the provenances in the trial are vital and show a good health condition without any determined pests.

INTRODUCTION

Douglas fir (*Pseudotsuga menziesii* (Mirb.)) is one of the ecologically most important, most productive and economically most interesting tree species in western North America. It has a reputation for good health and resistance to pests *(1–4)*. According to Herman and Lavander *(5),* the area presently occupied by Douglas fir in North America where it spreads naturally is 14.3 million ha in the USA and 4.5 million ha in Canada (slightly less than one-third of that in the USA). The range resembles an inverted »V« with uneven sides. From the apex in central British Columbia, the western half extends along the Pacific mountain ranges into California for about 2,200 km. The eastern half stretches along the Rocky Mountains of Canada and the United States into the mountains of central Mexico over a distance of nearly 4,500 km. The western half represents the range of the coastal variety (*Pseudotsuga menziesii* var. *menziesii*), and the eastern half the range of the interior variety (*P. menziesii* var. *glauca* (Beissn.) Franco) *(5)*. Within a region, Douglas fir can grow under a wide variety of climatic conditions *(6)*. Because of its broad natural range of success, in the horizontal as well as in the vertical sense (from California to British Columbia and from sea level up to an altitude of 1500 m) a variety of its provenances has been differentiated.

This highly productive species with good wood quality is also one of the most interesting North American tree species for the establishment of forest cultures all over the world. There are numerous data about Douglas fir plantings in several countries in Europe, South America (Chile, Argentina), New Zealand and Australia *(5–8)*. Its successful introduction is probably the result of a combination of favourable site conditions and suitable seed sources in early plantations in Scotland, Denmark and Germany *(9)*. According to Herman and Lavender *(5),* countries with the largest share of Douglas fir plantations in Europe in 1999 are France, Germany, the United Kingdom, and the Netherlands.

European foresters, thanks to their insight into Douglas fir productivity and usage in its native country, established at the beginning of the 19th century provenance tests and research on individual provenance successes outside the natural distribution of Douglas fir. In the framework of the IUFRO programme, numerous European countries, among them Croatia, began provenance tests with the aim of researching the adaptability of this valuable species. The importance and significance of Douglas fir is becoming increasingly evident in the conditions of changing climate and when the possible application of Douglas fir to establish forest cultures is taken into consideration. It can be established on uncovered forest and non-forest areas for wood supply or as a potential renewable energy source. Exploitation of wood and biomass from forest cultures enables the conservation of biodiversity and the survival of our natural forest ecosystems. Numerous research studies can be found in relation to Douglas fir provenances and their success in the world *(10–13)* and also in Croatia *(14–19)*.

Douglas fir is a very valuable species in this region because it is adaptable to a wide range of site conditions, it maintains high growth rates, and produces high quality wood *(8)*. In the context of climate change, Douglas fir appears to be a particularly interesting commercial species for Central Europe because the species' adaptive potential to warming might be superior to that of the Norway spruce (Picea abies (L.) Karst.), which is currently the economically most important species in the region *(20)*.

There are no pure Douglas fir monocultures or plantations in Croatia, except for a small amount established for scientific purposes. The good rates of survival, and the good diameter and height increment, as well as the production of biomass in these trials, are sound reasons for continued scientific research on Douglas fir in Croatia.

MATERIALS AND METHODS

The Douglas fir provenance trial in the locality of »Kontija« (Istria) is one of 8 field trials established with the aim of researching the adaptability and success of this species in different bio climates of Croatia. The trial, in which ten Douglas fir provenances were included, was established in the spring of 1969 in a completely randomised block design with four replications. In this field test, seven American (five from Washington and two from Oregon) and three European provenances (Denmark, Bulgaria, Croatia) were investigated. Basic information on their origin is presented in Table 1 and their natural distribution in Figure 1. The trial was established by planting three-year-old Douglas fir seedlings (2+1), with the exception of the CASTLE ROCK (T) provenance where two-year-old (2+0) seedlings were planted. For each provenance, 100 plants in total ware planted (25 plants per repetition) with 4 x 4 m spacing, with Austrian black pine planted between rows with 2 x 2 m spacing.

TABLE 1

Origin and geographic position of Douglas fir provenances.

Sigh	Provenance	Height above s. l.	Geographic coordinates	
		m	width	length
A	SHELTON, Washington	30–150	47° 11' N	123° 10' W
B	CORVALIS, Oregon	75	44° 35' N	123° 16' W
C	SHADY COVE, Oregon	1350	42° 36' N	122° 50' W
E	ELMA, Washington	100–200	47° 00' N	123° 30' W
J	HVIDILDE, Denmark	–	–	–
M	PE ALL, Washington	150–300	46° 45' N	123° 15' W
N	YELM, Washington	0–150	46° 45' N	122° 40' W
R	ŠIPKA, Bulgaria	650–780	42° 43' N	25° 20' E
S	BUZET, Croatia	10	45° 04' N	13° 38' E
T	CASTLE ROCK, Washington	–	–	–

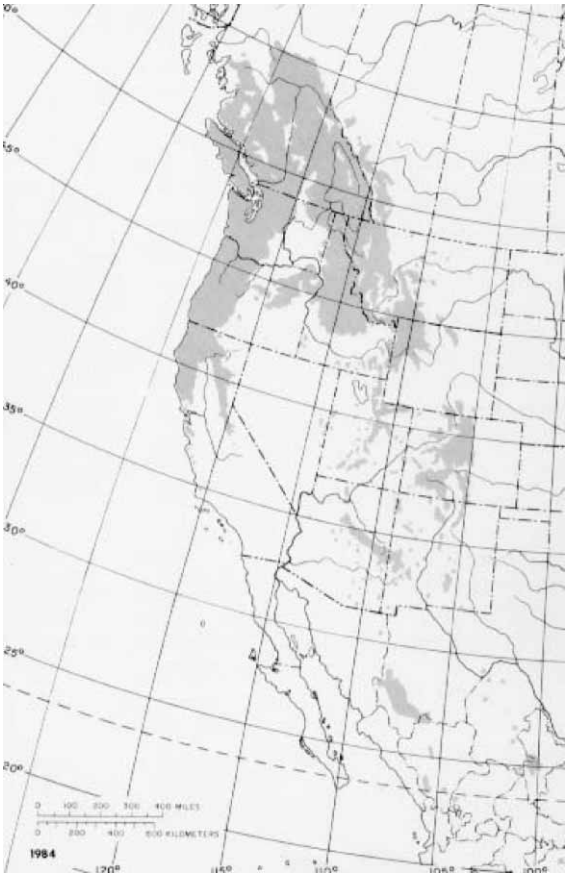

Figure 1. *Natural distribution of Douglas fir.*

This paper presents the Douglas fir survival rate forty years after the establishment of the trial, as well as the dendrometric parameters (DBH and tree height) on the basis of which wood volume was calculated for each provenance using the Schumacher-Hall formula.

Descriptive statistics were performed for all analysed variables (tree number (N), diameter at breast height (DBH), height (H) and volume (V)). The differences between provenances for the investigated variables were tested with a univariate analysis of variance (ANOVA). In cases where there was a significant statistical difference between provenances, the provenances which differed between themselves were determined by using the Tukey post hoc test *(21)*. According to the data on survival for all provenances, the average survival rate within the trial was estimated and tested with the test of proportion to determine which provenances differ statistically from the average survival rate. Using a non-hierarchical (k-means) cluster analysis, provenances were grouped according to standardised variables (N, DBH, H, V) *(22)*. A type I (α) error of 5% was considered statistically significant in all tests. In the same way, the species health condition was determined as was the resistance of the provenances to forest pests. All analyses and graphs were made by using the statistical programme STATISTICA 7.1 *(23)*.

RESULTS

Results of the descriptive analysis for the investigated variables (DBH, H, N, V) are presented in Table 2, as are the results of the test of proportion (t value) which is related to the average survival of all provenances which amounts to 64.8%. On the basis of data on survival, it is evident that the survival rate of the analysed provenances ranges from 52% (provenance PE ALL, M) to 77% (provenance ELMA, E).

From the results of the test of proportion, it is evident that the provenance ELMA (E) has a statistically significant higher survival rate in relation to the average survival ($t = 2.54$), while the provenances PE ALL (M) and YELM (N) have a statistically significant lower survival rate ($t = –2,67$ and $t = –2,46$, respectively). DBH analysis showed that the mean diameter at breast height for all Douglas fir provenances amounts to 37.45 cm, ranging from 35.02 cm for the provenance CASTLE ROCK (T) up to 40.17 cm for the provenance CORVALIS (B). The

TABLE 2

Descriptive statistics for analysed variables and test of proportion.

		Volume (m^3)		DBH (cm)		Height (m)		Test of proportion (H_0:p=p_0) p_0=0,648	
		N	mean	sd	mean	sd	mean	sd	t
	Total	648	1.51	0.66	37.45	7.95	26.37	3.70	
Provenances	A	66	1.65	0.69	38.05	7.58	27.98	3.50	0.25
	B	71	1.69	0.59	40.17	7.04	26.34	3.49	1.29
	C	74	1.11	0.52	34.00	7.55	23.11	2.77	1.92
	E	77	1.51	0.62	36.69	7.43	27.58	3.34	**2.54**
	J	63	1.69	0.66	39.45	7.01	27.80	3.46	–0.58
	M	52	1.74	0.63	39.98	7.75	27.38	2.80	**–2.67**
	N	53	1.60	0.77	38.87	7.89	25.89	4.10	**–2.46**
	R	63	1.49	0.61	37.24	7.39	26.60	3.12	–0.38
	S	66	1.44	0.67	36.24	8.98	26.08	4.07	0.25
	T	63	1.31	0.63	35.02	8.70	25.25	3.44	–0.38

Note: bolded t values are statistically significant(p<0,05).

mean height of the analysed provenances amounts to 26.37 m. The best height growth was shown by the provenance SHELTON (A) (27.98 m) which originates from lower altitudes in Washington, while the lowest growth was shown by the provenance SHADE COVE (C) (23.11 m) from higher areas of Oregon. Besides the lowest height values, this provenance also showed the lowest value of volume (1.11 m^3). The biggest volume was seen in the provenance PE ALL (M) (1.74 m^3). Six provenances out of a total of ten had a bigger volume than the average volume value of the trial which amounted to 1.51 m^3.

The results of the univariate (ANOVA) analysis of variance for DBH, height and volume are shown in Table 3, while graphs for each dimension are shown in Figures 2, 3, and 4. The results of the variance analysis (ANOVA) show that there is a statistically significant difference for all the analysed variables for the investigated provenances (Table 3).

For all the analysed variables (Figures 2, 3, 4) it is evident that the provenance SHADY COVE (C) has the lowest values. The results of the Tukey post hoc test show a statistically significant difference of this provenance from all other provenances by height ($p<0.05$) while it differs by DBH from the provenances CORVALIS (B), HVIDILDE (J), PE ALL (M) and YELM (N) ($p<0.05$).

TABLE 3

Results of ANOVA for analysed variables.

	SS	df	MS	F	p
Volume (m^3)	23.8	9	2.647	6.49	<0.001
DBH (cm)	2634.1	9	292.7	4.88	<0.001
Height (m)	1347.3	9	149.7	12.76	<0.001

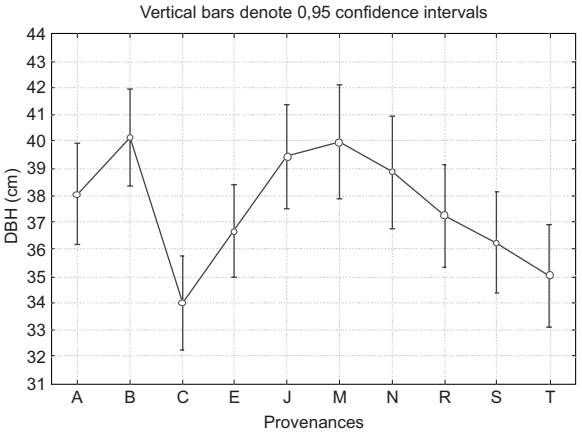

Figure 2. *Mean value and 0.95 confidence intervals of DAB (cm) of Douglas Fir by provenances.*

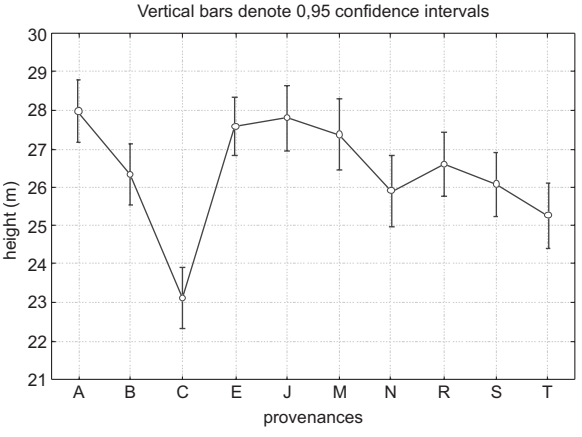

Figure 3. *Mean value and 0.95 confidence intervals of height (m) of Douglas Fir by provenances.*

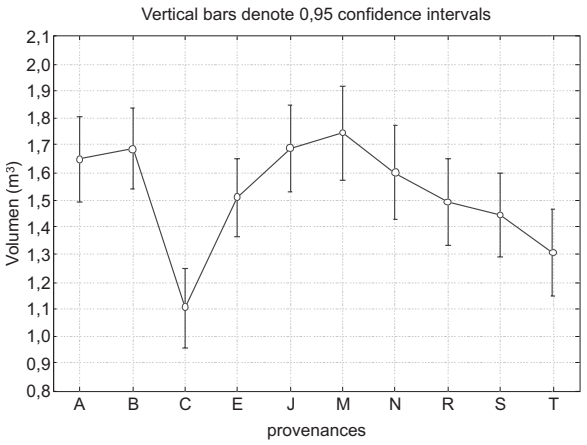

Figure 4. *Mean value and 0.95 confidence inetrvals of volumen (m^3) of Douglas Fir by provenances.*

This ultimately results in the statistically significant difference of this provenance by volume from all other provenances except BUZET (S) ($p=0.06$) and CASTLE ROCK (T) ($p=0.70$). This implies that the lower values of the DBH of the provenances BUZET (S) and CASTLE ROCK (T) also caused lower volume.

With the same test it was determined that the provenance SHELTON (A) does not differ statistically by DBH from the rest of the provenances. Its height growth means that this provenance differs significantly from the provenances SHADY COVE (C), YELM (N), BUZET (S) and CASTLE ROCK (T) ($p < 0.05$), while by volume it differs significantly only from the provenance SHADY COVE (C) ($p < 0.05$).

The Tuckey post hoc test also showed that the provenances HVIDILDE (J) and PE ALL (M) significantly differ ($p<0.05$) from the provenances SHADY COVE (C) and CASTLE ROCK (T) for all the analysed variables (DBH, H, V). The same test showed that the provenance YELM (N) significantly differs by height from the provenances SHELTON (A) and SHADY COVE (C), while by DBH and volume it differs only from the provenance SHADY COVE (C).

From the results of the k-means cluster analysis (Table 4, Figure 5), it is evident that ten Douglas fir provenances are grouped in four clusters. In cluster 1, only the provenance SHADY COVE (C) is included with a high number of trees with lower heights and a smaller DBH and volume. On the other hand, the provenances from cluster 3 (PE ALL (M) and YELM (N)) have in a small number of trees a higher DBH and volume. The rest of the provenances are grouped in two clusters (cluster 2 and cluster 4) with similar values but with the difference that the provenances SHELTON (A), CORVALIS (B), ELMA (E) and HVIDILDE (J) (cluster 2) have higher values than average for the analysed parameters, while the provenances ŠIPKA (R), BUZET (S) and CASTLE ROCK (T) (cluster 4) have values lower than average.

TABLE 4

Results of k-means cluster method for analysed provenances by N, DBH, H and V.

Provenances	Cluster	Distance
A	2	0.31
B	2	0.55
C	1	0.00
E	2	0.73
J	2	0.48
M	3	0.34
N	3	0.34
R	4	0.39
S	4	0.15
T	4	0.46

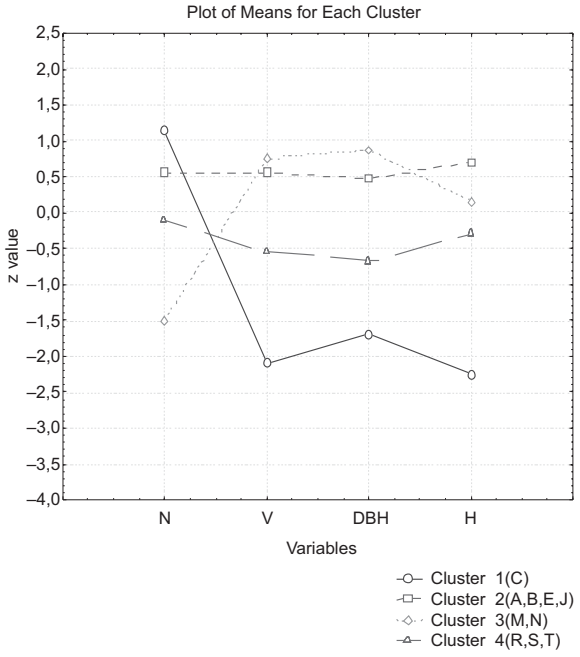

Figure 5. *Graph of means of each cluster for standardized variables.*

DISCUSSION AND CONCLUSIONS

The average survival rate of all ten Douglas fir provenances in the locality of »Kontija« at 44 years of age amounts to 64.8%. This percentage is high regarding the survival of the same species in different ages and in different localities in Croatia *(15–17, 19)*. Even in Northwest America where the Douglas fir has a large natural range, some studies on survival in provenance tests show different results. The research of Rowe and Ching *(24)* draw attention to great problems in the USA in relation to the continuation of field tests due to various natural disturbances (fire, frost, animals, etc.). According to the same authors, these factors reduced the number of investigated locations from 16 to 9. Seven locations of this

provenance test were omitted from further research either because of the total destruction or the too limited number of trees. At the age of nine, only two localities have a survival rate from 95 to 100% (British Columbia), while in the three localities in Oregon the range of the survival rate was very wide, e.g. in the locality of Salem it ranged from 33% to 82%. The study of the field performance of Douglas fir in this test 45 years after its establishment *(25)* concludes that the geographic pattern of the variation of Douglas fir provenances was weak which suggests the lack of convergence between natural populations and their native habitats, so the authors conclude that a broad transfer may not involve much risk. The large variation in growth within the provenances on each of the investigated sites indicates that selection within provenances over the species-wide range can increase the potential productivity of a site.

All established Douglas fir tests in Croatia are still in the research phase. Results are presented for the ages 13 and 22 (localities of Durgutovica, Slatki potok, Lokve, Kontija) (19), 13 and 27 (Krndija) (16) as well as 15 (Varaždin) (17), 26 (Lokve) (26) and 44 years after establishment (Kutina) (15). Generally, issues related to forest cultures and plantations in Croatia have been addressed by Matić *et al. (27)*.

The average survival rate for the localities ranged from 54% (Lokve) and 63% (Krndija) up to 81.8% (Varaždin). The average survival rate of Douglas fir in the locality of »Kontija« (64.8%) suggests a high survival rate forty years after establishment. Among the provenances with the highest survival rate is the provenance ELMA (E) from Washington from lower altitudes (100 to 200 m). In other tests in Croatia, this provenance, together with other provenances from Washington from altitudes up to 300 m a.s.l., showed good results *(19, 16, 17)*. These provenances were also generally superior in total growth in all localities except California in the USA where they are naturally distributed *(24)*. This suggests that provenances from Washington have adapted well in new bioclimatic conditions regardless of the different geographic longitude and altitude, moisture, temperature and precipitation, but under the influence of a similar altitude.

Even though provenances HVIDILDE (J) from Denmark and PE ALL (M) from Washington are geographically very distant, in the trial in Kontija they have nearly the same height, diameter and volume growth (Figures 2, 3, 4). The provenance from Denmark (HVIDILDE (J)) has greater height, a somewhat lower DBH and consequently a lower volume, while the provenance from Washington has, besides a lower height, a bigger DBH and volume.

Provenances PE ALL (M) and YELM (N) (cluster 3) in a small number of trees have the largest DBH and volume. In the trial in Kontija, these provenances proved to have the lowest survival rate (52% and 53%), but because of their high DBH and heights they are the most productive. According to Kleinschmitu *(28),* the best provenances in Germany are provenances which originate from the west part of the Olympic Peninsula and west of the Washington Cascades. According to Pintarić *(29),* the best results in Bosnia at the age of 10 in relation to quality and growth intensity were shown by the provenance Alberni from British Columbia from areas 150 m above sea level.

Govedar *et al. (30)* came to the same conclusions about the best provenances according to volume in the locality of »Lokva« near Gradiška. Research conducted in Austria *(31)* shows that local provenances in terms of growth intensity are the same as the best provenances from the USA. On the basis of this conclusion, their use is recommended in the future.

In the locality of Kontija, the provenance which showed the highest survival rate was the provenance ELMA (E) from the Washington area, at altitudes of 100 m to 200 m. Provenances PE ELL (M) and N proved the most productive provenances regardless of the lowest survival rate. The domestic provenance BUZET (S) showed slightly lower values for all analysed variables in relation to the average values in the trial.

In general, all provenances in the trial are vital and in good health without any determined pests. In past scientific research in Croatia *(17),* the vitality of Douglas fir provenances was estimated with three different degrees of vitality (0 good vitality; –1 medium vitality; –2 bad vitality). The only two provenances without negative points were the provenances from Washington, which is in accordance with the good growth results of the provenances from the Washington area which are presented in this paper.

According to Zas *et al. (32),* the heigh genetic variability and the biological significance of Douglas fir growth suggests its applicability in early selection. In the Netherlands, according to Vries *(33),* the results of provenance tests are used in regular practice. Therefore, our recommendation on the basis of the presented results is also to include it into the practical management of forest cultures in Croatia.

There are numerous scientific papers *(24)* which provide evidence that a long-rotation species, such as Douglas-fir, will be subjected to a great variety of climate change effects, as well as more frequent natural disturbances which will alter the expected growth patterns. Therefore, further scientific research on issues related to Douglas fir success in Croatia is certainly still needed, as is investigation of its possible pronounced significance under climate change conditions.

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