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Evaluation of the IUFRO provenance plot with grand fir in the Habr locality (Western Bohemia) at the age of 31 years

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ABSTRACT: In the framework of an international IUFRO provenance research of grand fir (*Abies grandis* /D. Don/ Lindl.), a series of research plots was established in the Czech Republic in 1980–1982. This paper focuses on an evaluation of experimental plot No. 213 – Habr (Western Bohemia), where 24 provenances of grand fir are investigated. Results of the evaluation of height, diameter at breast height, volume of large timber (diameter outside bark > 7 cm), and some qualitative parameters are presented for the age of 31 years. Results of the plot evaluation showed the best growth in provenances originating from the Washington state coastal region. Individuality of growth pattern was confirmed for different Vancouver provenances and those from Idaho and Montana states. These areas cannot be considered as homogeneous. The growth of all provenances originating from the Cascades, Washington, is below average. The lowest growth rates were documented for the Cascades, Oregon state provenances; superior characteristics of some of them probably result from the high mortality of others at earlier stages and larger growth space available at present.

Keywords: *Abies grandis*; provenance research; experimental plot; production

Grand fir grows naturally on the northwest coast of North America (39–51°E, 114–125°W) in the USA (Washington, Oregon, California, Idaho and Montana) and Canada (British Columbia), at the altitudes from the coastal areas to ca 2,000 m a.s.l. (Foiles, Marvin 1965). The climate ranges from temperate maritime to continental, the precipitation from 350 mm in the driest inland areas to 2,000 mm on the coast. Most precipitation falls in winter and spring, while summers are mostly very dry. Locally, temperature extremes occur (from –40 to +40°C). Vegetation periods usually last for 100–180 days (Beran 2006). Therefore, the natural range includes a wide amplitude of climatic conditions and, consequently, very variable site demands.

In the Czech Republic (CR), the ecological optimum of the species in oak-beech and beech-oak woods is at 350–500 m a.s.l. (Šika 1983). While it is a highly valued tree species, grown abundantly in some West European countries, it covered only 1208.59 ha in the CR in 2013 (http://eagri.cz), even though it is a highly productive tree species, outmatching even Douglas fir on most favourable sites (Fulín et al. 2013), and having a more positive effect on forest soils in comparison with other coniferous (Podrázský, Remeš 2008a). It responds well to fertilization and grows out in shelterwood (Podrázský, Remeš 2008b). The quality of planted stands is substantially influenced by the origin (genetic makeup) of the reproduction material.

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The material intended for Czech forestry can be imported only from certain areas and altitudinal zones of its range (Decree No. 139/2004). Principles of transfers are based mainly on provenance research results.

According to König (2005), the main aim of provenance research is to identify well growing and sufficiently adapted tree populations from different locations, which can be used as seed sources for reforestation. The primary reason to start provenance research was an effort to enhance the timber production for higher volume and quality. This is urgent at the time of increasing human population and material consumption worldwide. Only the knowledge of site factors is not sufficient to predict the performance of a provenance at a new site. Many factors such as pests or diseases which do not have an influence in localities of origin but which are present at the test site may play an important role in provenance adaptedness. Although there are some modern methods (e.g. DNA analyses) disposable in forestry research, the molecular assessment of adaptedness has not been available so far and from this point of view the provenance experiments are still unchangeable.

In the framework of an international provenance experiment of IUFRO, the seed collection of 47 provenances was organized in 1974–1976, with 25 participating institutions from 17 European and North American countries. In 1977, seeds of 32 provenances were imported to the CR; the seedlings were planted by the Forestry and Game Management Research Institute (FGMRI) on 7 research plots established in 1980–1982. The plots of Drahenice and Habr fully comply with the IUFRO methodology, while the establishment of the rest (Hrubá Skála, Ztracenka, Trhové Sviny, Strnady, Horní Stropnice) had to be modified with regard to the quantity of research material (Šika 1983; Beran 2006). For various reasons, some of the plots (Horní Stropnice, Trhové Sviny, Ztracenka) cannot be evaluated anymore at present. The basic description of the experiment, including the evaluation of seedlings, was published by Vančura (1980, 1981). There were published results of evaluation of some plots in the CR and Poland (Burzynski, Vančura 1985), as well as Czech data on mortality, shooting and late frost influence (Vančura, Šika 1987), on height, phenology, frost and drought influence (Vančura 1990), diameter at breast height (DBH) and survival rate (Beran 2006) and height, or DBH (Škorpík et al. 2013).

In our report, we try to evaluate the convenience of using the reproduction material of grand fir of the tested provenances; the study is based on assessment of their growth on the Habr research plot (western Bohemia) at the age of 31 years.

MATERIAL AND METHODS

Research plot No. 213 – Habr – was established by FGMRI in 1980 near the village of Volduchy in the Plzeň region (49°47'33.404''N, 13°38'46.325''E). At present, it is owned by Colloredo-Mansfeld Ltd. The area consists of two 0.5 ha rectangles, 80 m apart, divided into plots of 10 × 10 m. The total of 24 provenances (Fig. 1, Table 1) were planted with 25 seedlings in four blocks (replications), following a 2 × 2 m spacing. Originally, each provenance was represented by 100 individuals, i.e. 2,400 seedlings in all (Beran 2006).

The locality lies in Natural Forest Area 7 – the Brdská vrchovina Highlands. The altitude of the plot is 450 to 460 m a.s.l., south-east exposure, the average gradient 1%. The average annual temperature does not exceed 7°C, the average precipitation reaches 600–650 mm. The soil is pseudogley, the forest site type 5P1 (*Abietum piceosum variohumidum acidophilum* with *Luzula pilosa*). At the beginning, young seedlings were exposed to waterlogging (esp. blocks 1 and 3) and partly to frost hollow conditions (Beran 2006).

In the autumn of 2011, mortality was investigated (no regular tending intervention was carried out until the measurement; by then, only dead, damaged,

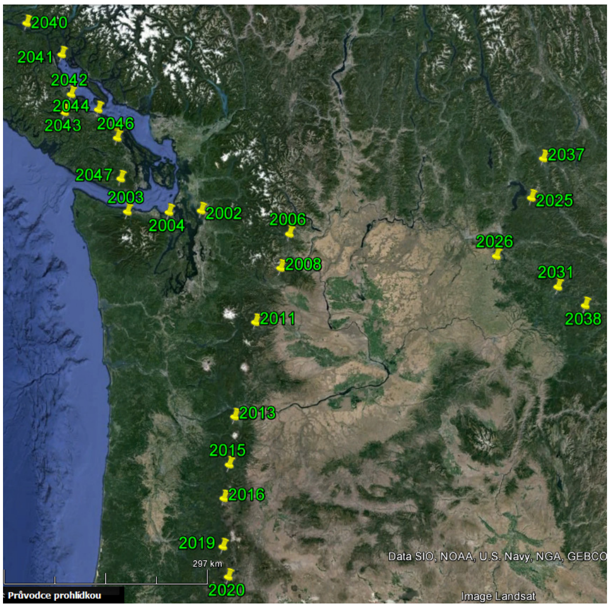

Fig. 1. Source locations of the tested populations of grand fir; codes of provenances are represented only by the last four numbers due to save their readability [Google Earth Pro 7.1.2.2041 (2013), Mountain View, USA]

Table 1. Characteristics of investigated provenances

Provenance	Zone			Coordinates		Elevation
	geographical	seed (former)	seed (actual)	N	W	(m a.s.l.)
Vancouver	**Ia**					
12040 Salmon River		1,020	maritime	50.3	125.8	50
12041 Oyster Bay		1,020	maritime	49.9	125.2	5
12042 Buckley Bay		1,020	maritime	49.5	124.9	45
12043 Sproat Lake		1,020	maritime	49.3	125.0	35
12044 Kay Road		1,020	maritime	49.3	124.3	50
12045 Yellow Point		1,020	maritime	49.1	123.8	30
12046 Mount Provost		1,020	maritime	48.8	123.8	75
12047 Sooke		1,020	maritime	48.4	123.8	20
Washington – coast	**Ib**					
12002 Tulalip		212	5 – Puget Sound	48.1	122.3	30
12003 Indian Creek		221	5 – Puget Sound	48.1	123.6	140
12004 Gardiner		221	5 – Puget Sound	48.1	122.9	30
Washington – Cascades	**II**					
12006 Eagle Creek - low		622	7 – Chelan	47.7	120.6	760
12008 Jack Creek		631	7 – Chelan	47.3	120.8	825
12011 Clear Lake		641	8 – Klickitat	46.6	121.3	945
Oregon – Cascades	**III**					
12013 Cooper Spur		661	8	45.5	121.7	1,040
12015 Sisi Butte		452	8	44.9	121.8	975
12016 Santiam Summit		473	9	44.4	121.9	1,400
12019 Roaring River		472	9	43.9	122.0	1,310
12020 Crescent Creek		681	9	43.5	121.9	1,375
Idaho, Montana	**IV**					
12025 Buckskin Creek		–	north	48.0	116.2	1,220
12026 Plummer Hill		–	north	47.3	116.9	850
12031 Bertha Hill		–	south	46.8	115.8	1,430
12037 Stanley Creek	(Montana)	–	not defined	48.3	115.9	800
12038 Clearwater		–	south	46.6	115.4	760

broken or uprooted trees had been removed). However, the first regular thinning was done in 2012, after the measurement, when it was harvested 5.15 m^3 of grand fir wood. Consequently, height of all individuals over 1.5 m [TruPulse 200 laser hypsometer (Laser Technology, Inc., Centennial, USA) to the nearest 0.5 m] and DBH were measured (millimetre calliper, two perpendicular measurements). Mean heights of provenances were compared with the upper heights which have been observed in Germany (Lockow, Lockow 2007). The volume formula for silver fir (Petráš, Pajtík 1991) was used to calculate the volume of large timber up to 7 cm top diameter outside bark (d. o. b.). For comparison, a formula for grand fir to calculate the stem volume developed in Germany was also used (Rau et al. 2008). Our article also includes results of the DBH measurement (July 2006), not published before.

Further parameters were determined by the following scales. Tree classes according to Kraft (1884): 1 – dominant (large crown extending above the general canopy), 2 – codominant (within the main canopy; symmetrical, well developed crown), 3 – intermediate (extends into the lower part of the canopy, individuals with a less developed crown), 4 – partly overtopped, 5 – entirely overtopped (dying, entirely shaded). Vitality (foliage quality) in accordance with IUFRO methodology (Leibundgut 1978): 1 – very vital (vigorous growth of an individual), 2 – normal (average growth of an individual with no unusual deviations), 3 – weak (substandard vitality, poorer foliage). Stem shape: 1 – straight, 2 – twin stem, but straight, 3 – slightly crooked (esp. in top parts), 4 – significantly bent, unshapely. Crown symmetry: 1 – symmetrical, 2 – partly asymmetrical, 3 – significantly asymmetrical. Branch diameter and density: 1 – thin sparse-whorled, 2 – thin densely-whorled, 3 – thick sparse-whorled, 4 – thick densely-whorled, 5 – irregular whorls. Health condition: 0 – undamaged, 1 – fungal diseases and rot, 2 –damage by game, 3 – insect pests, 4 – damage by human activities, 5 – other damage.

Data were processed using QC.Expert 3.1 (TriloByte Statistical Software, Pardubice-Staré Hradiště, Czech Republic), NCSS 2007 (NCSS Statistical Software, Kaysville, USA), STATISTICA 9.0 (SPSS, Tulsa, USA) and Past 2.07 (Øyvind Hammer, Natural History Museum, University of Oslo, Oslo, Norway). First, a fact-finding analysis was carried out, and then the Box-Cox transformation was done, based on the analysis. The mean values of heights and DBH of provenances represent retransformed means. ANOVA was used to evaluate significance ($P = 0.05$) of the differences in values between provenances; in cases of abnormal data distribution, the Kruskal-Wallis test. Subsequent methods of multiple comparisons (Tuckey-Kramer or Kruskal-Wallis post hoc test) were used. For PCA calculations, the data were reduced (particular provenances are characterized by retransformed means in quantitative indicators; in qualitative indicators, by medians of numerical values, assigned to trees by applicable classification scales). Data were scaled by Z-score. Variability, contained in the data, was sufficiently covered by the first two main components, which also met the Kaiser criterion 1.0.

RESULTS

At the time of evaluation, there were 1,438 individuals of all provenances growing on the plot. Mean values of all investigated quantitative and qualitative indicators are presented in Table 2.

Evaluation of height growth shows statistically significant differences between particular provenances

Table 2. Results of investigated provenances

Provenance	Number of growing individuals	Height (m)	$D_{1.3}$ (cm)	Volume of large timber o. b.[1)] (m³)	Volume of stem wood[2)] (m³)	Tree class	Vitality	Stem shape	Crown symmetry	Branch diameter and density	Health condition
Vancouver											
12040 Salmon River	51	18.3	20.5	0.33	0.29	2	2	1	2	1	0
12041 Oyster Bay	84	17.9	18.2	0.25	0.22	2	2	1	2	1	0
12042 Buckley Bay	78	14.9	14.0	0.14	0.11	2	2	1	2	1	0
12043 Sproat Lake	68	15.7	17.6	0.21	0.18	3	2	1	2	1	0
12044 Kay Road	92	16.2	15.4	0.17	0.15	2	2	1	2	1	0
12045 Yellow Point	71	15.9	16.6	0.20	0.17	3	2	1	2	1	0
12046 Mount Provost	76	16.6	17.1	0.22	0.19	2	2	1	2	2	0
12047 Sooke	75	15.9	16.2	0.19	0.16	3	2	1	2	2	0
Washington – coast											
12002 Tulalip	57	17.9	19.3	0.28	0.28	2	2	1	2	2	0
12003 Indian Creek	74	16.8	18.9	0.26	0.24	3	2	1	2	1	0
12004 Gardiner	66	17.7	17.7	0.24	0.20	2	2	1	2	1	0
Washington – Cascades											
12006 Eagle Creek – low	60	14.0	14.5	0.14	0.12	3	2	1	2	1	0
12008 Jack Creek	42	14.9	15.5	0.17	0.15	2	2	1	2	1	0
12011 Clear Lake	54	14.2	16.5	0.17	0.14	3	2	1	2	1	0
Oregon – Cascades											
12013 Cooper Spur	44	14.9	17.0	0.19	0.16	3	2	1	2	1	0
12015 Sisi Butte	43	14.4	14.9	0.17	0.12	3	2	1	2	1	0
12016 Santiam Summit	36	13.2	15.1	0.14	0.12	3	2	1	2	1	0
12019 Roaring River	27	13.3	17.1	0.18	0.14	2	2	1	2	2	0
12020 Crescent Creek	27	15.6	19.1	0.25	0.21	3	2	1	2	1	0
Idaho, Montana											
12025 Buckskin Creek	69	10.2	10.4	0.07	0.04	3	3	1	2	1	0
12026 Plummer Hill	24	13.1	14.9	0.15	0.11	2	2.5	1	2	1.5	0
12031 Bertha Hill	75	14.4	14.6	0.14	0.12	3	2	1	2	1	0
12037 Stanley Creek	50	15.0	16.5	0.18	0.16	3	2	1	2	1	0
12038 Clearwater	95	16.8	16.6	0.21	0.18	3	2	1	2	1	0
Mean	60	15.3	16.4	0.19	0.17	2.6	2.1	1	2	1.2	0

[1)]for *Abies alba*, according to Petráš, Pajtík (1991), [2)]for *Abies grandis*, according to Rau et al. (2008), o. b – outside bark

Table 3. Analysis of variance table – DBH (NCSS 2007)

Source term	Df	Sum of squares	Mean square	*F*-ratio	*P*	α = 0.05
Provenance	23	4991.504	217.0219	4.07	0.000000**	1.000000
S(A)	1,414	75443.44	53.35463			
Total (adjusted)	1,437	80434.95				
Total	1,438					

S(A) – sum of squares of deviations between individual levels of provenance, **significant at α = 0.05

(Tables 3 and 4). Provenance 12040 – Salmon River from Vancouver Island shows the highest values (18.3 m), followed by 12041 – Oyster Bay, and 12002 – Tulalip. Provenance 12025 – Buckskin Creek from Idaho and Montana (10.2 m) grows at the slowest rate. The height growth of Vancouver Island and the Washington state coastal areas provenances is above average, other geographical groups of provenances show rather below-average results, with the exception of 12020 – Crescent Creek, and 12038 – Clearwater.

The assessment of DBH variability also shows statistically significant differences (Tables 5 and 6). The highest DBH was recorded, again, in provenance 12040 – Salmon River (20.5 cm), followed by 12002 – Tulalip, and 12020 – Crescent Creek. The lowest DBH was recorded in provenance 12025 – Buckskin

Table 4. Tukey-Kramer Multiple-Comparison Test – DBH (NCSS 2007)

Group	Count	Mean	Different from groups
12025	69	11.51	12037, 12047, 12038, 12045, 12011, 12013, 12046, 12019, 12004, 12041, 12043, 12003, 12020, 12002, 12040
12042	78	14.71	12002, 12040
12031	75	14.96	12040
12006	60	14.98	
12008	42	15.26	
12044	92	15.42	
12015	43	15.52	
12016	36	15.77	
12026	24	15.98	
12037	50	16.48	12025
12047	75	16.57	12025
12038	95	16.64	12025
12045	71	16.96	12025
12011	54	17.29	12025
12013	44	17.50	12025
12046	76	17.65	12025
12019	27	17.73	12025
12004	66	17.89	12025
12041	84	18.03	12025
12043	68	18.16	12025
12003	74	18.93	12025
12020	27	19.29	12025
12002	57	19.48	12025, 12042
12040	51	19.97	12025, 12042, 12031

α = 0.05, Error term = S(A), Df = 1414, MSE = 53.35463, Critical value = 5.1542

Table 5. Kruskal-Wallis one-way ANOVA on ranks – height (NCSS 2007)

Method	Df	Chi-Squared Test (χ)	*P*	Decision (0.05)*
Not corrected for ties	23	170.2623	0.000000	reject H_0
Corrected for ties	23	170.4603	0.000000	reject H_0
Number of sets of ties	47			
Multiplicity factor	3453234			

*decision about rejecting/accepting of H_0 (there are not statistical differences between mean values of provenances heights) on α = 0.05

Table 6. Results of Kruskal-Wallis post hoc test – height (NCSS 2007)

Group	Count	Provenance
12025	69	12002, 12003, 12004, 12006, 12008, 12011, 12013, 12015, 12031, 12037, 12038, 12040, 12041, 12042, 12043, 12044, 12045, 12046, 12047
12016	36	12002, 12003, 12004, 12038, 12040, 12041, 12042, 12043, 12044, 12045, 12046, 12047
12019	27	12002, 12003, 12004, 12038, 12040, 12041, 12043, 12044, 12045, 12046
12026	24	12002, 12003, 12004, 12038, 12040, 12041, 12044, 12046
12006	60	12002, 12003, 12004, 12025, 12038, 12040, 12041, 12043, 12044, 12045, 12046
12031	75	12002, 12003, 12004, 12025, 12038, 12040, 12041, 12044, 12046
12011	54	12002, 12003, 12004, 12025, 12038, 12040, 12041, 12043, 12044, 12045, 12046
12008	42	12002, 12004, 12025, 12040, 12041, 12046
12015	43	12002, 12004, 12025, 12040, 12041
12013	44	12002, 12003, 12004, 12025, 12038, 12040, 12041, 12046
12037	50	12002, 12003, 12004, 12025, 12038, 12040, 12041, 12046
12042	78	12002, 12003, 12004, 12016, 12025, 12038, 12040, 12041, 12046
12020	27	12002, 12004, 12025, 12040, 12041
12045	71	12002, 12004, 12006, 12011, 12016, 12019, 12025, 12040, 12041
12047	75	12002, 12004, 12016, 12025, 12040, 12041
12044	92	12002, 12004, 12006, 12011, 12016, 12019, 12025, 12026, 12031, 12040, 12041
12043	68	12002, 12004, 12006, 12011, 12016, 12019, 12025, 12040, 12041
12038	95	12006, 12011, 12013, 12016, 12019, 12025, 12026, 12031, 12037, 12042
12003	74	12006, 12011, 12013, 12016, 12019, 12025, 12026, 12031, 12037
12046	76	12006, 12008, 12011, 12013, 12015, 12016, 12019, 12025, 12026, 12031, 12037, 12042
12004	66	12006, 12008, 12011, 12013, 12015, 12016, 12019, 12020, 12025, 12026, 12031, 12037, 12042, 12043,12044, 12045, 12047
12041	84	12006, 12008, 12011, 12013, 12015, 12016, 12019, 12020, 12025, 12026, 12031, 12037, 12042, 12043, 12044, 12045, 12047
12040	51	12006, 12008, 12011, 12013, 12015, 12016, 12019, 12020, 12025, 12026, 12031, 12037, 12042, 12043, 12044, 12045
12002	57	12006, 12008, 12011, 12013, 12015, 12016, 12019, 12020, 12025, 12026, 12031, 12037, 12042, 12043, 12044, 12045, 12047

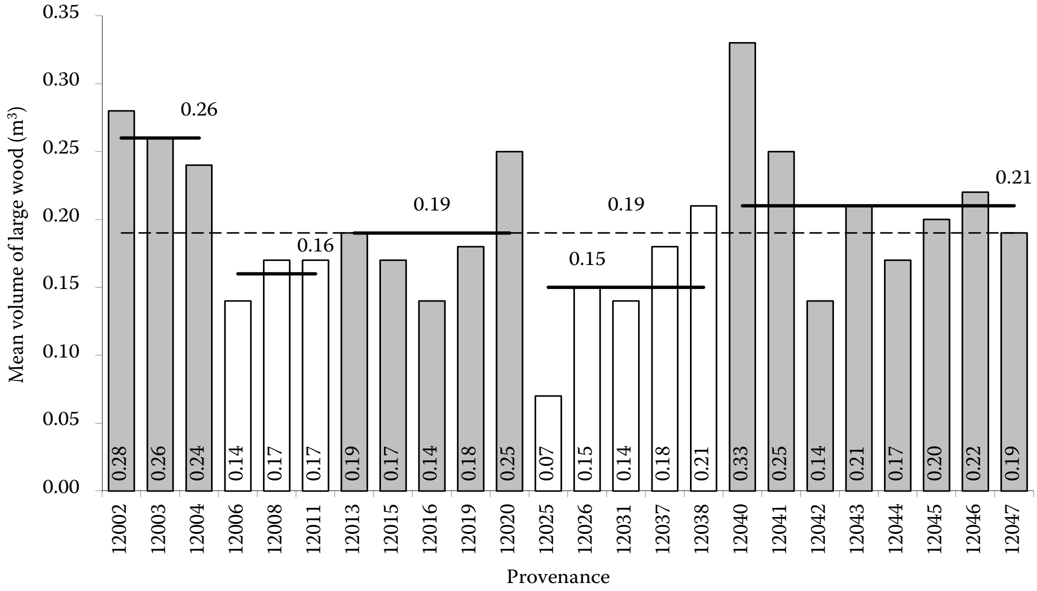

Fig. 2. Volumes of large timber o. b. grouped according to provenances geographical nearby

Creek (10.4 cm). Therefore, provenances from coastal Washington, Vancouver Island (except 12042 – Buckley Bay, and 12044 – Kay Road) and most provenances from the Oregon Cascades show an above-average DBH. The diameter of Washington Cascades, Idaho and Montana provenances oscillates from average to below-average.

The mean volume of large timber o. b. (Petráš, Pajtík 1991) on the whole plot was 0.19 m^3 (Fig. 2), and the medians of particular provenances oscillated from 0.07 m^3 (12025) to 0.33 m^3 (12040). Coastal Washington (0.26 m^3) and Vancouver Island (0.21 m^3) provenances stood out from all the geographical zones. The Oregon Cascades matched the average values of the plot. The mean stem volume (Rau et al. 2008) on the whole plot was 0.17 m^3.

The results of evaluation of other parameters (social status, vitality, stem shape, crown symmetry, branch diameter and density, health condition) are presented as provenance medians in Table 2. The obtained data were consequently used to calculate PCA.

In the framework of PCA (Fig. 3), height and DBH are positively correlated while being in negative correlation with vitality and altitude of the provenance

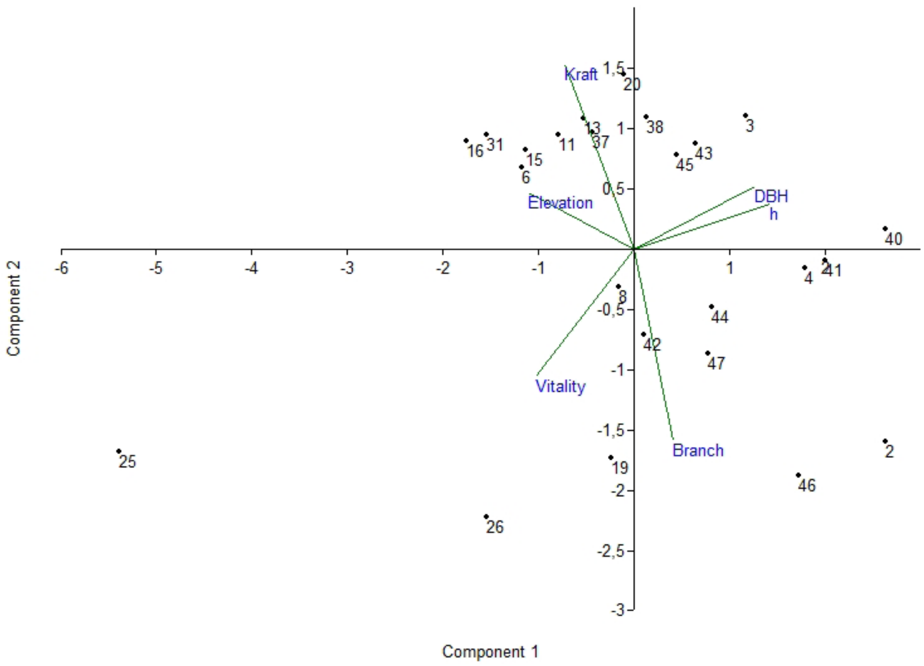

Fig. 3. Results of the PCA, presented are the last two numbers of the code

origin. The first main component is characterized especially by height, DBH, and altitude, the second by branches and social status according to Kraft. The provenances formed groups, and, at the same time, some provenances stood out. Provenances 12026, 12019, 12046, 12002, and especially 12025 are the most distinctive ones. Provenances 12047, 12042, 12044 and 12008 form a group characterized by similar results; the same applies to provenances 12040, 12041 and 12004. The remaining provenances form the third group. The provenances differ especially in features of the second component; provenance 12025, though, varies also in the first main component.

DISCUSSION

The results of the experiment, initiated in France in 1961 (30 provenances), showed a significant difference in the growth of grand fir provenances from the Pacific coast, Cascades and inland. The coastal provenances grew fastest and flushed earliest; the inland provenances flushed later. The tests in climatic chambers demonstrated that the Cascades and inland provenances were more resistant to drought and frost than the coastal provenances (Šika 1983). Research in Germany brought similar results (Scholz, Stephan 1982).

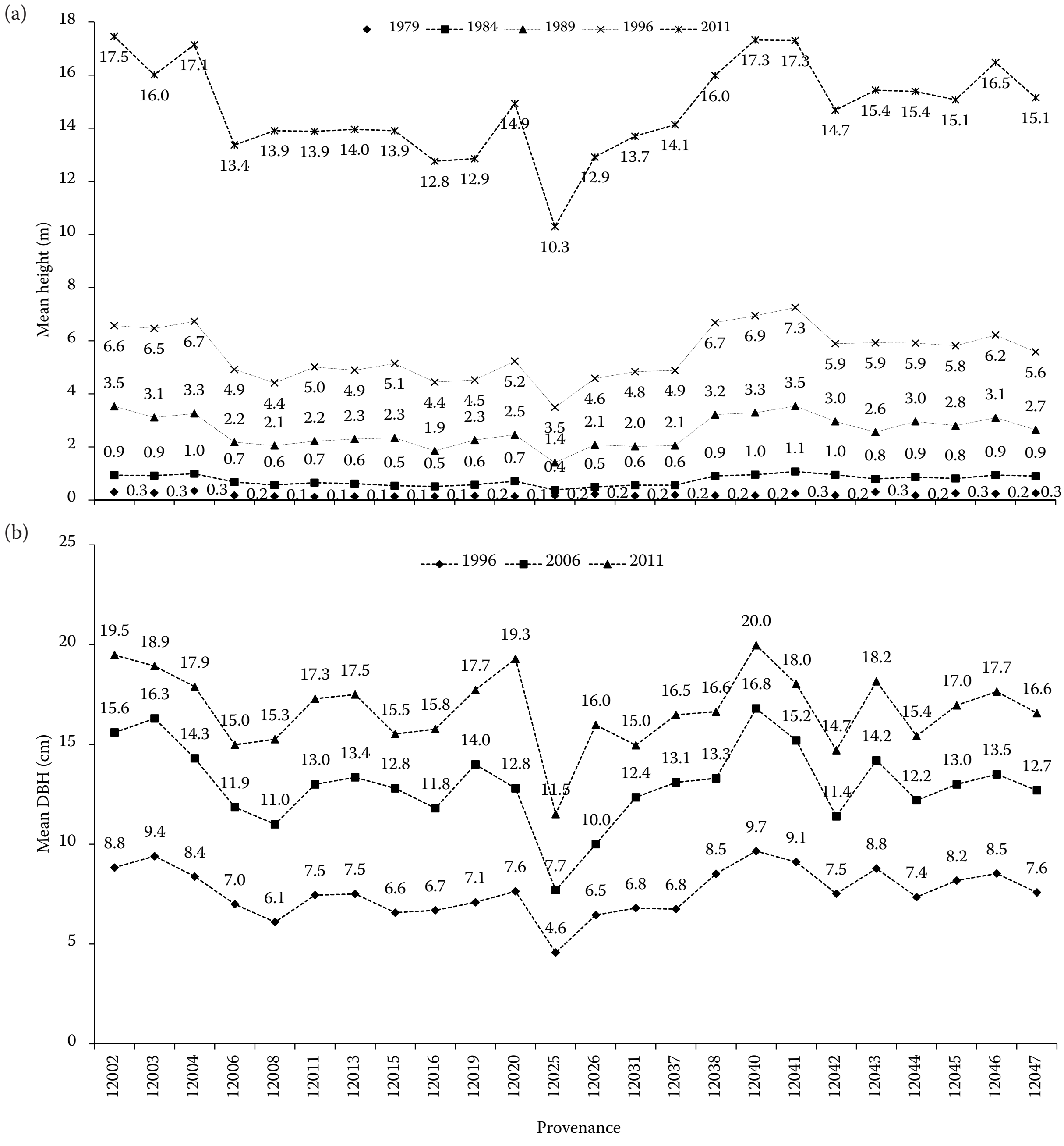

Fig. 4. Mean height (a) (Vančura 1981, 1990; Šika, Vančura 1985; Vančura, Beran 1996; 2011 – unpublished data); mean DBH (b) (Vančura, Beran 1996; Beran 2006; 2011 – unpublished data) of provenances during their evaluation

The fast growth of Washington coast provenances (e.g. 12003 – Indian Creek, 12004 – Gardnier, 12005 – Bear Mountain) or British Columbia provenances (Vancouver), and the slower growth of Oregon Cascades and Washington provenances (e.g. 12013 – Cooper Spur, 12016 – Santiam Summit, 12020 – Crescent Creek) were confirmed by our investigation as well. Inland provenances belong to the fast growing (on Habr plot it is for instance 12038 – Clearwater from Idaho), medium and slow growing ones (Burzynski, Vančura 1985; Vančura, Šika 1987; Beran 2006).

New measurements in the Habr plot confirm the previous results (Vančura 1981, 1990; Šika, Vančura 1985; Vančura, Beran 1996; Beran 2006), see Fig. 4. Coastal Washington and Vancouver provenances get the best results, whereas the Cascades and most inland provenances (with the exception of 12038 from Idaho, again) grow more slowly. Recently, Škorpík et al. (2013) assessed the Strnady plot (the same series) which was of similar age (28 years). Even there, coastal Washington provenances got the best results. The fastest growth was characteristic not only of several provenances from British Columbia but also of some provenances from the Washington Cascades (including all three provenances of the Habr plot assortment), Idaho and Montana (including provenances 12025, 12026 and 12031 of the Habr plot assortment) as well as of one Oregon Cascades provenance.

The uniqueness coastal Washington and Vancouver Island provenances was proved by Kleinschmit et al. (1996). Once again, Idaho and Montana provenances showed very variable results, therefore this zone cannot be judged generally. The notably better diameter growth of some Oregon Cascades provenances (observed on Habr plot as well) is explained by a high mortality rate at young stages – the canopy opening offered a more growth space to other individuals. This applies to the Habr research plot as well. Finally, Rau et al. (2008) published the results of a huge fir growth at different locations in Germany at the age of 27 years. The best growing provenances originate from West Washington, Vancouver Island and British Columbia. Coastal provenances of South Oregon exhibit poor production and quality.

In a research plot in the Polish Carpathians (700 to 720 m a.s.l., 30 years of age), 12040 Salmon River (Vancouver) provenance reached the highest mean height (12.2 m) of the seven monitored provenances, which was even more than in coastal Washington provenances (Kulej, Socha 2008). This provenance was the second highest on Habr plot (18.3 m) and the best in DBH and volume. At a relatively comparable age (difference 1 year), the provenance on Habr plot grows 6 m higher on average than the same provenance in mountainous conditions in Poland. Although the age of compared forest stands differs by one year, it cannot justify such a high relative difference in their average height.

The coastal Washington provenances were recommended also for Great Britain by Samuel (1996); he pointed out, though, that a slower diameter growth of other provenances might provide higher wood density. Wood quality of the species is often queried among experts but according to some studies it is sufficient for various purposes, and grand fir might be a good substitute for Norway spruce in some cases (Zeidler et al. 2015).

Measurements of grand fir (age 20–45 years) on 23 research plots in Germany (altitude ranged from 53 to 150 m a.s.l., average annual rainfall 500 to 580 mm, average annual temperatures 7.5–8.5°C) made it possible to set up a top height (H_{100}) volume diagram (Lockow, Lockow 2007). Mean heights of provenances (age 31 years) in the Habr provenance test have not reached the value of the top height (21 m) in the 1st site quality or top height (18 m) in the 2nd site quality reached in Germany. However, mean heights of provenances No. 41, 2 and 4 are fairly close to the value of the top height for the 2nd site quality, despite having been calculated only from the tallest trees.

Grand fir production data are found in British yield tables. The growing stock o. b. of a 30-years-old main stand is 220–408 $m^3 \cdot ha^{-1}$ (605–1,273 trees) according to yield class (Christie, Lewis 1961). No yield tables for grand fir are available in the CR. Silver fir mensurational tables (ÚHÚL, VÚLHM 1989) mention also possible exploitation of grand fir; when average data of all provenances on the plot are considered (15.3 m; 16.4 cm), 300 $m^3 \cdot ha^{-1}$ growing stock can be estimated, which is roughly the medium value stated in the British tables (with 2.876 trees per 1 ha, though). In the Czech Republic, grand fir does not reach the size like in Great Britain, France, Denmark or Germany, owing to rather a continental climate (Hofman 1963). The biggest individuals in the CR can be found in the Bukovina arboretum in Hrubá Skála; at the age of 95 years, their height was 45 m and DBH 110 cm (Beran 2006).

A comparison of results which were obtained according to the formulas for silver fir (Petráš, Pajtík 1991) and for grand fir (Rau et al. 2008) showed that the values of volume for grand fir are lower. This can be partially influenced by the fact that the values for grand fir represent only stem, while values for silver fir used in the Czech Republic represent large timber. Nevertheless, this result is rather surprising.

It is a well-known fact that coastal provenances flush earlier and react more sensitively to climatic extremes, while Cascades and inland provenances flush later and are more resistant. In comparison with Douglas fir, grand fir is less sensitive to winter transpiration and frequent waterlogging followed by soil desiccation (Vančura, Šika 1987; Vančura 1990). In the past, the Habr plot suffered from waterlogging and frosts; more than 50% of all Vancouver and coastal Washington provenances survived, though (Beran 2006). These provenances showed above-average values of survival also in other IUFRO plots in the CR (Drahenice, Hrubá Skála, Strnady). By contrast, Kleinschmit et al. (1996) observed a high mortality of Oregon Cascades provenances in research plots in Germany.

Coastal Washington and British Columbia (1020) provenances were recommended for broader utilization in the CR (especially in former seed areas 221, 212, 202, 201 – see Table 1 for the conversion key to contemporary seed zones). Northern Idaho provenances (> 800 m a.s.l.) are also worth considering for their expected growth and resistance (Burzynski, Vančura 1985; Vančura, Šika 1987). Beran (2006) cautioned against growing coastal provenances in frost hollows and at altitudes > 500 m a.s.l. as the provenances flush rather early and are less resistant to winter frosts. Northern Washington Cascades provenances represent a good choice too (403, 402, 104). The growth of these firs is average but their resistance to climatic extremes is significantly higher (Vančura, Šika 1987). Former seed zones 231, 232, 030, 240, 041, 411, 401, 402, 621, 622 and the inland part of Idaho were also recommended for import (Vančura 1990). Idaho and Montana provenances are expected to be highly resistant to drought and frost but their growth is unimpressive. For the CR, Beran (2006) recommended provenances 12038 – Clearwater and 12026 – Plummer Hill, but not on gleyed or waterlogged sites. He considered Oregon Cascades provenances unsuitable, for the most part. New measurements on the Habr plot vindicate his opinion. The utilization of Washington Cascades provenances still remains a question (Vančura, Šika 1987) as the growth of all individuals on the Habr plot is below average. At present, FGMRI prepares a revised set of rules for the transfer of grand fir reproduction material from North-American areas to the CR, taking into account the results of the new provenance research. The question remains whether to use the domestic, time-tested material for further reproduction of grand fir in the Czech Republic.

CONCLUSIONS

On the Habr plot, all three provenances from the Washington coast reached above-average height, diameter and volume growth. Vancouver Island provenances provide less convincing figures. While the results of provenance 12040 – Salmon River are the best of all, and another five provenances of the same origin show above-average growth, the remaining provenances 12042 – Buckley Bay and 12044 – Kay Road reach below-average growth results.

The growth potential of provenances from the Washington Cascades, Oregon Cascades, Idaho and Montana, in terms of mean heights, $d_{1,3}$ and volumes, can be described as rather below-average, with the exception of provenances 12038 – Clearwater and 12020 – Crescent Creek. Provenance 12038 reached the highest survival rate and also above-average diameter growth with the stand almost closed. An overall positive evaluation of provenance 12020 is challenged, though, by a high mortality rate.

Therefore, the results of the Habr plot evaluation confirm the best growth of coastal Washington provenances. At the same time, a certain particularity of Vancouver Island and partly Idaho and Montana provenances was confirmed as well. No area can be considered homogeneous, in view of the growth variability. All Washington Cascades provenances show below-average growth figures; Oregon Cascades provenances are the smallest. The above-average diameter or volume growth of some of them is brought about only by a larger growth space, caused by higher mortality at young age.

On the basis of the new evaluation of the Habr plot, it is legitimate to follow former recommendations of importing grand fir to the CR. Only Washington Cascades provenances raise doubts as their growth in the plot is below-average on the whole. At present, a revised set of rules for the transfer of grand fir reproduction material from North-American areas to the CR is being prepared.

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