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Evaluation of the provenance plot "Hrubá Skála" (Northern Bohemia) with grand fir at the age of 36 years

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Abstract

Fulín M., Novotný P., Podrázský V., Beran F., Dostál J., Jehlička J. (2017): Evaluation of the provenance plot "Hrubá Skála" (Northern Bohemia) with grand fir at the age of 36 years. J. For. Sci., 63: 75–87.

The article aims to evaluate the research provenance plot established in 1980 in locality No. 214 – Hrubá Skála (in the north of the Czech Republic), where nine provenances of grand fir (*Abies grandis* (Douglas ex D. Don) Lindley) provided in the framework of the International Union of Forest Research Organizations project, and one provenance of grand fir, Norway spruce, silver fir and Douglas-fir from a standard commercial source are tested. We present the results of tree height, stem DBH, stem volume production and health status after 36 years. The results correspond with similar experiments in the Czech Republic and abroad and suggest that grand fir provenances from Vancouver Island (British Columbia, Canada) and the Washington (USA) State coastal region show the best production features, while the Oregon Cascades, Idaho and Montana provenances grow more slowly. Comparison with other tree species indicates that the production of grand fir at the investigated age exceeds the production of both Norway spruce and silver fir, and equalizes or gently exceeds even Douglas-fir.

Keywords: *Abies grandis*; growth; qualitative traits; quantitative traits; IUFRO

Grand fir (*Abies grandis* (Douglas ex D. Don) Lindley) is characterized by fast growth on suitable sites, by high production of considerable timber, and is appreciated for its landscaping and gardening value. The production of ornamental brush and Christmas trees is also relatively important. Its fastest growth comes between 20 and 30 years of age (Foiles 1965) and in its homeland, the height of the species can reach up to 100 m. It has low demands on soil quality but shows the best growth on fresh to nutrient-rich, water-surplus sites. Grand fir tolerates shade (Hofman 1963; Šika 1983). The first grand firs were imported to Bohemia in 1831. The introduction of the species was studied more extensively in the past in the Czech Republic (Hofman 1963; Vančura 1981; Šika 1983) due to the decline of na-

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tive silver fir (*Abies alba* Miller) in Central Europe. In European conditions, the introduction of exotic species not only helps foresters meet their production targets, but also aims to stabilize and improve forest sites (Podrázský 2003; Podrázský, Remeš 2007, 2008). Grand fir is one of the most productive species in the Czech environment (Kouba, Zahradník 2011; Čáp et al. 2012; Fulín et al. 2013; Fulín, Remeš 2015). Nowadays, the issue of planting grand fir as a response to silver fir decline is less important because of silver fir regeneration, which, together with activities aimed at nature protection, has contributed to a lessened interest in the grand fir cultivation at present. As a result of past activities, the actual area of this species is 1,230 ha in the Czech Republic (http://eagri.cz, 2015).

The vast range of grand fir in its native location can result in significant differences in the production of different provenances. Therefore, the range was formally subdivided into smaller geographic regions (Fletcher 1986). Research of provenances has resulted in the valuable knowledge of grand fir exploitation in the Czech Republic. Among other findings, it was revealed that grand fir is more tolerant to drought than silver fir (it is true especially of eastern provenances of grand fir), although its mortality increases in dry conditions. In North America, grand fir often suffers from root and stem rot; in Europe it is afflicted by honey fungus and *Heterobasidion annosum* (Fries) Brefeld. It is less damaged by game than silver fir (Foiles 1965; Šika 1983; Beran 2006). Grand fir is less sensitive to winter transpiration than Douglas-fir. Inland provenances from the Oregon Cascades (area IV), the Washington Cascades (area II), Idaho and Montana (III) show the best frost resistance (Fig. 1). By contrast, the least tolerant are coastal populations from Washington (Ib) and the Canadian Vancouver Island (Ia). Early budding provenances were not affected by late frosts but nonetheless they are not recommended for establishment in frost hollows. The worst damage is not caused by climate extremes but by unsuitable soil conditions (permanent waterlogging), seedling damage by large pine weevil, forest weeds and mechanical damage. In comparison with Douglas-fir, grand fir tolerates alternating waterlogging and drying-out of the soil (Vančura 1990).

Although the possibilities of genetic analysis are in progress, provenance research can still provide us with important findings applicable in forest regeneration. The aim of the present study is therefore to compare the growth characteristics of grand fir provenances on the research plot Hrubá Skála (northern Bohemia) at the age of 36 years. Special attention is paid to a comparison of the basic climatic characteristics of the North American regions of the origin of tested grand fir provenances with the climatic conditions of the Czech Republic in terms of the suitability of their possible use in forestry.

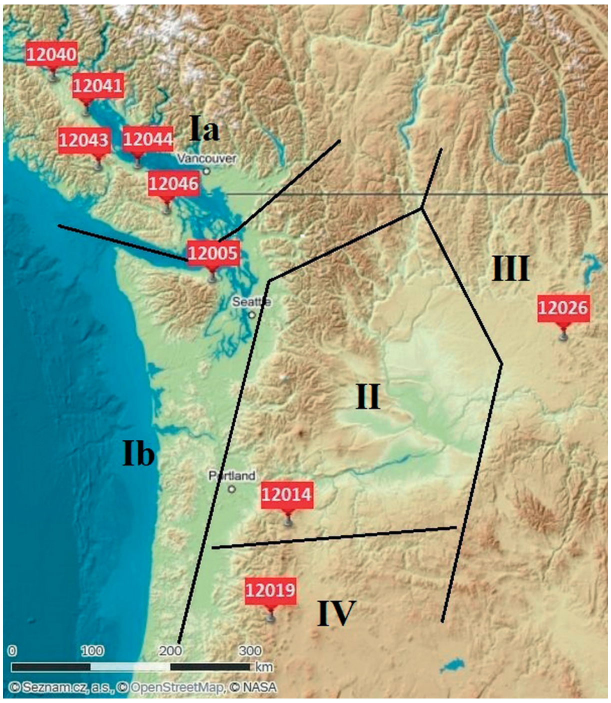

Fig. 1. Source locations of the tested populations of grand fir, geographical zones according to Fletcher (1986) are marked by Roman numerals (for details see Table 1), map background source: https://www.seznam.cz/

Ia – Vancouver, Ib – Washington – coast, II – Washington – Cascades, III – Idaho, Montana, IV – Oregon – Cascades, 12005 – Bear Mountain, 12014 – Beaver Creek, 12019 – Roaring River, 12026 – Plummer Hill, 12040 – Salmon River, 12041 – Oyster Bay, 12043 – Sproat Lake, 12044 – Kay Road, 12046 – Mount Prevost

MATERIAL AND METHODS

In 1977, the Czech Republic (Forestry and Game Management Research Institute) obtained seeds of 32 provenances from the International Union of Forest Research Organizations (IUFRO): 8 provenances from the geographical area Ia, 4 from area Ib, 6 from area II, 9 from area III and 5 from area IV. A part of the seeds were planted in IUFRO plots in the Drahenice and Habr localities, and the remaining material of some provenances was used in 1980–1982 to establish additional plots in Hrubá Skála, Ztracenka, and Trhové Sviny. The plot in

Strnady is unique as all 32 provenances were planted there, with 30 seedlings of each. More information about the entire experiment see for example Krejzek et al. (2015).

Provenance plot No. 214 – Hrubá Skála (50°32'53''N, 15°10'53''E) was founded in provenance region 18 – North Bohemian sandstone plateau at 350–360 m a.s.l. in 1980. The plot is administered by the Forests of the Czech Republic, forestry office in Hořice, Hrubá Skála forest district (forest stand 116 A_{3a}). A former meadow embedded in the forest complex was chosen for the plot establishment. There, the average annual air temperature is 7.8°C and the average annual amount of precipitation 703 mm. The plot is located on the slope with north-west exposure and 5% gradient. The plot is on platform sediments of the Bohemian Cretaceous Basin in the Jizera lithofacies area (the Upper Cretaceous, Coniacian-Upper Turonian stage, Teplice formation). The underlying bedrock is formed of cuboid (thick-bedded) quartz sandstones (Týma et al. 2001). From a hydrological point of view, it is a combined fissure-porous aquifer of mid to high transmissivity $T = 7.2 \times 10^{-5}$ to 1.9×10^{-3} $m^2 \cdot s^{-1}$ (Zícha, Janušková 2001). It is classified as the 3H1 forest type (*Querceto-Fagetum illimerosum mesotrophicum*, *Oxalis acetosella* with *Carex pilosa* on Luvic Cambisols on gentle slopes and slope bases). Phytocenologically, the site indicates local deposits of loess or loess loam over sandstone.

The soil layer is thin and cannot be reliably differentiated. Pedological research (Jedlička et al. 1969a, b) confirmed the soil profile of Modal Cambisol on cuboid (thick-bedded) sandstone in the locality. New maps (http://mapy.geology.cz/pudy/, 2014) show there Arenic Podzol (measurements influenced by vegetation cover and different probe placement). The soil has an argillo-arenaceous texture, with admixed clay or dust in places with loess deposits.

The research area is an irregular trapezoid of 0.84 ha. Nine IUFRO provenances plus commercial seed of grand fir, Norway spruce, silver fir and Douglas-fir (one provenance of each) are tested there in the system of random blocks (Table 1, Fig. 1). The number of replications is three. Sections are 18 × 12 m in size with spacing of 2 × 2 m. Originally 54 seedlings were planted in each section (9 seedlings in 6 rows). Three-years-old grand

Table 1. Characteristics of investigated provenances

Provenance	Zone			Coordinates		Elevation (m a.s.l.)
	geographical*	seed (former)	seed (actual)			
Vancouver	Ia					
12040 Salmon River				50°18'N	125°48'W	50
12041 Oyster Bay				49°54'N	125°12'W	5
12043 Sproat Lake		1020	maritime	49°18'N	125°00'W	35
12044 Kay Road				49°18'N	124°18'W	50
12046 Mount Prevost				48°48'N	123°48'W	75
Washington – coast	Ib					
12005 Bear Mountain		221	3 – Puget Sound	48°00'N	123°00'W	825
Washington – Cascades	II					
12014 Beaver Creek		671	8	45°06'N	121°42'W	1,040
Oregon – Cascades	IV					
12019 Roaring River		472	9	43°54'N	122°00'W	1,310
Idaho, Montana	III					
12026 Plummer Hill		–	North	47°18'N	116°54'W	850
Trade seed (grand fir)	II					
93 Washington – Cascades		403	5 – Skagit	–	–	–
Trade seed (other species)	–					
91 Potštejn – Czech Republic (*Abies alba* Miller)	26 – Foothills of the Orlické hory Mts.		–	50°06'N	16°18'E	–
92 Michalová – Slovak Republic (*Picea abies* (Linnaeus) H. Karsten)	38B – Veporské vrchy Hills, north		–	48°48'N	19°48'E	–
94 British Columbia (*Pseudotsuga menziesii* (Mirbel) Franco)	–	–	–	–	–	–

*according to Fletcher (1986)

Table 2. Results of the Kruskal-Wallis post hoc test for heights – NCSS (Version 07.1.18, 2007)

Group	Count	Different from groups
12019	64	12005, 12014, 12026, 12040, 12041, 12043, 12044, 12046, 93
93	78	12005, 12019, 12040, 12041, 12043, 12044, 12046
12026	87	12005, 12019, 12040, 12041, 12044, 12046
12014	86	12005, 12019, 12040, 12041, 12044, 12046
12043	82	12005, 12019, 12040, 93
12044	72	12014, 12019, 12026, 12040, 93
12046	79	12014, 12019, 12026, 12040, 93
12041	74	12014, 12019, 12026, 12040, 93
12005	90	12014, 12019, 12026, 12040, 12043, 93
12040	75	12005, 12014, 12019, 12026, 12041, 12043, 12044, 12046, 93

12019 – Roaring River, 93 – Washington, 12026 – Plummer Hill, 12014 – Beaver Creek, 12043 – Sproat Lake, 12044 – Kay Road, 12046 – Mount Prevost, 12041 – Oyster Bay, 12005 – Bear Mountain, 12040 – Salmon River

fir seedlings were containerized in 4 l bags. The seedlings of reference tree species were bare-rooted. 162 seedlings of each provenance were planted, i.e. 2,106 in total. By 2003, only dead and uprooted trees were removed. The first cultural practice was done in 2003. It was a negative thinning to help trees develop healthy, full-size crowns. The second thinning, aimed to enhance the stand stability, improve slenderness ratio and balanced tree distribution, was realised in 2014 after profound measurements of the plot (in total 43.46 m^3 were felled, 26.99 m^3 of which was grand fir, 9.43 m^3 Douglas-fir and 7.04 m^3 Norway spruce).

The measurements were done in autumn 2013 at the age of 36 years. Heights and stem DBH of all trees were measured and their health condition was visually assessed and marked: 1 = excellent, 2 = good (lower quality, no apparent damage), 3 = declining or damaged (substantial decrease of vitality). Based on volume equations for silver fir and Norway spruce (Petráš, Pajtík 1991) and Douglas-fir (Bergel 1973), the volume of large wood over bark was calculated. The volume equation for grand fir was used to calculate the stem volume (Nagel 1988 ex Rau et al. 2008) as well as the volume tables (Christie, Lewis 1961) for the stem volume of grand fir designed for Great Britain (England, Scotland, and Wales). The calculation of growing stock per ha was based on the number of growing trees. An analysis of specimens convinced Fulín (2016) to suggest the equation of Nagel (1988) ex Rau et al. (2008) as the most convenient for calculating the stem volume of grand fir in domestic conditions; growing stock per ha was therefore calculated on that basis. To allow for a further comparison of the results with other studies, we consider it important to present stem volume values calculated differently by other authors.

Medians were calculated for heights, DBH and (stem, large wood) volumes of provenances. Due to the data abnormality, statistical significance of differences between provenances was assessed in all cases by the Kruskal-Wallis one-way ANOVA. Arranging provenances into homogeneous subgroups was based on the Kruskal-Wallis post hoc test (Tables 2 and 3). Statistical calculations were done by the NCSS program (Version 07.1.18, 2007).

In order to compare the climatic conditions of the provenance origin with the climatic conditions in the Czech Republic, we constructed simplified Walter-Lieth climate diagrams based on the weather stations closest to the provenance sources using available data on long-term monthly average temperatures and rainfall (www.climatemps.com). Monthly thermopluviograms were also constructed for a more detailed assessment of the differences in climate conditions (Kožnarová et al. 1997).

RESULTS

In total, 787 grand firs were measured. The median of the height of all trees on the plot reached 22.8 m. The smallest tree was 5.4 m tall, the tallest 31.2 m. The highest value of mean tree height (Fig. 2) was reached by provenance 12040 Salmon River from Vancouver Island (25.3 m), followed

Table 3. Results of the Kruskal-Wallis post hoc test for DBH – NCSS (Version 07.1.18, 2007)

Group	Count	Different from groups
12019	64	12005, 12014, 12040, 12041, 12046
12026	87	12005, 12040, 12041
12043	82	12005, 12040
93	78	12005, 12041
12014	86	12019
12044	72	12019
12046	79	12019
12041	74	12019, 12026
12005	90	12019, 12026, 12043, 93
12040	75	12019, 12026, 12043, 93

12019 – Roaring River, 12026 – Plummer Hill, 12043 – Sproat Lake, 93 – Washington, 12014 – Beaver Creek, 12044 – Kay Road, 12046 – Mount Prevost, 12041 – Oyster Bay, 12005 – Bear Mountain, 12040 – Salmon River

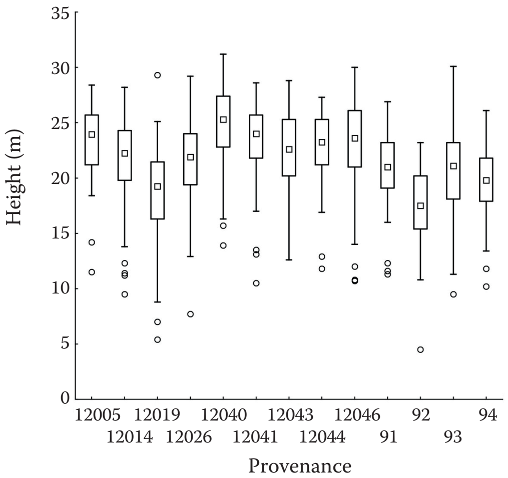

Fig. 2. Box-plot for heights of provenances

12005 – Bear Mountain, 12014 – Beaver Creek, 12019 – Roaring River, 12026 – Plummer Hill, 12040 – Salmon River, 12041 – Oyster Bay, 12043 – Sproat Lake, 12044 – Kay Road, 12046 – Mount Prevost, 91 – Potštejn (Czech Republic), 92 – Michalová (Slovak Republic), 93 – Washington, 94 – British Columbia

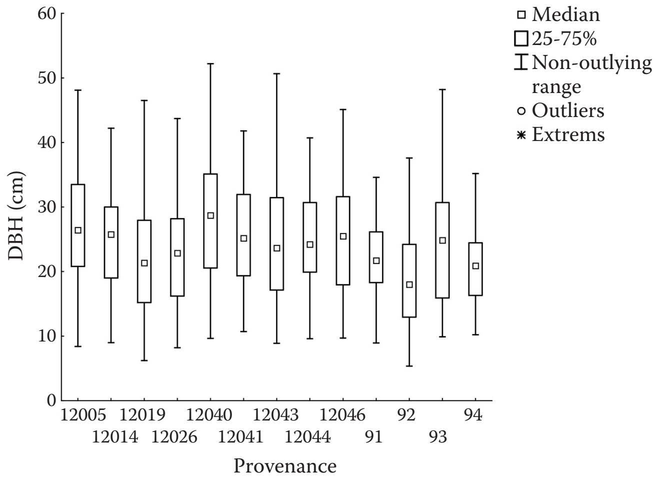

Fig. 3. Box-plot for DBH of provenances (for details see Fig. 2)

by provenances 12005 Bear Mountain, 12041 Oyster Bay (24.0 m both), 12046 Mount Prevost (23.6 m), and 12044 Kay Road (23.3 m). The mean tree height of Washington-originated grand fir grown from commercial seed was only 21.1 m. The height growth of the Oregon Cascades and Idaho-Montana provenances was slower. Provenance 12019 Roaring River had the smallest mean height (19.3 m).

The median of the stem DBH of all trees was 24.9 cm (Table 4). DBH of the thinnest tree was 6.2 cm, and the thickest 52.2 cm. A comparison of ten grand fir provenances showed the best DBH (28.7 cm on average) in provenance 12040 from Salmon River (Fig. 3), followed by provenance 12005 Bear Mountain (26.4 cm) and 12046 Mount Prevost (25.5 cm). The smallest DBH median (21.4 cm) was recorded in provenance 12019 Roaring River from the Oregon Cascades.

The stem volume median (Nagel 1988 ex Rau et al. 2008) was 0.483 m^3 (Table 4), while the volumes of individual trees ranged from 0.009 to 2.592 m^3. The provenance with the greatest stem volume (0.698 m^3) was provenance 12040 Salmon River (Fig. 4), followed by 12005 Bear Mountain (0.584 m^3) and 12046 Mount Prevost (0.552 m^3). Provenance 12019 Roaring River from the Oregon Cascades had the smallest stem volume at only 0.383 m^3.

The mean growing stock of grand fir (including the commercial provenance) reached 600 $m^3 \cdot ha^{-1}$ (Table 4). Provenance 12005 Bear Mountain from the Washington coast had the highest growing stock (811 $m^3 \cdot ha^{-1}$), followed by 12040 Salmon River (807 $m^3 \cdot ha^{-1}$) and 12046 Mount Prevost (673 $m^3 \cdot ha^{-1}$) from Vancouver. The lowest growing stock production (316 $m^3 \cdot ha^{-1}$) was found in provenance 12019 Roaring River from the Oregon Cascades. The commercial grand fir provenance from Washington showed a growing stock level of 530 $m^3 \cdot ha^{-1}$. A comparison with other species planted on the plot shows that the growing stock of Douglas-fir is 463 $m^3 \cdot ha^{-1}$, Norway spruce 429 $m^3 \cdot ha^{-1}$ and silver fir 286 $m^3 \cdot ha^{-1}$.

In accordance with the tree sociological position system (Kraft 1884), most provenances were classified as dominant (class 2), except for provenance 12019 classified as codominant (class 3). The health of all provenances at the age of 36 years was considered excellent.

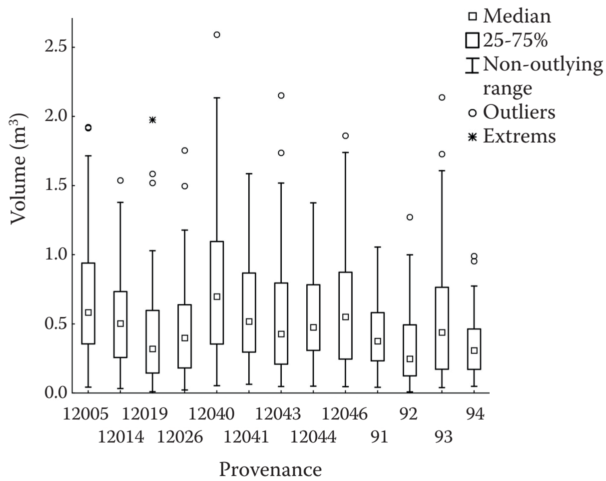

Fig. 4. Box-plot for the stem volume (Nagel 1988 ex Rau et al. 2008) of *Abies grandis* (Douglas ex D. Don) Lindley provenances and large wood volume (Bergel 1973; Petráš, Pajtík 1991) of *Picea abies* (Linnaeus) H. Karsten (No. 91), *Abies alba* Miller (No. 92) and *Pseudotsuga menziesii* (Mirbel) Franco (No. 94) provenances (for details see Fig. 2)

Table 4. Results of investigated provenances

Provenance	No. of growing individuals	Height (m)		DBH (cm)			Volume (m^3)				Growing stock ($m^3 \cdot ha^{-1}$)	Health condition	Tree class (Kraft 1884)
		1989[1]	2013	1994[2]	2006[3]	2013	large wood over bark[4]	stem wood[5]	large wood[6]	stem[7]			
Vancouver													
12040 Salmon River	75	3.7	25.3	12.4	21.3	28.7	0.847	0.698	0.700	0.769	807	1	2
12041 Oyster Bay	74	2.5	24.0	10.8	18.9	25.2	0.633	0.518	0.520	0.562	592	1	2
12043 Sproat Lake	82	2.5	22.6	10.5	18.2	23.7	0.525	0.427	0.429	0.468	540	1	2
12044 Kay Road	72	2.6	23.3	11.1	18.7	24.2	0.584	0.475	0.480	0.503	528	1	2
12046 Mount Prevost	79	2.7	23.6	10.6	18.8	25.5	0.671	0.552	0.553	0.566	673	1	2
Washington – coast													
12005 Bear Mountain	90	3.7	24.0	13.7	21.9	26.4	0.714	0.584	0.589	0.617	811	1	2
Oregon – Cascades													
12014 Beaver Creek	86	3.3	22.3	12.9	19.3	25.8	0.614	0.503	0.504	0.548	668	1	2
12019 Roaring River	64	2.1	19.3	10.3	18.0	21.4	0.383	0.320	0.311	0.326	316	1	3
Idaho, Montana													
12026 Plummer Hill	87	3.6	21.9	11.0	17.6	22.9	0.481	0.399	0.392	0.424	536	1	2
Trade seed (grand fir)													
93 Washington	78	–	21.1	–	18.6	24.9	0.523	0.440	0.428	0.483	530	1	2
Trade seed (other species)													
91* Potštejn (Czech Republic)	74	–	21.0	–	17.1	21.7	0.376	–	–	–	429	–	2
92** Michalová (Slovak Republic)	75	–	17.5	–	11.9	18.0	0.247	–	–	–	286	–	3
94*** British Columbia	95	–	19.8	–	17.6	20.9	0.381	0.317	0.309	0.319	463	–	2
Median (arithmetic mean)	(79.3)	(3.0)	22.8	(11.5)	(18.2)	24.9	0.583	0.483	0.478	0.527	600	1	2

*Norway spruce, **silver fir, ***Douglas-fir, [1]Vančura (1990), [2]Vančura and Beran (1996), [3]Beran (2006), [4]for *Abies alba* Miller (No. 92) and *Picea abies* (Linnaeus) H. Karsten (No. 91), according to Petráš and Pajtík (1991), [5]for *Abies grandis* (Douglas ex D. Don) Lindley, according to Nagel (1988) ex Rau et al. (2008), [6]for *Pseudotsuga menziesii* (Mirbel) Franco, according to Bergel (1973), [7]according to Christie and Lewis (1961)

In all, provenances 12040 Salmon River from Vancouver Island and 12005 Bear Mountain from Washington showed the greatest productivity. Provenance 12019 Roaring River from the Oregon Cascades had the least favourable features in Hrubá Skála. Vancouver grand fir provenances as well as 12005 Bear Mountain from the Washington coast reached above-average growth but trees from the commercial seed of unknown locality in Washington grew more slowly. The slowest growth was documented in provenances from the Oregon Cascades and Idaho-Montana. In volume, Norway spruce exceeded only the worst provenance of grand fir. The same applies to Douglas-fir.

DISCUSSION

Douglas-fir did not surpass the production of grand fir, although there was a higher number of Douglas-fir individuals. The higher number of Douglas-firs is probably due to excessive slenderness ratio, as this species is known by poor self-reduction ability. Silver fir had the lowest volume, despite being in fairly rich and wet microsite conditions. Poor results might be caused not only by provenance but also by the shade of surrounding trees, faster-growing tree species. A comparison of grand fir provenances showed similar results in provenance tests in Germany (König 1995; Kleinschmit et al. 1996; Rau et al. 2008), where provenance Bear Mountain from the Washington coast and Salmon River from Vancouver and other provenances from the same regions were the most productive.

On 5 research plots in Austria, Liesebach et al. (2008) also confirmed the predominance of grand fir on acidic soils over silver fir and Norway spruce, and productivity comparable with Douglas-fir. Most of the 19 evaluated provenances of grand fir came from the Cascades, which the authors considered more resistant to drought and late frosts. It was proved especially among provenances of the Cascades above 1,300 m a.s.l. and one provenance from Idaho, while the other Cascadian provenances were identified as fairly resistant only. As for early frost hardiness, two provenances from the western slopes of the Cascades showed an intermediate resistance (Larsen 1978). Identical provenances grew differently on different plots and only a handful excelled in all localities. Due to the young age of the material the authors considered the results still preliminary. Nonetheless, they pointed out the issue of susceptibility to honey fungus, plaguing some of the plots (Liesebach et al. 2008).

Measurements of grand fir (age 20–45 years) on 23 research plots in Germany (altitude from 53 to 150 m a.s.l., 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 36 years) in Hrubá Skála are similar to the values of the top height (24 m) in the 1st site quality or top height (22 m) in the 2nd site quality reached in Germany. However, mean heights of provenances in Hrubá Skála have not been calculated only from the tallest trees, but from all trees.

There are results of past measurements available for the research plot of Hrubá Skála (Vančura 1990; Vančura, Beran 1996; Beran 2006), therefore it is possible to compare the development of provenances in time (Figs 5a, b). Both mean heights and mean DBH indicate roughly similar growth tendencies since the young stages of growth. Past evaluations of grand fir growth in the Czech Republic showed that provenances from the western

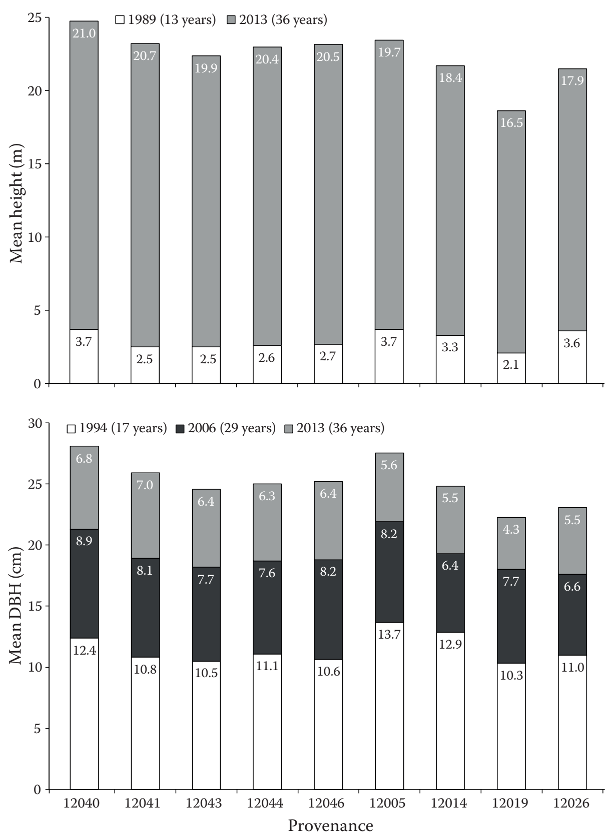

Fig. 5. Mean tree height, including data published by Vančura (1990) (a), mean DBH, including data published by Vančura and Beran (1996) and Beran (2006) (b) of provenances during their evaluation

12040 – Salmon River, 12041 – Oyster Bay, 12043 – Sproat Lake, 12044 – Kay Road, 12046 – Mount Prevost, 12005 – Bear Mountain, 12014 – Beaver Creek, 12019 – Roaring River, 12026 – Plummer Hill coast of British Columbia, Canada, and Washington, USA, always excelled on research plots – a detailed study see Krejzek et al. (2015).

Relatively newer results are available from the research plot in Strnady (central Bohemia) evaluated at the age of 28 years (Škorpík et al. 2013) and from the Habr research plot (western Bohemia) evaluated at the age of 31 years from planting (Krejzek et al. 2015). In Strnady (Škorpík et al. 2013), provenances from Vancouver Island and the Washington coast showed the best results, while provenances from the Oregon Cascades the worst ones, which corresponds with studies of other authors. The best growth was confirmed in provenances from western and northern areas (positive correlation between the latitude and height growth). In Habr (Krejzek et al. 2015), where 24 provenances from 5 regions have been tested, provenance 12040 Salmon River was evaluated as a superior performer in view of all considered parameters. The mean tree height was 18.3 m and the mean DBH 20.5 cm. The large wood volume was 0.33 m^3. Provenance 12040 Salmon River was followed by provenance 12002 Tulalip from the coastal Washington with the mean height of 17.9 m, DBH of 19.3 cm and volume of 0.28 m^3. In Hrubá Skála, seven identical provenances were tested (five from Vancouver, one from the Oregon Cascades and one from Idaho). When considering the provenances by a wider area, according to Fletcher (1986), their evaluation does not differ from other studies.

The production can also be compared with a published evaluation of grand fir in central Bohemia (Fulín et al. 2013); at the age of 35 years grand fir reached the growing stock volume of 725 $m^3 \cdot ha^{-1}$ (3S = *Querceto-Fagetum mesotrophicum*, 320 m a.s.l., an untended forest stand), or 563 $m^3 \cdot ha^{-1}$ (4P = *Querceto-Abieum variohumidum acidophilum*, 430 m a.s.l., a moderately thinned forest stand). Another stand (3O = *Abieti-Querceto-Fagetum variohumidum mesotrophicum*, 420 m a.s.l., a tended monoculture) had the growing stock volume of 689 $m^3 \cdot ha^{-1}$ at the age of 45 years. According to the studies, young grand fir shows a greater difference in growing stock compared to Norway spruce and silver fir than at an older age, given its more intensive growth and earlier culmination of growth increment in pure stands. Later, the growth increment dynamics slows down in comparison with other tree species. When compared with Douglas-fir, production of grand fir is similar or higher (by as much as 15%). A comparison with tabular values from the Yield Tables for the Czech Republic (Černý et al. 1996) shows that the growing stock of grand fir at 35 years is 57% higher than that of Norway spruce and 46% higher than that of silver fir. At the age of 45, the difference was only 39% against Norway spruce and 24% against silver fir. A similar comparison of the mean growing stock volume of grand fir in Hrubá Skála with Norway spruce and silver fir (age 35) confirms a volume of the introduced species 66% higher vs. Norway spruce, and 55% higher compared to silver fir.

According to Beran (2006), the provenances from Vancouver should not be grown in frost hollows and on sites above 500 m a.s.l. as their bud burst starts earlier and they are more vulnerable to winter frosts. The growth of inland Idaho and Montana provenances is indifferent, but they are less vulnerable to drought and frost. Provenances 12038 Clearwater and 12026 Plummer Hill from the above-mentioned areas are unsuitable on gleyed and waterlogged sites in the Czech Republic. Provenances from the Oregon Cascades also seem to be unsuitable in the Czech Republic; Kleinschmit et al. (1996) and others pointed out their high mortality rate. Descendants of southern Oregon provenances were reported by König (1995) to show not only a high mortality rate but also a significant number of forked individuals. All findings of the growth of grand fir provenances on research plots were considered in a new proposal for selecting source regions within the North-American range – a convenient area for the Czech Republic to import reproduction material from (Beran et al. 2016). The existing list of regions in Washington has therefore been extended to comprise provenance import from southern parts of Vancouver Island, British Columbia. Provenances from the seed region of northern Idaho are also considered to be tested in the Czech Republic for their hoped-for tolerance of drought – a phenomenon that has to be anticipated in Europe as a significant limiting factor.

Attention must therefore be paid to the climatic characteristics of the sites of provenance origin and, at the same time, to the climate of potential planting sites in the Czech Republic. Based on the analysis of climatograms of the regions of provenance origin (Table 5, Fig. 6) it can be concluded that the climatic conditions of the Czech Republic are analogous to those of the source sites of provenances 12005 Bear Mountain, 12014 Beaver Creek and 12026 Plummer Hill. Provenance 12005 Bear Mountain was evaluated as the second best in growth in this study. However, the remaining two grand fir provenances exceed domestic tree species in growth. The thermopluviograms (Fig. 7) also suggest that the climate of the Czech Republic is

Table 5. Source data from the respective weather stations (www.climatemps.com)

State	Provenance	Nearest weather station (altitude m a.s.l.)	Average value	Month												Annual average/Σ
				I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
British Columbia (BC), Vancouver	12040 Salmon River	Chatham Point, BC (23)	Temperature (°C)	2.8	4.2	5.7	8.1	11.3	13.9	15.7	15.8	13.0	9.1	5,4	3.3	9.0
			Precipitation (mm)	259.0	213.5	192.3	126.7	115.3	110.1	85.2	97.3	117.9	272.3	299.3	296.4	2,185.3
	12041 Oyster Bay	Campbell River, BC (106)	Temperature (°C)	0.9	2.7	4.5	7.2	10.8	14.2	16.7	16.7	13.0	8.1	4.1	1.5	8.4
			Precipitation (mm)	185.7	144.5	136.6	74.5	58.7	49.3	39.5	42.9	61.6	155.4	226.7	233.5	1,408.9
	12043 Sproat Lake	Port Alberni, BC (76)	Temperature (°C)	2.0	3.5	5.7	8.2	11.4	14.5	17.2	17.8	14.5	9.8	5.1	2.4	9.3
			Precipitation (mm)	256.7	253.3	207.2	107.3	75.1	47.3	28.8	32.0	71.5	199.3	307.7	299.7	1,885.9
	12044 Kay Road	Nanaimo, BC (19)	Temperature (°C)	2.3	4.1	5.7	8.4	11.8	15.1	17.5	17.6	14.4	9.6	5.2	2.8	9.5
			Precipitation (mm)	163.7	127.9	116.1	59.8	46.9	39.4	24.3	30.0	44.0	101.5	189.5	201.4	1,144.5
	12046 Mount Prevost	Gladman Point, BC (60)	Temperature (°C)	–34.2	–34.9	–31.4	–22.0	–9.8	1.0	7.2	5.2	–0.9	–11.2	–23.6	–29.8	–15.4
			Precipitation (mm)	1.7	2.3	2.5	5.5	9.4	10.0	23.5	25.9	18.9	13.2	5.0	2.3	120.2
Washington (WA), coast	12005 Bear Mountain	Port Angeles, WA (27)	Temperature (°C)	4.2	5.4	6.7	8.6	11.2	13.7	15.4	15.7	14.0	10.2	6.6	4.5	9.7
			Precipitation (mm)	102.4	65.0	51.1	34.0	25.1	19.8	13.5	20.1	31.5	58.9	102.6	110.5	634.5
Oregon (OR), Cascades	12014 Beaver Creek	Moro, OR (570)	Temperature (°C)	–0.7	2.2	5.2	8.0	11.9	16.2	19.8	19.6	15.1	9.6	3.8	–0.2	9.2
			Precipitation (mm)	37.8	24.9	26.4	19.8	19.6	15.7	7.1	11.9	13.7	19.0	42.2	44.2	282.3
	12019 Roaring River	Eugene, OR (114)	Temperature (°C)	4.9	6.8	8.6	10.3	13.2	16.7	19.6	19.8	17.1	12.3	7.8	5.1	11.8
			Precipitation (mm)	200.9	143.3	140.2	79.0	54.9	36.3	13.0	27.4	42.4	86.6	211.3	218.7	1,254.0
Idaho	12026 Plummer Hill	Spokane, WA (721)	Temperature (°C)	–2.7	0.7	3.7	7.7	12.2	16.7	20.4	20.2	14.9	8.5	1.7	–2.3	8.5
			Precipitation (mm)	50.3	37.8	37.8	30.0	35.8	32.0	17.0	18.3	18.5	25.1	54.6	61.5	418.7
Czech Republic (CZ), Hrubá Skála	Plot No. 214	Praha-Ruzyně, CZ (365)	Temperature (°C)	–2.0	–0.6	3.1	7.6	12.5	15.6	17.1	16.6	13.2	8.3	3.0	–0.2	7.8
			Precipitation (mm)	23.6	22.6	28.1	38.2	77.2	72.7	66.2	69.6	40.4	30.5	31.9	25.3	526.3

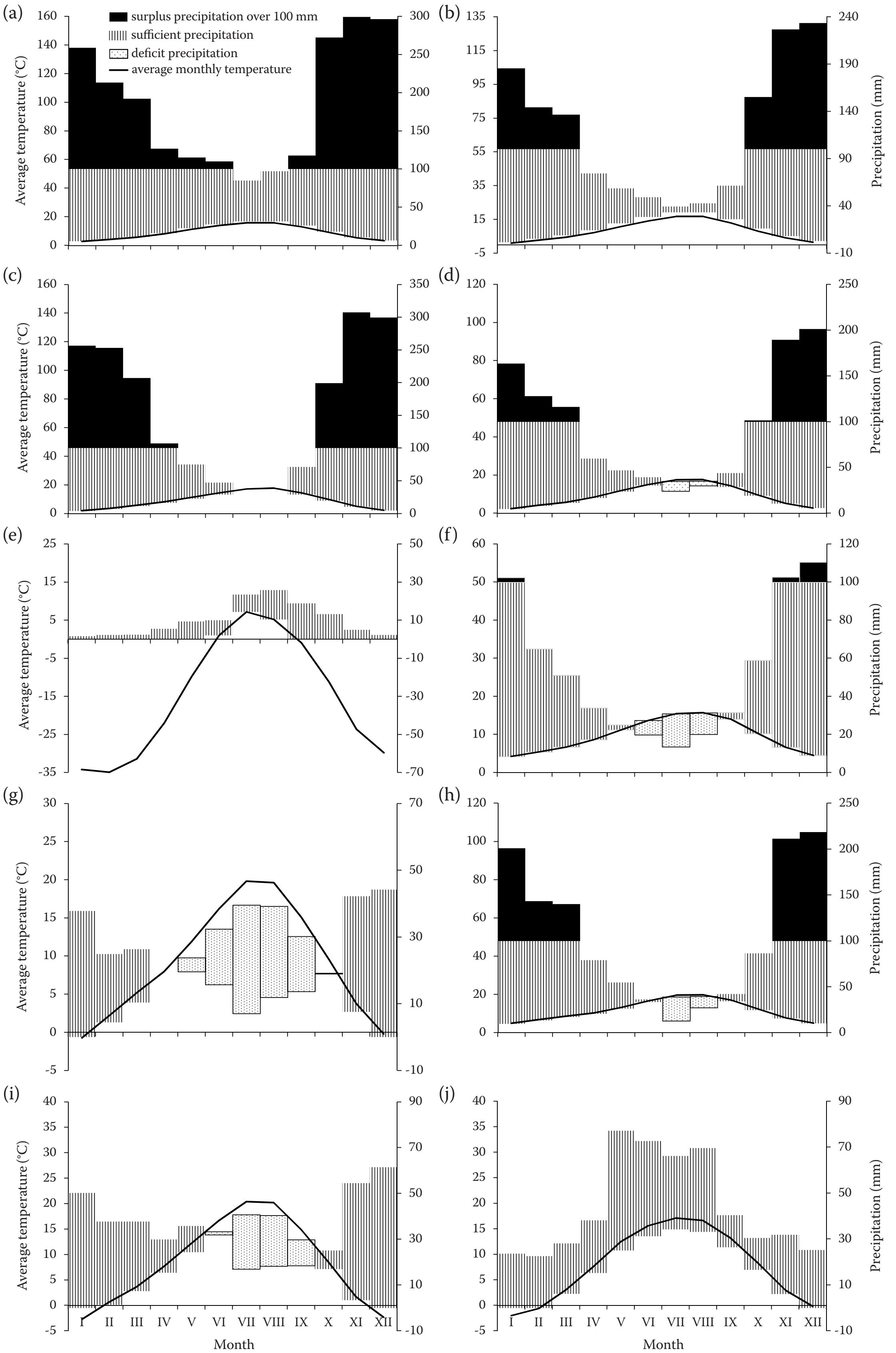

Fig. 6. Climatograms obtained from weather stations closest to the sites of the provenances with the available data: 12040 – Chatham Point, British Columbia (BC), 23 m a.s.l. (a), 12041 – Campbell River, BC, 106 m a.s.l. (b), 12043 – Port Alberni, BC, 76 m a.s.l. (c), 12044 – Nanaimo, BC, 19 m a.s.l. (d), 12046 – Gladman Point, BC, 60 m a.s.l. (e), 12005 – Port Angeles, Washington (WA), 27 m a.s.l. (f), 12014 – Moro, Oregon (OR), 570 m a.s.l. (g), 12019 – Eugene, OR, 114 m a.s.l. (h), 12026 – Spokane, WA, 721 m a.s.l. (i), Prague-Ruzyně, Czech Republic, 365 m a.s.l. (j)

similar to the climate of the source sites of provenances 12005 and 12014. With regard to long-term average temperatures in the Czech Republic, the most distinct provenances are 12046 Mount Prevost (the third most productive provenance in the experiment), 12026 Plummer Hill and 12019 Roaring River (the worst-growing provenance in the experiment). In comparison with the Czech

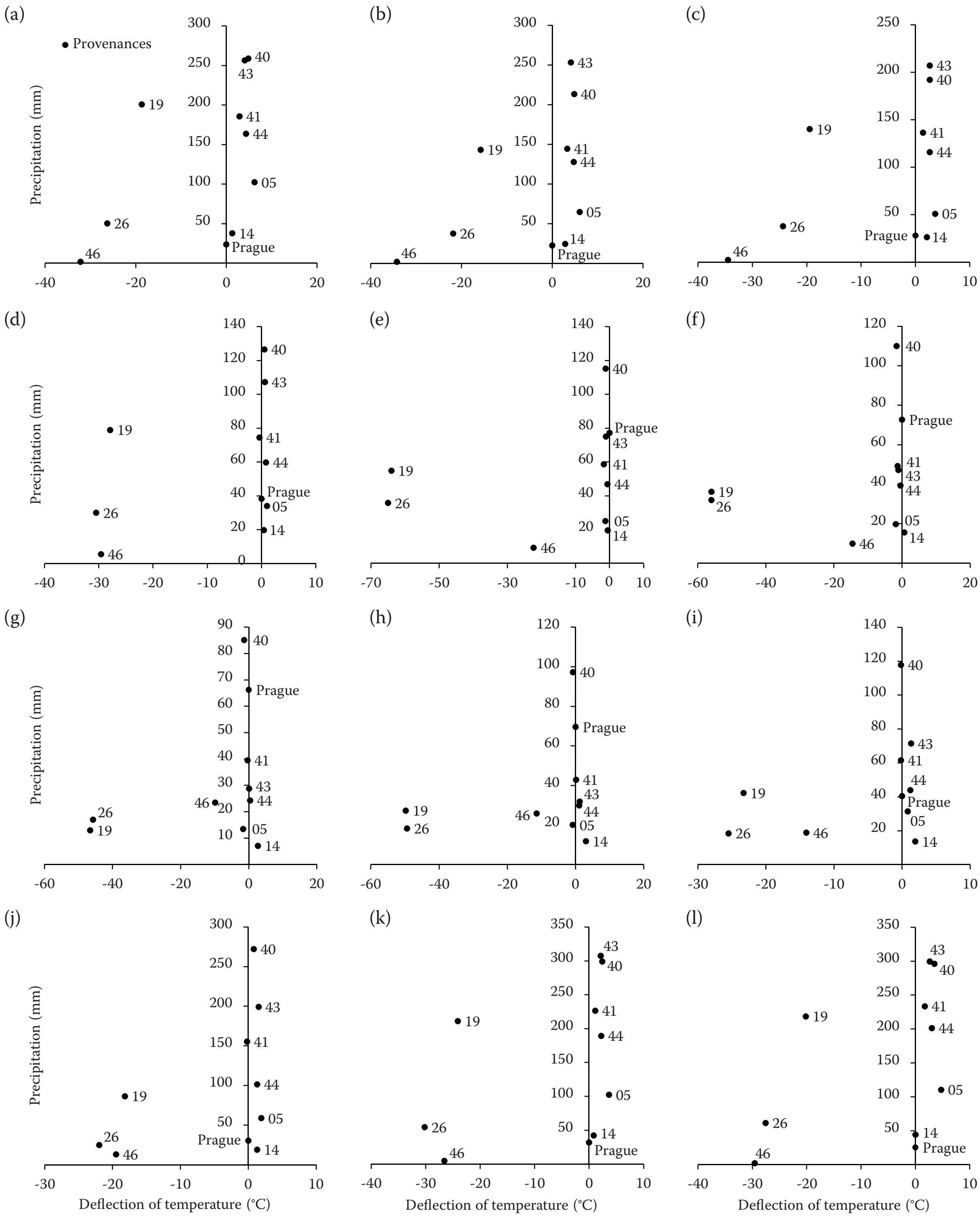

Fig. 7. Thermopluviograms according to Kožnarová et al. (1997): January (a), February (b), March (c), April (d), May (e), June (f), July (g), August (h), September (i), October (j), November (k), December (l)

05 – Bear Mountain, 14 – Beaver Creek, 19 – Roaring River, 26 – Plummer Hill, 40 – Salmon River, 41 – Oyster Bay, 43 – Sproat Lake, 44 – Kay Road, 46 – Mount Prevost

Republic, the climate of some provenance regions differs by much higher rainfall (most 12040 Salmon River and 12043 Sproat Lake). When considering the volume of production and at the same time the similarity of climate conditions, it is desirable for the Czech Republic to pay more attention to the areas of Washington coast and Oregon Cascades (western slopes) that meet both conditions. However, it is necessary to examine individual characteristics of the growth of different provenances (e.g. provenance 12019 Roaring River does not meet the growth requirements in the experiment). As for the Idaho area, which also has a similar climate, the tested provenance growth is unsatisfactory.

CONCLUSIONS

Results of the evaluation of grand fir research plots in Hrubá Skála suggest – in accordance with similar experiments carried out in the Czech Republic and abroad – that provenances of the species from Vancouver Island, British Columbia, and the coast of Washington show the highest productivity, while provenances from the Oregon Cascades, Idaho and Montana grow more slowly. This leads us to consider which provenances will be used in the Czech forestry to enhance forest production. From the perspective of the ongoing climate change it is, however, necessary to pay attention also to the climatic characteristics of the source regions of provenances.

When compared with other tree species, productivity of grand fir at the age of 36 exceeds both Norway spruce and silver fir, and was almost the same or even slightly higher than that of Douglas-fir.

The plot will be monitored to 50 years of age at least. Unfortunately, we cannot prevent a possible worsening of the health status of the stands in the Czech Republic where grand fir is declining and even dying out have already been observed. Its roots are often afflicted by the honey fungus and the trees are consequently colonized by bark insects. Presently, massive attacks of bark beetle (*Pityokteines* Fuchs, 1911) and balsam woolly aphid (*Dreyfusia* Börner, 1908) are reported from the Bolehošť locality (eastern Bohemia), preceded by the honey fungus. The damage is apparently related to the extreme drought in summer 2015. Therefore it depends not only on the provenance, but also on the choice of a site for grand fir planting. Moist and rich soils are not suitable for its cultivation due to the high threat of biotic pests, while acidic soils are much better.

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