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Evaluation of silver fir provenances at 51 years of age in provenance trials in the Předhoří Hrubý Jeseník and Nízký Jeseník Mts. regions, Czech Republic

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Abstract: In 2021, measurements were done at two international provenance research trials for silver fir originating from the same series of experiments. The investigation was carried out in the location Vítkov and Úsov, where both trials were established. Biometric data (tree height, diameter at breast height) were measured and qualitative traits (stem shape, occurrence of stem forking, stem damage, bark pattern, and defoliation) were assessed during the early mature stage of the experiment. Overbark stem volume and per-hectare standing volume were also calculated. Sixty-five provenances of domestic and foreign origin were evaluated in both trials. Although the results do not indicate unequivocally the most suitable or most productive provenance in the trials, provenances of Czech origin including the ones originating from the surrounding natural forest areas perform consistently better than the average. The least productive provenances, on the other hand, were those from parts of Bulgaria, Austria, and especially Italy, which achieved the poorest results even in stem shape. In Czech conditions, therefore, Italian fir provenances have not proved so successful as they have in the United Kingdom.

Keywords: *Abies alba*; provenance plot; production; phenotypic characteristics; variability

Silver fir (*Abies alba* Mill.) is one of the basic tree species of Central Europe, extending from the Pyrenees to the Balkan Peninsula (Farjon 2010; Praciak et al. 2013). In terms of the elevation distribution, fir is the most widespread in forest altitudinal zones 2–6, which roughly cover the altitudinal range of 290–850 m a.s.l. (Málek 1983). It is the fourth most abundant coniferous tree species in the Czech Republic, with representation of 1.2% (Ministry of Agriculture 2021). Moreover, (Podrázský et al. 2018) an advantage of its cultivation is its good effect on soil improvement. In the past, at the time

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when significant anthropogenic influences started to occur, its representation even reached an average of 19.8% (Ministry of Agriculture 2015). The greatest expansion of fir in Europe was recorded during the 14th–16th centuries, when it gradually came to occupy the area at the expense of beech. However, in the last century, repeated dieback of silver fir in its northern natural range has been recorded, which has reduced its abundance (Málek 1983). Having such a large natural range, the area of which is also discontinuous in nature (Musil, Hamerník 2007), different provenances developed over the long term while adapting to local environmental conditions. Genetic characterization of silver fir in the Czech lands was carried out by Cvrčková et al. (2015) and Fulín et al. (2016), of foreign authors for example Longauer (2001), Paule et al. (2001) and Loungauer et al. (2003) dealt with this topic. Silver fir variability allows it to respond to changing conditions and naturally persist in woodlands, as shown by its fluctuation in the past. Morphological variability of silver fir was assessed in several publications, e.g. by Dobrowolska (2008) and Skrzyszewska and Chłanda (2009). Moreover, in the Balkans, hybridization between silver fir and Greek fir (*Abies cephalonica* Loudon) occurred in the contact zone of their natural ranges, resulting in hybridogenous Macedonian fir (*Abies* × *borisii regis* Mattf.) (Novotný et al. 2022). The genus *Abies* is therefore often used in breeding programmes dealing with interspecies hybridization. Hybridization trials have been conducted for a long time, for example by Kormuťák (1985), Greguss (1988), Kobliha and Pokorný (1990), and Kobliha et al. (2013). Provenance trials are also carried out to investigate adaptability and use in forestry while focusing on both native and introduced tree species. From the evaluated research areas, current real data are obtained that are informative for resolving economic, breeding, or legislative situations. Provenance trials specifically on fir trees were conducted in the Czech Republic for example by Šindelář et al. (2008), Kýval et al. (2012), and Čáp et al. (2013), and in neighbouring countries for instance by Paule (1986), Larsen and Mekic (1991), Mihai et al. (2018), and Gunia (2019).

The aim of this paper is to evaluate the growth and morphological characteristics of silver fir provenances at intermediate felling age at two sites in northern Moravia and Silesia and which reflect the variability, resistance, and ecological requirements of the tree species since their establishment. Differences in characteristics between individual provenances will indicate the suitability of silver fir subpopulations planted within a given environment.

MATERIAL AND METHODS

In the 1970s, international cooperation began regarding the exchange of reproductive material for silver fir and foreign firs. The Forestry and Game Management Research Institute obtained seed lots representing 153 provenances, which were also evaluated for seed quality. Twenty provenance trials were planted between 1973 and 1977 from the material grown from these seeds, 14 of these trials were with silver fir only and the remaining 6 trials were mixed with native and non-native firs. Due to the limited amount of seed, a varying number of provenances and repetitions were planted. The repetition was usually done four times, but in some cases only three times. Thus, after the planting and fencing of all trials, the 1973–1977 *Abies* research series was created, from which the trials of silver fir provenances at Šternberk, Úsov-Velebor No. 70 and Vítkov, Kerhartice No. 71 were measured in 2021 (Figure 1). Both trials were established in the same way using the double grid method with plot size set at 10 m × 10 m. The seedlings were planted at 2 m × 1 m spacing with 50 trees in each plot. A total 6 050 seedlings were planted at research site 70, which consists of 121 plots of 25 provenances with 4 repetitions and 7 provenances with 3 repetitions, for a total of 32 provenances (Table 1). The trial size is 1.3 ha, exposure is southeastern, slope is 10–20%, and altitude is 400–420 m. The habitat conditions are based on the subsoil of Quaternary loam and stone sediment and soil type Dystric Cambisol. The forest type at the site is designated 3K3 – acidic oak-beech woodland with Luzula cover (Viewegh et al. 2003). Annual rainfall total is 551–600 mm and mean annual temperature is in the range of 8.1–10 °C. At research site 71, the total number of fir trees planted was 9 600, corresponding to 192 plots with 48 silver fir provenances (Table 1) with 4 repetitions. The trial is 1.92 ha in size with southern exposure, slope of 12–33%, and altitude of 400–450 m. The habitat conditions are based upon culm greywacke with shale and the soil type is predominantly Mesobasic Cambisol with Gley and Ranker. The forest type on the site is designated 3S1 – lush oak-beech woodland with Oxalis. Annual rainfall total

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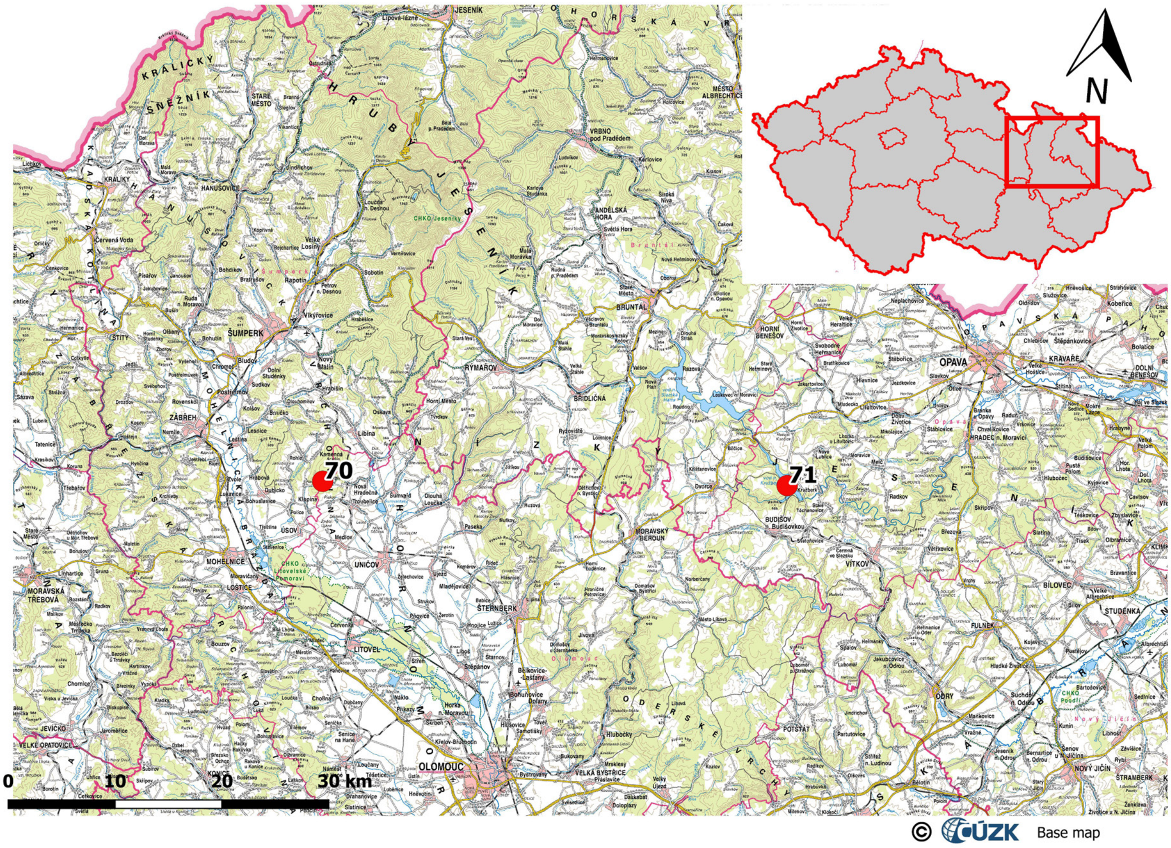

Figure 1. Display of research trials No. 70 (Úsov) and No. 71 (Vítkov) in the Czech Republic

is 651–700 mm and mean annual temperature is in the range of 7.1–9 °C.

In the provenance trials, biometric data of each tree were measured, namely the diameter at breast height (*DBH*) was read twice perpendicularly using a millimetre calliper (Haglöf, Sweden), and the tree height using a Vertex VL ultrasound hypsometer (Haglöf, Sweden) to the nearest 0.1 m. From these parameters, the overbark volume was calculated according to the volumetric formula for fir (Petráš, Pajtík 1991) and subsequently the per-hectare standing volume of provenances was calculated. Qualitative traits were also evaluated, such as stem shape (1 – completely straight; 2 – unilaterally curved at near-ground level; 3 – unilaterally curved along the entire length; 4 – strongly curved in S-shape; 5 – multiply curved, crooked), the occurrence of stem forking (1 – continuous; 2 – forking in the upper third; 3 – in the second third; 4 – in the lower third; 5 – shrubby, 3 or more stems at near-ground level), damage to the stem (1 – no damage; 2 – damaged only in the upper part; 3 – multiply damaged in the past, good overgrowth; 4 – multiply damaged in the past, poor overgrowth; 5 – damaged in the lower part of the stem (mechanical, fungi), bark pattern (1 – smooth; 2 – scaly; 3 – ridged; 4 – deeply ridged) and defoliation 1–5 (by increments of 20%). Trait indices were calculated for each provenance as medians of tree classification rankings.

Height and *DBH* data sets from the Úsov and Vítkov provenance trials were evaluated using a one-factor analysis of variance (α = 0.05), and Tukey-Kramer multiple comparisons test was performed in NCSS 10 (Version 10.0.6, 2015). The null hypothesis was rejected. Multidimensional principal component analysis (PCA) and cluster analysis (CLU) methods were used to reveal the structure and association between the studied traits. By combining both methods, a biplot was created, which combines the advantages of both analyses and better creates a visual image. For the calculation of PCA and CLU (using Statistica, Version 12, 2013; PAST, version 2.07, Hammer et al. 2001), the data was reduced so that the individual traits of the assessed provenances were represented by their medians.

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Table 1. Description of site characteristics of parent stands of provenances present in our research trials

State	Provenance		Trial		Longitude (E)	Latitude (N)	Altitude (m a.s.l.)	Average annual temperature (°C)	Average year precipitation (mm)	European forest zones*	Natural forest region	Climatype**	Former silvicultural region
	code	name	70 (Úsov)	71 (Vítkov)									
CZ	1–15	Kamenice n. L. – Losy	X	X	15°14'	49°21'	680	5.4	729	3.13.0	16	6	II
	16–30	Jihlava – Popice	X	–	15°31'	49°21'	600	7.5	603	3.13.0	16	6	II
	32	Nýrsko – Dešenice	X	X	13°13'	49°17'	500	7.4	650	3.05.4	12	6	Ib
	35	Petrohrad – Oráčov	–	X	13°28'	50°08'	400	7.2	526	3.05.4	9	6	II
	36	Červené Poříčí – Kaliště	–	X	13°27'	49°32'	500	6.8	583	3.06.0	6	6	II
	43	Vsetín – Hošťálková	–	X	17°57'	49°21'	490–530	7.0	833	6.07.0	41	7	IV
	48	VLS Plumlov – Stínava	–	X	16°58'	49°20'	400	7.5	597	3.14.0	30	7	IV
	49	Přibyslav – Hamry	–	X	15°54'	49°33'	590	6.1	744	3.13.0	16	6	II
	51	VLS Lipník n.Bečvou – Podhoří	X	X	17°25'	49°35'	600	6.0	811	3.05.1	39	7	IV
H	52	Sopron – School Forest District	X	–	16°53'	47°65'	450	9.8	760	6.10.0	–	10	–
CZ	59	Velké Karlovice – Vranča	–	X	18°13'	49°12'	590–680	6.5	1 045	6.07.0	41	7	IV b
	64	Dobříš – Chouzavá	–	X	14°12'	49°50'	420	7.3	605	3.07.0	10	6	II
	68	Vyšší Brod – Běleň	X	X	14°20'	48°38'	680	6.2	810	3.05.4	13	6	I b
	70	Ždírec n. Doubravou – Maleč	X	X	15°42'	49°47'	400	7.3	789	3.13.0	16	6	II
	71	Plumlov – Ruprechtov	X	X	16°58'	49°20'	450–510	7	655	3.14.0	30	7	IV
	74	Milevsko – Klučenice	–	X	14°14'	49°34'	380	7.8	577	3.12.0	10	6	II
	75	Rájec-Jestřebí – Černá Hora	–	X	16°39'	49°18'	350	7.7	612	3.14.0	30	6	IV
	76	Nýrsko – Suchý Kámen	X	–	13°06'	49°16'	620	6.7	751	3.05.4	12	6	I b
	81	Vyšší Brod – Vítkův Kámen	–	X	14°15'	48°37'	800–900	5.4	1063	3.05.4	13	6	I b
	82	Vizovice – Bratřejov	X	X	17°56'	49°13'	550	6.6	946	6.07.0	38	7	IV
	85	Kašperské Hory – Kašperské Hory	–	X	13°34'	49°10'	800	5.5	854	3.05.4	13	6	I b
	86	VLS Hořovice – Strašice	X	–	13°48'	49°44'	650 (530)	6.1	789	3.07.0	7	6	I b
	87	VLS Hořovice – Jince	X	–	13°58'	49°46'	520-540	6.9	556	3.07.0	7	6	I b
	88	VLS Hořovice – Mirošov	X	–	13°42'	49°42'	620	6.3	783	3.07.0	7	6	I b
	90	Prachatice – Včelná	–	X	13°51'	49°01'	750–1 020	5	790	3.05.4	13	6	I b

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Table 1. to be continued

State	Provenance		Trial		Longitude (E)	Latitude (N)	Altitude (m a.s.l.)	Average annual temperature (°C)	Average year precipitation (mm)	European forest zones*	Natural forest region	Climatype**	Former silvicultural region
	code	name	70 (Úsov)	71 (Vítkov)									
	93	Wörschachwald – Steiermark	X	X	14°06'	47°34'	1 100–1 200	5.3	1 600	5.04.3	–	4	–
A	94	Schneegattern – Kobernsusserwald	X	–	13°23'	48°00'	550–750	7	1 200	5.01.3	–	4	–
	95	Gröbming – Steiermark	X	X	13°53'	47°27'	850	6.5	1 350	5.04.3	–	4	–
	96	Thal – Wechselgebiet	X	–	16°11'	47°36'	550	8.5	850	5.03.0	–	4	–
	101	Velké Karlovice – Brodská	–	X	18°11'	49°22'	700–760	5.6	1 212	6.07.0	41	7	IV b
CZ	106	Kácov – Psáře	–	X	14°58'	49°46'	420	7.5	603	3.12.0	16	6	II
	130	Nasavrky – Podhůra	–	X	15°48'	49°51'	370	7.6	711	3.13.0	16	6	II
BG	131	Pirin – Razlog	–	X	23°24'	41°49'	1 600	4.7	1 549	6.26.0	–	10	–
	132	Rila – Borovec	X	X	23°36'	42°14'	1 600	5.1	988	6.26.0	–	10	–
	146	Schwarzwald mit Baar – Schönmünzach	X	–	7°59'	48°35'	530–650	5.8	1 833	3.32.0	–	4	–
D	147	Schwäb.-Fränkischer Wald – Geschwend	X	X	9°45'	48°57'	480–530	7.2	1 000	3.21.0	–	4	–
	148	Schwarzwald mit Baar – Gengenbach	X	X	8°01'	48°24'	465–740	6.0	1 707	3.32.0	–	4	–
	149	Ostbayer - Viechtach	X	X	12°55'	49°05'	700–780	6.5	1 364	3.05.4	–	6	–
	186	Šternberk – Řídeč	–	X	17°17'	49°46'	380–500	6.6	745	3.05.1	29	7	IV
CZ	194	Karlovice – Karlovice sever	–	X	17°25'	50°06'	720	5.5	974	3.05.1	27	7	I b
	198	Vítkov – Budišov n. Budišovkou	–	X	17°38'	49°50'	500–570	6	754	3.05.1	29	7	IV
	199	Krnov – Horní Benešov	–	X	17°35'	49°59'	500–600	6.5	689	3.05.1	28	7	IV
PL	203	Stary Sacz	–	X	20°36'	49°33'	300	7.8	725	6.06.4	–	7	–
	205	Bílovec – Skřípov	–	X	17°54'	49°50'	440	7.0	729	3.05.1	29	7	IV
	207	Nové Město n. M.	–	X	16°04'	49°35'	630	5.9	740	3.13.0	16	6	I b
CZ	209	Nové Město n. M. – Lísek	–	X	16°12'	49°36'	680	5.2	724	3.13.0	16	6	IV
	210	Nové Město n. M. – Cikháj	X	–	15°59'	49°39'	690	5.4	882	3.13.0	16	6	I b
	211	Nové Město n. M. – Vojnův Městec	X	–	15°55'	49°40'	660	5.5	852	3.13.0	16	6	I b

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Table 1. to be continued

State	Provenance		Trial		Longitude (E)	Latitude (N)	Altitude (m a.s.l.)	Average annual temperature (°C)	Average year precipitation (mm)	European forest zones*	Natural forest region	Climatype**	Former silvicultural region
	code	name	70 (Úsov)	71 (Vítkov)									
PL	212	Nieskurzow	X	–	21°12'	50°50'	480	6.6	661	6.05.0	–	7	–
RO	214	Prahova-Mineciu	–	X	25°15'	46°25'	1 200	7.5	800	6.19.0	–	8	–
	217	Neamt –Gircina	X	–	26°10'	46°45	950	8.1	710	6.19.0	–	8	–
BiH	222	Gornja Stupčanica	–	X	18°46	44°07'	1 060	5.7	1 088	6.22.0	–	9	–
	224	Sokolac – Kaljina Bioštica	–	X	18°41	44°05	1 060	7.6	820	6.22.0	–	9	–
	225	Vitez – Kruščica	–	X	17°49'	44°05'	1 200	9.2	844	6.22.0	–	9	–
I	227	Popi e Bibbiena – Arezzo	X	–	11°52'	43°47'	1 000–1 100	8	2 000	9.12.0	–	5	–
	228	Vallombrosa – Reggello, Firenze	–	X	11°37'	43°43'	900–1 120	9.8	1 386	9.12.0	–	5	–
	230	Spadola e Serra San Bruno – Catanzaro	–	X	16°22'	38°32'	1 100	9.6	1 636	9.14.0	–	5	–
PL	231	Baligród	–	X	22°17'	49°20'	550	6.5	945	6.06.1	–	7	–
SK	S1	Banská Bystrica – Badín	X	X	19°02'	48°42'	800	5.2	700	6.07.0	46	7	VII
	S5	Ružomberok – Korytnica	–	X	19°16'	48°54'	750	5.6	925	6.06.4	43	7	VI b
	S6	Čierny Váh – Čierny Váh	X	–	19°56'	49°00'	850	4.8	925	6.06.4	43	7	VI b
	S9	Kriváň – Snohy	X	X	19°33'	48°36'	630	6	925	6.07.0	47A	7	VI b
	S10	Čierny Balog – Krám	X	–	19°36'	48°47'	600	5.7	675	6.07.0	47A	7	VI b
	S13	Bardejov – Zborov – Kružlov	X	–	21°08'	49°18'	580	5.3	750	6.06.1	42C	7	X
	S14	Svidník – Giraltovce – Vyšný Komárnik	–	X	21°42	49° 23'	480	5.8	750	6.06.1	41A	7	X

*according to Rubner et Reinhold (1953); **according to Svoboda (1953); CZ – Czech Republic; H – Hungary; A – Austria; BG – Bulgaria; D – Germany; PL – Poland; RO – Romania; BiH – Bosnia and Herzegovina; I – Italy; SK – Slovakia

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RESULTS

A total of 1 041 trees were evaluated in the Úsov provenance trial (Table 2). The highest numbers of surviving trees in the trial were found in Czech provenances 76 Nýrsko – Suchý Kámen (44 individuals, 22% survivors) and 86 VLS Hořovice – Strašice (42 individuals, 21% survivors). In contrast, Italian provenance 227 Popi e Bibbiena – Arezzo (18 individuals, 9% survivors), Czech provenance 211 Nové Město n. M. – Vojnův Městec (19 individuals, 10% survivors) and Austrian provenance 93 Wörschachwald – Steiermark (16 individuals, 11% survivors) had the lowest values. A total of 1 420 trees were measured in the Vítkov provenance trial (Table 3). With 55 individuals (28% survivors), Czech provenance 75 Rájec-Jestřebí – Černá Hora had the highest number of surviving trees. This was followed by Bulgarian provenance 131 Pirin – Razlog (53 individuals, 27% survivors). Italian provenance 228 Vallombrosa – Reggello, Firenze (5 individuals, 3% survivors) and Polish provenance 231 Baligród (7 individuals, 4% survivors) had the lowest values.

The median height of all trees in the Úsov trial was calculated to be 22.0 m. The best provenance in terms of height was Czech provenance 71 Plumlov – Ruprechtov, with median height of 23.4 m. This was followed by Slovak provenance S10 Čierny Balog – Krám and German provenance 149 Ostbayer – Viechtach, with the same median height of 23.1 m. The lowest median height of 18.6 m was recorded for Bulgarian provenance 132 Rila – Borovec and the second shortest provenance (at 19.7 m) was Czech provenance 82 Vizovice – Bratřejov. In the second trial, Vítkov, an overall median height of 23.0 m was recorded. Within the provenance trial, the highest median height was measured in Czech provenance 194 Karlovice – Karlovice sever with a result of 25.5 m, and the second highest measured height of 24.9 m was in Czech provenance 70 Ždírec n. Doubravou – Maleč and Slovak S5 Ružomberok – Korytnica provenances. In contrast, the lowest height values were recorded for foreign provenances, namely from Austria 93 Wörschachwald – Steiermark (18.4 m) and from Italy 230 Spadola e Serra San Bruno – Catanzaro (18.9 m).

The second data set was for *DBH*. The median *DBH* value of all trees in the trial was found to be smaller in the Úsov provenance trial, at 22.9 cm, than in the Vítkov trial, at 25.7 cm. In the Úsov trial, the largest diameters by provenance were recorded for Czech provenance 16–30 Jihlava – Popice, with median value of 25.5 cm, followed by provenance 87 VLS Hořovice – Jince, with median *DBH* of 24.7 cm. Contrarily, the lowest values in the trial were measured for Italian provenance 227 Popi e Bibbiena – Arezzo, with median diameter of 20.5 cm, and Bulgarian provenance 132 Rila – Borovec, with median value of 20.6 cm. The largest median diameter of 31.9 cm was recorded for the Vítkov trial for Czech provenance 194 Karlovice – Karlovice sever and Polish provenance 231 Baligród, at 29.5 cm. At the other extreme, Austrian provenance 93 Wörschachwald – Steiermark had a median value of 17.4 cm and Bulgarian provenance 131 Pirin – Razlog had median diameter of 21.8 cm. From both trials, provenances from abroad, mainly from Bulgaria, had the lowest *DBH* values.

After calculating the mean stem volume (over-bark volume), the overall median was 0.50 m^3 in the Úsov trial, and in the Vítkov trial it was greater by 0.13 m^3 (0.63 m^3). The highest median values in the Úsov trial were found in Czech provenance 16–30 Jihlava – Popice, with a volume of 0.64 m^3, and provenances 87 VLS Hořovice – Jince from the Czech Republic and S10 Čierny Balog – Krám from Slovakia with the same median volume of 0.59 m^3. A smaller median volume was recorded for Bulgarian provenance 132 Rila – Borovec (at 0.35 m^3) and Italian provenance 227 Popi e Bibbiena – Arezzo (0.38 m^3). In the Vítkov provenance trial, the largest median value of stem volume was found to be 1.03 m^3 for Czech provenance 194 Karlovice – Karlovice sever and Polish provenance 231 Baligród, with median value of 0.89 m^3. By contrast, the smallest volumes were recorded for Austrian provenance 93 Wörschachwald – Steiermark, with median value of 0.25 m^3.

The calculated standing volume averaged 435.5 $m^3 \cdot ha^{-1}$ in the Úsov trial, with the largest standing volume reached by the provenances from the Czech Republic 87 VLS Hořovice – Jince (at 662.5 $m^3 \cdot ha^{-1}$) and from the Slovak Republic S10 Čierny Balog – Krám (609.1 $m^3 \cdot ha^{-1}$). The smallest standing volumes were found for Italian provenance 227 Popi e Bibbiena – Arezzo (170.5 $m^3 \cdot ha^{-1}$) and Czech provenance 211 Nové Město n. M. – Vojnův Městec (238.5 $m^3 \cdot ha^{-1}$). In the second study trial, Vítkov, the average standing volume was 487.0 $m^3 \cdot ha^{-1}$. The largest standing volume was cal-

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Table 2. Results of biometric and phenotypic data from trial No. 70 (Úsov)

State	Provenance code	Provenance name	No of individuals (% of survivors)	Median tree height (m)	Median of *DBH* (cm)	Mean stem volume[1] (m^3)	Standing volume ($m^3 \cdot ha^{-1}$)	Stem form index[2]	Occurrence of stem forking index[2]	Stem damage index[2]	Bark pattern index[2]	Defoliation index[2]
CZ	1–15	Kamenice n. L. – Losy	28 (14)	22.5	24.4	0.58	406.4	1	1	1	1	1
	16-30	Jihlava – Popice	25 (13)	22.8	25.5	0.64	400.1	1	1	1	1	1
	32	Nýrsko – Dešenice	40 (20)	22.0	22.6	0.49	485.9	1	1	1	1	1
	51	VLS Lipník n.Bečvou – Podhoří	37 (19)	20.2	22.3	0.43	395.6	1	1	1	1	1
H	52*	Sopron – School Forest District	23 (15)	22.6	24.0	0.53	403.9	1	1	1	1	1
CZ	68	Vyšší Brod – Běleň	36 (18)	22.3	22.3	0.50	450.0	1	1	1	1	1
	70	Ždírec n. Doubravou – Maleč	31 (16)	23.0	23.9	0.58	446.7	2	1	1	1	1
	71	Plumlov – Ruprechtov	39 (20)	23.4	23.7	0.55	538.6	1	1	1	1	1
	76	Nýrsko – Suchý Kámen	44 (22)	22.3	22.9	0.49	537.4	1	1	1	1	1
	82	Vizovice – Bratřejov	40 (20)	19.7	23.4	0.45	452.3	1	1	1	1	1
	86	VLS Hořovice – Strašice	42 (21)	22.9	24.1	0.55	579.3	1	1	1	1	1
	87*	VLS Hořovice – Jince	34 (23)	22.6	24.7	0.59	662.5	2	1	1	1	1
	88	VLS Hořovice – Mirošov	40 (20)	21.9	22.5	0.52	516.8	1	1	1	1	1
A	93*	Wörschachwald – Steiermark	16 (11)	22.1	22.1	0.45	240.4	1.5	1	1	1	1
	94	Schneegattern – Kobernsusserwald	39 (20)	21.7	22.5	0.49	480.5	2	1	1	1	1
D	95*	Gröbming – Steiermark	22 (15)	23.0	23.5	0.57	417.7	1	1	1	1	1
A	96	Thal – Wechselgebiet	31 (16)	20.6	21.9	0.42	322.7	1	1	1	1	1
BG	132	Rila – Borovec	37 (19)	18.6	20.6	0.35	327.9	1	1	1	1	1
D	146*	Schwarzwald mit Baar – Schönmünzach	30 (20)	22.2	24.2	0.56	558.0	1	1	1	1	1
	147	Schwäb.-Fränkischer Wald – Geschwend	35 (18)	22.8	23.3	0.54	476.4	1	1	1	1	1
	148	Schwarzwald mit Baar – Gengenbach	34 (17)	22.9	23.3	0.52	442.2	1	1	1	1	1
	149*	Ostbayer – Viechtach	26 (17)	23.1	23.1	0.52	453.7	1	1	1	1	1

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Table 2. to be continued

State	Provenance code	Provenance name	No of individuals (% of survivors)	Median tree height (m)	Median of *DBH* (cm)	Mean stem volume[1] (m^3)	Standing volume ($m^3 \cdot ha^{-1}$)	Stem form index[2]	Occurrence of stem forking index[2]	Stem damage index[2]	Bark pattern index[2]	Defoliation index[2]
CZ	210	Nové Město n. M. – Cikháj	30 (15)	21.7	24.4	0.55	415.7	2	1	1	1	1
	211	Nové Město n. M. – Vojnův Městec	19 (10)	21.6	22.4	0.50	238.5	2	1	1	1	1
PL	212	Nieskurzow	29 (15)	19.8	22.4	0.40	290.5	1	1	1	1	1
RO	217	Neamt –Gircina	26 (13	22.9	22.9	0.54	352.3	1	1	1	1	1
IT	227	Popi e Bibbiena – Arezzo	18 (9)	20.1	20.5	0.38	170.5	1	1	1	1	1
SK	S1	Banská Bystrica – Badín	38 (19)	22.7	22.2	0.48	456.0	1	1	1	1	1
	S6	Čierny Váh – Čierny Váh	41 (21)	22.4	22.2	0.47	481.8	1	1	1	1	1
	S9	Kriváň – Snohy	41 (21)	20.0	21.5	0.39	399.8	1	1	1	1	1
	S10*	Čierny Balog – Krám	31 (21)	23.1	24.3	0.59	609.1	1	1	1	1	1
	S13	Bardejov – Zborov – Kružlov	39 (20)	22.7	23.0	0.54	526.5	1	1	1	1	1
Summary values			1 041 (17)	22.0	22.9	0.50	435.5	1	1	1	1	1

*only 3 repetitions of plots; [1]stem volumes were calculated using to volume equations of Petráš and Pajtík (1991); [2]stem shape (1 – completely straight; 2 – unilaterally curved at near-ground level; 3 – unilaterally curved along the entire length; 4 – strongly curved in S-shape; 5 – multiply curved, crooked), the occurrence of stem doubling (1 – continuous; 2 – doubling in the upper third; 3 – in the second third; 4 – in the lower third; 5 – shrubby, 3 or more stems at near-ground level), damage to the stem [1 – no damage; 2 – damaged only in the upper part; 3 – multiply damaged in the past, good overgrowth; 4 – multiply damaged in the past, poor overgrowth; 5 – damaged in the lower part of the stem (mechanical, fungus)], bark pattern (1 – smooth; 2 – scaly; 3 – ridged; 4 – deeply ridged) and defoliation 1–5 (by increments of 20%); CZ – Czech Republic; H – Hungary; A – Austria; BG – Bulgaria; D – Germany; PL – Poland; RO – Romania; SK – Slovakia

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Table 3. Results of biometric and phenotypic data from trial No. 71 (Vítkov)

State	Provenance code	Provenance name	No of individuals (% of survivors)	Median tree height (m)	Median of *DBH* (cm)	Mean stem volume[1] (m^3)	Standing volume ($m^3 \cdot ha^{-1}$)	Stem form index[2]	Occurrence of stem forking index[2]	Stem damage index[2]	Bark pattern index[2]	Defoliation index[2]
CZ	1–15	Kamenice n. L. – Losy	28 (14)	24.0	28.5	0.80	561.3	1	1	1	1	1
	32	Nýrsko – Dešenice	44 (22)	24.0	26.5	0.69	763.5	1	1	1	1	1
	35	Petrohrad – Oráčov	40 (20)	22.8	23.7	0.56	556.9	2	1	1	1	1
	36	Červené Poříčí – Kaliště	39 (20)	20.9	25.1	0.56	544.0	1	1	1	1	1
	43	Vsetín – Hošťálková	34 (17)	23.3	28.2	0.78	660.6	1	1	1	1	1
	48	VLS Plumlov – Stínava	47 (24)	20.7	24.4	0.51	598.4	2	1	1	1	1
	49	Přibyslav – Hamry	40 (20)	24.2	27.8	0.82	817.5	1	1	1	1	1
	51	VLS Lipník n.Bečvou – Podhoří	43 (22)	22.6	24.7	0.55	590.3	2	1	1	1	1
	59	Velké Karlovice – Vranča	24 (12)	23.1	23.3	0.50	302.3	1	1	1	1	1
	64	Dobříš – Chouzavá	41 (21)	24.4	29.2	0.87	895.6	2	1	1	1	1
	68	Vyšší Brod – Běleň	32 (16)	24.3	28.5	0.84	669.8	1	1	1	1	1
	70	Ždírec n. Doubravou – Maleč	30 (15)	24.9	27.8	0.80	601.6	1	1	1	1	1
	71	Plumlov – Ruprechtov	38 (19)	24.0	25.8	0.67	636.0	1	1	1	1	1
	74	Milevsko – Klučenice	44 (22)	24.2	25.9	0.68	744.4	2	1	1	1	1
	75	Rájec-Jestřebí – Černá Hora	55 (28)	21.0	22.3	0.43	588.7	2	1	1	1	1
	81	Vyšší Brod – Vítkův Kámen	31 (16)	21.2	24.2	0.50	388.3	2	1	1	1	1
	82	Vizovice – Bratřejov	34 (17)	23.6	27.7	0.78	660.7	1	1	1	1	1
	85	Kašperské Hory – Kašperské Hory	33 (17)	23.8	28.7	0.74	611.4	1	1	1	1	1
	90	Prachatice – Včelná	23 (12)	24.2	26.2	0.74	423.6	1	1	1	1	1
A	93	Wörschachwald – Steiermark	24 (12)	18.4	17.4	0.25	151.3	2	1	1	1	1
D	95	Gröbming – Steiermark	20 (10)	24.8	25.2	0.63	317.5	1	1	1	1	1
CZ	101	Velké Karlovice – Brodská	29 (15)	23.9	28.1	0.73	526.0	1	1	1	1	1
	106	Kácov – Psáře	45 (23)	21.3	23.6	0.51	568.9	2	1	1	1	1
	130	Nasavrky – Podhůra	46 (23)	22.0	25.7	0.61	702.1	2	1	1	1	1
BG	131	Pirin – Razlog	53 (27)	20.4	21.8	0.46	612.3	1	1	1	1	1
	132	Rila – Borovec	23 (12)	22.8	26.2	0.63	364.4	1	1	1	1	1

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Table 3. to be continued

State	Provenance code	Provenance name	No of individuals (% of survivors)	Median tree height (m)	Median of *DBH* (cm)	Mean stem volume[1] (m^3)	Standing volume ($m^3 \cdot ha^{-1}$)	Stem form index[2]	Occurrence of stem forking index[2]	Stem damage index[2]	Bark pattern index[2]	Defoliation index[2]
D	147	Schwäb.-Fränkischer Wald – Geschwend	39 (20)	22.3	24.0	0.55	537.9	1	1	1	1	1
	148	Schwarzwald mit Baar – Gengenbach	22 (11)	23.0	22.6	0.51	279.8	2	1	1	1	1
	149	Ostbayer – Viechtach	14 (7)	24.4	28.8	0.84	292.3	1	1	1	1	1
CZ	186	Šternberk – Řídeč	25 (13)	23.2	25.4	0.70	435.2	1	1	1	1	1
	194	Karlovice – Karlovice sever	12 (6)	25.5	31.9	1.03	308.8	1	1	1	1	1
	198	Vítkov – Budišov n. Budišovkou	14 (7)	24.6	24.6	0.64	223.8	1.5	1	1	1	1
	199	Krnov – Horní Benešov	20 (10)	23.1	26.7	0.68	340.2	1	1	1	1	1
PL	203	Stary Sacz	23 (12)	21.8	24.7	0.57	327.0	1	1	1	1	1
CZ	205	Bílovec– Skřípov	25 (13)	22.2	26.0	0.63	391.4	1	1	1	1	1
	207	Nové Město n. M.	10 (5)	23.5	27.3	0.72	180.9	2	1	1	1	1
	209	Nové Město n. M. – Lísek	31 (16)	23.7	26.3	0.68	526.3	1	1	1	1	1
BiH	222	Gornja Stupčanica	25 (13)	23.1	26.8	0.65	405.3	1	1	1	1	1
	224	Sokolac – Kaljina Bioštica	30 (15)	21.1	24.5	0.53	399.3	1	1	1	1	1
	225	Vitez – Kruščica	27 (14)	22.9	25.2	0.61	410.4	1	1	1	1	1
I	228	Vallombrosa – Reggello, Firenze	5 (3)	21.6	22.6	0.48	60.2	1	1	1	1	1
	230	Spadola e Serra San Bruno – Catanzaro	14 (7)	18.9	23.9	0.45	159.1	3	1	1	1	1
PL	231	Baligród	7 (4)	23.6	29.5	0.89	155.5	1	1	1	1	1
SK	S1	Banská Bystrica – Badín	31 (16)	23.1	26.2	0.66	511.5	1	1	1	1	1
	S5	Ružomberok – Korytnica	41 (21)	24.9	27.2	0.78	799.5	1	1	1	1	1
	S9	Kriváň – Snohy	29 (15)	23.7	26.8	0.72	522.0	1	1	1	1	1
	S14	Svidník – Giraltovce – Vyšný Komárnik	36 (18)	24.3	28.9	0.85	765.0	1	1	1	1	1
Summary values			1420 (15)	23.0	25.7	0.63	487.0	1	1	1	1	1

For abbreviation explanations, see Table 2

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culated for Czech provenance 64 Dobříš – Chouzavá (at 895.6 m^3·ha^{-1}), followed by another Czech provenance 49 Přibyslav – Hamry (817.5 m^3·ha^{-1}). The lowest standing volume values were calculated for Italian provenance 228 Vallombrosa – Reggello, Firenze, with only 60 m^3·ha^{-1}, followed by Austrian provenance 93 Wörschachwald – Steiermark with the volume of 151.3 m^3·ha^{-1}.

The evaluation of morphological traits of silver fir in both trials showed low variability, especially for stem forking, stem damage, bark pattern, and defoliation, where the median value for provenances was the same everywhere, that is to say 1, indicating mainly a straight stem without damage, smooth bark, and crown defoliation between 0% and 20%. The only more variable trait was stem shape. In the Úsov trial, only 5 provenances were distinguished: 70 Ždírec n. Doubravou – Maleč, 87 VLS Hořovice – Jince, 94 Schneegattern – Kobernsusserwald, 210 Nové Město n. M. – Cikháj, and 211 Nové Město n. M. – Vojnův Městec. These had median value of 2 – unilaterally curved at near-ground level. In one provenance, 93 Wörschachwald – Steiermark, the median value was 1.5, which marked the range between unilaterally curved stem at near-ground level and straight stems. The other provenances had a median value of 1 – straight stem. In the Vítkov trial, the evaluation of stem shape was similar. Italian provenance 230 Spadola e Serra San Bruno – Catanzaro had the poorest shape score of 3 – unilaterally curved along its entire length, followed by 12 provenances: 35 Petrohrad – Oráčov, 48 VLS Plumlov – Stínava, 51 VLS Lipník n. Bečvou – Podhoří, 64 Dobříš – Chouzavá, 74 Milevsko – Klučenice, 75 Rájec-Jestřebí – Černá Hora, 81 Vyšší Brod – Vítkův Kámen, 93 Wörschachwald – Steiermark, 106 Kácov – Psáře, 130 Nasavrky – Podhůra, 148 Schwarzwald mit Baar – Gengenbach, and 207 Nové Město n. M., which reached a median value of 2 – unilaterally curved stem at near-ground level, and provenance 198 Vítkov – Budišov n. Budišovkou reached a value of 1.5, which again marked the range between unilaterally curved stems at near-ground level and straight stems. Most of the other provenances were evaluated at a median value of 1 – straight stem.

In examining multivariate statistics for the Úsov provenance trial, tree height, *DBH*, stem shape, and mortality proved to be significant indicators in the biplot (Figure 2). Other indicators such as occurrence of stem forking, stem damage, bark pattern and defoliation are not statistically significant (α = 0.05). Two outlying provenances, 227 Popi e Bibbiena – Arezzo from Italy and 132 Rila – Borovec from Bulgaria, stand out promi-

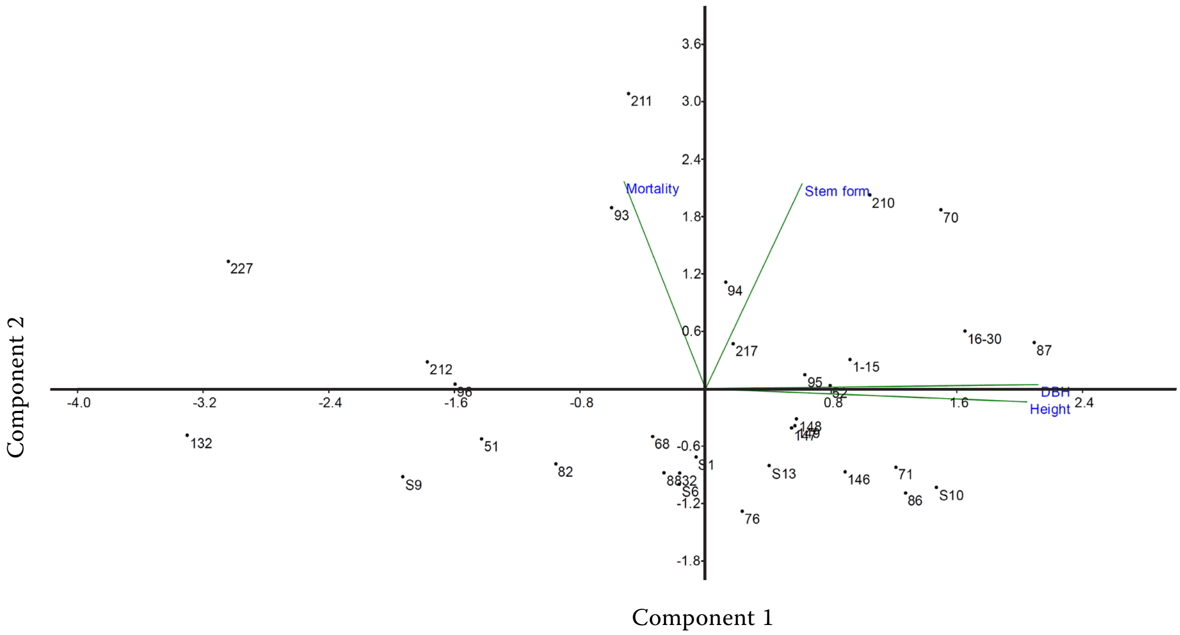

Figure 2. Biplot from the measured data of research trial No. 70 (Úsov)

For provenance codes, see Table 1.

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nently as differentiated groups. Another group is composed of provenances 211 Nové Město n. M. – Vojnův Městec from the Czech Republic and 93 Wörschachwald – Steiermark from Austria. Closer clustering is visible in the three German provenances 147 Schwäb.-Fränkischer Wald – Geschwend, 148 Schwarzwald mit Baar – Gengenbach, and 149 Ostbayer – Viechtach. Overall, the distribution of the other provenances is more or less evenly spread over the three quadrants. The biplot (Figure 3) created from the data obtained from the Vítkov trial has the same significant indicators as from the previous plot. Similarly to Úsov, two provenances are clearly differentiated, namely 93 Wörschachwald – Steiermark from Austria and 230 Spadola e Serra San Bruno – Catanzaro from Italy. Provenance 228 Vallombrosa – Reggello, Firenze from Italy also stands off slightly from the main cluster, but this is not so obvious as for the previously named two provenances. In the second quadrant, provenances 194 Karlovice – Karlovice sever (CZ), 231 Baligród (PL) and 149 Ostbayer – Viechtach (D) stand out as a separate group. The other provenances are mostly evenly distributed in all quadrants and create no visibly separated group. When comparing the two biplots overall, they show a similar distribution of provenances, and also most importantly, the separation of the Italian provenances as an individual group from all other provenances.

DISCUSSION

Quantitative and qualitative parameters of silver fir from provenance trials No. 70 (Úsov) and No. 71 (Vítkov) can be compared with the published results from other silver fir provenance trials in the territory of the Czech Republic that had been established in a similar manner (Čáp et al. 2009, 2011, 2013; Šindelář et al. 2006; Kýval et al. 2012). It is possible to compare the frequency of surviving individuals, or their mortality, by region and, sometimes, even by provenance. The highest numbers of individuals in both provenance trials are recorded mainly in Czech provenances; the only exception in the Vítkov trial being Bulgarian provenance 131 Pirin – Razlog with 53 trees, which is confirmed by results from the Pivoň, Trhanov provenance trial (Kýval et al. 2012), where this Bulgarian fir dominated over the Czech provenances with the lowest mortality. On the contrary, the lowest numbers of surviving individuals were recorded in Italian provenances and one Austrian provenance 93 Wörschachwald – Steiermark. Similar results were obtained in other provenance trials Hůrky, Písek (Čáp et al. 2013), Nové Hrady,

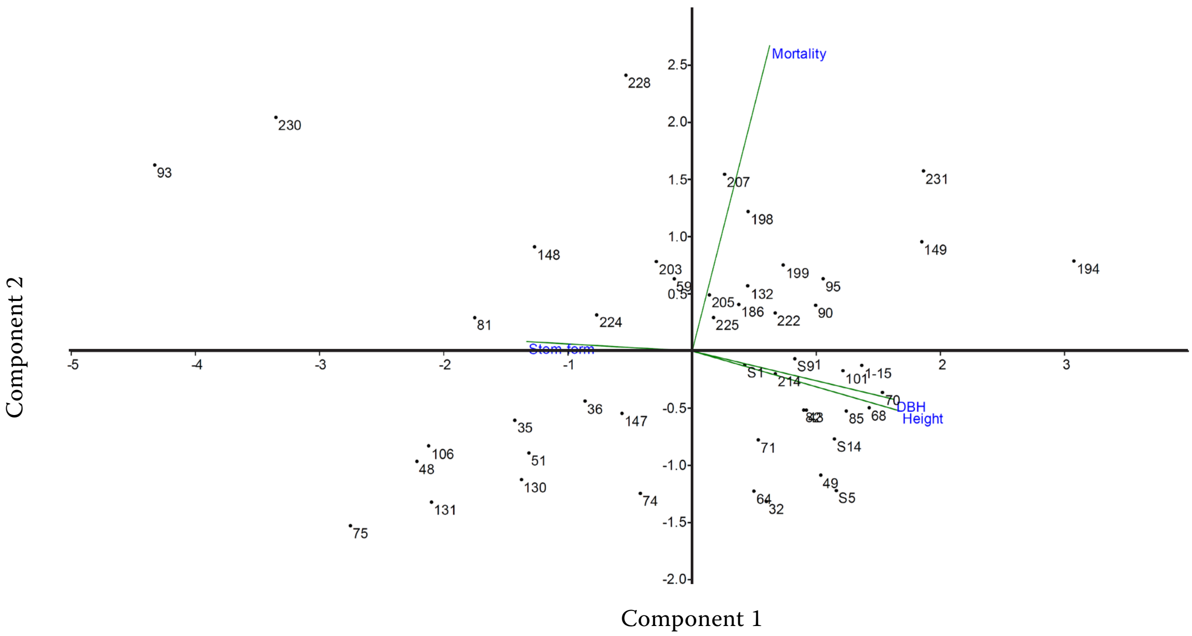

Figure 3. Biplot from the measured data of research trial No. 71 (Vítkov)

For provenance codes, see Table 1.

https://doi.org/10.17221/181/2022-JFS

Konratice (Šindelář et al. 2006), and Pivoň, Trhanov (Kýval et al. 2012).

In the evaluation of tree heights by provenance, the best results were achieved by Czech provenances from the vicinity of the provenance trials, that is from Plumlov and Ždírec nad Doubravou. Contrarily, the lowest trees were of Austrian (93 Wörschachwald – Steiermark), Italian (230 Spadola e Serra San Bruno – Catanzaro), Bulgarian (132 Rila – Borovec), and Czech (82 Vizovice – Bratřejov) provenances. There is also partial agreement with Čáp et al. (2009), who stated that the tallest trees were found in the Czech provenance from Plumlov and the lowest in the Austrian, Romanian, and Czech provenances. The evaluation of the poorest-growing provenances is also confirmed by the results of Čáp et al. (2011).

In the evaluation of *DBH* and mean stem volume, the best provenances proved to be Czech provenances and in one case also Polish provenance (provenance 231 Baligród), but this is due to the high mortality of trees in the trials and therefore higher light increment. Again, the provenances from Bulgaria, Italy, and Austria proved to have the smallest increment, which is confirmed by the results of Čáp et al. (2009, 2011). Regarding the forest stand volume, which was greatest for the Czech provenances from the Brdy area and lowest for the Italian provenances, similar results were obtained by Kýval et al. (2012), with a difference being that the largest standing volume was in the Czech provenance Losy (Kamenice nad Lipou).

In terms of morphological traits, a significant difference was found only in stem shape, which was assessed as straight in most provenances except for two provenances from Austria and three Czech provenances from the Vysočina region. These provenances have the majority of stems with unilateral curvature at near-ground level. In comparison with Čáp et al. (2011), where the Austrian provenances were best and the German and Czech provenances the poorest, and Kýval et al. (2012), where a Slovak provenance was best and a French fir provenance the poorest, the best and poorest provenances in terms of the quality of stem shape are not clearly confirmed in our case. Thus, it can be concluded that the results of the stem shape index from different trials are influenced by local factors (the environment) so that their original inherited features are suppressed. Considering the other morphological traits (occurrence of stem forking, stem damage, bark pattern and defoliation) evaluated in the measured provenance trials of silver fir, which had identical median values (1), two influencing factors for this result can be inferred, namely the implementation of thinning to unify the stand and moderate evaluation of quality traits by the evaluator.

In the evaluation of results, tree height, *DBH*, mortality and stem shape were the main variables of interest for the evaluation of the analyses. No statistical differences were found for the other indicators and therefore they were not used in the PCA and CLU. When assessing the differences in provenances using multivariate statistics, the provenances from the south of the Czech Republic, falling according to the classification by Rubner and Reinhold (1953) into the Inner Alps – Eastern Subregion (5.04.3), Central Bulgarian Mountains (6.26.0), Northern Apennine Mountain Forest (9.12.0), and Southern Apennine Mountain Forest (9.14.0) were the most distinct. Similar findings were reported also by Šindelář et al. (2006) and Čáp et al. (2009, 2011), where 5 – Alpine region, 6 – Eastern and Southern European region of oak and beech woodlands, and 9 – Southern European region of hardwood and chestnut forests were distinguished from the other regions based on the lowest values for tree heights.

From the overall evaluation of the measured provenance trials Úsov and Vítkov, the provenances from Italy performed most poorly. That is in contrast to provenance trials in the UK, which show that Italian provenances from Calabria are thriving (Kerr et al. 2015). Even Danish trials with Italian fir provenances suggest that had the trees not suffered from frost damage, their growth would have been rated very well (Hansen, Larsen 2004). A possible reason for the unsuccessful growth of Italian provenances at both our sites may be due to the continental climate. It is also interesting to note that Italian, Austrian, and Bulgarian provenances originating from altitudes higher than 1 000 m a.s.l. suffered in the study trials and did not achieve any good growth results. The combination of the two factors may be decisive for the growth development of some foreign provenances in the Czech Republic. Another reason for the differences in provenances is the reduced phenotypic diversity and adaptability of silver fir in central Europe (Larsen 1986) compared to the southwestern and southeastern parts of its natural range due to postglacial development. Confirmation of this

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hypothesis was provided by Bergmann et al. (1990), who provided evidence of the diversity of individual provenances by means of enzyme analyses (genetic level). Significant differences in the geographic distribution of silver fir have also been recorded by genetic analyses (Longauer 2001; Paule et al. 2001; Longauer et al. 2003). The differentiation of this tree species has arisen during its evolution by adaptation to local climatic and habitat conditions. A summary more detailed description confirming the differentiation of silver fir regarding the genetic structure, development and adaptation is also presented in the review by Dobrowolska et al. (2017).

CONCLUSION

The Forestry and Game Management Research Institute deals with issues affecting the forest environment and seeks methods to improve its condition for future generations. One of the many activities of the Forest Tree Species Biology and Breeding Department is long-term provenance trials of native and non-native tree species. Investigations in two international provenance trials in the northern part of Moravia and Silesia in the Czech Republic showed that, at stand age of 51 years, provenances from Plumlov and Ždírec nad Doubravou (i.e. Czech provenances from the surrounding area) were the most prominent. In terms of *DBH*, best performing were the Czech provenances from Vysočina and Jeseníky. The standing volume as the best aggregate measure reflecting the survival, tree height and *DBH* was found to be the greatest in the fir from the Brdy area in the Czech Republic. On the contrary, firs from Bulgaria, Austria, and Italy performed most poorly. In evaluating the qualitative traits, the differentiation among provenances in stem shape was significantly evident, and differences among the other traits evaluated were statistically insignificant in this case. The evaluation of stem shape from both plots was excellent for most provenances (straight stem), except for Czech provenances from the vicinity of Nové Město na Moravě, as well as one Austrian and one Italian provenance, which more often produced a curved stem. Overall, the Italian provenances were the poorest in terms of production and quality. Long-term provenance research shows that it can be recommended to grow silver fir from local sources of reproductive material and provenances of the Brdy area.

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