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The first Polish provenance experiments with silver fir *Abies alba* Mill.

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Abstract. Silver fir *Abies alba* Mill. provenance trials started in Poland a few years after Pavari (1951) proved that the origin of this tree species influences its genetic variability. Further confirmation came from provenance trials, which selected provenances for cultivation in Denmark and showed provenance-dependent genetic variability even within a relatively small area such as the Czech Republic. The Polish trial, started in 1960, compared 6 provenances from the West and Central Carpathian region (4 from Poland, 2 from Slovakia) and 3 from the Hercinic region (Czech Republic). The trial was established in the Experimental Forests of the Warsaw University of Life Sciences in Rogów, at the northern border of the natural silver fir range. Results from the nursery stage experiments proved the existence of latitudinal and altitudinal clines based on data for seed weight, height growth, number of terminal buds as well as bud and needle development. The Polish provenance 'Stary Sącz' and two Slovak provenances, 'Čierný Váh' and 'Beňuš', were early flushing, whereas the Polish provenance 'Rogów' behaved differently and was late flushing. Even at the nursery stage, the positive influence of tree selection on height growth and progeny characteristics of the two Czech provenances was evident. The Carpathian provenances were furthermore evaluated according to the index of cultivation and breeding: very good – 'Rogów'; good 'ŚPN (Świętokrzyski PN)', 'Stary Sącz' and 'Skarżysko'; poor – 'Čierný Váh' and 'Beňuš'.

Keywords: silver fir, provenance trial, seedlings, height growth, terminal buds phenology

1. Introduction

In Poland, the first studies on silver fir *Abies alba* Mill. Provenances were launched in 1960 (Gunia 1975), in view of the observed differentiation of Polish silver fir stands and the results of the provenance trials carried out in other European countries.

Silver fir genetic diversity was not recognized up until the mid-1900s. This was due to the misguided view of Engler (1905), who installed the first provenance trial in Switzerland in an attempt to study the silver fir genetic diversity. The author compared seedlings (2/0) and seedlings transplanted after two years growth (2/2) grown from the seeds collected from 10 trees growing in one of the regions of the Alps, at an altitude of 680–330 m a.s.l. The results obtained at that time showed distinctions neither in the height of the trees studied nor in the bud phenology; hence, it was concluded that in silver fi , there was no genetic diversity related to the site of origin, in contrast to Scots pine *Pinus sylvestris* L. and Norway spruce *Picea abies* (l .) h . Karst. It was much later (1925–1949) when this conclusion was proved incorrect by the results of the two provenance trials carried out in the Apennine Mts. in Italy and published by Pavari (1951). This author compared 18 silver fir provenances, mostly from the Italian and Austrian parts of the Alps (950–1500 m a.s.l.), the northern Apennines (1000 and 1350 m a.s.l.), the southern Apennines (Calabria; 1000 m a.s.l.) and the sub-Alpine regions in Austria and France (the Pyrenees, the Vosges, Normandy).

Significant diversity of silver fir provenances in terms of survival and growth characteristics was found in the not replicated provenance trials carried out in Vallombrosa near Florence (1000 m a.s.l.) and in Alta Val Parma (1470 m a.s.l.). In Vallombrosa, the best results in terms of survival,

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height and DBH were achieved by silver firs of Serra San Bruno (Calabria) and local Vallombrosa origins, whereas silver firs of Burgenland (Austria) origin showed the poorest results. In Alta Val Parma, the provenances originating from southern regions could not withstand the local mountain climate. All the provenances studied were characterized by a clear diversity of morphological and needle features.

Next trials on silver fir diversity were carried out in Denmark (the mid-1930s), outside the natural range of this species. The aim of the studies then undertaken was to choose the best provenances for reforestation that was carried out to counteract the adverse effects of deforestation due to expansion of agriculture. In Denmark, forest restoration began already in the mid-1800s with the introduction of non-native forest tree species, including silver fi . It turned out that the latter tolerated local climate quite well, and was productive enough, notwithstanding the fact that young plantations were injured by spring frosts and drought, whereas older stands were damaged due to strong winds (Henriksen 1957). The biological strength of silver fir introduced in Denmark on inland dunes was evidenced by the fact that naturally regenerating second generation turned into silver fir stands, characteristic of diversified height and biosocial structure (Gunia 1978)

In 1934, the first provenance trial (without replications) was carried out in Denmark on seven analogous plots. Then, 20 provenances were compared, including 3 representing Danish stands introduced earlier, and 17 originating from silver fir range in Europe (excluding Poland) (Løfting 1954, 1959, 1977). Along with the growth characteristics, there was studied resistance to aphids *Dreyfusia nordmannianae* (Eckstein 1890). The provenances from central Europe proved to be more sensitive to aphid infestation when compared to those from Europe's eastern and southern regions. Initially, the greatest resistance and favourable growth characteristics were identified in the provenance from Lapus situated in the Romanian Carpathians (700 m a.s.l.), Gargilione–Calabria (1600 m a.s.l.) and Perister planina-Macedonia (1500 m a.s.l.). The provenance from Calabrian Gargilione showed the best characteristics later on –at the age of 44 years, its thickness values were significantly higher (160%) when compared to the other silver fir provenances observed within the research area established in Frijsenborg (Larsen 1981). In general, the provenance from lower altitudes showed better growth values when compared with those originating from higher heights above sea level. The provenances from eastern and southern Europe were characterized by greater vitality due to better moisture conditions in their new environment, more favourable for tree growth when compared to those in indigenous habitats.

In 1955, additional provenance trials (4) were established in Denmark (Løfting 1959), and these included 6 silver fi provenances from Poland: the Świętokrzyskie Mts. (seeds from the collection of the Forest Research Institute – IBL), the Świętokrzyski National Park (seeds from German collection), Tomaszów Lubelski, Brzezin and from the Carpathian Mts.: 2 provenances imprecisely labelled 'Kraków' (probably Stary Sącz) and 'Rzeszów' (probably the Beskid Niski Mts.). The provenances from Poland were compared with those from France (Normandy) and the progeny of a silver fir stand introduced earlier to Denmark. The first results did not confirm the expected greater resistance of Polish provenances to drought, but showed their some what greater resistance to spring frosts.

The provenance from the Świętokrzyskie Mts. achieved the best standard values on two research plots: $\overline{h}$ = 1.6 s (on the firs and second plot:174 cm at the age of 15 years and 211 cm at the age of 16 years, respectively). On the third plot, 16-year-old provenance from Tomaszów Lubelski (278 cm) and the provenance 'Kraków' (288 cm) achieved the result $\overline{h}$ > 1.0 s.

In Czechoslovakia, where silver fir is an important forest-forming species, provenance studies were initiated by Vinš in 1956 (Vinš 1966). These were carried out in two series comprising the progeny of 3–10 maternal trees from 10 different locations in Czechia and Moravia. There was evaluated the growth of seedlings (2/0) and transplanted seedlings made from them under nursery and research plot conditions. Both silver fir seedlings and transplanted seedlings that originated from the relatively small geographical region sunder the study showed statistically significant differences. Seedlings from Czechia showed lower height values when compared with those from Moravia. However, no relationship was found between the features (as assessed in forest valuation) of maternal trees and growth traits of their progeny.

At that time, there were established provenance studies on silver fir in Germany (then GDR) by the Institute of Selective Breeding of Forest Trees in Graupa (Meyer 1956). Based on the results of the initial tests, in the years 1957–1961, there were imported silver fir seeds from Poland, collected in: Kraków surrounding area (267 kg) and Przemyśl (71 kg), and handed over to the forest administration units in the Western Kruszcowe Mountains. The results of these studies have not yet been compiled and analysed (Hartig 2012).

The results of the abovementioned studies, especially those carried out in Denmark, showed a high probability of occurrence of genetic diversity in silver fir (also growing under Poland's conditions), as well as a note worthy cultivation and silvicultural value of its provenances. The diversity was developed under variable environmental conditions during long-distance and long period migration after the glacier retreat from their refugiumon the Apennine and Balkan Peninsulas, through the Carpathians to the North European Plain (comprising *the Wyżyny i Niziny* Środkowopolskie),where silver fir reached the north-eastern boundary of its current natural range (Kral 1980; Środoń 1983). The creation of the boundary was forced by both adverse climatic conditions (mainly humidity) and expansion of agriculture on fertile and wet soils.

In Poland, silver fir provenance studies have been carried out with the aim to understand the genetic diversity in the native provenances and to show the prospects of its use in forest crop growing and silviculture. The trials were initiated in 1960 (Gunia 1975) and were carried out in subsequent years, so a set of provenances tested gradually expanded (Gunia 1984, 1985, 1994; Szeligowski 2006; Szeligowski et al. 2011). One of the milestones was the possibility of conducting provenance trials in the area of northern boundary of silver fir natural range, that is, in the Rogów Experimental Forests of the Warsaw University of Life Sciences SGGW, with satisfactory climatic and soil conditions – conducive to silver fir growth and development. The results of these studies encouraged the establishment of further silver fir provenance trials in Poland, for example, under the nationwide program Jd PL 86/90 (Sabor et al. 1996; Skrzyszewska 1999, 2010), as well as those established in the Sudety Mts. and other regions of Poland (Barzdajn 2009, 2010), and also – the Program for testing Polish fir populations was launched (Klisz et al. 2016).

The stage of seedling production and related initial testing constituted the basis for a series of further studies on the growth and developmental stages of 9 silver fir provenances from Poland, Slovakia and the Czech Republic in the period of over 50 years.

The purpose of the study was to assess the cultivation and silvicultural value of silver fir provenances from the Carpathian Region, based on the average values of standardized features of seeds (weight, vitality, germination) and those of derived seedlings (height and growth, morphological features, phenology).

Figure 1. Geographical location of silver fir *Abies alba* Mill. tested in WULS Experimental Forests in Rogów

Table 1. Provenance of seeds of silver fir *Abies alba* Mill. used for research in the Experimental Forests of the Warsaw University of Life Sciences (WULS) in Rogów

n o	Provenance	Country	Origin region	Geographical region	Forest seed region	Geographic coordinates		a ltitude a.s.l. [m]
						l atitude n	Longitude E	
1.	Rogów	Polska	Region Zachodnio- i Środkowo-karpacki[1]	Wyżyna Łódzka	318/6 – 651[2]	51°40'	19°58'	190
2.	Skarżysko	Polska		Puszcza Świętokrzyska	342/6 – 604[2]	51°08'	20°55'	350
3.	Świętokrzyski Park Narodowy	Polska		Góry Świętokrzyskie	342/6 – 604[2]	50°55'	21°00'	350
4.	Stary Sącz	Polska		Beskid Sądecki	513/8 – 803[2]	49°35'	20°40'	340
5.	Čierný Váh	Słowacja		Mała Fatra	34 a [3]	49°00'	19°56'	850
6.	Beňuš	Słowacja		Niżne Tatry	46 B[3]	48°52'	19°44'	700
7.	Karlovice	Czechy	Region Hercyński[1)]	Jesioniki (Sudety)	27[4]	50°06'	17°25'	850
8.	Kaliště	Czechy		Szumawa	13[4]	49°30'	13°19'	450
9.	Boubín	Czechy		Szumawa	13[4]	49°03'	13°47'	950

[1] Svoboda (1953)
[2] Leśna Regionalizacja dla nasion i sadzonek w Polsce (1996)
[3] Ministerstvo Pôdohospodárstva Slovenskej Republiky (2001)
[4] Hynek (2000)

Table 2. Characteristic of seeds of silver fir *Abies alba* Mill. used for research in the WULS Experimental Forests in Rogów

n o	Provenance	Place of cone harvesting	Age of seed trees [years]	Seed characteristics			
				Purity [%]	1000 seed weight [g]	Viability [%]	Seedling percentage [%]
1	Rogów	drzewostan	60–90	98	51.0	48	25.5
2	Skarżysko	drzewostan	90–100	96	56.2	68	9.3
3	Świętokrzyski P. N.	drzewostan	100–120	97	49.9	54	44.4
4	Stary Sącz	drzewostan	90–110	93	51.1	55	10.7
5	Čierný Váh	drzewostan	95	91	39.2	28	15.0
6	Beňuš	drzewostan	90	91	39.2	28	14.6
7	Karlovice	3 drzewa doborowe	120	92	42.2	41	26.0
8	Kaliště	3 drzewa doborowe	95	95	30.7	31	36.1
9	Boubín	4 drzewa doborowe	90	92	28.5	28	5.9

2. Study object and methodology

The studies were carried out on9 silver fir provenances (Fig. 1, Tab. 1): 6 provenances from the Western and Central Carpathian Region, including 4 provenances from Poland –Rogów, Skarżysko, Świętokrzyski National Park (ŚPN, the Małopolska Kraina Leśna) and Stary Sącz (the Kraina Karpacka); 2 provenances from Slovakia – ČiernyVáh (Stredoslovenská oblas) and Benuš (Horehronsko-hnilecká oblas); and 3 provenances from the Czech Republic –the Hercyni region –Karlovice (Sudetská oblas) as well as Kalište and Boubín (Šumavská oblas). The Polish and Slovak provenances tested were the progeny of seed stands, and each of the three Czech populations was derived from a mixture of seeds collected from 3–4 maternal trees of each provenance under the study (Tab. 2).

Polish and Slovak seed stands grow at an altitude of 190–850 m a.s.l., in a strip between the lines of longitude: 19°44'E and 21°00'E, situated in the northern boundary of silver fir range in Poland and stretching to the southern range boundary in Slovakia. In the Czech Republic, silver fir stands are situated more westerly (13°19'E–17°25'E) –in the Sudetes (Jeseníky, 850 m a.s.l.), and Šumava (450 and 950 m a.s.l.), near the southern border of Poland.

Silver fir seeds were obtained in the autumn of 1960 and evaluated shortly after harvesting, using the methods established by the Forest Research Institute – IBL (Załęski 2000). The seeds of local origin from Rogów were collected in the Forest Sub-district Jasień (the Zacywilki Uroczysko, the Rogów Experimental Forests). The evaluated seeds of the other Polish provenances tested were obtained from Prof. S. Tyszkiewicz, Dept. of Seed and Selection of Forest Trees, IBL. The seeds of the Slovak and Czech provenances were obtained under the cooperation with Dr. B. Vinš from the Institute of Forestry and Hunting (VÚLHM) in Prague.

The seedlings were produced within a 6-acre ground of a forest nursery established in the unit 141d of the Rigor Experimental Forests, surrounded by Scots pine stands (IV/V age class),growing on deciduous forest site (Zeeland 1993; Zeeland et al. 1993) with poor-quality pods soils, formed from silts on glacial tilts (Konecka-Betley et al. 1993).

Weather data during seedling production period were obtained from the meteorological station in Rogów (Bednarek 1993; Ożga 2001). In December 1960, positive average temperature (2.1°C) allowed to carry out late autumn sowing in the nursery. In the 4-year period of seedling production, the average annual temperature in 1961 (7.8°C) was slightly higher than the long-term average (7.4°C), and in the remaining years, it was lower (6.4; 6.3 and 6.7°C). Higher temperature and higher rainfall in the spring of 1961 favoured seed germination and seedling emergence. In 1963 and 1964, sufficient precipitation enhanced the growth of the transplanted seedlings. During the first two study years, the sums of annual precipitation (748 mm and 677 mm) significantly exceeded the long-term average (595.6 mm). In the third year, the sum of precipitation was lower (534 mm) when compared to the long-term average, and in the last year of observations, the sum of precipitation amounted to 608 mm.

All the provenances tested (9) were seeded in the late autumn of 1960 in the randomized block design (3 blocks). After two years, seedlings (2/0) were transplanted (2/2) in order to obtain also in three repetitions, in the same block

Table 3. Growth characteristics of seedlings and transplants of silver fir provenances *Abies alba* Mill. tested in the nursery of the WULS Experimental Forests in Rogów

n o	Provenance	Mean heights of plants in the succesive years [cm]				Mean number of side twigs by 2/2-transplants	Mean number of terminal buds by 2/2-transpants	Survival of 2/2-tr ansplants [%]
		Seedlings		t ransplants				
		Age of plants [years]						
		1.	2.	3.	4.			
1	Rogów	3.43	7.21	10.26	14.88	2.42	3.57	83.8
2	Skarżysko	3.22	7.03	9.75	14.45	2.18	3.33	72.0
3	Świętokrzyski P. N.	3.81	7.94	10.91	15.47	1.99	3.33	81.0
4	Stary Sącz	3.99	7.98	11.43	15.80	2.15	3.53	72.5
5	Čierný Váh	3.41	6.60	9.53	14.52	2.09	3.23	62.9
6	Beňuš	3.45	7.31	10.49	14.25	2.01	3.17	89.3
7	Karlovice	3.73	7.49	10.64	15.66	3.24	3.27	81.4
8	Kaliště	3.91	7.86	11.19	16.14	4.01	3.26	92.5
9	Boubín	3.33	6.63	9.23	13.69	2.53	2.97	63.1

system. In the spring of1961, the efficiency of emergence was determined, and in the spring of 1964, the survival of the transplanted seedlings.

The height achieved by the seedlings in the first two years of growth, and by the transplanted seedlings in the next two years was measured with an accuracy of 1 mm. There were also assessed the numbers of lateral branches and apical buds on the main shoot of the transplanted seedlings (2/2) (t ab. 3).

The results of tree height measurements were analysed according to the following formula:

$$\overline{h}_i = \mu + P_i + E_{ij}$$

where:
$\overline{h}_i$ – average height of plants of *i* provenance,
μ – overall average,
P_i – the effect of *i* provenance,
E_{ij} – relationship between *j* site conditions and *i* provenance traits.

Numerical results of the examined traits were evaluated by means of the mathematical and statistical methods (Snedecor 1957; Elandt 1964; Oktaba 1966). Correlations and regressions were calculated and analysed with the use of Statgraphics Plus Software 4.1. Curvilinear relationships, if possible, were transformed into linear (if possible) by transformation of variables. Details and symbols of the variables are given when presenting the relevant calculations.

The results of assessing the differences between the experimental variants were marked with the following signs:

X – no significant di ferences,
X^+ – minor differences at a significance leve $\alpha = 0.10$,
X^* – significant di ferences at $\alpha = 0.05$,
X^{**} – very significant di ferences at $\alpha = 0.01$.

The number of degrees of freedom (*N*–1) was marked with *f*. Symbols of the tested traits are presented in the section where the results are described. The cultivation-silvicultural value (W_{u-h}) of the tested provenances was determined using the function ordering normalized values of the assessed traits (Perkal 1963):

$$W_{u-h} = \frac{1}{7}(x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7)$$

where:
x_1 – weight of 1000 seeds,
x_2 – efficiency of seedling eme gence,
x_3 – height of transplanted seedlings (2/2)
x_4 – *b* coefficient of equations of lines for seedling and transplanted seedlings height increases $h = a + b_t$,
x_5 – transplanted seedlings (2/2) survival rates,
x_6 – number of side branches of transplanted seedlings (2/2),
x_7 – number of buds at the top of transplanted seedlings (2/2).

The following classes of the cultivation-silvicultural value (W_{u-h}) were distinguished:

- very good: $W_{u-h} > 0.50$,
- good: $0.00\ W_{u-h} < 0.50$,
- weak: $-0.50 \leq W_{u-h} < 0.00$,
- bad: $-1.00 < W_{u-h} < -0.50$,
- very bad: $-W_{u-h} \leq -1.00$.

During the growing season in 1964, there were carried out phenological observations on the development of apical buds in the transplanted seedlings (2/2) of the Polish and Slovak provenances from the Carpathian Region. On each plot, being a repetition, 30 transplanted seedlings (2/2) were randomly selected, that is, a total of 90 specimens of each provenance. During the subsequent observation periods (*d*), every two days, there was determined the number of transplanted seedlings (2/2) in the following development stages:

- start of budding – cracking of the resin layer and bud scales; appearance of light brown or greenish stripes,
- bud opening – visible green needles between opened scales on the bud top,
- needle development – scales widely opened and fully visible needles.

For statistical analysis of percentage data (*p*), development stages of transplanted seedlings' buds (2/2) of individual provenances, the logistic equations (Płochinskij 1961) were used:

$$p = 100/1+10^{a-bd}.$$

After the log transformation, they took the form of the straight line equations, to calculate exponents:

$$\log (100/1- 1) = a - bd$$

Comparisons of the equations relating to individual provenances were carried out at $p = 50\%$, when $a+b\,t=0$, therefore: $d=a/b$.

After starting height increase by 2/2-transplanted seedlings in the fourth observed growing season, it's size was measured with an accuracy of 1 mm: day 1 (May 10), day 26 (June 5), day 34 (June 13), day 48 (June 27) and day 71 (July 15).

3. Results

3.1. Seeds

The heaviest seeds were of Polish origin (Tab. 2) –the weight of 1000 seeds (1,000 kernel weight – 1,000 K) was about 50 g. Seeds of Slovak origin were almost 10 g lighter – even though they were collected in tree stands (likewise Polish seeds). The Czech seeds from Karlovice and Kalište (collected from selected trees) showed the weight similar to that of the Polish seeds. The seeds of the Czech provenance from Boubín showed the lowest weight value.

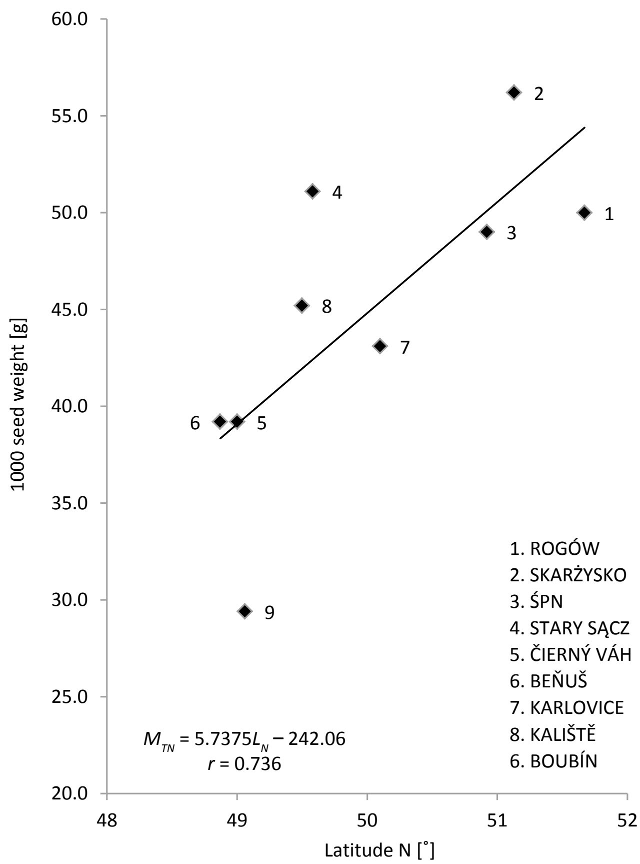

Figure 2. Relationship of thousand seed weight (M_{TN}) of silver fir provenances with latitude North (ϕ_N)

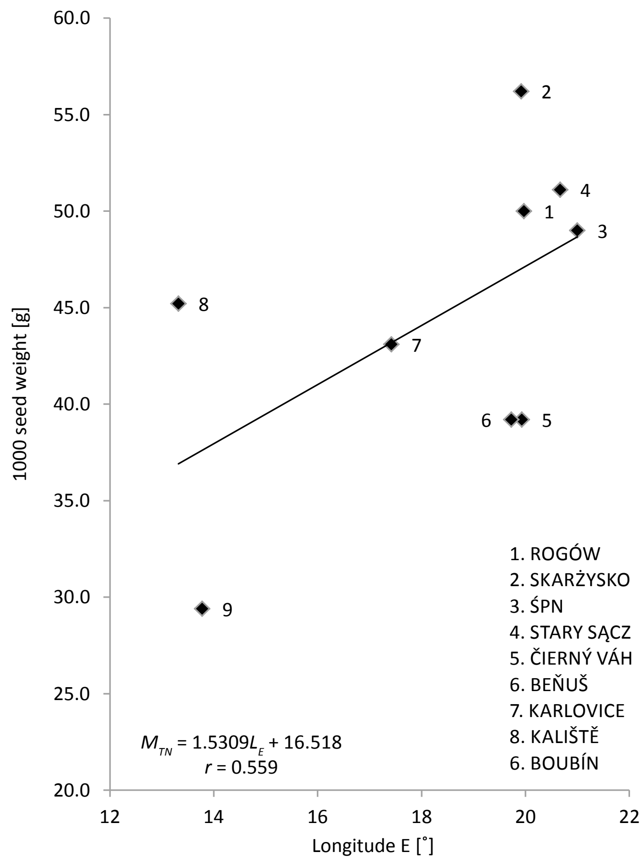

Figure 3. Relationship of thousand seed weight (M_{TN}) of silver fir provenances with longitude East (λ_E)

There was found a significant relationship between 1,000 K and northern latitude (ϕ_N) of maternal seed stand sites. The 1,000 K value increased with increasing ϕ_N (Fig. 2), and the relationship between 1,000 K and the site eastern longitude proved to be weak (Fig. 3). Nonetheless, there was observed a very significant correlation (r = 0.864**) between decreasing 1,000 K values and increasing altitudes a.s.l. (A) of seed stand site locations (Fig. 4).

The simultaneous analysis of the effects of both independent variables (ϕ_N) and (A) on the 1,000 K values in the tested provenances (r = 0.900**), confirmed stronger impact of altitude a.s.l. changes seed stands rather than changes in north latitude.

It was also found that the 1,000 K values in the tested provenances significantly deter ined (r = 0.959**) seed vitality (health – Z_d).

Due to the comparatively higher 1,000 K values, silver fir seeds from Poland showed much higher vitality than those from Slovakia and the Czech Republic (Table 2). Their Z_d values increased significantly (r = 0.768*), as did the 1,000 K values, with the increase in the latitude of the place of origin. It also decreased significantly (r = -0.708*) with increasing altitude a.s.l..

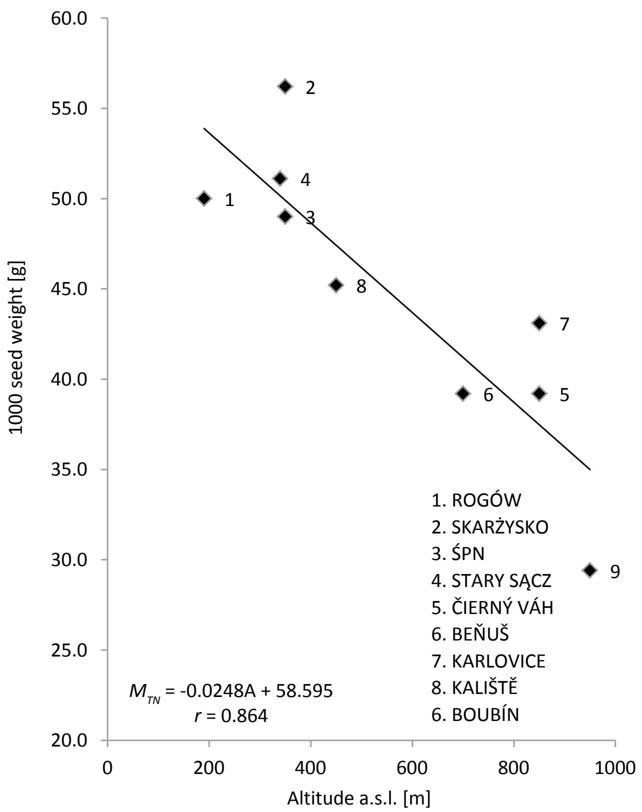

Figure 4. Relationship of thousand seed weight (M_{TN}) of fir provenances with altitude (A) of seed stands sites

3.2. Production efficiency and increase in seedling height increment

The end result of the production of seedlings, intended for establishing experimental crops, depended both on silver fir seed germination and seedling emergence and survival of transplanted seedlings.

The overall seedling emergence ($\overline{W}_w$) was 20.8 ± 12.5% (Tab. 2) and significantly differed from the expected emergence calculated based on the assessment of seed vitality (r = 0.075$^-$). $\overline{W}_w$ exceeded only 2 provenances: ŚPN and Kalište. In the provenance Boubín, seedling efficiency of emergence showed the value below 8.3. The value of $\overline{W}_w$ in Skarżysko provenance was close to it.

77.6 ± 10.6% 2/2-transplanted seedlings was obtained from the 2/0 seedlings. The transplanted seedlings derived from Rogów and Kalište showed the highest survival rates, and the lowest –transplanted seedlings derived from Čierný Váh and Boubín. No relationship was observed between the survival rates and the average tree height, the number of branches, the number of buds, as well as the geographical location of maternal stands. In the case of W_w, there was observed a weak effect (r = 0.615$^+$)

The average height of all seedlings taken to transplanting was in the first year 3.59 ± 0.47 cm. In the second study year, the average height value increased to 7.34 ± 0.91 cm. The transplanted seedlings obtained from them reached the height of 10.38 ± 1.23 cm in the third study year, and 14.98 ± 1.32 cm in the fourth study year (Tab. 3). The values of coefficients of variation ($V_{\%1}$ = 13.2%, $V_{\%2}$= 12.4%, $V_{\%3}$= 11.8%, $V_{\%4}$= 8.8%) showed decreasing height differentiation with increasing seedling age.

During the 4-year-long period, the Czech provenance Kalište from Šumava showed the uppermost height values. These slightly exceeded the height values in the Polish provenance from Stary Sącz. Both provenances maintained their leading ranking positions throughout their growth in the nursery. The lowest position in the ranking had the Czech provenance from Boubín, (also from Šumava), but from the parent stand at the higher altitude above sea level (Tab 3).

The ranking of the provenances in terms of the average seedling height did not change much with tree age. The largest displacements of the height ranking items occurred among the seedlings. The position of transplanted seedlings of individual provenances was very similar in both the 3rd and 4th year.

Since the increase in seedling height and transplanted seedlings of the tested provenances run in a relatively straight line, it was equalized by a straight equation:

$$\overline{h} = a + b_{t,}$$

where:
$\overline{h}$ – average height in cm achieved at the age of t years,
a, b – coefficients of the equation

The very significant dependency of $\overline{h}$ on t, expressed by the correlation coefficient r, was located in the estima-

Table 4. e quations (*h=a+bt*) determining the height of seedlings and transplants of silver fir provenances tested in nursery of the WULS Experimental Forests in Rogów and theirs distances from X axis

n o	Provenance	$h = a + bt$	r	$\pm s_{h.t}$	Y_D [cm]
4.	Stary Sącz	h = 0.087+ 3.886 t	0.995**	0.46	9.802 *a*[1]
8.	Kalište	h = - 0.230+ 4.002 t	0.991**	0.67	9.775 *a*
3.	Świętokrzyski P. N.	h = - 0.045+ 3.795 t	0.990**	0.64	9.442 *ab*
7.	Karlovice	h = - 0.357 + 3.895 t	0.975**	1.87	9.380 *ab*
1.	Rogów	h = -0.017 + 3.557 t	0.960**	1.34	8.945 *ab*
6.	Beňuš	h = - 0.017+ 3.557 t	0.956*	1.34	8.875 *ab*
2.	Skarżysko	h = - 0.497 + 3.643 t	0.990*	0.64	8.610 *b*
5.	Čierný Váh	h = - 0.552 + 3.627 t	0.974**	1.03	8.515 *b*
9.	Boubín	h = - 0.200 + 3.368 t	0.960**	1.20	8.220 *b*

[1] The same letter indicates statistically homogeneous values, at $\alpha = 0.05$

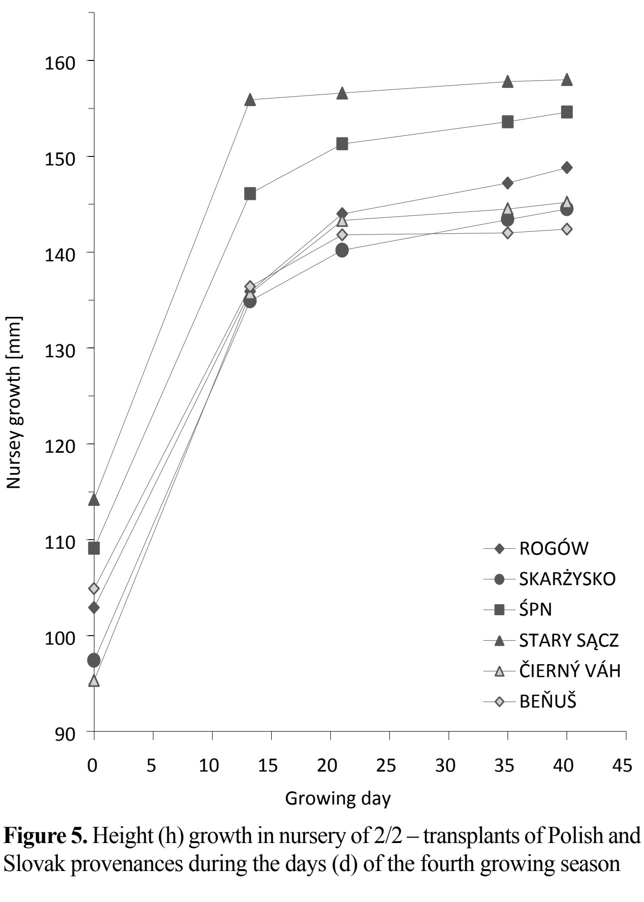

Figure 5. Height (h) growth in nursery of 2/2 – transplants of Polish and Slovak provenances during the days (d) of the fourth growing season

ted provenances in the range 0.956**-0.995**, on average 0.976 ± 0.016 (Tab. 4).

A comparison of slope coefficients *b* of the equations relating to individual provenances, carried out by means of analysis of covariance (ANCOVA) (Snedecor 1957), showed no significant differentiation (F = 1.78-; f_1 = 8; f_2 = 140) of *b* coefficients in all the tested provenances, even though the values ranged from 3.368 to 4.002. Hence, it was assu-med that the growth straight lines were approximately paral-lel, with a common slope coefficient $\bar{b}$ = 3.587.

However, the location of growth straight lines in relation to the $x(t)$ axis were significant y differentiated (F = 11.17 **; f_1 = 8, f_2 = 260). The growth of plants of tested provenances took place at different levels, and therefore, varied in. The position of the straight lines representing growth of the compared provenances was assessed using a multiple range test (Oktaba 1966) based on the tables for Duncan's multiple range tests $D_{0.05}$ and D_{001} (t ab. 4).

The highest positions (Tab. 4) in relation to the axis $x(t)$ were taken by the growth lines of the provenances: Stary Sącz, Kalište, ŚPN and Karlovice. There were no significant relationships between the average height of the transplanted seedlings (2/2) of the tested provenances and the geographical coordinates, because with ϕ_N r = 0.228 and with $\lambda_e r$ = 0.019-, and with the altitude above sea level (A), the stands of seed stands were obtained with r = 0.456-.

The growth of the Polish and Slovak transplanted seedlings in the nursery on days (d) of their fourth growing season (Tab. 5; Fig. 5) was in line with the following equation:

$$\bar{h} = a - b \log d$$

ANCOVA showed no significant differences between directional coefficients *b,* that ranged from 2.1504 to 2.8473, (F = 2.30, f_1 = 5; f_2 = 18); therefore, a common coefficient $\bar{b}$ = 2.5276 was adopted. Very significant differences between the provenances have been shown.

As for the four-year period, the provenance Stary Sącz held the highest ranking position. The average height () of his transplanted seedlings differed significantly from the value in

Table 5. Equations determining the height increase ($h = a + b \log d$) transplants of silver fir of Polish and Slovak provenances during the days (d) of the fourth growing season and the mean distances of these curves (Y_D) from X axis

n o	Provenance	$h = a - b \log d$	r	$\pm s_{h./1/d}$	Y_D [cm]
4	Stary Sącz	$h = 11.4842 + 2.4817 \log d$	0.994**	0.2336	14.700 a[1]
3	Świętokrzyski P. N.	$h = 10.9626 + 2.5416 \log d$	0.996**	0.2048	14.256 b
1	Rogów	$h = 10.2725 + 2.5324 \log d$	0.998**	0.1469	13.554 c
6	Beňuš	$h = 10.5330 + 2.1539 \log d$	0.993**	0.2233	13.324 c
5	Čierný Váh	$h = 9.5905 + 2.8473 \log d$	0.992**	0.3009	13.280 c
2	Skarzysko	$h = 9.7911 + 2.6122 \log d$	0.987**	0.1742	13.176 d

[1] The same letter indicates statistically homogeneous values, at $\alpha = 0.05$

the provenance from ŚPN, and very significantly from values in other provenances tested. This second provenance in terms of dominated over all others. The provenance from Rogów was the third in the ranking and significantly different only from the provenance from Skarżysko. With respect to of the other provenances, the differences were statistically insignificant

The increase in values was initially very intense. After 26 days, the silver fir provenance Rogów reached 93.1% of the final height, from Skarżysko – 93.3%, Čierný Váh – 93.7%, ŚPN – 94.1%, Stary Sącz – 94.9%, and Beňuš – 95.3%. After 48 days, transplanted seedlings increased and reached the following percentages of final heightin the provenances: Rogów – 97.6%, Čierný Váh – 97.7%, Skarżysko – 98.1%, ŚPN – 98.4%, Stary Sącz – 99.1% and Beňuš – 99.2%.

The earliest, on the 53rd and 54th day, the final height was reached by 2/2 transplanted seedlings Slovak provenances Beňuš and Čierný Váh and immediately after them, on the 55th day – the Polish provenance from Stary Sącz. Then, on the 59th day, the increase in tree height was completed by the provenance from ŚPN, and on the 61st day – by that from Skarżysko. At the latest, after 66 days, grown-ups to the final height – the transplanted seedlings from Rogów.

It turned out that the end of the growth of the transplanted seedlings of individual provenance was very significantly straight related ($r = 0.961^{**}$) to north latitude. The more to the north the stand in which the seeds were collected, the longer was time to grow to the height of the seedlings.

3.3. Number of side branches in tree crown

The height of the transplanted seedlings (2/2)had no significant effect ($r = 0.527^{-}$) on the number of side branches. There was also no relationship between tree height and the northern latitude ($r = 0.099$) and altitude (a.s.l) of the maternal seed stand site ($r = 0.10^{-}$). However, a significant decrease in the number of branches ($r = 0.782^{*}$) was found along with the increase in the eastern longitude (λE) of the location of the stands:

$$G = 5.048 - 0.139.L_E$$

$$s_{y.x} = \pm 0.270 \text{ szt./1}^{o}$$

The transplanted seedlings grown from the seeds collected in the western regions of the Czech Republic had, on average, somewhat more side branches (2.5–4.0) than the transplanted seedlings of Slovak and Polish provenance (2.0–2.4 items), from the positions located more to the east.

3.4. Apical bud numbers and stages of development

The number of apical buds (P) on the main shoot did not depend on the height of the transplanted seedlings (2/2) ($r = 0.554^{-}$). Apical bud numbers vaguely increased with the increase in the latitude of the northern locations of maternal seed stands($r = 0.646^{+}$). However, the bud numbers decreased very significantly ($r = 0.829$ **) with increasing altitude a.s.l. of the maternal seed stands:

$$P = 3.595 - 0.000535\,A$$

$$s_{y.x} = \pm 0.108 \text{ szt./m}$$

There was observed a weak correlation between the number of apical buds and the eastern longitude ($r = 0.593^{+}$) of maternal stand sites.

In the 4th study year, the development of apical buds of transplanted seedlings (2/2) of the Polish and Slovak provenances started on 10 April, 1964. This phase was completed at the earliest, on 27 April by transplanted seedlings of the provenances from Stary Sącz and Čierný Váh, and at the latest – by the provenances from Beňuš and Rogów, on 13 May.

The analysis of covariance of exponents of the logistic curves of all the tested provenances showed a significant differentiation of b coefficients ($F = 3.17^{*}$, $f_1 = 5$, $f_2 = 72$). According to this criterion, the provenances were divided into 2 groups, with insignificant differences in b coefficients. The first group comprised the Polish provenances from: ŚPN, Stary Sącz, Rogów and Skarżysko ($F = 0.54^{-}$, $f_1 = 3$, $f_2 = 43$), with $\overline{b} = -0.1187$. The second group included the Slovak provenances from Čierný Váh and Benuš ($F = 0.30^{-}$, $f_1 = 1$, $f_2 = 24$) with $\overline{b} = -0.1005$. In both groups, the location of the provenances was similar.

Table 6. Values of selected characteristics expressed in standardized units and breeding value of silver fir provenances tested in nursery of the WULS Experimental Forests in Rogów

n o	Provenance	1000-seed weight	Seedling percentage	Height of 2/2 transplants	Coefficient *b* of equations $h = a + bt$	Survival	n umber of twigs	n umber of terminal buds	Breeding value index	Breeding value of provenance
		Standardized index of characteristic value								
1.	Rogów	0.64	0.29	0.12	0.08	0.58	-0.13	1.50	0.44	good
2.	Skarżysko	1.41	-0.97	-0.65	-0.41	-0.53	-0.49	0.17	-0.21	poor
3.	Świętokrzyski P. N.	0.63	1.84	0.60	0.36	0.32	-0.76	0.17	0.45	good
4.	Stary Sącz	0.78	-0.54	1.00	0.83	-0.48	-0.53	1.28	0.33	good
5.	Čierný Váh	-0.69	-0.51	-0.56	-0.49	-1.39	-0.62	-0.39	-0.66	bad
6.	Beňuš	-0.69	-0.54	-0.89	-0.85	1.10	-0.74	-0.72	-0.48	poor
7.	Karlovice	-0.21	0.37	0.83	0.87	0.36	1.07	-0.17	0.45	good
8.	Kaliště	0.05	1.18	1.41	1.42	1.41	2.21	-0.22	1.07	very good
9.	Boubín	-1.90	-1.12	-1.57	-1.82	-1.37	0.03	-1.83	-1.37	very bad

In the majority of the provenances under the study, bud opening began on 27 April, 1964, and ended at the earliest on 13 May in the provenance from Stary Sącz, 2 days later than in the provenance from Beňuš and Skarżysko, and 4 days later than in the provenance from Čierný Váh. At the latest, on May 23, this phase was finished by the provenances from Rogów and ŚN .

Analysis of covariance showed a significant differentiation of coefficients *b* of the equations of exponents of logistic curves (F = 10.93**, f_1 = 5, f_2 = 42) and the identified 2 groups with comparable $\overline{b}$ coefficients. The first group comprised the provenances: Stary Sącz, Čierný Váh and Rogów (F = 3.00$^-$, f_1 = 2, f_2 = 19), with the average $\overline{b}$ = -0.2042, and the second –ŚPN, Beňuš and Skarżysko (F = 1.37$^-$, f_1 = 2, f_2 = 23) with $\overline{b}$ = -0.1187

In the majority of the provenances tested, needle development started on 9 May 1964 (in the provenance from Rogów-2 days later). At the earliest, on 17 May, this phase was completed by the transplanted seedlings of the provenances: Stary Sącz, Čierný Váh and Beňuš, and at the latest by those from Rogów (23 May).

The course of bud developmental stages was consistent with the logistic function. Analysis of covariance showed no significant differences (F = 1.18$^-$, f_1 = 5, f_2 = 25) between *b* coefficient of exponential equations, which allowed to adopt the common coefficient $\overline{b}$ = -0.5309. However, the differences between the positions of the straights representing individual provenances proved to be very significant (F = 48.02**, f_1 = 5, f_2 = 30). A similar location was characteristic for the provenances Stary Sącz and ŚPN. A separate group, very different from these two, was formed by Beňuš, Rogów, ČiernýVáh and Skarżysko.

It should be noted that the real data from phenological observations are consistent with those calculated according to the logistic equations (R^2_{ol}). It fluctuated between 91.7 and 99.8%, averaging 97.3±2.2%

3.5. Assessment of provenance silvicultural value

The assessment of the cultivation-silvicultural value of the provenances from the Carpathian Region (Tab. 6) was based on the average values of seven standard features representing the stages of growth and development of seedlings of the provenances observed under nursery conditions. Among the tested Czech provenances, which were the progeny of selected trees, the provenance from Kalište deserved the highest grade (1.07). The provenance Karlovice achieved worse by half rating (0.45). According to these criteria, the value of their assessment indicators exceeded the value of the progeny of the Polish provenances: ŚPN (0.45), Rogów (0.44), Stary Sącz (0.33),and Skarżysko (-0.21), and –especially – rating of the Slovak provenances: Beňuš (-0.48) and Čierný Váh (-0.66). The progeny of the Czech provenance from Boubín (-1.37) was the last in the ranking, despite the fact that it was derived from selected maternal trees (in the same way as the progenies of the provenances from Kalište and Karlovice).

4. Conclusions

The third successive European provenance trials conducted at the SGGW Experimental Forests nursery confirmed the existence of genetic diversity in silver fi , which was related to the geographical location of the site of origin of seeds. The results obtained showed significant inter-origin diversity in the area between 14^o and 21^{o}of eastern longitude and 49^o and 52^{o}of northern latitude in the area of Poland, Slovakia and the

Czech Republic. This diversity included both seed characteristics (weight, vitality, germination) and derived seedlings (tree growth and height, as well as morphology and phenology).

The seed weight, which largely determines their sowing value (Sabor 1984), showed higher values in the Polish provenances when compared with those from the Czech Republic and Slovakia as well as showed an increase with latitude N and a decrease with increasing altitude location of the seed stands. The same applied to seed vitality, as this feature is closely related to seed weight. Nevertheless, these seed characteristics did not correlate with seed germination and the number of seedlings emerged, which makes it impossible to predict the silvicultural effects. Predicting the production efficiency of silver fir seedlings based on the results of the test of seed cross-cutting or dyeing the embryos often gives unreliable data. It would be advisable to use more objective methods for assessing seed germination, for example, with the use of the germination plate after seed cold stratification in H_2o_2 or without this treatment, or else– by means of X-ray contrast radiography (Załęski 2000).

In the present study, an important feature of silver fir seedlings tested, in addition to the average height achieved in the subsequent observation years, was their growth – proceeding approximately rectilinear, in line with equation: $\overline{h} = a + bt$. The results obtained using this equation were more consistent with the real data than those obtained based on the exponential function ($\overline{h} = at^b$), although it reflects accurately the increase of height

The height of seedlings of the assessed provenances did not affect the number of tree side branches and the number of apical buds, so it could be assumed that these were rather individual traits of the specimens rather than of the population.

Statistically significant variability, expressed in a decrease in the number of apical buds on the main shoot in the examined silver fir provenances from the Carpathian Region and an increase in the altitude a.s.l. of maternal seed stands above sea level found no confirmation regarding the number of side branches

On the other hand, phenological observations showed clival variability consisting in delaying apical bud development and growth during the growing season along with the increasing northern latitude and approaching the northern silver fir range boundar .

The increase in tree height in the growing season lasted not longer than about 70 days and proceeded in a similar way to that observed several years later in a plantation of 10-year-old seedlings of silver fir provenance from ŚNP (Michalak 1977a, b).

Among the well-rated Polish silver fir provenances, the very poor cultivation–silvicultural value of the provenance from Skarżysko proved to be inexplicable, especially when compared with the high ranking of that from ŚNP, which was derived from the neighbouring area. This proves that for the purposes of selective breeding, a specific provenance should be taken into consideration in relation to the parental stand, and not just to a given region.

Considering the positive results of the assessment of the progeny of the selection trees (the provenances from Kaliśte and Karlovice proved the desirability of individual selection), very poor assessment results of the provenance from Boubín can be explained by the adverse effect high-altitude site conditions of the maternal stand on the growth and development traits of the progeny when cultivated under extremely different conditions. For this reason, the Slovak high mountain provenance was poorly adapted to the conditions of the present study, that is, examinations carried out in the environment of natural silver fi occurrence, situated at the lowest altitude a.s.l. in the area of silver fir northern range, which confirms the validity of using vertical regionalization when transferring reproductive material.

Among the examined factors affecting behaviour of the tested silver fir provenances under the conditions of silver fir natural range edge, the altitude above sea level of the sites of parental stands was of decisive importance.

Conflict of interest

The authors declare no potential conflicts

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