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Comparison of the growth of the provenances of silver fir (*Abies alba* Mill.) on research plots in the regions Novohradské hory and Českomoravská vrchovina at the age of 50 years

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Abstract: The study evaluates the results of a long-term research trial lasting 50 years in two research plots established in the 1970s aimed at solving the decline of the silver fir in the Czech Republic. A total of 103 different provenances occurring naturally across 12 countries were planted in research plots No. 67, Černovice (Českomoravská vrchovina), and No. 77, Nové Hrady (Novohradské hory). The total tree height, diameter at breast height (*DBH*) and assessment of the health status of all trees in the area were measured with the same methodology. Subsequently, the volume of large wood was calculated by the volume equation, and the growing stock per hectare was recalculated. Based on our analysis of average height growth, it was found that trees with the best growth came from provenances that included the Czech provenances CZ 70 – Ždírec nad Doubravou, CZ 82 – Vizovice, CZ 42 – Lukov, CZ 76 – Nýrsko, Suchý Kámen, and CZ 53 – Opočno. The last three mentioned provenances also dominated in other growth parameters (*DBH* and volume of large wood). Of the foreign provenances, D 146 – Schwarzwald mit Baar, S 9 – Kriváň, and S 6 – Čierny Váh produced trees that showed above-average values. The smallest growth in height was found in the trees from the provenances BG 132 – Rila, Borovets, F 104 – Departement de l' Aude, I 228 – Vallombrosa, A 93 – Wörschachwald. Although some trees of Italian provenance achieve above-average volume, due to high mortality, they are not suitable for economic use in the forests of the Czech Republic. Based on the European zoning for forests, the units from the Central European region (3.11.0 – České Polabí, 3.32.0 – Schwarzwald with foothills and Baar, and 9.14.0 – Southern Apennine Mountains) were the best rated in all parameters. Specimens from 9.12.0 – Mountain forest of the northern Apennines, and 4.05.0 – Vosges showed the lowest parameters.

Keywords: Czech Republic; European forest zoning; morphological characterisation; provenance research

Silver fir (*Abies alba* Mill.) is a native tree species in forests in the Czech Republic, and together with beech, it forms a significant part of the primaeval upland forests. The current reduced area of silver fir growth in the Czech Republic is 32 272 ha (i.e. 1.2% of total land area), while its representation could increase to 7.6% in the future (Ministry of Agriculture 2022). Fir is one of the most valuable coniferous trees; therefore, it deserves the attention of research focused on its variability and growth development, including a constant expansion of the knowledge of its biology, its adaptability

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to changing environmental conditions and the use of different genetic approaches.

To understand the variability and evolutionary development of silver fir, it is necessary to know its history from the beginning of gymnosperm development. Gymnosperms in the fossil record have been dated to the Carboniferous period of the Palaeolithic era, when some species massively died off, while others gradually evolved. The greatest expansion of morphological diversity occurred in the Triassic and Jurassic periods of the Mesozoic era, when new families were created, and the formation of new genera continued until the early Tertiary (Lu et al. 2014). In this period, the genus *Abies* also formed (approximately 80 million years ago) by separation from the genus *Keteleeria*. The proof is in the Californian fir *Abies bracteata*, which has the ancestral characteristics of both of its predecessors (Semerikova, Semerikov 2014). In the early Cenozoic (beginning of the Tertiary), angiosperms also began to develop, gradually suppressing and displacing gymnosperms (Lu et al. 2014).

In the Miocene and Pliocene epochs (late Tertiary of the Neogene period), the already established genus *Abies* spread over land bridges from today's Turkey to Spain, Morocco and Algeria. In this period, fir species such as *A. alba*, *A. cilicica*, *A. pinsapo*, *A. numidica*, and *A. cephalonica* gradually developed. The land bridges were gradually parted by the increasing expansion of the Mediterranean Sea until the complete separation of Spain and African countries. During the late Pliocene and early Pleistocene, silver fir spread to the southern part of Europe (the Balkans, the Apennine Peninsula, and the Pyrenees) and later gradually reached the northern part of the continent, with the biggest obstacle being the alternation of the ice and interglacial periods in the Pleistocene period. The formation of alpine and continental glaciers in the global north caused, in some cases, a return of silver fir to southern Europe, a slowdown in migration and, for some populations, the creation of small refugia before their release in subsequent periods (Linares 2011). During the Preboreal and Boreal periods (an early epoch of the Holocene; 10–8 thousand years BC), the postglacial development of silver fir progressed by returning to Central Europe from three streams, namely, from the refugia of Italy, the Pyrenees and the Balkans. These three streams were subsequently connected in the northern Alps during the Atlantic era (8–5 thousand years ago), including in our territory. Silver fir reached its greatest extent in the sub-Atlantic period (2500–present), due to a decrease in temperature and an increase in rainfall, while it still occupied lower elevations (Málek 1983; Musil, Hamerník 2007). The distribution of silver fir has been preserved to this day, even though the extent of its natural area has been modified by humans (Figure 1).

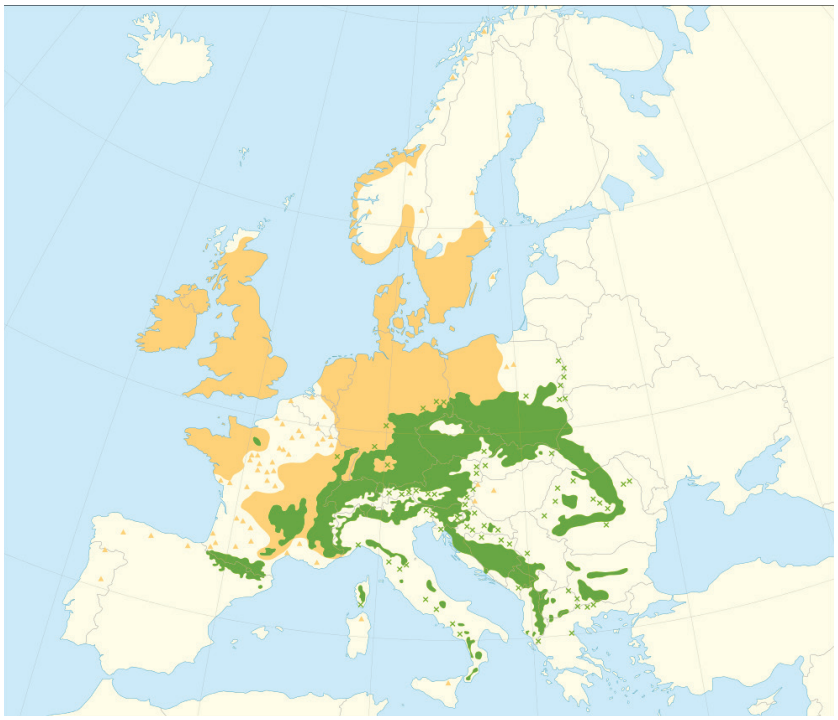

Figure 1. Silver fir area

Green colour – the original natural distribution; orange colour – spread of the tree due to human activity
Source: Caudullo et al. 2017

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Even with the current small representation in forest stands, fir is very important in mixed stands for strengthening them against the adverse effects of wind, where it has a beneficial effect on the structure of the forest soil due to its root system and litter. In terms of the production of domestic tree species, silver fir has the highest growth rate and gives the highest yields of wood, which has the same quality as the economically most important spruce wood. The loss of fir from forests is strongly manifested only in some parts of the natural range of this tree species. Thus, it can be assumed that within the range of the silver fir, there are subpopulations that show higher resistance and viability than domestic populations do in our conditions (Šindelář 1975).

It is necessary to research the silver fir provenances of both domestic and foreign origin while considering their use in forestry practice. The aim of our work was to determine the growth and morphological characteristics of silver fir with a representation of domestic and foreign provenances in research plots. Knowledge of the growth capabilities of particular provenances will allow the selection of appropriate cultivation methods in the future.

MATERIAL AND METHODS

The subject of the presented article is the evaluation of biometrics for selected quantitative characteristics and the classification of some qualitative characteristics for each provenance of silver fir in research plot No. 67 – Pelhřimov, Černovice (Figure 2) in comparison with the evaluation of biometrical data from research plot No. 77 – Nové Hrady, Konratice. These areas were chosen because they represented the largest number of provenances within the entire provenance experiment. The purpose of the evaluation is to assess the possibilities

Figure 2. Research plot No. 67 – Pelhřimov, Černovice

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of using different provenances of silver fir in forest management in the Czech Republic, with a selection of suitable domestic and foreign provenances.

The examples of provenance areas used in this research belong to a series of 20 test sites established in 1973–1977 for provenance research. In the original experimental series, 153 provenances of silver fir were used, as well as several foreign species of the genus *Abies*. The frequency of use was limited by the available number of seedlings grown from seed obtained in 1970–1971 (Šindelář 1975).

Plot No. 67 – Pelhřimov, Černovice was planted in the spring of 1976 on the territory of the former Pelhřimov forestry enterprise. The plantation is located at an altitude of 690 m a.s.l. with southern exposure and a slope of 5%. The average annual temperature is 6.5 °C, the average annual rainfall is 650–700 mm, and the parent rock is gneiss. It is located in the natural forest region (NFR) 16 – Českomoravská vrchovina (Czech-Moravian Highlands) – and belongs to economic group 55, food habitats of higher altitudes. Typologically, these locations are forest types 5S1 – fresh fir-beech – modal. An area of 2.24 ha was established by a completely randomised block design with four replications. The total number of plots of 10 m × 10 m was 224. Planting was carried out in a 2 m × 1 m clip, with 50 seedlings planted on individual parcels, i.e. 200 seedlings for each provenance. The number of provenances was 56, and a total of 11 200 seedlings were planted.

Plot No. 77 – Nové Hrady, Konratice was planted in 1977 on the territory of the former Nové Hrady forestry enterprise. The plantation is located at an altitude of 625–660 m a.s.l. with eastern exposure and a slope of up to 20%. The average annual temperature is 6.8 °C, and the average annual precipitation is 820 mm. The patent rock is gneiss. The site is located in NFR 14 – Novohradské hory and it belongs to economic group 53, acid habitats of higher altitudes. Typologically, these are forest types 5I1 – acid loam fir beech – modal. With an area of 3.24 ha, 81 provenances and a total number of 16 200 seedlings, this is one of the largest areas with the highest number of provenances that was established as part of the abovementioned project. The establishment of all research areas was carried out according to a uniform scheme, which was a block arrangement with four replications.

An overview of the basic regional, geographical and climatic characteristics of the original locations is given in Table S1 in the Electronic Supplementary Material (ESM).

The evaluation of individual plantings was carried out at the ages of 9, 15, 36 months, and 50 years after sowing the seeds.

The last measurements of the height and diameter at breast height (*DBH*) of individual trees were carried out in 2020–2021 with an ultrasonic altimeter Vertex III with an accuracy 0.1 m (Haglöf, Sweden) and a Haglöf calliper with an accuracy of 0.1 cm (Haglöf, Sweden). Subsequently, the values of the volumes of large wood were calculated using the volume equation (Petráš, Pajtík 1991) and the average growing stock per hectare was also calculated for individual provenances.

On the basis of a visual assessment, all individuals growing on the site were classified into classes by stem form (1 – straight, 2 – slightly curved, i.e. slightly bent on one side, and 3 – strongly curved, i.e. multiply bent or significantly bent on one side) and health status (1 – completely healthy, 2 – drying out, and 3 – dying, i.e. with defoliation > 75%).

QC Expert (Version 3.3.6.5, 2016), NCSS (Version 10.0.6, 2015), Statistica (Version Cz 12, 2013), and Past (Version 2.17c, 2001) programs were used for statistical data analysis. After exploratory analysis, a one-factor ANOVA ($\alpha = 0.05$) was performed to evaluate the differences between the provenances, followed by the Tukey-Kramer multiple comparison test (Table S2 in the ESM). Considering the high number of provenances, only the tabular form of the determined values is published. Graphical documentation is available from the authors of the article upon request.

RESULTS

In 2021, 2 969 trees, i.e. 18.3% of those originally planted, were measured in research area No. 77 – Konratice. The highest representation (52 pieces, i.e. 26%) of growing individuals from the 200 pieces originally planted was found in the Czech provenance CZ 130 – Nasavrky, i.e. from the provenance characterised by a lower altitude with relatively higher rainfall. Czech provenances are present on the site in the same ratio of approximately 24–25%. Only 2 Bulgarian provenances from the Pirin and Rila mountains can be included in the same category. The provenance of local origin No. 80 – Nové Hrady in the research area

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experienced great losses and had a representation of only 9.5% of the originally planted individuals.

The average height of the trees across the entire area was 25.88 m at the age of 50 years. The height range of the individuals, represented as the ratio of the tallest and the shortest tree within the provenance, was very balanced. The exception was provenance CZ 102 – Velké Karlovice (18.8–31.3 m, which is a difference of 12.5 m). In site class I, the average value of the height of the main stand at 50 years should be 30.2 m, according to the growth and taxation tables for firs (Černý et al. 1996). The average height found on the plot (25.88 m) therefore corresponds to site class II in these tables for the age of 49 years. The Czech provenances CZ 76 – Nýrsko, Suchý Kámen (27.5 m) and No. CZ 42 – Lukov (27 m), both from higher altitudes, can be rated as the fastest growing in height. Of the foreign provenances, the originally Slovak provenances S 9 – Kriváň (27.25 m) and S 6 – Čierny Váh (27.2 m) were rated as the best growing, as well as the German D 148 – Schwarzwald mit Baar (26.8 m). The smallest growth in height was found for the Bulgarian provenance BG 132 – Rila, Borovets (24.2 m) and the French F 104 – Departement de ľ Aude (24.1 m).

The average *DBH* of all provenances reached a value of 28.11 cm. The diameters of individual trees, for example, in the provenance RO 216, ranged from 8.0 to 52.5 cm, which also was the greatest difference in *DBH* among provenances. A high *DBH* was also found in provenance No. 230 – Serra San Bruno (39.0 cm). Although this provenance shows an above-average height growth, compared to other provenances, it only achieves average values in the volume of large wood. Other foreign provenances, including I 228 – Vallombrosa (35.3 cm) and RO 213 – Maramures (31.9 cm), also produce trees with the greatest increase in *DBH*. Czech provenances with a significant increase in thickness are CZ 211 – Nové Město na Moravě (34.0 cm) and CZ 76 – Nýrsko, Suchý Kámen (27.5 m). The weakest growth in *DBH* was recorded in the same provenances that were weak in heights: the French F 104 – Departement de ľ Aude (23.4 cm) and the Austrian A 96 – Thal (24.8 cm). The median volume of large wood reached 0.862 m^3 (Table S3 in the ESM). The highest value was generally recorded in the trees from foreign provenances, especially the Italian I 230 – Serra San Bruna (1.59 m^3) and I 228 – Vallombrosa (1.28 m^3). Of the Czech provenances, the largest volume was found for provenance CZ 211 – Nové Město na Moravě (1.11 m^3) and CZ 76 – Nýrsko (1.03 m^3). The lowest values of this indicator were found in provenances F 104 – Departement de ľ Aude (0.51 m^3) and BG 132 – Rila (0.59 m^3). When recalculating the growing stock of over-bark (o. b.) for 1 ha of area (Table S3 in the ESM), there were significant changes when the highest growing stock was found in Slovak provenances S 6 – Čierny Váh (1 315.81 $m^3 \cdot ha^{-1}$) and S 12 – Smolnická Osada (1 128.14 $m^3 \cdot ha^{-1}$), together with Czech CZ 134 – Nasavrky (1 132.57 $m^3 \cdot ha^{-1}$). In contrast, the lowest values were found for provenances I 228 – Vallombrosa (182.42 $m^3 \cdot ha^{-1}$), I 229 – Campobasso (249.04 $m^3 \cdot ha^{-1}$) and Czech CZ 211 – Nové Město na Moravě (307.43 $m^3 \cdot ha^{-1}$). The significant difference in the ranking of provenances in the volume of large wood and growing stock per 1 ha of area must be attributed to the high mortality of trees from the Italian provenances and Czech provenance CZ 211 – Nové Město na Moravě.

In the conditions of the research area, most of the stems were straight or slightly bent, while deformed stems were an exception. In the previous educational interventions, when dry, broken and fallen stems were removed along with misshapen or double stems, the health status in the evaluated area was balanced and generally rated as grade 1.

When the provenance groups are divided into units by the European zoning of forests (Rubner, Reinhold 1953), a total of 24 areas and subareas from 5 regions are represented on the site (Table S4 in the ESM). The highest average height (27 m) was found in offspring from unit 6.06.4 and unit 3.07.0 with a height of 26.6 m. On the other hand, below-average growth was shown by offspring from units 4.05.0 (24.10 m), 6.22.0, and 5.01.3 (24.35 m). While height growth with a broadly balanced central belt can be assessed as balanced overall, this cannot be said for the assessment of *DBH*. Considering the physical age of the research area, the average values can be characterised as almost equal; however, there are considerable differences in the marginal values. A value of 39.2 cm was found for trees from unit 9.14.0, which increased in *DBH* the most; by contrast, the lowest dimension (23.4 cm) was measured in trees from unit 4.05.0. From the average values above, the differences between provenances representing different units of forest zoning are significant (Table S5 in the ESM).

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Research area No. 67 – Černovice was evaluated in the period after the end of the growing season in 2020 and is therefore comparable at the age of 50 years with research area No. 77 – Konratice. In the assessment year, there were 2 762 trees in the area, i.e. 24.6% of those originally planted. The highest representation (68 pieces, i.e. 34%) of growing individuals out of the original 200 was found to be those from the Slovak provenance S 14 – Svidník and Polish PL 204 – Susiec (32.5%), followed by the Czech provenances in the range of 30–31%, which included the provenance of local origin CZ 1–15 – Kamenice nad Lipou and CZ 16–30 – Jihlava, Popice. Only 14 and 15% of surviving individuals are of Italian origin (I 228 – Vallombrosa and I 230 – Catanzaro). Of the Czech provenances in the research area, provenances CZ 210 – Nové Město na Moravě and CZ 83 – Kašperské Hory had a high mortality rate with the smallest number of surviving individuals (15% and 17%, respectively) of those originally planted. During the evaluation period, the average height of growing individuals was 23.09 m. According to the growth and taxation tables for firs (Černý et al. 1996), the average height of the main stand at site class I is 30.2 m. The average height of firs (23.09 m) found physically on the surface at the age of 49 corresponds to a site class IV rating in these tables. The Czech provenance CZ 76 – Nýrsko, Suchý Kámen can be rated as the fastest growing in height. The height range of the individuals, as calculated by the ratio of the tallest and shortest tree within the provenance, was also balanced. A significant difference in the height ranges found within the individual provenances can be noted for the almost-local provenance CZ 16–30 – Jihlava, Popice (29.4–10.7 m, i.e. a difference of 18.7 m) and provenance CZ 190 – Frenštát pod Radhoštěm (30–13.5 m, i.e. a difference of 16.5 m).

The provenances from the Czech Republic significantly represented the highest growth in the Černovice research area. Almost equal growth was found for provenances 53 – Opočno (25.4 m), 70 – Ždírec nad Doubravou (25.2 m), 83 – Vizovice (25 m), and 16–30 – Jihlava, Popice (24.8 m). Only the German D 146 – Schwarzwald mit Baar (24.5 m) and the Slovak S 5 – Ružomberok (24.2 m) can be included among this almost-compact group of Czech provenances. At the opposite end of the spectrum, the predominant provenances are Italian, e.g. I 228 – Vallombrosa (18.7 m), Austrian A 93 – Wörschachwald (19.75 m), and the originally Yugoslav provenance BIH 224 – Sokolac (21.9 m). Among the Czech provenances, in terms of height growth, provenance CZ 210 – Nové Město na Moravě, Cikháj (21.8 m) was rated worst. The average *DBH* of all provenances was a value of 25.81 cm, while individual provenances had diameters that ranged from 9.3 to 46.8 cm (CZ 16–30 – Jihlava, Popice), 13.7 to 51.4 cm (CZ 1–15 – Kamenice nad Lipou), and 15.1 to 46.8 cm (CZ 35 – Saint Petersburg). I 228 – Vallombrosa (19.87 cm), A 93 – Wörschachwald (20.98 cm), RO 215 – Vilcea, Voineasa (21.85 cm), and BG 132 – Rila (22.82 cm) showed the smallest increases.

The median volume of large wood reached 0.666 m^3 for the area (Table S3 in the ESM). The highest value was found for provenance I 230 – Serra San Bruno (0.906 m^3) together with a group of mainly Czech provenances with a range from 0.877 to 0.702 m^3. The provenances I 228 – Vallombrosa (0.283 m^3) and A 93 – Wörschachwald (0.352 m^3) showed significantly lower values of this indicator. The growing stock (Table S3 in the ESM) was the highest, especially in the Czech provenances CZ 16–30 – Jihlava, Popice (1 248.19 $m^3 \cdot ha^{-1}$), CZ 102 – Malé Karlovice (1 041.69 $m^3 \cdot ha^{-1}$), and CZ 86 – VLS Hořovice (1 036.74 $m^3 \cdot ha^{-1}$). In contrast, the lowest values were found for provenance I 228 – Vallombrosa (307.96 $m^3 \cdot ha^{-1}$) and CZ 210 – Nové Město na Moravě (385.64 $m^3 \cdot ha^{-1}$). In the conditions of the research area at the Černovice locality, most of the stems were straight, and the discovery of a slightly bent or otherwise deformed stem was rather an exception. With regard to the previous educational interventions, the health status in the assessed area was balanced and generally assessed as grade 1.

Regarding the comparison of provenance groups divided into units by the European zoning of forests (Rubner, Reinhold 1953), a total of 22 areas and subareas from 5 regions are represented in the area (Table S2 in the ESM). The highest average height (25.4 m) was found in offspring from unit 3.11.0.1, followed by groups of offspring from units 3.12.0 and 3.32.0, with values of 24.75 m and 24.5 m, respectively. On the other hand, provenances from units 9.12.0 (18.7 m) and 6.22.0 (21.9 m) showed below-average height growth. The increase in *DBH* is again very different, and the units with the biggest increase are 9.14.0 (31.2 cm) and 3.32.0 (30.4 cm). In contrast, 17.7 cm was the small-

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est growth found from unit 9.12.0, and 22.85 cm was found from unit 5.04.3 (Table S6 in the ESM). The ANOVA results calculated for both research areas distinguished significant differences between individual provenances (Table S2 in the ESM).

DISCUSSION

The research sites from 1973–1977 were evaluated several times during the fifty years of their existence, and the results were published in a number of scientific works. The first results of a large-scale assessment of the growth of silver fir on these research plots were continuously published in 1983–1989 (Hynek 1983a; 1983b; 1989). Over the next few years, further evaluations were carried out, the last of which took place in the years 2019–2021, i.e. at the physical age of 48–50 years and were subsequently continuously published, e.g. Fulín et al. 2023. In addition to the publication of scientific articles, the evaluation of selected research areas was also the subject of a number of degree-granting theses (Mochán 1994; Kohoutová 1995; Podlena 1995; Karban 2000; Kýval 2012). Part of the research was a comparison and evaluation of the growth of *Abies alba* with other exotic species of the genus *Abies* (Šindelář, Beran 2002; Šindelář et al. 2006a; Čáp et al. 2012).

Due to the planned educational interventions with harvester technology, the determination of biometric indices was carried out on the monitored research areas No. 67 – Černovice and 77 – Konratice in advance of these mining interventions to ensure more accurate dendrometric data, especially the height and *DBH*, for which there was a distortion of the data in the overall evaluation.

From the measurements at a younger age, it follows that, for example, provenances BG 131 – Pirin mountains, Razlog, and I 228 – Vallombrosa, I 230 – Serra San Bruno, were generally evaluated as growing at above-average rates. This conclusion was already formulated by Pastuzska (1989), who, however, added that Calabrian firs or firs originally from Romania are among the very well-rated provenances planted in various European locations. In the established experiment in the Czech Republic, however, provenances of this origin are mostly evaluated at an older age as poorly growing and with high mortality. A specific representative of the Italian provenances, provenance I 230 – Serra San Bruno, which was also planted on test plots in Denmark together with other Calabrian provenances (Larsen 1981; 1986), achieves above-average ratings, especially on research plot No. 77 – Nové Hrady, Konratice, just like individual trees. Due to the high mortality, however, it only achieves below-average results, which is related to the ability to adapt to changing environmental conditions. When evaluating the growth of Calabrian provenances in research sites established in the Předhoří Hrubého Jeseníku and Nízký Jeseník areas and evaluated in the same time interval as the aforementioned research areas, Fulín et al. (2023) outlined the influence of the interaction of the continental climate and an altitude of more than 1 000 m a.s.l. on the development of the growth of foreign provenances in the territory of the Czech Republic.

Szeligowski et al. (2011) compared plantings of foreign and domestic silver fir. During the evaluation at the ages of 30 and 35 for five Polish and one German provenance from the Schwarzwald region, the planting of trees from the German provenance in the given location was not recommended. In the Konratice research area, provenance D 148 – Schwarzwald mit Baar, Gengenbach was assessed as average in growth, as it was in the other established research areas No. 73, 76, and 79 (Čáp et al. 2011; 2013).

In the locations of Nové Hrady and Černovice, large groups of silver fir with provenances from the entire area were planted. In this area, it was confirmed that units of local origin are the most productive (Šindelář et al. 2006b). In a similar experiment with Czech provenances planted in a research plot in Denmark, Czech provenances showed only below-average growth (Larsen, Mekic 1991; Hansen, Larsen 2004). Several southern Italian provenances also grow on the research plots in the Czech Republic and Germany (5 of these provenances are in the Konratice locality), and the assumptions from the findings on the plots in Denmark were not confirmed in the Czech Republic and Germany. A certain dependence on specific conditions in the place of origin was also demonstrated in the areas established in 1977 in Poland. Trees of provenance CZ 210 – Nové Město na Moravě planted in Nové Hrady and in Poland show poor growth and high mortality. The different growth of individual provenances is obvious when comparing the units as a whole. On the basis of the European forest zoning, the units from the Central European region 3.11.0 – České Polabí, 3.32.0 – Schwarzwald with

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foothills and Baar, and 9.14.0 – Southern Apennine Mountains were rated best in all parameters. In contrast, the lowest parameters were from units 9.12.0 – Mountain forest of the northern Apennines and 4.05.0 – Vosges (Table S6 in the ESM). From the comparison of both research areas, significant differences in height and *DBH* growth were found between provenances planted in both research areas (Table S3 in the ESM). At the Konratice location, the provenance CZ 1–15 – Kamenice nad Lipou is 2.8 m higher than at the Černovice location. As with BG 132 – Rila, which is among the worst growing at both locations, the values in all monitored parameters for the Konratice location are higher than those at the Černovice location. Not only do climatic conditions have an effect on the successful growth of forest tree populations, but soil conditions and sufficient tree nutrition are also integral parts of the correct choice of locations for intended plantings (Novotný 2023; Podrázský et al. 2018).

According to the findings within the monitored research sites from the 1973–1979 series, the greater variability of growth can be monitored in the growth of the provenance itself, rather than the entire set of individual provenances. During the fifty-year observation of the growth of individual provenances, the growth of individual provenances was balanced in the later periods. Climatic conditions at the place of origin have a significant influence expressed genetically in the new environment. Even though some individuals can achieve growth values higher or above average in the new environment than the provenance of origin, high mortality rates make their use for planting impossible.

CONCLUSION

The study of silver fir in the form of provenance experiments helps researchers understand its specific needs and conditions for growth and optimise its use in forestry. Long-term observation of individual fir provenances provides insights into how the conditions for the growth and development of silver fir change as a result of climate changes and its possible interactions with other plant species. Together with research focused on the genetic variability of populations, this study should help obtain more accurate information on how different provenances react not only to climate changes but also to various abiotic and biotic stresses throughout their range. When evaluating the results of field investigations from the research sites in this series, the most universally appropriate provenances for reforestation in the Czech Republic, in the event of a lack of planting material in the place of origin, are provenances CZ 16–30 Jihlava, Popice, CZ 86 VLS – Hořovice, CZ 76 – Nýrsko, and the provenance from the Carpathian region, e.g. CZ 102 – Malé Karlovice. Imported populations mainly from Bulgaria (Rila Mountains), Romanian RO 215 – Vilcea, and some provenances from Italian Calabria appear to be less suitable for possible planting in the forests of the Czech Republic. These provenances can reach above-average values as individuals; however, in view of their high mortality rate, the growing stock per 1 ha of area is small. Of the Czech provenances, the provenance CZ 210 – Nové Město na Moravě is the least successful in the research areas.

It is also worth mentioning the possibilities of growing and testing fir in hydroponic systems and their adaptation in planting sites. In cooperation with all the scientific fields mentioned above, it is possible to identify provenances that can adapt to specific climatic and natural conditions, which would increase the productivity of economic forests. Overall, it can be expected that research on the provenance of silver fir will continue and bring new knowledge, enabling a more detailed understanding of this important forest tree and ensuring its sustainable use in the future. Considering the need for long-term studies and the relative slowness of the growth of new individuals, many more years should be devoted to this research.

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