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Growth and morphological characteristics of indigenous Elms (*Ulmus* sp. L.) planted in The Arboretum Borová hora

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Abstract: The work deals with the assessment of growth and morphological characteristics of *Ulmus laevis* Pall., *Ulmus glabra* Huds., and *Ulmus minor* Mill. Altogether, 134 indigenous individuals native to various localities of Slovakia were assessed. The results of measuring dendrometric characteristics showed significant differences in height, tree trunk diameter and crown width especially with the tree species *Ulmus laevis* Pall. which was assessed in four stands with different environmental conditions (dried out and waterlogged sites with various soil types). The largest individuals growth on sites with high soil moisture and bedrock diluvia with tufaceous material. Their height average was 24.4 m and diameter average $d_{1,3}$ 76.5 cm. In the other tree stand (two dry and one moisture and poor soil) were ranged height average from 13.6m to 24.7 m, diameter average $d_{1,3}$ from 21.0 cm to 25.3 cm. On the basis of dendrochronological analyses, the four individuals representing each stand were assessed also with regard to their mean radial increment reaching the values of 2.8 – 7.5 mm per year.

The age and position of *Ulmus* trees individual influenced their heights, diameters and crown projections. Health of the assessed species was satisfactory, no considerable damage or attacks by quarantine tracheomycosis *Ophiostoma novo-ulmi* Brasier were found.

Keywords: *Ulmus* sp., autochthonous origins, biometrical characteristics, radial increment.

Introduction

Nowadays, the occurrence of the genus *Ulmus* sp. in the territory of Slovakia (data from the year 2013, GREEN REPORT 2014) is minimal, it presents only 655 ha (0.03%) of the total forest area and its portion in forest ecosystems continually decreases. According to PAGAN & RANDUŠKA (1987) there was *Ulmus* sp. abundance of 0.12% in the year 1953 and in 1970 it increased to 0.2%. In the course of the following decades, it gradually decreased its value sevenfold. The sharp fall in elm abundance in natural localities after 1970 is closely connected with another wave of elm dieback that started in the 1970s – 1980s and that is practically continuing until today. It is caused by a more aggressive mutated strain of *Ophiostoma novo-ulmi* (BREISER 1991). The whole attacked tree will die in the course of five years, while typical symptoms of the disease are gradual wilting and chlorosis of leaves, later on their turning brown. On the cross-section of branches or stems, there appears a typical brown ring caused by toxic excretes of a fungus with high protein from which the most important is cerato-ulmin (TAKAI 1974). *Ophiostoma novo-ulmi* is most frequently spread by the carrier *Scolytus multistatus* which carries conidia or fungal spores on its body and in its digestive tract (ZÚBRIK et al. 2008). In closed elm stands, the direct infection can occur by means of intertwined, touching roots (D'ARCY 2000). From among autochthonous elms in the territory of Slovakia, the most prone to dieback are European field elm (*Ulmus minor)* and Scotch elm (*Ulmus glabra).* A relatively most resistant appears European white elm *Ulmus laevis* (SÁDOVSKÝ 2002). At present was recorded new invasive pest *Aproceros leucopoda* (zigzag elm sawfly) in numerous localities in Slovakia. His spreading is caused by climate change and is expanding northwards from South Europe (ZÚBRIK et al. 2017) and worsens the health of already weakened elms. STAŠIOV et al. (2012, 2017) recorded a broad biodiversity of Millipede communities (21 species) and Opiliones communities (17 species) on *Ulmus leavis* stand in Arboretum Borová hora.

Ulmus leavis and *Ulmus minor* are tree species of more southern warmer areas occurring especially on nutritive soils of hard-wood floodplain forests in the vegetation zones 1 and 2. *Ulmus minor* makes also a so-called dry edaphotype, where it grows in the forest steppe communities with *Quercus pubescens* Willd*., Quercus cerris* L. and *Qurecus petraea* (Matt.) Liebl. In these localities, it is usually of a short, shrubby shape, with smaller leaves, frequant cork strips and it is part of varied thermophilic communities with *Cornus mas* L., *Cerasus mahaleb* (L.) Mill., *Sorbus torminalis* (L.) Crantz, *Tilia cordata* Mill., *Acer campestre* L.*, Acer platanoides* L. and others.

At an early age *Ulmus laevis* tolerates also higher shading, with an increasing age it become light-demanding. The edaphotype of floodplain forests tolerates also longer-lasting floods, partially it can grow also in the conditions of soft-wood floodplain forest. However, it develops also the ecotype growing on drier sites, resistant to drought and salting soils. The northernmost occurrence of *Ulmus laevis* in Slovakia is given by JARČUŠKA (2010) in the orographic unit of Levočské vrchy hills to the south of the village of Brezovica at an altitude of 655 m. The population is made up of more than 100 individuals in height of 2 – 15 m and with a diameter of $d_{1,3}$=1-24 cm in the understorey of a 120-year- old stand of *Larix deciduas* Mill. along with *Corylus avellana* L. and *Prunus spinosa* L.

Ulmus glabra is the most voluminous and long-lived species of the three indigenous elms growing in the conditions of Slovakia. It occurs up to the vegetation zone 6 and optimally grows on well-aerated moist soils of the vegetation zones 4 and 5 supplied with nutrients or on colder exposures of the vegetation zone 3. In the conditions of the Slovak Republic we have preserved seed sources of elms in a category of *seed trees* in number of 129 individuals with *Ulmus glabra* and 57 individuals with *Ulmus minor*. *Certified seed stands* are only with *Ulmus glabra*, in number of 26 including 18 autochthonous stands. Moreover, *Ulmus glabra seed orchard* has been established, approved in 2013. There were outplanted 352 grafted plants from different original localities of this valuable tree species ("Databáza stromov Lesného reprodukčného materiálu SR" – *Database on trees of Forest Reproductive Material, Slovak Republic*, 2014).

Basic knowledge of ages and growth rates of trees is essential not only for a better understanding of physiology of an individual tree but also for the proper application of various treatments such as pruning and thinning (JACKSON 1952). This knowledge is commonly obtained from measurements of trees in the Permanent Research Plots (PRPs). The monitoring period of most PRPs spans just a fraction of the ages of trees, which often results in a lack of accurate long-term data on ages and growth of commercial tree species (GROENENDIJK et al. 2014). An alternative and relatively fast approach to obtain tree ages and growth data is the use of the tree-ring analysis (BRIENEN, ZUIDEMA 2006). For many deciduous ring-porous tree species (such as those in the elm and ash family), a clear boundary can be seen between cell types making growth rings easily identifiable (BARTENS et al. 2012), which makes these species suitable for the dendrochronology analysis. Trees respond to environmental impacts with corresponding changes in their annual growth rings (ZHANG et al. 1999). Tree-ring width characteristics are a direct measure of macroclimatic and site variations and can be used to estimate the amount of environmental stress on the growth (FRITS 2001).

The specific objectives were to determine: (1) how are the selected morphological and growth characteristics of all three elms native to the arboretum conditions and (2) how radial growth patterns of *Ulmus leavis* vary under different growth conditions.

Material and methods

Study area

The material was obtained by assessing autochthonous species of elms outplanted in the area of Borova Hora Arboretum. Each individual (taxonomic unit) is a subject of separate evaluation and observation. The individuals grow in different parts (stands) of the arboretum which are typical of these parent bedrock: stand 3b – travertine diluvia with loess admixture, 4a loess diluvia with travertine admixture, 2c, 4b – diluvia of tufaceous material with travertine and silicous gravel admixture, 5b – middle-grained alluvial sediment loads of the Hron river, 6e – diluvia of tufaceous material (locally with an admixture of loess loam and siliceous sands), 10a, 10c, 10f – diluvia of tufaceous material and subsoil kaolinized andesite tuff. Climatic characteristics of the locality are: altitude range from 291m to377 m; average annual temperature + 8.8 °C; average temperature in the vegetation period + 15.6 °C; average annual precipitation 640 mm; average annual precipitation in the vegetation period 399 mm (LUKÁČIK et al. 2005).

Field measurement and assessment

The outplanted elm species are given in Tab. 1. To assess variability and growth characteristics of studied individuals (134 ones, Tab. 2), we have used the following methodical procedures:

Assessment of the tree habit:

1 Shape:
   a) canopy closure,
   b) solitaire: ba) ovoidal; bb) irregular ovoidal; bc) irregular; bd) globular; be) overhanging; bf) columnar; bg) undeveloped, others.

2 Quantitative characteristics:
   a) height (m) with accuracy of 0.1 m,
   b) diameter (cm) with accuracy of 1 mm at a height of 1.3 m ($d_{1,3}$),
   c) crown diameter (m) with accuracy of 0.1 m – two diameters perpendicular to each other in the directions of N-S, E-W.

3 Crown density:
   a) dense (more than 10 branches per 1 m of stem length),
   b) medium-dense (5 – 9 branches per 1 m of stem length),
   c) open (less than 5 branches per 1 m of stem length).

Health condition of all individuals was also assessed (insects, *Ophiostoma novo-ulmi*).

At a height of 1.3 m above ground, we cored four European white elm individuals growing in different soil and site conditions.

Tab. 1. Characteristics of Elm species (*Ulmus* sp.) origins outplanted in Arboretum Borova Hora

tree species	registration number	stand	date of planting	original/native locality	altitude (m)	coordinate	note
U. laevis	1279	2c	11/1969	Zv. kotlina basin, Sliačska kotlina basin, Vlkanová	310	48° 40' 00 19° 09' 00	Hron riverside, seeds
U. laevis	1279	3b	11/1969	Zv. kotlina basin, Sliačska kotlina basin, Vlkanová	310	48° 40' 00 19° 09' 00	Hron riverside, seeds
U. laevis	1279	4a	11/1969	Zv. kotlina basin, Sliačska kotlina basin, Vlkanová	310	48° 40' 00 19° 09' 00	Hron riverside, seeds
U. laevis	1279	5b	03/1971	Zv. kotlina basin, Sliačska kotlina basin, Vlkanová	310	48° 40' 00 19° 09' 00	Hron riverside, seeds
U. glabra	3534	10f	11/1993	Pieniny, Červený kláštor, Kláštorná hora	500	49° 24' 00 20° 26' 00	young plants
U. glabra	3237	10c	10/1990	Slánske vrchy hills, Simonka, LS Hanušovce, Lipníky, Pod dielami	430	49° 00' 00 21° 25' 00	young plants
U. glabra	3236	10c	10/1990	Slánske vrchy hills, Milič, LS Slanec, Nový salaš, Pod Uhliskom	330	48° 37' 00 21° 29' 00	young plants
U. glabra	3151	10a	4/1989	Volovské vrchy hills, Zlatý stôl, LS Stará voda, Švedlár, Lipový vrch	550	48° 46' 00 20° 42' 30	young plants
U. glabra	989	6e	11/1967	TANAP, Tatranská Lomnica, ŠS Nový Smokovec, Pod lesom II	750		seeds
U. minor	2275	4b	11/1977	Podunajská rovina lowland, Palárikovo pheasantry	110	48° 01' 00 20° 04' 30	seeds

Data processing

The obtained values of biometrical characteristics were analysed by the basic statistical methods such as arithmetic means of heights, diameters ($d_{1,3}$), standard deviations, maxima and minima for the outplanted elm species.

The obtained increment cores were air-dried, mounted on wooden boards and sanded with progressively finer sandpaper according to COOK, KAIRIUKSTIS (1992). To ensure accuracy of the measurements obtained from the core samples, two independent analysts marked the annual rings of each series. The first analyst scanned the samples using the Epson Expression 10000XL scanner and measured the ring widths with WinDendro® software, the latter one measured the ring widths using the LINTAB 5. The analysts independently agreed on all of the ring measurements. The measured ring-sequences were plotted and the patterns of wide and narrow rings were cross-dated among trees. We confirmed the accuracy of cross-dating by COFECHA software (HOLMES 1983). In order to remove variations due to tree maturation and stand dynamics we performed a standardization of the individual ring-width series using the program ARSTAN (GRISSINO-MAYER et al. 1993). Significant differences between mean tree ring widths of the sampled elms were tested by means of ANOVA. After that the Duncan test were used to identify the pairs of means that differ among the four samples. To describe the mean tree ring widths – age relationship, the polynomial function was used and to assess the goodness of fit, the coefficient of determination (R^2) was calculated. In order to characterize the variability in the ring-width series the standard deviations, mean sensitivities and first-order autocorrelations were calculated (FRITS 2001).

Results and discussion

Growth characteristics obtained by measuring elm individuals are given in Tab. 2. It shows the assessment of growth characteristics in the arboretum, which are considerably influenced by age, but also a position of an individual within other tree species in the given stand.

Tab. 2. Basic dendrological characteristics, morphological evaluation and number of assessed elms (*Ulmus* sp.)

tree species	registration number	stand	age	number of individuals (pc)	height average (m)	diameter average $d_{1,3}$ (cm)	crown width (m)		shape	crown density
							N-S	E-W		
Ulmus laevis	1279	2c	46	2	24.4±2.9	76.5±13.4	11.5±0.7	9.8±1.1	broadly irregular ovoidal	dense
	1279	3b	46	13	13.6±2.6	25.3±7.4	6.6±1.8	5.3±1.7	canopy closure	dense
	1279	4a	46	29	18.4±2.5	22.5±6.1	6.0±1.4	5.6±1.5	canopy closure	dense
	1279	5b	44	71	24.7±5.1	21.0±8.9	6.8±1.8	6.2±1.8	canopy closure	medium dense
Ulmus glabra	989	6e	48	5	19.2±1.0	33.1±9.8	8.2±2.5	4.6±2.0	irregular	medium dense
	3151	10a	26	2	11.00±0.7	21.8±1	4.5±0.7	5.0±1.4	irregular	medium dense
	3237	10c	25	1	12.8	15.6	4.0	3.0	irregular	medium dense
	3236	10c	25	1	13.6	33.5	8.0	8.5	irregular	medium dense
	3534	10f	22	8	8.6±6.5	8.1±4.5	3.3±1.9	2.2±1.5	irregular	medium dense
Ulmus minor	2275	4b	38	2	4.85±0.5	16.4±2.1	6.8±0.3	5.5±0.7	desintegrated globular	dense

Among *Ulmus leavis* populations outplanted in the arboretum two individuals excel at above-standard growth as solitaires in the stand 2c. They have the greatest heights and diameters. The diameter $d_{1,3}$ of one of them reaches 80 cm (base of slope) in the orientation of E-W, 92 cm in the orientation of N-S. The two individuals are 10 m distant from each other and they grow in the conditions which are evidently the most suitable for the taxon in question. It concerns bedrock rich in nutrients – diluvia of the tufaceous material with local loess and siliceous sands admixtures supplied amply with underground as well as surface water from more highly located spring areas. In the stands 3b and 4a, the individuals of the same origin and age are planted, however, in less suitable site conditions. This concerns travertine and diluvia of travertine with sufficient soil water predominantly only in spring months. These stands in the arboretum are typical of an almost forest steppe character of vegetation conditioned by a nearby travertine heap with an active small travertine lake. Despite this fact their mean diameter is higher than with other species in the stand 5b, where the most numerous planting is situated on predominantly medium-grained sediments of the Hron river alluvia in the lowest flat parts of the arboretum area. Elms in this site reach on average the greatest heights from among elms grown in the canopy. Their mean diameter, however, is the lowest of European white elms growing in the arboretum (Tab. 3). Individuals *Ulmus laevis* planted on dried subsoil of travertine in the stands 3b and 4a document an adaptability of European white elm obtained from riparian vegetations of the Hron River. Though its mean height in the stand 3b is up to 10 m behind the heights of elms growing on sites well-supplied with water, these individuals reached higher values in diameter. From the standpoint of wood quality, it would be interesting to compare wood quality from the dried site (3b, 4a) and from the flooded and waterlogged site (5b) in the Arboretum Borova Hora. Stems of individuals in the stands 3b and 4a are 90% overgrown with dense adventitious shoots (epicormics), while the stems of elms planted in alluvia of the Hron river are almost without adventitious shoots (5%). As the individuals of this origin were planted in approximately equal spacing in the stands 3b, 4a, and 5b, mean crown diameters are approximately equal and corresponding to their growth space. All individuals of *Ulmus laevis* growing in the arboretum are of a relatively good health state, there is not any damage by quarantine fungal disease *Ophiostoma novo-ulmi* causing elm tracheomycosis on them. JARČUŠKA (2010) mentions that till now the northernmost localized *Ulmus leavis* population in the Levočské vrchy hills has probably originated autochthonously, which results from a considerable diameter and height variability, he does not mention their being attacked by tracheomycosis. SÁDOVSKÝ (2002) refers to massive regeneration of autochthonous *Ulmus leavis*, especially on lower river courses, to its comparable or better resistance to *Ophiostoma novo-ulm.* Therefore, he does not recommend outplanting Siberian elm (*Ulmus pinnato-ramosa* Dieck) which might be more resistant to tracheomycosis, however, in the conditions of Slovakia it could become an invasive species.

Resistance to *Ophiostoma novo-ulmi* or to *Ophiostoma novo-ulmi* ssp. *americana* ×*novo-ulmi* in the conditions of Central Europe from several points of view was studied by ĎURKOVIČ et al. (2013, 2015). By the suspension of hybrid M3 spores (*Ophiostoma novo-ulmi* ssp. *americana* ×*novo-ulmi*), he inoculated one-year tissues of ten-year-old elm hybrids: 1 'Groeneveld' [*Ulmus hollandica* 49

× *Ulmus minor* ssp. *minor*] and 2 'Dodoens' [*Ulmus glabra* 'Exoniensis' × *Ulmus wallichiana* P39] growing in experimental plots in Banska Bela. He mentions that growth of leaves and respiration of the hybrid 'Dodoens' [*Ulmus glabra* 'Exoniensis' × *Ulmus wallichiana* P39] was not influenced by infecting the tissues with fungal disease DED, which predestines it as a genetic base for further elm breeding concerning their resistance to tracheomycosis. Individuals of *Ulmus scabra* outplanted in the arboretum come from five natural localities and they are uneven-aged. The oldest species (registration number 989) come from Smokovec and they reach the vastest dimensions. Crown projections of this species correspond more or less to the closed stand. It is worth mentioning that the crown size of outplanted individual – solitaire no. 3237 from Slánske vrchy hills (forest district of Hanušovce) reaching the highest values compared with *Ulmus glabra* outplanted at approximately the same time. The highest Scotch elm recorded in Slovakia reaches a height of 41 m and a diameter of $d_{1,3}$ 78 cm and it is from the locality of Hrončokovský grúň (HOLEKSA et al. 2009). Increased *Ulmus glabra* representation is given also by DANKOVÁ (2013) in the National Nature Reserve Sitno, where she mentions up to 2.8 % representation in experimental plots. However, the taxon in question occurs here only in the lower and middle layer, with a mean diameter of $d_{1,3}$ = 21.8 cm, in the upper layer it practically does not occur.

The identified species *Ulmus minor* outplanted in the arboretum comes from the pheasantry in Palárikovo and it has a rather shrubby character. Individuals outplanted in 1977 have a rounded, partially disintegrated crown reaching a height of 5 metres and probably representing a dry edaphotype of *Ulmus minor*. None of individuals *Ulmus glabra*. and *Ulmus minor* outplanted in the arboretum showed the attack by quarantine fungal disease *Ophiostoma novo-ulmi.*

Average growth rates of elms in our study ranged between 2.8 mm.year^{-1} – 7.5 mm.year^{-1}. If we compare this with black alder (2.4 – 4.7 mm.year^{-1}) (BALANDA et al. 2012) and grey alder (2.4 – 3.5 mm.year^{-1}) (BUGALA & PAROBEKOVÁ, 2016), which are considered to be fast-growing tree species, we can state that elm in optimal conditions and with correct tending has a production potential comparable with that of fast-growing tree species. Compared with pubescent oak (0.6 – 1.7 mm.year^{-1}) and Scots pine (0.7 – 2.8 mm.year^{-1}) (PASCALE et al. 2007), the production potential of elm is practically double.

Tree-ring chronologies for the four elms under study are shown in Fig.1. The correlations among these chronologies were low suggesting that the spatial heterogeneity of site conditions in Borova Hora Arboretum is very high. Only the specimens 3b and 4a showed a generally similar growth pattern (and they were successfully cross-dated) with high growth at a young age, decrease in middle years and increase in recent years. The specimen 2c showed exactly the opposite growth pattern and the specimen 5b had a relatively constant growth with a slight decrease over time. As shown in Fig. 1 and Tab. 3, the growth performance of the specimen 3b was lower compared to the other specimens except the early growth phase (up to the year 1995), where it showed a similar growth with the specimen 5b. The specimen 2c showed the highest mean ring width reflecting its fast radial growth relative to other species. The detected difference in radial growth in the year 2015 was approximately twice as high in comparison with other specimens. These results were confirmed also by means of the ANOVA and Duncan test. The mean sensitivity of tree ring width series was nearly the same for all studied specimens with exception of 2c which showed the lowest mean sensitivity suggesting that its ring widths had the lowest inter-annual variability and it was less sensitive to yearly environmental changes. The first-order autocorrelations ranged from 0.51 to 0.75 for the four chronologies suggesting the existence of low frequency variation (long period) in the chronologies caused by propagation of climatic effects from one year to the following ones or by long-term effects of tree physiology.

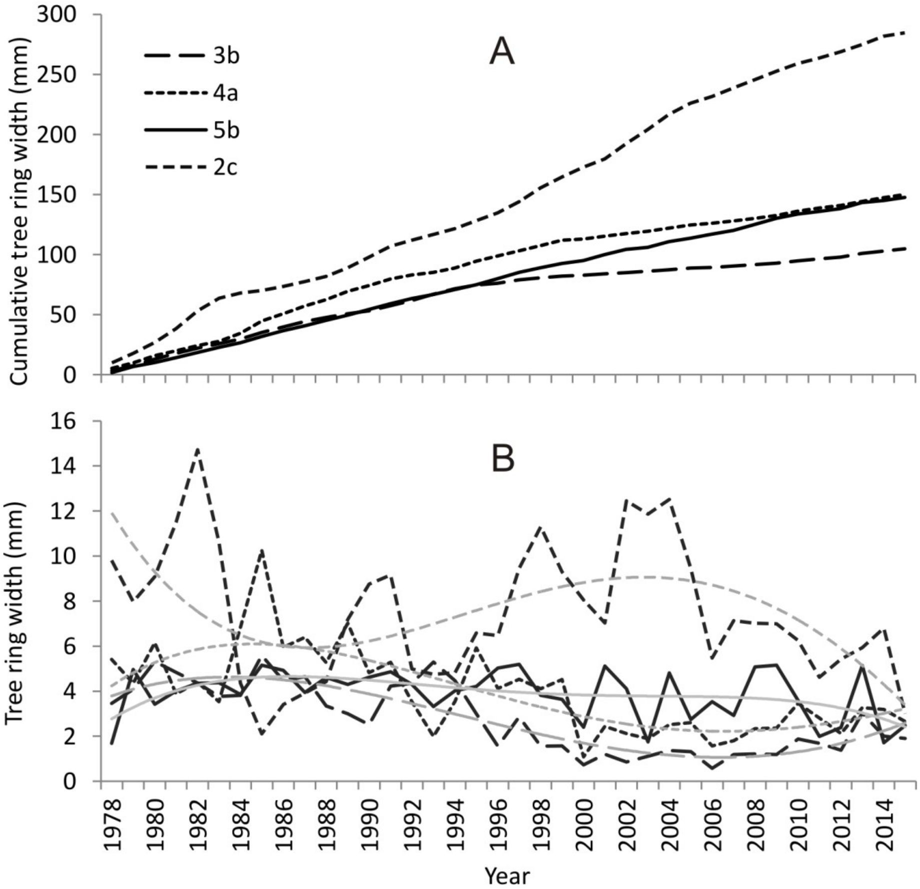

Fig. 1. Cumulative stem diameter growth curves (A) and ring width chronologies fitted with polynomial function (grey lines) (B) of the four sites

Tab. 3. Statistics of *Ulmus leavis* tree ring data in all sites.

site	number of rings	tree ring width (mm)			mean sensitivity	first-order autocorrelation
		mean ±SD*	min.	max.		
3b	43	2.8 ±1.5 [a]	0.6	6.5	0.31	0.75
4a	43	3.9 ±1.9 [b]	1.1	10.3	0.32	0.58
5b	40	3.9 ±1.1 [b]	1.7	5.2	0.32	0.51
2c	38	7.5 ±3.0 [c]	2.1	14.7	0.26	0.64

Pattern matching in tree rings, or cross-dating, became a fundamental principle of the science of dendrochronology (COOK & KAIRIUKSTIS 1992, FRITTS 2001). Cross-dating is possible because climate or other regional environmental factors limiting annual radial growth produce the common year-to-year variation in tree rings across a large number of individuals (MAXWELL et al. 2011). On the other hand, a lack of a growth-limiting factor that synchronizes cambium activity in a given species leads to varying growth patterns among individual trees as local growing conditions are likely more influential than climate factors (GROENENDIJK et al. 2014). This was our case too. We were able to successfully cross-date only the specimens 3b and 4a growing under the same site conditions. We were not able to successfully cross-date the specimens 2c and 5b with different water and soil conditions and in case of 2c also with a solitary growth. To ascertain the accuracy of ring-sequences we used two methods and two analysts to measure the ring widths. The analysts independently agreed on all of ring measurements and so we are confident that dating of our rings were absolute. Low correlations between ring width and climate of urban trees were found also by BARTENS et al. (2012). He suggests that site-specific conditions (microclimate and soil properties) strongly influence tree growth including the case when trees grow near one to another. Several dendroclimatological studies showed a relatively weak relationship between the annual tree growth and climate factors (temperature, precipitation) under wet conditions (LINDERHOLM & LEINE 2004, DOUDA et al. 2009, BALANDA et al. 2012, BUGALA & PAROBEKOVÁ 2016). Therefore, in the case of specimens 2c and 5b, we were not able to cross-date these specimens. Apparently, local conditions were so variable that broad climatic factors became hidden or distorted and so the cross-dating was impossible.

Conclusions

Elms (*Ulmus* sp.) are irreplaceable part of forest ecosystems. The fastest-growing elm of autochthonous species outplanted in Borova Hora Arboretum was *Ulmus leavis* from the stand 2b growing on the soil rich in nutrients whose subsoil is made up of deluvia of the tufaceous material with a local admixture of loess and siliceous sands with good moisture conditions. The origin *Ulmus laevis* Pall. from Vlkanova grows also on dried sites in forest steppe parts of the arboretum where, however, it does not reach a mean height comparable with mean height of individuals from other stands. However, these facts point out to its high adaptability to changes in the environment conditions and thus also an ability to successfully survive in natural conditions of forest communities.

The origins *Ulmus laevis* from the area of Vlkanova as well as the species *Ulmus glabra*. and *Ulmus minor* outplanted in the Arboretum Borova Hora can be considered valuable genetic resources.

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