Variability in the growing season of selected European and East-Asian woody species in relation to air temperature changes

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Abstract

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Data series for leaf unfolding and leaf fall phenophases of European and East-Asian trees were analysed and related to air temperature at the Mlyňany Arboretum SAS. Over a period 1971–2011, annual mean air temperature (T_{am}) and mean spring air temperature (T_{24}) increased by 1.41 °C or 1.06 °C, respectively. The temperature increase affected onset of phenophases and length of growing season. Beginning of growing season (BGS) advanced by 19 days for European (1990–2011) and 9 days for Asian taxa (1991–2008). End of growing season (EGS) delayed by 2 or 4 days for European and Asian species, respectively. Length of growing season (LGS) extended by 10.31 or 7.58 day / decade for European and Asian species, respectively. The earlier onset of BGS was more prominent for European than Asian taxa and the difference was significant. On the other hand, a difference in EGS or LGS between European and Asian species was not significant. Relationships between BGS and T_{am} or T_{24} were significant for all species, and the relationships were closer for European species. Strong and significant correlation was detected between T_{am} and LGS of European trees, however it was weak and non-significant for Asian species.

Keywords
air temperature, climate change, Mlyňany Arboretum SAS, tree phenology

Introduction

In the temperate zone an annual timing of phenological events of woody plants is mainly driven by air temperatures after the plant dormancy is released. Phenological observations are one of the most sensitive data in identifying how plants respond to climate conditions and they are also used in the study of climate change and global warming (e.g. CHMIELEWSKI and RÖTZER, 2001; DONNELLY et al., 2006). In the last years number of papers on changes in timing of plant phenological events in response to changing climate is permanently increasing (BEAUBIEN and FREELAND, 2000; MENZEL, 2000; CHMIELEWSKI and RÖTZER, 2001; BRASLAVSKÁ and KAMENSKÝ, 2002; CHMELIEWSKI, 2002; BISSOLLI et al., 2004; DONNELLY et al., 2006; ŠKVARENINOVÁ, 2007, 2008, 2009; BEDNÁŘOVÁ and MERKLOVÁ, 2007; IBÁÑEZ et al., 2010; HÁJKOVÁ et al., 2010, 2012; ŠKVARENINOVÁ and SNOPKOVÁ, 2010). Recent results indicate that phenological trends of native trees in Europe correspond well with current climatic changes (CHMIELEWSKI and RÖTZER, 2001; CHMELIEWSKI, 2002). Seasonal timing of spring events such as budding, leafing or flowering of plants does depend highly on air temperature. In many studies a good correlation between the spring phenophases and air temperature was found (WALKOVSZKY, 1998; WIELGOLASKI, 1999; CHMIELEWSKI and RÖTZER, 2000; SPARKS and MENZEL, 2002; DONNELLY

et al., 2006). Average air temperature between February and April was proved to be decisive for onset of the spring phenological events of native trees in Europe (CHMIELEWSKI and RÖTZER, 2000, 2001). A length of growing season is an important measure in agriculture, horticulture and forestry. One of the evidence that plants are responding to the current climate change in the temperate zone is the lengthening of their growing season (MENZEL and FABIAN, 1999; CHMIELEWSKI and RÖTZER, 2001; HÁJKOVÁ et al., 2010; IBÁÑEZ et al., 2010). In general, the observed extension of growing season is mostly the result of an advance of spring phenophases than a delay of autumn ones (MENZEL, 2000; CHMIELEWSKI and RÖTZER, 2001, HÁJKOVÁ et al., 2010). Not all plant species are responding similarly to the climate change and understanding of interspecific variation in changes of growing season length is limited. In most phenological studies a response of native plant species to temperature changes in particular geographic regions is studied. Here, we use a dataset of phenological events of native European and introduced East-Asian woody plant taxa in spring (leaf unfolding) and autumn (leaf fall) in the Mlyňany Arboretum SAS (south-western Slovakia) to study the length of growing season. Introduction and acclimatization of allochthonous woody species has been the primary field of dendrological research in the Mlyňany Arboretum SAS. Hundreds of non-native taxa of woody species has been intentionally introduced to the arboretum since its establishment at the end of 19th century and their acclimatization has been studied mostly for their use as ornamentals, (e.g. BENČAŤ, 1961, 1967; BENČAŤ et al., 1986; TÁBOR and TOMAŠKO, 1992; HOŤKA, 2004, 2005; HOŤKA and BARTA, 2012). During a scientific expedition to eastern China in 1960, seeds of many woody taxa were obtained from their natural habitats. A small part of the collected species was used to set up a specialized phenological garden in the arboretum to study their acclimatization (BENČAŤ, 1961, 1962). The arboretum, as a member of the International Phenological Gardens (IPG) network, has also been recording phenological events on a collection of native trees. The opportunity of having data on phenology of European and East-Asian species allowed us to compare a response of these taxa to the local climatic changes.

The goal of this study was to evaluate the annual variability in leaf unfolding and leaf falling phenological events, delimiting the length of growing season, of selected woody taxa of European and East-Asian origin growing under conditions of the Mlyňany Arboretum SAS within a 20-year period. Our further aim was to study onset of beginning and end of the growing season in relation to air temperature.

Material and methods

To investigate the annual variability in the beginning and the length of growing season, phenology of 16 woody plant species, nine native European and seven introduced East-Asian taxa (Table 1) was studied. The main precondition for a choice of those species was a continuous set of phenological data for at least 20 consecutive years. The chosen native taxa were vegetatively propagated plants (clones) obtained from the International Phenological Gardens (IPG) network (CHMIELEWSKI, 1996) and each taxon/clone is identified by its particular IPG code. The plants of East-Asian species come from seeds collected at their natural area of distribution in eastern China in 1960. The phenological observations were carried out at the Mlyňany Arboretum SAS (MA SAS) (48°19'11.08" N, 18°22'08.30" E) (IPG garden no. 051) situated in south-western Slovakia. While the native taxa evaluated in this study are scattered in different parts of the arboretum, the introduced Asian species are grown in the Experimental phenological garden. This garden (approx. 0.4 ha) is located in the north-western part of the arboretum. To create a special microclimate, the garden is intentionally surrounded by stands of conifers. It is bordered by alleys of *Thuja occidentalis* L. 'Malonyana' (from the south side), *Thuja occidentalis* L. (from the east side) and *Thuja plicata* Donn ex D. Don (from the northern and western side). The longer side of the garden (approx. 107 m) is oriented approximately in the east-west direction.

Phenophases were specified according to the BBCH system (MEIER, 1997). For the purpose of this study two phenological events were investigated, leaf unfolding (BBCH 11) and leaf fall (BBCH 95). Dates for the leaf unfolding event in the spring were used to define the beginning of the growing season (BGS) and for the end of the growing season (EGS) the timing of leaf fall event in the autumn was used. The length of the growing season (LGS) was determined from the number of days between BGS and EGS. For the purpose of the study the data sets of BGS, EGS and LGS were combined for native and East-Asian species separately to obtain mean BGS (mBGS), mean EGS (mEGS) and mean LGS (mLGS). The phenological analyses were performed on data collected between 1990 and 2011 for the native (IPG) taxa and between 1991 and 2008 for the East-Asian taxa. The data set of BGS and EGS used in the study are expressed in Julian day (JD) – the ordinal day in the year, when phenophase occurred.

Meteorological data (average daily air temperatures) were obtained from the local meteorological station situated at MA SAS (48°19'24.57" N, 18° 22'06.81" E, 190 m a.s.l.).

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Table 1. List of tree species with their provenance included in the phenological study at the Mlyňany Arboretum SAS

Species	Provenance of plants
Betula pubescens Ehrh.	Vegetatively propag., IPG code 211, Germany
Fagus sylvatica L.	Veget. propag., IPG code 222, Düdelsheim, Germany
Populus × canescens (Ait.) Smith	Veget. propag., IPG code 231, Germany
Populus tremula L.	Veget. propag., IPG code 236, E-Poland
Prunus avium L.	Veget. propag., IPG code 241, Bovenden, Germany
Sorbus aucuparia L.	Veget. propag., IPG code 271, Czech Republic
Ribes alpinum L.	Veget. propag., IPG code 311, Austria
Salix × smithiana Willd.	Veget. propag., IPG code 324, Germany
Salix aurita L.	Veget. propag., IPG code 321, Germany
Acer davidii Franch.	Seeds collected in China, 1960
Acer grosseri Pax	Seeds collected in China, 1960
Magnolia denudata Desr.	Seeds collected in China, 1960
Magnolia liliiflora Desr.	Seeds collected in China, 1960
Magnolia officinalis var. *biloba* Rehd. et Wils.	Seeds collected in China, 1960
Spiraea thunbergii Sieb.	Seeds collected in China, 1960
Spiraea japonica L.	Seeds collected in China, 1960

For calculation of linear trends of phenological events the least-squares regression was used, with year as the independent variable and the day of phenophase occurrence (in JD) as the dependent variable. Linear regression was also used to test the relationships between BGS and spring temperature and annual mean temperature and to study the relationship between LGS and annual mean temperature. Pearson correlation analyses were used to test the sensitivity of phenophase occurrence (in JD) to spring air temperature and annual mean temperature. The spring air temperature was calculated as a mean air temperature from February to April. The regression and correlation analyses, including tests of significance, were performed by BioStat 2008® (© 2008 AnalystSoft Inc.).

Results and discussion

Over a 40-year period 1971–2011, annual mean air temperature (T_{am}) and mean spring air temperature (T_{24}, average February to April inclusive) increased by approx. 1.41 °C or 1.06 °C, respectively, at MA SAS. T_{am} increased on average by 0.35 °C/decade and T_{24} increased by 0.26 °C/decade within the period. Both the air temperatures showed a clear indication of warming over this period. The positive trends in T_{am} ($T_{am} = 0.0353 \times$ year – 60.418, p < 0.01) and T_{24} ($T_{24} = 0.0264 \times$ year – 47.108, p > 0.05) are displayed in Fig. 1. Figure 2 shows deviations of T_{am} and T_{24} over the 40-year period and it can be seen that positive deviations prevail mostly after 1989. On average, higher mean temperatures were recorded during 1989–2011, when compared with 1971–1988 period. Between 1971–1988 and 1989–2011, mean values of T_{am} and T_{24} increased by 0.85 °C and 0.96 °C, respectively. The differences between the means for both T_{am} and T_{24} were significant (T_{am}: $t_{1.684} = -3.480$, p < 0.05; T_{24}: $t_{1.684} = -2.335$, p < 0.05). The positive trend of T_{am} recorded in MA SAS is generally in accordance to the estimated increase of T_{am} (0.055 °C/decade) for the Northern hemisphere in the period 1861–2000 (JONES and MOBERG, 2003). Similar change in T_{am} was also observed by CHMIELEWSKI and RÖTZER (2000, 2001) in Europe during 1969–1998. CHMIELEWSKI and RÖTZER (2000, 2001) also recorded noticeable increase in T_{am} after 1989 that corresponds well with the situation at MA SAS. Compared with the long-term T_{am}, most years after 1988 were warmer in Europe (CHMIELEWSKI and RÖTZER, 2000, 2001; CHMIELEWSKI et al., 2012). As can be seen in Fig. 2, T_{am} and T_{24} deviations in MA SAS fully correspond with this general climate trend in Europe. CHMIELEWSKI and RÖTZER (2000) explained the abrupt changes in T_{am} after 1989 by changes in the circulation pattern (North Atlantic Oscillation Index) over Europe.

Generally, seasonal timing of spring phenological events such as leaf unfolding of trees depends highly on air temperature. The temperature changes in Europe mentioned above affected BGS and after 1989 early dates of BGS onset prevail (CHMIELEWSKI and RÖTZER, 2000). During a period of 1990–2011, when phenological observations were carried out in this study, T_{am} and T_{24} increased on average by 0.74 °C or 0.55 °C, respectively. To evaluate an impact of the temperature increase on BGS and LGS, data series for leaf unfolding
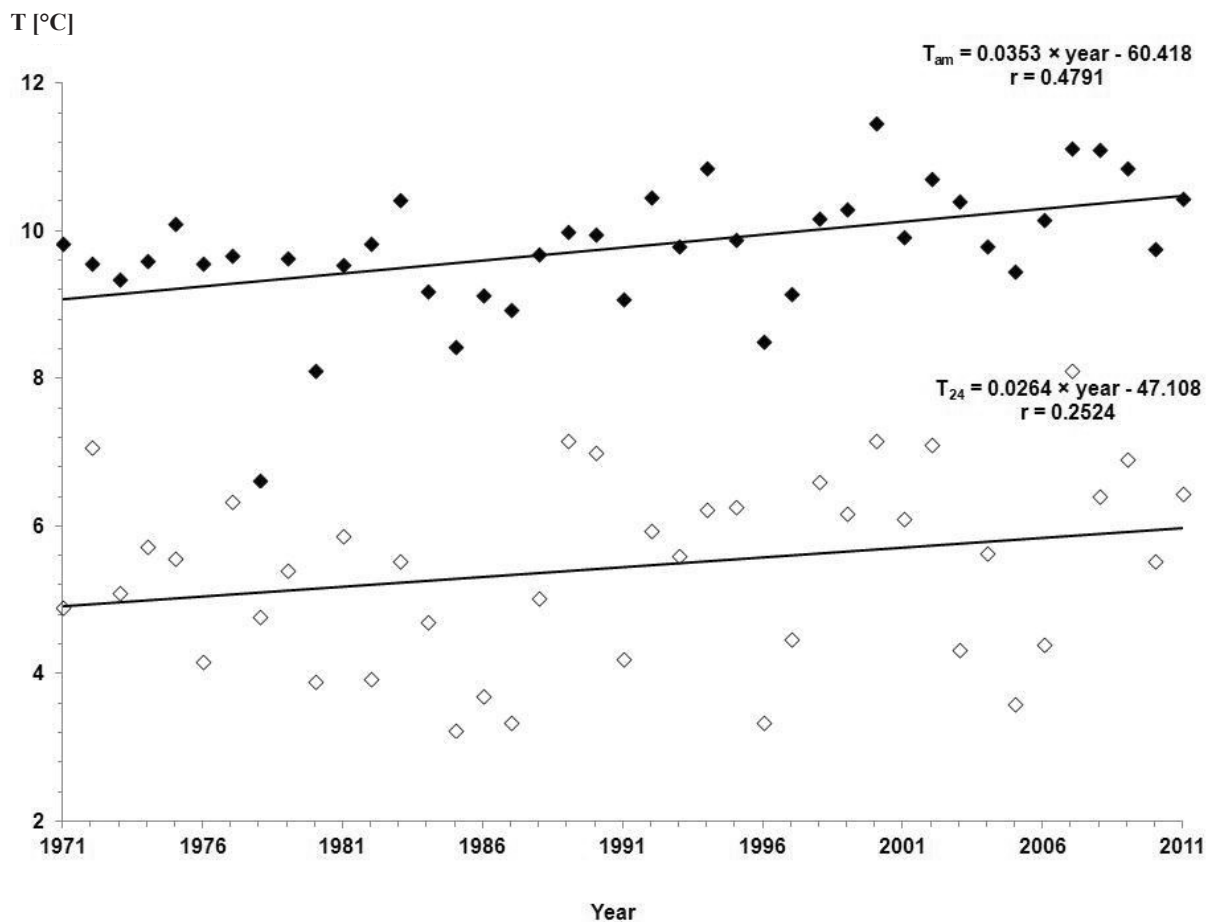
Fig. 1. Trends in annual mean air temperature (T_{am}) and mean air temperature from February to April (T_{24}) at the Mlyňany Arboretum SAS, 1971–2011.
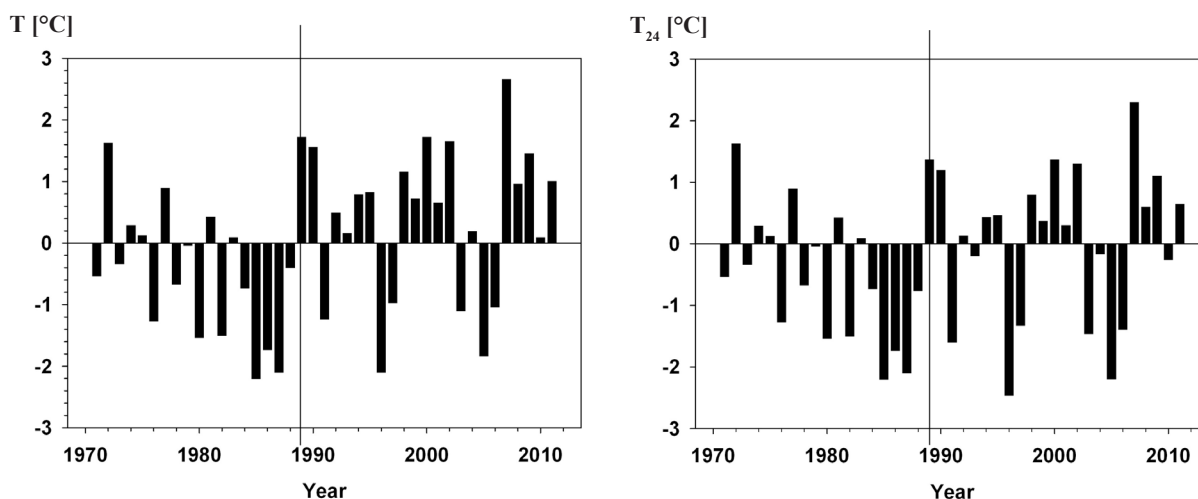

Fig. 2. Deviations of the mean annual air temperature (ΔT_{am}) and the spring air temperature (ΔT_{24}) at the Mlyňany Arboretum SAS, 1971–2011.

and leaf fall events for 9 European (IPG) and 7 East-Asian species growing at MA SAS were analysed and related to temperature series. Data for BGS, EGS and

LGS of all the woody taxa are presented in Table 2. Over the evaluated period, BGS of IPG species varied between 10 (100 JD) and 29 April (119 JD), depending

on species. mBGS based on combined data for the IPG taxa occurred on 23 April and during the 22-year period it advanced altogether by approx. 19 days. This corresponds to a significant trend (r = –0.7704, p < 0.001) of –8.85 day/decade. All IPG species showed a negative trend in the date of leaf unfolding occurrence over the period and the onset of BGS varied among years. The earliest start of growing season was observed in 2008 (11 April) and the latest occurred in 1993 and 1997 (5 May). Leaf fall event occurred between 3 November (307 JD) and 14 November (318 JD) depending on IPG species. For most species leaf fall occurrence delayed with years during the period, however this positive trend was not significant (p > 0.05). Negative trend in onset of EGS was only observed for *P. × canescens* and *R. alpinum*. mEGS of IPG taxa appeared on 9 November and over the 22-year period it delayed by approx. 2 days. Compared to mBGS, mEGS showed non-significant (r = 0.1639, p > 0.05) trend. mLGS of IPG trees, as indicated by the number of days between mBGS and mEGS, reached 199 days, however its value varied among species. The longest LGS was observed for *R. alpinum* with 210 days and the shortest for *S. aucuparia* with 189 days. All IPG species showed positive trends in LGS and mLGS significantly extended by approx. 1 day each year (r = 0.7525, p < 0.001).

mBGS of East-Asian taxa occurred on 19 April (109 JD) and varied between 8 (98 day) and 26 April (116 day), depending on species. Over the evaluated period (1991–2008), mBGS of the introduced taxa significantly advanced by 5.11 day/decade (r = –0.6528, p < 0.05). The negative trend was observed for all Asian species (Table 2). mBGS appeared 4 days earlier (19 April) when compared with IPG species, however the difference is not significant ($t_{2.035}$ = –1.441, p > 0.05). mEGS of Asian species fell on the same day (9 November) as that of IPG species and our analysis revealed a positive trend in the leaf fall event occurrence within the evaluated period for all the species. On average, mEGS delayed by 2.47 day/decade (r = 0.4212, p > 0.05). mLGS of Asian taxa reached 204 days and significantly extended by 7.58 day/decade (r = 0.6722, p < 0.05). The extension of LGS was observed for all Asian species, but trends of individual species varied from 5.07 day/decade to 14.06 day/decade.

mLGS of Asian taxa was longer by 5 days than that of IPG species, however the difference was not significant ($t_{2.035}$ = 1.449, p > 0.05). On the other hand, the mean trend in the growing season extension of IPG species was significantly stronger ($t_{2.145}$ = 2.318, p < 0.05) than that of Asian taxa. In Europe, CHMIELEWSKI and RÖTZER (2000) determined mBGS of native tree species

Table 2. Average beginning (BGS), end (EGS) and length (LGS) of growing season with linear trends (days/decade) of native (1990–2011) and East-Asian (1991–2008) species at the Mlyňany Arboretum SAS

Plant species	BGS ± SD	Trend	EGS ± SD	Trend	LGS ± SD	Trend
B. pubescens	110 ± 8.47	–9.381**	318 ± 7.67	+5.067	208 ±11.66	+14.448**
F. sylvatica	117 ± 8.11	–7.973**	312 ±12.10	+1.406	195 ±15.97	+10.078
P. × canescens	114 ± 8.47	–7.286*	313 ± 7.51	–2.338	199 ±12.28	+5.030
P. tremula	118 ±10.07	–13.797**	310 ± 8.82	+3.805	192 ±15.48	+20.826**
P. avium	113 ± 7.14	–6.506**	310 ± 7.05	+0.559	197 ± 8.35	+6.211
S. aucuparia	117 ± 8.61	–7.929	307 ± 8.59	+5.263	189 ±10.50	+14.088*
R. alpinum	100 ±15.04	–11.602*	310 ± 6.47	–2.925	210 ±15.91	+15.614*
S. aurita	119 ±11.91	–13.273**	317 ±10.00	+1.902	198 ±15.95	+15.256**
S. × smithiana	113 ±10.80	–10.956*	318 ±10.15	+0.441	205 ±10.81	+11.397*
Average for native trees	113 ± 7.38 (23 April)	–8.849**	313 ± 2.66 (9 Nov.)	+1.064	199 ± 8.93	+10.305**
A. davidii	110 ± 7.59	–8.910**	307 ± 5.00	+4.802*	197 ±12.10	+14.058**
A. grosseri	114 ± 5.81	–5.458*	313 ± 4.51	+3.470	200 ± 9.14	+9.125*
M. denudata	114 ± 4.88	–4.941*	311 ± 4.53	+1.271	197 ± 7.55	+6.212
M. liliiflora	116 ± 5.42	–5.315*	308 ± 6.06	+0.479	192 ± 9.10	+5.785
M. officinalis	105 ± 5.48	–4.459	309 ± 5.35	+0.610	204 ± 7.33	+5.069
S. thunbergii	98 ±10.06	–3.929	312 ± 9.69	+2.752	215 ±15.85	+6.681
S. japonica	109 ± 7.18	–2.791	329 ± 9.13	+3.275	220 ± 9.14	+6.066
Average for Asian species	109 ± 4.84 (19 April)	–5.106*	313 ± 3.63 (9 Nov.)	+2.474	204 ± 6.97	+7.580*

Significant at *P ≤ 0.05, **P ≤ 0.01, SD – standard deviation of a mean, BGS and EGS in Julian days.

on 23 April based on a long-term average (1969–1998) that corresponds with our observations. CHMIELEWSKI and RÖTZER (2001) calculated that mLGS of native trees lasts 193 days in Europe with large regional differences. And for the region of Slovakia they estimated its length within a range of 180 and 200 days. The length of 199 days, calculated for native species in MA SAS, fits the range, although the mLGS of Asian taxa exceeded the range. Our observations indicate that LGS of both IPG and Asian species extended over the evaluated period as a result of earlier onset of BGS and delayed EGS. And it is evident that the extension was mainly the result of an earlier onset of spring phenophase than a later occurrence of leaf fall in autumn. The earlier onset of mBGS was more prominent for European than Asian taxa and difference between trends of these two groups of species was significant ($t_{2.145} = 3.970$, $p < 0.001$). On the other hand, a difference between mEGS of IPG and Asian species was not significant ($t_{2.145} = –0.739$, $p > 0.05$), although the trend of mEGS delay was stronger for Asian taxa. Our observations confirm results of other long-term phenological studies of woody plants, when the spring phenophases occurred earlier leading to extension of growing season. For example, spring phenophases of deciduous and coniferous trees occurred 7 days earlier in southern Norway during a period of 1971–2005 (NORDLI et al., 2008). In Europe, leaf unfolding event advanced on average by 2.10 day/decade, whereas autumn events, such as leaf colouring, delayed on average by 1.50 day/decade during 1959–1996 period (MENZEL, 2000). Within a 30-year period (1969–1998), the beginning of growing season in Europe advanced altogether by 8 days (CHMELIEWSKI, 2002). In Czech Republic, a bud burst stage of European beech (*Fagus sylvatica* L.) appeared 5.70 days earlier and a leaf fall started 6.10 days later during a period 1992–2008 (HÁJKOVÁ et al., 2010). A bud burst stage of Norway spruce (*Picea abies* (L.) Karst.) growing up to 500 m a.s.l. started earlier by 3.30–8.50 days during a period 1996–2008 in Slovakia (ŠKVARENINOVÁ and SNOPKOVÁ, 2010). CHMIELEWSKI et al. (2012) found out that the mLGS of native trees in Europe extended by approx. 14 days (1969–2010) with a significant trend of 3.26 day/decade. And a similar trend in LGS extension was detected by MENZEL (2000), 3.60 days/decade within a period of 1959–1996, or by MENZEL and FABIAN (1999), 3.10 days/decade within a period of 1959–1993. Our analyses indicate greater extension of growing season, especially that of IPG species, when compared with abovementioned studies. This can be explained for example by shorter period of phenological observations evaluated in this study, by studying phenology in geographically rather small area of single locality, and finally by the fact that our observations were carried out during the period with significantly increased T_{am}. NORDLI et al. (2008) pointed out that results of trend studies are very sensitive to a choice of start-

ing year/decade. They found out that trends starting in cold decades were in most cases statistically significant, whereas those starting in warm decades were usually not. However, this was not our case. As presented in Fig. 2, we started phenological observations in warmer period (after 1989) and the trends for mBGS and mLGS of both IPG and Asian species were significant (Table 2). However, trends of individual species varied. While the trends of most IPG species were significant, only four or two Asian taxa showed significant trend in BGS or LGS, respectively.

Relationships between mBGS and mean temperature for February, March, April, May, February to March, February to April, February to May and annual mean temperature were tested (Table 3). Correlations for temperature in April (T_4), February to April (T_{24}) and annual mean temperature (T_{am}) were only significant ($p < 0.05$) for both groups of species, therefore the strength of a linear relationship between these three temperature parameters and BGS of individual species were evaluated (Table 4). Our results clearly demonstrate the effect of temperature increase in spring or mean annual temperature increase on advanced leafing of woody species during the evaluated period. An increase of 1 °C in spring temperatures (T_4 and T_{24}) and T_{am} resulted in an advance of mBGS of IPG trees by approx. 2 or 6 days, respectively. In case of Asian species, an increase of spring temperatures and T_{am} by 1 °C brought mBGS forward by 2 or 3 days, respectively. In many studies a good correlation between spring phenophases and air temperature was found (WALKOVSZKY, 1998; WIELGOLASKI, 1999; CHMIELEWSKI and RÖTZER, 2000, 2001; SPARKS and MENZEL, 2002). For example, a strong negative correlation between T_{24} and mBGS of native trees was detected during a 30-years period in Europe and an increase of the early spring temperature of 1 °C corresponded to an advanced BGS by approx. 7 days (CHMIELEWSKI and RÖTZER, 2000). Although the effect of temperature was obvious for evaluated species in our analyses, the strength of relationship differed between native and introduced taxa. The relationship was closer for native species as demonstrated by correlation coefficients. A certain level of variability in the effect of temperatures on the start of growing season was recorded among individual species (Table 4). All correlations were negative except for that between BGS of *P. avium* and T_{24}, where even week positive relationship was observed, which, however, was not significant ($r = +0.0091$, $p > 0.05$). As presented above the starting dates for growth and development are species-specific and the effect of temperatures on the start of growing season may vary between species that was also de-monstrated in other phenological studies (HEIDE, 1993). In general, phenological phases of plants, such as leaf unfolding and leaf fall of trees, are driven besides temperature also by other environmental factors such as pests, diseases, competition, soil factors,

genetics and age. Variability in BGS is often also found between cultivars or ecotypes within a plant species (Myking and Heide, 1995) and, due to genetic variations, even between individuals (Schirone et al., 1990) and with the age of trees (Ununger et al., 1988).

As mentioned above, mLGS in MA SAS lasts 199 days (for IPG species) or 204 days (for Asian taxa). There was a strong and significant correlation ($r = +0.5811$, $p < 0.001$) between T_{am} and mLGS of IPG taxa, however the relationship was weak and non-significant ($r = +0.1623$, $p > 0.05$) for Asian species. The regression equations indicate that 1°C increase in T_{am} is associated with an extension of mLGS by approx. 7 days for IPG species and 3.5 days for Asian species. These trends are very similar to results of phenological observations of native trees carried out in Europe during 30 years, which revealed that an increase of T_{am} by 1 °C led to an extension of LGS by 5 days (Chmielewski and Rötzer, 2001). Results of Pearson correlation between LGS of individual species and T_{am} are showed in Table 4. Correlation coefficients varied within an interval of +0.1438 and +0.6273, depending on species and the closest relationship was observed for *M. liliiflora* ($r = +0.6273$), *B. pubescens* ($r = +0.5820$) and *P. × canescens* ($r = +0.5241$). This indicates that different species respond to increasing T_{am} by lengthening their growing season with a different extent.

We can summarise that the air temperature increase recorded in the Mlyňany Arboretum SAS considerably influenced the length of growing season of both, native and introduce woody plants. Phenological observations revealed advanced onset of spring phenophases and delayed onset of autumn phenological events in all evaluated species, what finally lead to extension of growing season. The extension was mainly the result of an earlier onset of spring phenophase. The native species respond more considerably to the temperature increase by significantly earlier onset of mBGS and stronger trend in the growing season extension than introduced Asian taxa.

Table 3. Results of Pearson correlation between the mean beginning of growing season (BGS) and mean monthly temperatures in February (T_2), March (T_3), April (T_4), May (T_5), from February to March (T_{23}), from February to April (T_{24}), from February to May (T_{25}) and annual mean temperature (T_{am}) and between mean length of growing season (LGS) and (T_{am}) at the Mlyňany Arboretum SAS

	Correlations	r	P	a	b
IPG species	BGS vs.T2	−0.0028	0.9898	−0.0084	112.78
	BGS vs.T3	−0.2975	0.1580	−1.2882	119.48
	BGS vs.T4	−0.5665	0.0039	−2.4413	139.56
	BGS vs.T5	−0.1475	0.4916	−0.6833	123.42
	BGS vs.T23	−0.1521	0.4780	−0.6646	114.97
	BGS vs.T24	−0.3982	0.0450	−2.3654	126.58
	BGS vs.T25	−0.3847	0.0634	−2.5415	133.78
	BGS vs. T_{am}	−0.5450	0.0059	−5.7497	171.05
	LGS vs. T_{am}	+0.5811	0.0046	+7.1563	126.64
East-Asian species	BGS vs.T2	−0.1354	0.2161	−0.6309	110.16
	BGS vs.T3	−0.0141	0.6994	−0.3211	110.88
	BGS vs.T4	−0.4141	0.0176	−2.1221	131.92
	BGS vs.T5	−0.0256	0.6015	−0.4409	116.02
	BGS vs.T23	−0.1084	0.2721	−0.4192	111.82
	BGS vs.T24	−0.2852	0.0480	−1.8911	119.71
	BGS vs.T25	−0.1243	0.2374	−0.4558	116.78
	BGS vs. T_{am}	−0.2324	0.0495	−2.9308	138.68
	LGS vs. T_{am}	+0.1623	0.1722	3.5313	168.25

r – correlation coefficient, P – at 95% significance level, a – slope and b – intercept of linear regression equation.

Table 4. Results of Pearson correlation between beginning of the growing season (BGS) of individual tree species and average air temperature in April (T_4), from February to April (T_{24}) and mean air annual temperature (T_{am}), and correlation between length of growing season (LGS) and mean air annual temperature (T_{am})

Plant species	BGS/T_4	BGS/T_{24}	BGS/T_{am}	LGS/T_{am}
B. pubescens	−0.3991	−0.5089*	−0.5726**	+0.5820
F. sylvatica	−0.5426**	−0.4715*	−0.6038**	+0.3352
P. × canescens	−0.2533	−0.2744	−0.4836*	+0.5241*
P. tremula	−0.5396**	−0.3157	−0.5452**	+0.4421
P. avium	−0.3252	+0.0091	−0.2593	+0.1940
S. aucuparia	−0.1360	−0.1984	−0.0706	+0.1391
R. alpinum	−0.3278	−0.4530*	−0.4340*	+0.4859
S. aurita	−0.6423	−0.2318	−0.3615	+0.1438
S. × smithiana	−0.4847	−0.0567	−0.2645	+0.3208
A. davidii	−0.4178	−0.1740	−0.2179	+0.1759
A. grosseri	−0.5651*	−0.2149	−0.3477	+0.2974
M. denudata	−0.4676	−0.3749	−0.3335	+0.3385
M. liliiflora	−0.7469**	−0.6473*	−0.5810*	+0.6273*
M. officinalis	−0.5883*	−0.4092	−0.4033	+0.3075
S. thunbergii	−0.2727	−0.6012*	−0.2734	+0.1440
S. japonica	−0.4248	−0.2630	−0.4086	+0.2174

Significant at *$P \leq 0.05$, **$P \leq 0.01$.

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Variabilita vegetačného obdobia vybraných európskych a východoázijských drevín vo vzťahu k zmenám teploty vzduchu

Súhrn

V Arboréte Mlyňany SAV sme hodnotili nástup jarných a jesenných fenofáz a celkovú dĺžku vegetačného obdobia 9 druhov domácich (1990−2011) a 7 druhov východoázijských (1991−2008) drevín. Počas obdobia 1971−2011, priemerná ročná teplota vzduchu (T_{am}) v Arboréte Mlyňany SAV stúpla o 1,41 °C a priemerná teplota na jar (T_{24}) stúpla o 1,06 °C. Signifikantný (p < 0,05) nárast teplôt bol zaznamenaný v období 1989−2011. Nárast teplôt vzduchu ovplyvnil nástup jarných a jesenných fenologických fáz a dĺžku vegetačného obdobia hodnotených drevín. V priebehu hodnoteného obdobia nastal priemerný začiatok vegetačného obdobia domácich druhov drevín o 19 dní a východoázijských drevín o 9 dní skôr. Koniec vegetačného obdobia sa oneskoril v priemere o 2 dni pri domácich a 4 dni pri východoázijských druhoch drevín. Vegetačné obdobie sa predĺžilo v priemere o 22 dní u domácich a o 13 dní u introdukovaných druhoch. Skorší začiatok vegetačného obdobia bol výraznejší pri domácich druhoch a rozdiely medzi oboma skupinami drevín bol štatisticky preukazný. Na druhej strane neskorší koniec vegetačného obdobia nebol štatisticky preukazne rozdielny medzi domácimi a ázijskými taxónmi. Takisto nebol preukazný ani rozdiel medzi nárastom dĺžky vegetačného obdobia medzi oboma skupinami drevín, hoci trend vyjadrujúci nárast dĺžky vegetačného obdobia bol pri domácich druhoch štatisticky signifikantný. Pri všetkých hodnotených druhoch bola preukázaná závislosť medzi začiatkom vegetačného obdobia a priemernými teplotami T_{am} a T_{24}. Táto závislosť bola výraznejšia pri domácich taxónoch. Silná a štatisticky preukazná korelácia bola zistená aj medzi priemernou ročnou teplotou (T_{am}) a dĺžkou vegetačného obdobia domácich drevín, tento vzťah bol však v prípade východoázijských druhov iba mierny a štatisticky nepreukazný.