Phenology of four broad-leaved forest trees in a submountain beech forest

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ABSTRACT: The phenology of four deciduous forest tree species (*Carpinus betulus* L., *Fagus sylvatica* L., *Quercus dalechampii* Ten., *Tilia cordata* Mill.) was studied in a submountain beech forest stand in Central Slovakia. Two spring phenological phases – bud-burst and leaf unfolding as well as one autumn phase – autumn leaf colouring were monitored over the period of 13 years. The results documented interannual variability in the dating of phenological phases within the species, while the differences among the species were also revealed. Significant correlations ($P < 0.05$) were detected between the dating of leaf unfolding and air temperature; the coefficients of correlation (r) ranged from –0.86 (hornbeam and beech) to –0.92 (oak). Significant relationships were also revealed between cumulative precipitation amounts and timing of autumn leaf colouring phase (r-value ranged from –0.73 in oak to –0.81 in hornbeam). The trend analysis showed that the onset of phenological phases was slightly shifted to the earlier dates during the period of 13 years. However, the trends were not statistically significant.

Keywords: submountain beech forest; phenology; vegetative phenological phases; air temperature; precipitation

Four autochthonous broad-leaved tree species (European beech, oak, hornbeam and lime-tree) take up approximately 50% of the forest stand area of the Slovakia (Collective 1998). Excepting hornbeam, these tree species belong to woody plants subjected to phenological monitoring in the framework of the International Phenological Gardens Program (Chmielewski 1996). The climatological monitoring, which is coordinated by the Slovak Hydrometeorological Institute (SHMI), also includes phenological observations of the above forest trees in Slovakia (Braslavská 2000). Phenology, usually defined as the study of the seasonal timing of life cycle events, is a suitable tool enabling us to study the response of living organisms to the changes in the environment connected with the current global change (Bolliger et al. 2000; Saxe et al. 2001; Cleland et al. 2007). It is known that the beginning and the course of phenological events are not the same among the years. This variability is primarily connected, in addition to biological characteristics, with the seasonal variability of the climate characteristics (Menzel et al. 2001). In the ecosystems of deciduous forests in the temperate zone, mainly the factors such as temperature, moisture as well as photoperiod influence the intensity of life events in plants (Gill et al. 1998; Ahas et al. 2000; Kikuzawa 2003). Negative effects of the climate change on trees have been expected. Increased probability of late frost damage because of the earlier onset of leaf emergence could be caused by increased temperature sums during the spring period (Kramer 1995; Dittmar et al. 2005). Water deficit during the growing season could also cause the weakening of competitive ability of

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some tree species, e.g. beech (Gessler et al. 2007). On the other hand, we can expect a relatively positive effect – longer duration of the growing season (Chmielewski, Rötzer 2001). But it is not clear how these changes can affect the behaviour of trees when their regulatory mechanisms are disrupted.

The aim of the present study is to analyze variability in the onset of selected vegetative phenological phases in four deciduous forest tree species in a submountain beech forest stand during the period of 13 years. Potential relationships between selected climatic factors and phenological phases were also studied.

MATERIAL AND METHODS

Study site

Investigations were carried out in a submountain beech forest stand at the Beech Ecological Experimental Station (BEES), which is localized in the south-east part of the Kremnické vrchy Mts. (48°38'N, 19º04'E, 450–520 m a.s.l.). The study area is situated on a slope 5–15° oriented to the west-southwest. The soil cover is skeletal Cambisol with moderate acid reaction and skeleton content ranging from 10 to 60% (Kukla et al. 1998). European beech (*Fagus sylvatica* L.) at about 100 years of age is a dominant woody species (85%). Fir (8%), oak (4%), hornbeam (2%), and lime-tree (1%) are associated species. The vegetation cover mostly consists of patches of *Carici pilosae-Fagetum* Oberd. 1957 and *Dentario bulbiferae-Fagetum* (Zlatník 1935) Hartmann 1953 associations. Herbal species, such as *Carex pilosa* Scop., *Carex digitata* L., *Carex sylvatica* Huds., *Dentaria bulbifera* L., *Galium odoratum* Scop., *Athyrium filix-femina* L. (Roth), *Dryopteris filix-mas* (L.) Schott, represent the permanent elements of the associations (Kontriš et al. 1993). The investigated area belongs to the moderately warm region and moderately warm and humid hilly land subregion (according to Lapin et al. 2002). The mean annual air temperature and mean annual rainfall totals are 6.8°C and 780 mm, respectively. On average, the coldest month is January (–4°C), while the warmest one is July (17°C). About 55% of the annual precipitation amount falls from April to September (Střelec 1992). More information detailing the BEES was described in papers published by Kodrík (1993), Barna (2004), Kuklová et al. (2005), Kellerová and Janík (2006).

Phenological monitoring and meteo-data

Phenological observations were done according to slightly modified methodology used by the Slovak Hydrometeorological Institute (Slovenský hydrometeorologický ústav – SHMI 1996). Monitoring (for the period 1995–2007) usually started on March 1 and was repeated twice or three times a week during the spring season. Autumn phenological monitoring was carried out once a week. A set of 10 sample adult trees with good health condition was observed within each of the four species studied (hornbeam – *Carpinus betulus* L., European beech – *Fagus sylvatica* L., oak – *Quercus dalechampii* Ten., lime tree – *Tilia cordata* Mill.). The Julian day when the phase was observed on 50% of the studied trees was taken as the beginning of the phenological phase. The following phenological phases were

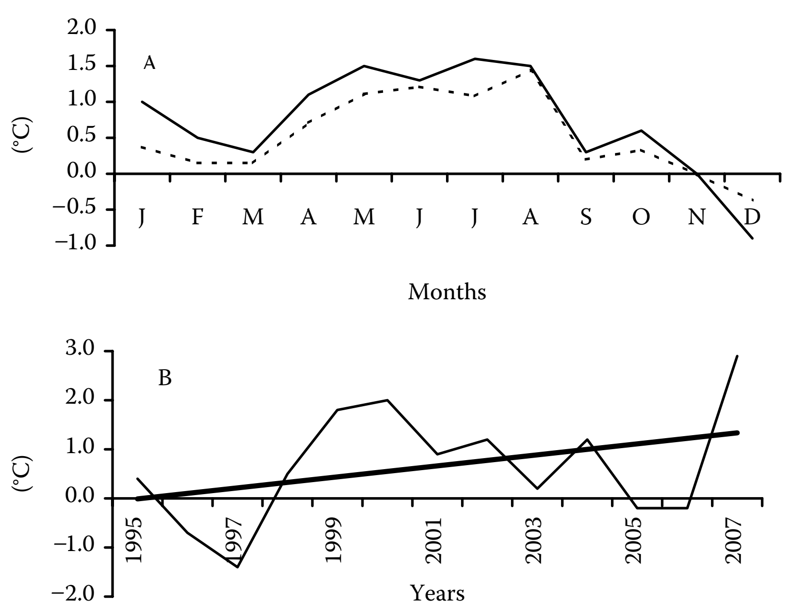

Fig. 1. Absolute (solid line) and standardized (dashed line) differences between mean monthly air temperatures (1995 to 2007) and long-term mean (1951–1980) (A) and linear trend of temperature deviations averaged for the period March–April (B) in Sliač (Central Slovakia)

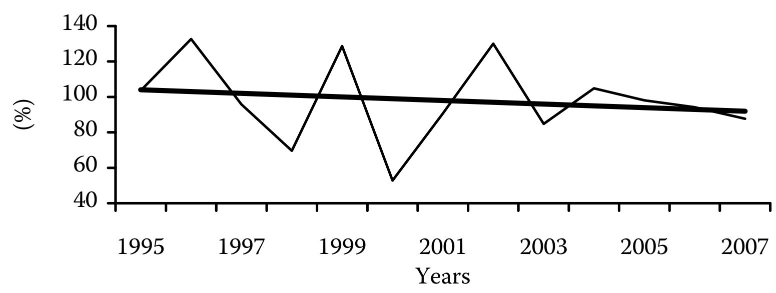

Fig. 2. The trend of cumulative rainfall totals for the period May–August between 1995–2007 (long-term mean $_{(1951–1980)}$ is 100%)

evaluated: 10% bud-burst (BB), 10% leaf unfolding (LU) and 10% autumn colouring (AC).

Meteorological data (monthly air temperature means and monthly precipitation amounts) for the period of 13 years (1995–2007) were obtained from the meteorological station in Sliač (monitored by SHMI), which is situated at a direct distance of 4 km from the study area. Both absolute (Δ) and standardized (Δ/standard deviation) differences between mean monthly air temperatures (averaged for the period 1995–2007) and long-term mean (1951–1980) reached the positive values from January to November, an evident increase was detected for the period of April–August (Fig. 1A). The values of the air temperature deviations, averaged for the period of March–April, were increased during the decade (Fig. 1B). The trend of the rainfall totals averaged for the period of May–August adverts to a slight decrease between 1995 and 2007 (Fig. 2). Having regard to the phenological development of

Table 1. The onset of phenological phases (Julian days) in four forest tree species studied between 1995 and 2007

	Phenological phases											
	Bud-burst				Leaf unfolding				Autumn colouring			
Tree species*	F.s.	C.b.	T.c.	Q.d.	F.s.	C.b.	T.c.	Q.d.	F.s.	C.b.	T.c.	Q.d.
Minimum	101	90	106	108	110	106	110	112	254	251	245	255
Maximum	120	111	120	120	124	126	130	131	273	279	270	280
Mean	111	103	114	115	117	117	122	123	265	264	261	268
Variance range	19	21	14	12	14	20	20	19	19	28	25	25
St. deviation (±)	4.7	5.9	4.4	3.6	4.0	5.0	5.0	5.0	6.1	8.0	7.2	6.5
CV (%)	4.2	5.8	3.9	3.2	3.4	4.2	4.1	4.1	2.3	3.0	2.7	2.4

*F.s. – *Fagus sylvatica*, C.b. – *Carpinus betulus*, T.c – *Tilia cordata*, Q.d. – *Quercus dalechampii,* CV (%) – coefficient of variation

Table 2. The duration of interphase intervals (in days) in the tree species studied between 1995 and 2007

	Interphase intervals							
	Bud-burst – Leaf unfolding				Leaf unfolding – Autumn colouring			
Tree species*	F.s.	C.b.	T.c.	Q.d.	F.s.	C.b.	T.c.	Q.d.
Minimum	4	9	4	4	133	134	120	129
Maximum	9	24	12	12	163	166	154	164
Mean	6	15	8	9	148	147	139	145
Variance range	5	15	8	8	30	32	34	35
St. deviation (±)	1.7	3.9	2.5	2.7	7.7	8.5	8.4	8.7
CV (%)	27.3	26.9	31.6	31.2	5.2	5.8	6.0	6.0

*F.s. – *Fagus sylvatica*, C.b. – *Carpinus betulus*, T.c. – *Tilia cordata*, Q.d. – *Quercus dalechampii,* CV (%) – coefficient of variation

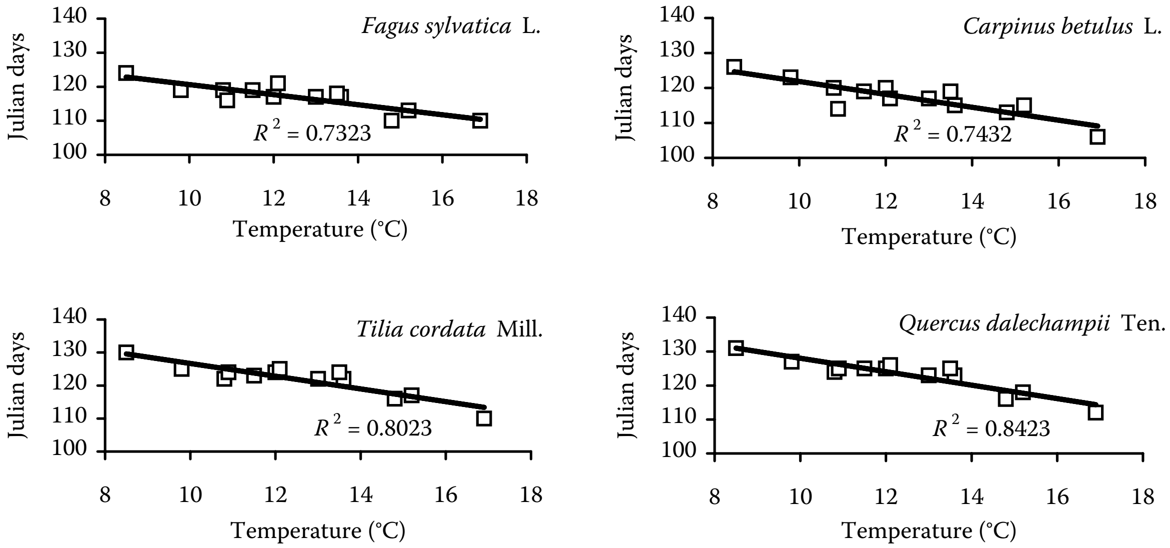

Fig. 3. The relationships between dating of leaf unfolding and temperature (CPAMAT) calculated for the period of March–April during 1995–2007

studied trees, temperature sums, used in the correlation analysis, were calculated as the sums of cumulated positive average monthly air temperatures (CPAMAT) over the period from March to April (according to Braslavská, Borsányi 1996; Schieber 2006a). The rainfall totals were calculated for the period of May–August (according to Kamenský, Braslavská 1999). The degree of correlation of two variables – onset of phenological phase (expressed as a Julian day) versus temperature or precipitation, respectively, was couched in a coefficient of linear correlation (Pearson's product moment).

RESULTS

During the period of phenological monitoring (1995–2007), interannual variability in the onset of two spring phenological phases as well as one autumn phenological phase within the species was determined (Table 1). Among the species, the earliest onset of bud-burst on average was observed in hornbeam (103rd day), the latest one was in oak (115th day). The variability (standard deviation) in the onset of this phase within the species ranged from 3.6 days (oak) to 5.9 days (hornbeam). As for the leaf unfolding phase, the earliest onset on average was observed in beech and hornbeam (117th day), while the latest occurrence was in oak (123rd day). The variability in the onset of leaf unfolding ranged from 4.0 days (beech) to 5.0 days (other species). The earliest occurrence of autumn colouring, averaged for the period of 13 years, was determined in lime-tree (261st day), while the latest one was observed in oak (268th day). The variability in the dating of this phase ranged from 6.1 days (beech) to 8.0 days (hornbeam).

The dynamics of the assimilatory apparatus development is presented by means of the interphase interval bud-burst-leaf unfolding (BB-LU) duration. It is clear that the lowest dynamics was observed in hornbeam, while the leaf development in beech was more rapid (Table 2). The shortest duration, on average, was observed in beech (6 days), the longest duration was in hornbeam (15 days). Interannual variability in the duration of the interval BB-LU within the species ranged from 1.7 days (beech) to 3.9 days (hornbeam). On the other hand, the shortest interphase interval leaf unfolding-autumn colouring, which represents the vegetation period of trees, was observed in lime-tree. Longer vegetation period, detected in other species, reached nearly equal values. The length of the interphase interval from leaf unfolding to autumn colouring (LU-AC) ranged from 139 days (lime-tree) to 148 days (beech). The variability in the duration of LU-AC within the trees reached the limit values from 7.7 days (beech) to 8.7 days (oak).

The correlation analysis between air temperature and onset of leaf unfolding confirmed a statistically significant correlation ($P < 0.05$) in all species studied between 1995 and 2007 (Fig. 3). The coefficients of correlation reached the following values: beech and hornbeam ($r = -0.86$), lime-tree ($r = -0.89$) and oak ($r = -0.92$). The correlation between the beginning of autumn leaf colouring and rainfall totals calculated for the period of May–August also revealed

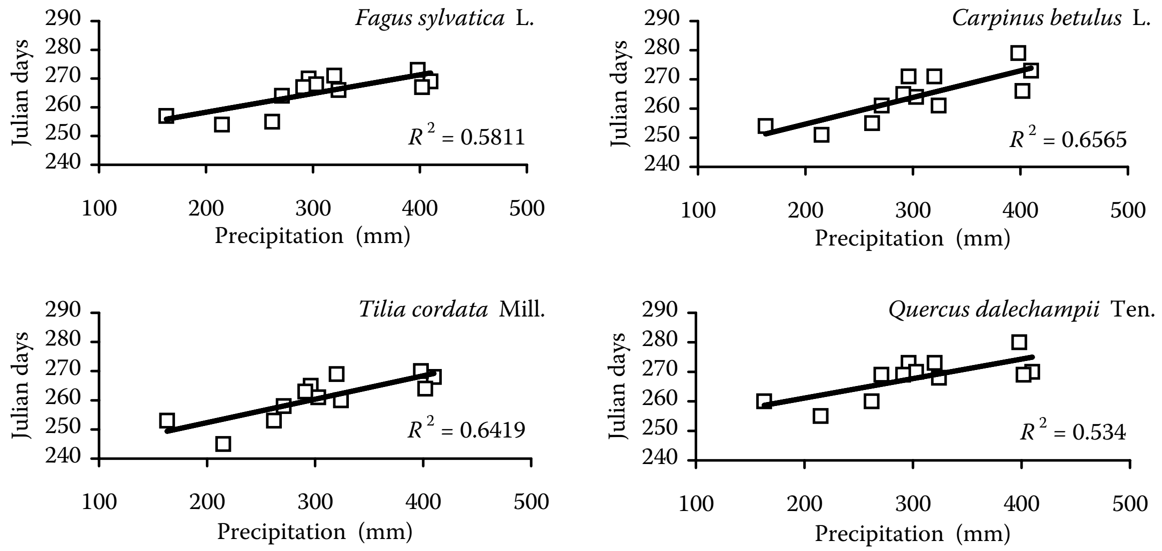

Fig. 4. The relationships between dating of autumn leaf colouring and cumulative rainfall amounts calculated for the period of May–August during 1995–2007

a significant correlation. The values of correlation coefficients ranged from $r = -0.73$ (oak) to $r = -0.81$ (hornbeam, Fig. 4). The interannual course in the onset of leaf unfolding as well as autumnal leaf colouring for the species studied between 1995 and 2007 is illustrated in Figs. 5 and 6. Linear trends showed that the onset of both phenological phases was slightly shifted to the earlier dates during the period of 13 years. However, the trends were not statistically significant ($P < 0.05$).

DISCUSSION

The data in Table 1 show differences in the dating of phenological phases among the species studied between 1995 and 2007. On average, the earliest onset of both spring phases was observed in hornbeam. Especially in the case of bud-burst the leading of hornbeam is evident. We suppose that this fact is related to its biological characteristics, e.g. lower sensitivity to the day-length compared to beech (Heide 1993). On the other hand, the latest onset of both spring phases was observed in oak, which is more exacting on temperature conditions compared to the other species. On average, the earliest autumn colouring was observed in lime-tree, the latest one was detected in oak. It is possible that the reason for this pattern is the higher sensitivity of lime-tree to drought compared to oak.

Interannual differences in the onset of phenological phases within the species are influenced by a

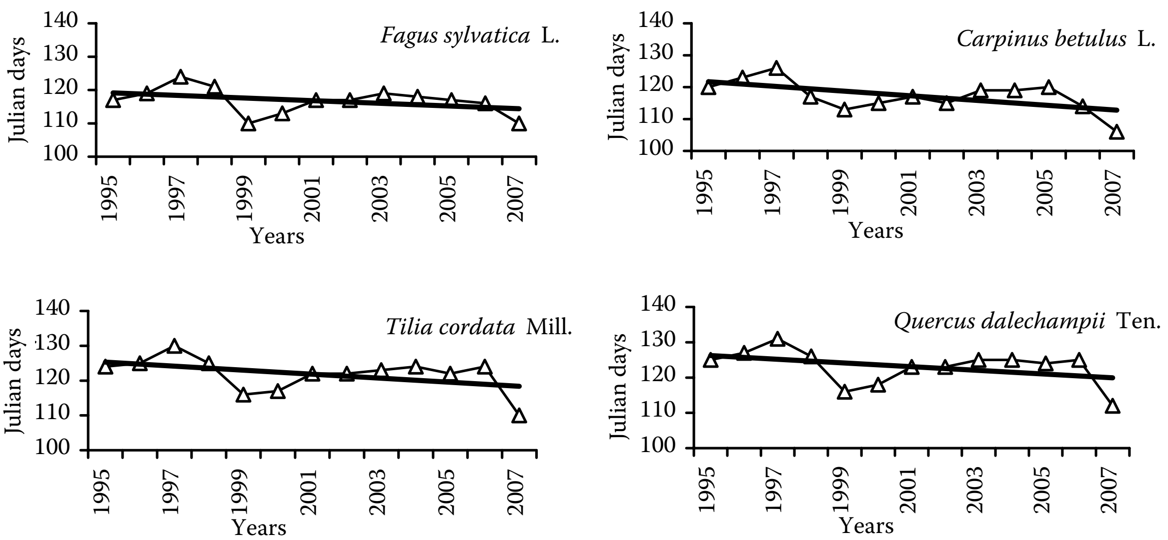

Fig. 5. The onset of leaf unfolding in the species studied between 1995–2007. A linear trend is evident

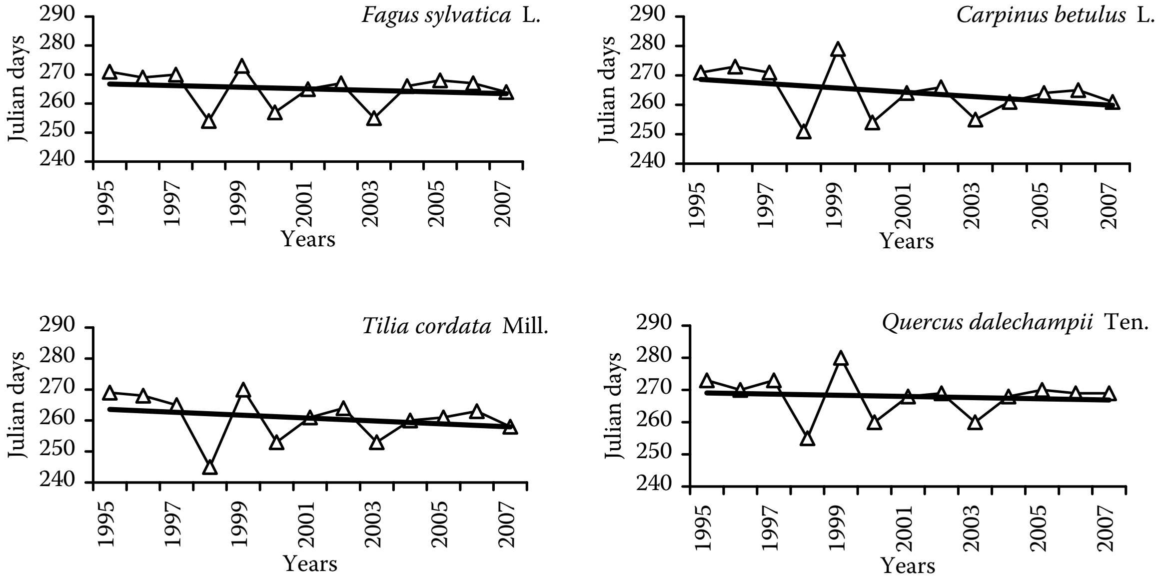

Fig. 6. The onset of autumn leaf colouring in the species studied between 1995–2007. A linear trend is depicted

range of factors (Häkkinen, Hari 1988; Schieber 2006b). Temperature and moisture are considered to be the most important ecological factors influencing the intensity of life manifestations (Von Wuehlisch et al. 1995; Wielgolaski 1999). Therefore, using the correlation analysis, we examined the relationships between the dating of the onset of phenological phases and meteorological factors (temperature, rainfall amounts) in the foregoing period. The analysis revealed the correlation between the beginning of leaf unfolding phase in the studied species and air temperature, namely the CPAMAT summary value. The sum of CPAMAT over the periods of March–April correlates significantly with the beginning of this phenophase in all species. In the years with the highest summary value of temperatures (1999, 2000 and 2007) we observed the earliest beginning of this phenological phase. Contrariwise, the lower temperature sums of CPAMAT (1996 and 1997) were related to later onset. The trend of the dating of leaf unfolding over the period 1995–2007 showed a shift to the earlier dates. We suppose that there is a possible relation between the earlier onset of this phenological phase and climate warming in the last decade (see Fig. 1B). A similar trend was observed by other authors (Murray et al. 1989; Chmielewski, Rötzer 2001; Menzel et al. 2001; Schieber 2005; Bednářová, Merklová 2007). The phenological phase of autumn leaf colouring signalizes the ending of the vegetation period. A decrease in chlorophyll contents in the assimilatory apparatus is evident, thereby there is a change in the colour of leaf blade. Excluding the biological characteristics of the species, extreme dating of the beginning of autumn leaf colouring reflects the interannual variability with extremities (above-average or below-average characteristics) of the climatic variables (e.g. drought or low air temperatures). Our correlation analysis showed that there is a significant relationship between rainfall amounts in the period of May–August and dating of this autumn phase. In all species, the earliest onset was observed in 1998, the latest one was detected in 1999. In 1998, there was an evident deficit of soil moisture at the beginning of autumn (70% amount of the long-term normal) with a clear decrease in the minimal air temperature. On the other hand, there were favourable ecological conditions (sufficient soil moisture and temperature regime) during the same period in 1999. These findings correspond to those published by Kamenský and Braslavská (1999). It is interesting that both extremes were found in two successive years. It could be connected with natural variability in the seasonal course of climate characteristics, having together with the biological factors a dominant effect on the course of life activities (e.g. phenological phases) in woody plant species.

CONCLUSION

The phenology of four deciduous forest tree species (*Carpinus betulus* L., *Fagus sylvatica* L., *Quercus dalechampii* Ten., *Tilia cordata* Mill.) was studied in a submountain beech forest stand, which is localized in the Kremnické vrchy Mts. (Western Carpathians, Central Slovakia). Two spring phenological phases – 10% bud-burst and 10% leaf unfolding as well as one autumn phase – 10% autumn leaf colouring were monitored from 1995 to 2007. The results documented interannual variability in the dating of phenological phases within the species, while the differences among the species were also revealed. The reasons for the variability are not only biological (genetic, physiologic) characteristics of the species but also the climatic factors play an important role in the dynamics of phenological development. There were significant relationships between the onset of leafing and the sum of air temperatures during the spring period (March–April). Similarly, the beginning of autumn colouring was significantly correlated with rainfall amounts during the period from May to August. The beginning of phenological phases was slightly shifted to the earlier dates between 1995 and 2007. However, the trends were not statistically significant ($P < 0.05$).

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Fenológia štyroch druhov listnatých drevín v submontánnej bučine

ABSTRAKT: Študovali sme fenológiu štyroch opadavých lesných drevín (*Carpinus betulus* L., *Fagus sylvatica* L., *Quercus dalechampii* Ten., *Tilia cordata* Mill.) v podmienkach submontánnej bučiny na strednom Slovensku. V priebehu 13 rokov boli monitorované dve jarné vegetatívne fenofázy – rozpuknutie pupeňa a zalisťovanie – a jedna jesenná vegetatívna fenofáza – jesenné prefarbovanie listov. Výsledky poukazujú na medziročnú variabilitu v nástupe fenologických fáz v rámci druhov ako aj na rozdiely medzi druhmi. Zistili sa štatisticky významné ($P < 0,05$) vzťahy medzi nástupom zalisťovania a teplotou vzduchu; hodnoty koeficientov korelácie (r) sa pohybovali od –0,86 (hrab, buk) do –0,92 (dub). Takisto aj medzi nástupom jesenného prefarbovania listov a zrážkami boli zistené významné vzťahy (hodnota r sa pohybovala od –0,73 u duba do –0,81 u hraba). Trendová analýza nástupu fenofáz za obdobie 13 rokov poukazuje na ich mierny posun ku skorším termínom, avšak trendy nie sú štatisticky významné.

Kľúčové slová: submontánna bučina; fenológia; vegetatívne fenofázy; teplota vzduchu; zrážky

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