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THE IMPACT OF SITE EXTREMES ON THE ONSET OF PHENOLOGICAL PHASES OF SELECTED TREE SPECIES

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Abstract

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In the years 2007–2013 we performed phenological observations of common hazel (*Corylus avellana* L.), blackthorn (*Prunus spinosa* L.), and hawthorn (*Crataegus oxyacantha* L.) at two locations of central Slovakia situated at elevations of 300 m and 530 m a.s.l. The phenophase of first leaves of all tree species started in the second half of April on average, and was conditioned by the average daily air temperatures above 0 °C. The earliest onset was observed at both locations in 2007 due to the highest average air temperature during the observed period, which in March reached the value of 6.1 °C. Colouring of leaves started in the second and third decades of September. Both phenophases began earlier at the location situated at the higher elevation due to the effect of aspect, terrain, and soil depth. During the last 7 years, the average length of the growing season of tree species situated at an elevation of 300 m was from 136 to 152 days, in more extreme conditions at an elevation of 530 m the growing season was shorter by 12 days in the case of blackthorn and by 5 days in the case of hawthorn.

Keywords: Phenology, central Slovakia, forest tree species, site extremes

INTRODUCTION

Climate changes and their negative impacts directly influence natural forest ecosystems that represent one of the major components of environment. They can cause changes in phenological processes, which could affect and change the natural distribution of tree species. Long-term phenological observations can provide us with the answers on climate development. They can be used not only for modelling the phenological phases of tree species under the potential impact of climate changes, but also for the prognosis of their further distribution and vitality (Bednářová, Merklová, 2006). Regular and long-term observations of the onset of developmental and growth phases of tree species in individual regions can provide us with the knowledge about the climatic character of the region and reveal the changes in the length of the growing season, as well as the possible risks of frost damage. The importance of phenological observations is reflected in the understanding of the relationships between the phenological trends of populations and climate development as it is documented in several works (Škvareninová 2009). Therefore, tree species can be considered as bioclimatic indicators of environmental changes.

Climate changes include temperature changes and changes in precipitation distribution over the year. Due to the temperature increase and predicted changes in precipitation distribution, longer dry periods and shorter periods with extreme precipitation events, as well as periods with temperature extremes are expected to occur (Minďáš, Škvarenina, 2003). Phenology can be a tool that can give us the information about the organism requirements on site conditions depending on the climatic factors. Air temperature plays a decisive role because it can accelerate or decelerate plant development (Kurpelová, 1972). Therefore, if we want to assess possible effects of climate change on the development of forest ecosystems in Europe, we need to understand how meteorological factors influence the timing of vegetation phenological phases during individual years (Saxe *et al*., 2001). Several studies stated that in the last decades plants intensively reacted to increasing air temperature. Fast temperature increase and another stress can easily interfere with the reactions of living organisms, their cohesion, and can lead to changes in species communities and their eventual extinction (Root *et al*., 2003; Scheifinger *et al*., 2007).

Long-term phenological records represent useful values at species level, which can be a good prediction of their biological reactions to climate changes in the temperate regions with changing seasons. Appropriate phenological models can partially extrapolate this information to different places, for which the traditional observations are missing. They will help us to get an idea about the possible changes of environment on the base of the phenological events.

The majority of authors are mainly interested in the shifts of spring phenological phases due to their good correlation with spring temperatures that show inter-annual variation, to which plants flexibly react with their phenological answers. The combination of early spring warming with the following late frosts can be harmful to the species living at the edge of their climatic regions (Parmesan *et al*., 2000). Myking (1997) found out that in Scandinavia global warming can shift bud-bursting of some species to earlier dates, which can increase the risk of their damage by late spring frosts. The question whether sufficient amount of water will be available for plants if they are to utilise higher temperatures and longer growing seasons, remains open. The length of the period with full leaf coverage is an important factor that affects transpired water amount and wood biomass production. Along with other factors, this length is crucial for the total production of tree species. Net production of deciduous tree species depends on the length of warm season, during which trees have foliage, while in the case of full leaf coverage the length of the growing season can also affect the quantity and quality of throughfall (Priwitzer *et al*., 2007).

MATERIAL AND METHODS

During the years 2007–2013 we performed phenological observations of selected phenological phases of common hazel (*Corylus avellana* L.), blackthorn (*Prunus spinosa* L.), and hawthorn (*Crataegus oxyacantha* L.) at two locations named Zvolen (1) and Boky (2) in central Slovakia. The first location is situated at the south-western edge of the Zvolen highlands, which belong to Zvolenská kotlina orographic unit. At elevations of 290 to 380 metres, the region has a hilly character; in the alluvium of the river Hron we can also find flat terrain. Northern and north-western aspects prevail. From the climatological point of view, the location is characterised by long-term annual average temperature of 8.1 °C and average precipitation totals of 714 mm (Labanc *et al*., 1992).

The second location called Boky is located in the southern part of the Kremnica hills at an elevation of 530 m on the slope with southern aspect. The annual average air temperature is 7.5 °C, and the annual average precipitation totals reach 720 mm. The investigated tree species occur on the steep southern slope situated at higher elevations. These parts are covered with open forests or are treeless, and particularly in summer they are exposed to intense solar radiation and temperature extremes. Overall topography, aspect and soil depth significantly affect the character of the microclimate at this site, although the meteorological elements of both locations are almost equal.

Phenological observations were performed following the methodology (Anonymus, 1984) prepared by the Slovak Hydrometeorological Institute in Bratislava. We observed ten individuals of each tree species. We recorded the onset of each phenophase, if it was observed on at least 10% of the trees. For the statistical analysis of the onset of phenophases in the individual years we used an absolute number of the day of the year (so called Julian day). We observed the following phenological phases:

- *first leaves – FL* (leaves have their normal shape, but they do not have their normal size and colour),
- *colouring of leaves – CL* (first yellow leaves occur).

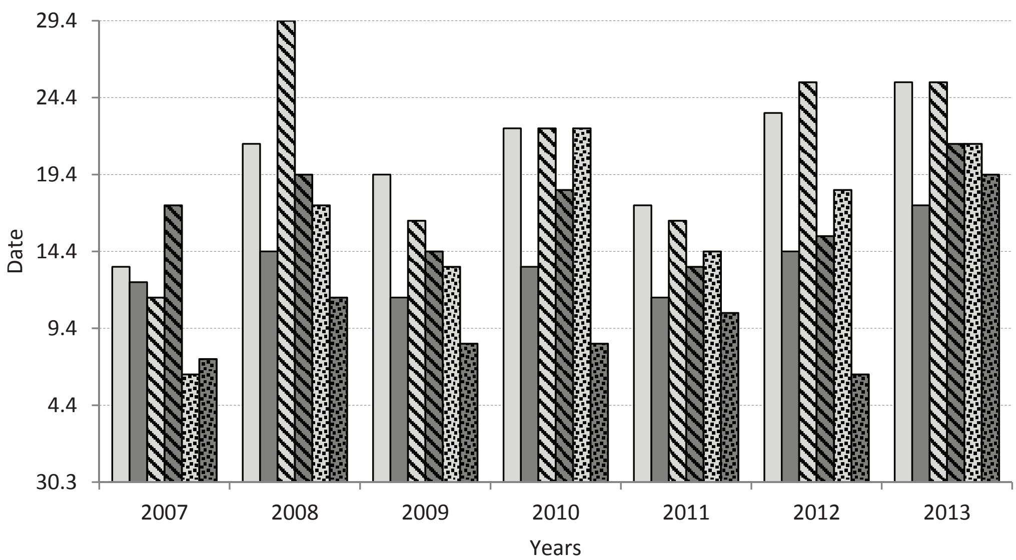
Many authors (Heide, 1993, Priwitzer, Minďáš, 1998; Šiška, Špánik, 1999; Bednářová *et al*., 2008) evaluate the onset of the phenophase in relation to the temperature sum. The temperature sum (TS) is the sum of daily average air temperatures from the beginning of the year until the time when the particular phenological phase reaches its threshold value. It is bound to the threshold values, at which specific physiological activities of plants begin. Most frequently, these values are temperatures of 0° C, 5° C, 8° C, and 10°C. The temperature sum with the lowest variability is decisive. The relationship between the onset of the phenophases and the temperature sums works well in the case of spring phenological phases, as their progress is influenced by the temperature regime only. Summer and autumn phenophases are also modified by other environmental factors (moisture, drought, wind).

RESULTS AND DISCUSSION

The evaluation of first leaves at two locations situated at different elevations during 7 years revealed the following results. At Zvolen, the phenophase of hawthorn, hazel, and blackthorn started on average on April 17, 21, and 22, respectively. At Boky site, first leaves of tree species occurred in the same order, but by 4–7 days earlier than at Zvolen in spite of the higher elevation (Fig. 1). In the year 2007, the earliest onset was observed at both locations due to the highest average air temperature in March (6.1 °C). In the same year, we also recorded the highest temperature maximum of 20.9 °C, which was measured on March 14. The late onset of the phenophase observed in the year 2013 was connected with cool weather at the beginning of spring. In that period, the average monthly temperature in March reached the lowest value during the assessed period (1.7 °C), although the average monthly temperatures in May of the years 2007 and 2013 were almost equal (Fig. 2). Hence, we can state that at both locations the progress of first leaves was influenced by average air temperature in March. Greater variability (s_x = 2 – 5.7%) was caused by varying onsets of first leaves phenophase connected with great fluctuations of daily air temperatures in spring months (Tab. 1). At Zvolen, we observed a later onset of the phenophase in spite of the lower elevation. Early first leaves of all tree species at Boky (530 masl) results from the site location. At this site no fogs occur and it is overheated during a day because of the southern aspect of slope. In England, Harper (2007) found negative correlation between the first leaves of hawthorn and the average monthly air temperature in March, and a significant influence of the increasing air temperature in April on the earlier onset of flowering. From both results of the correlation it is clear that air temperature is a significant factor affecting the onset and the progress of spring phenological phases of tree species.

Škvareninová *et al.* (2007) found the later onset of first leaves of hawthorn in Drahanská vrchovina in Morava region (625 masl) shifted by 10 days (April 22). This plot is situated on the north-eastern slope. The location belongs to mildly wet and mildly warm regions with the long-term annual average temperature of 6.6 °C and annual precipitation totals of 683 mm. This information documents significant impact of site conditions on the onset of phenological phase in comparison with Boky location.

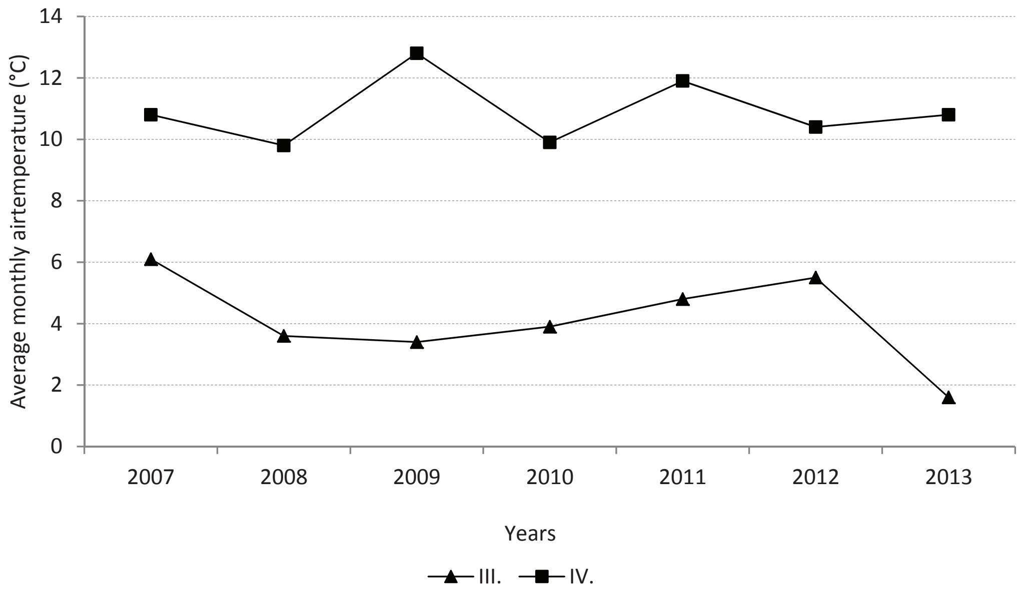
The onset of spring phenophases is driven by the beginning of spring warming, while spring weather considerably varies every year. Our results showed that the increase of average daily temperature above 0 °C affected the onset of first leaves phenological phase. Temperature sums TS0 for tree species ranged from 283.3 to 488.5 °C at Zvolen location, and from 224.3 to 473.2 °C at Boky location (Fig. 3). At Boky, all tree species needed lower average temperature sums for the onset of first leaves, by 55.8 to 77 °C. Although the phenophase of all tree species occurred in the second and third



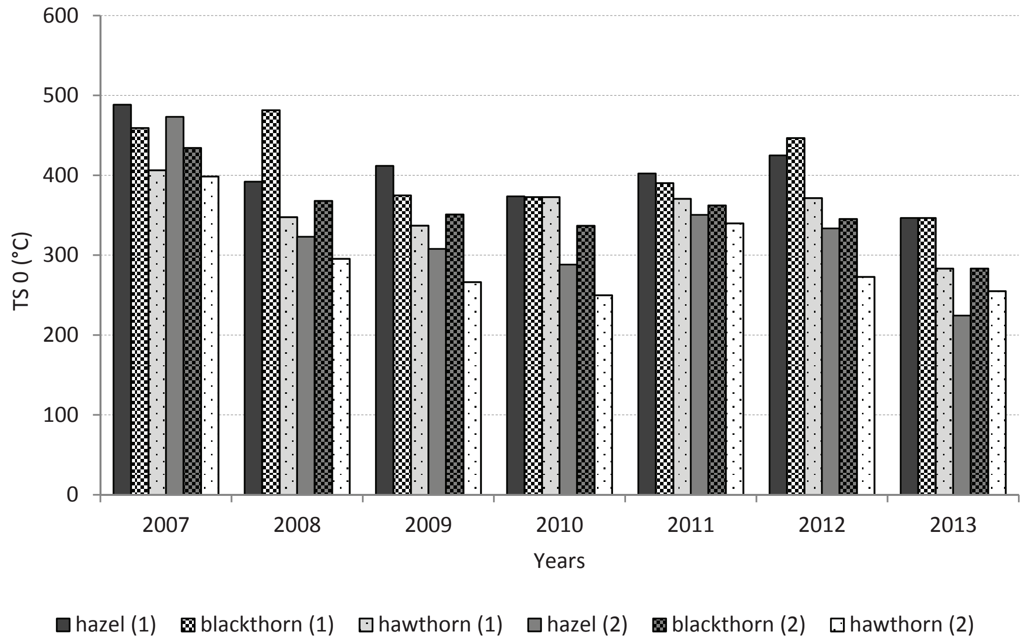
1: *The onset of first leaves of the examined tree species at Zvolen (1) and Boky (2) locations in the years 2007–2013*

I: *Statistical characteristics of first leaves phenophase of tree species at Zvolen and Boky (2) locations in the years 2007–2013 (Ø – average onset, min – the earliest onset, max – the latest onset, s_x% – the coefficient of variation)*

	***Corylus avellana* L.**				***Prunus spinosa* L.**				***Crataegus oxyacantha* L.**			
	Ø	min	max	s_x%	Ø	min	max	s_x%	Ø	min	max	s_x%
1	April 21	April 14, 2007	April 26, 2013	3.6	April 22	April 12, 2007	April 26, 2013	5.7	17. 4.	April 7, 2007	April 23, 2013	5.1
2	April 14	April 13, 2007	April 18, 2013	2.0	April 18	April 14, 2011	April 22, 2013	2.7	11. 4.	April 8, 2007	April 20, 2013	4.3



2: *Average monthly air temperatures in March and April at Sliač weather station in the years 2007–2013*



3: *Temperature sums TS0 for first leaves of selected tree species at Zvolen (1) and Boky (2) locations in the years 2007–2013*

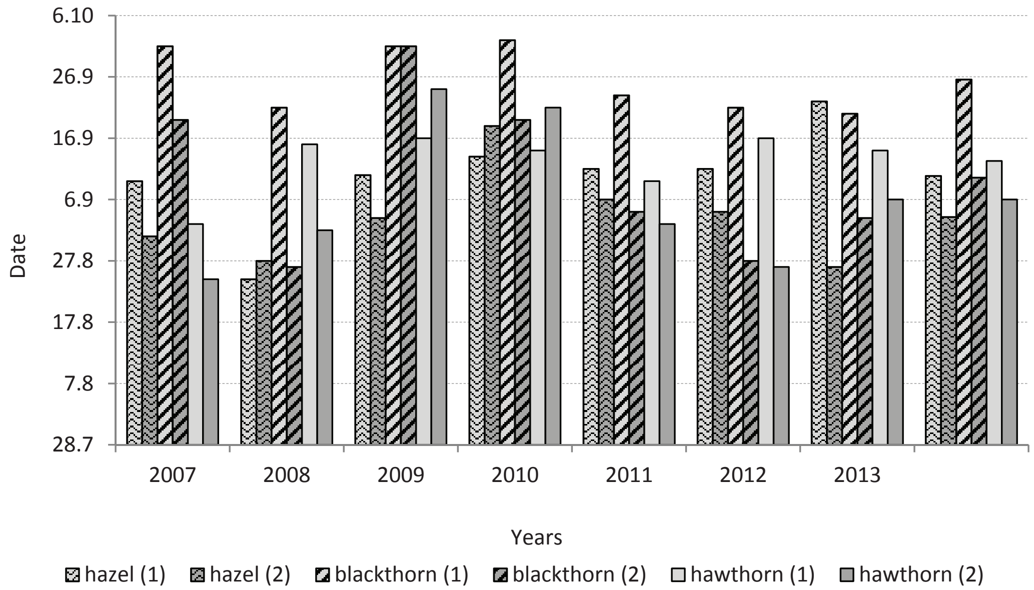
decades of April, the highest temperature sums were needed for first leaves of blackthorn at both locations.

During the years 2007–2013, the phenological phase colouring of leaves of hazel, hawthorn, and blackthorn started at Zvolen location on average on September 10, 13, and 27, respectively (Tab. II). At Boky, we observed earlier onset of colouring of leaves by 6 days in the case of hazel and hawthorn, and by 16 days in the case of blackthorn in spite of the fact that this location is situated at an elevation of 530 m. Due to the southern aspect, the site is overheated and its shallow soils dry out, which causes early leaf colouring already in the last decade of August. The onset of this phenophase varies less than of first leaves as was proven by lower coefficients of variation (2.0–4.3%).

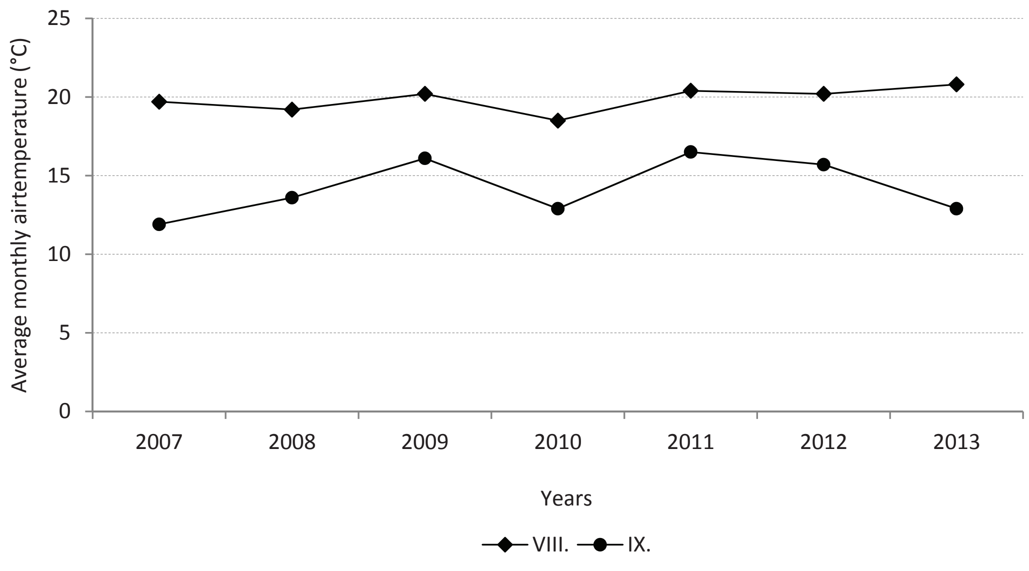
The onset values of colouring of leaves are shown in Fig. 4. In the individual years, they were affected by air temperature and precipitation in summer. Figs. 5 and 6 present the data on the average monthly air temperatures and monthly precipitation totals. Although the end of the summer 2011 was the warmest and the driest within the assessed period, in that year we did not record the earliest onset of colouring of leaves at either of the locations. This is caused by high precipitation total in July

II: *Statistical characteristics colouring of leaves phenophase of tree species at Zvolen and Boky (2) locations in the years 2007–2013 (Ø – average onset, min – the earliest onset, max – the latest onset, s_x% – the coefficient of variation)*

	***Corylus avellana* L.**				***Prunus spinosa* L.**				***Crataegus oxyacantha* L.**			
	Ø	**min**	**max**	**s_x%**	**Ø**	**min**	**max**	**s_x%**	**Ø**	**min**	**max**	**s_x%**
1	Sept. 10	August 25, 2008	Sept.23, 2013	3.4	Sept.27	Sept. 21, 2013	Oct. 3, 2010	2.1	Sept.13	Sept.3, 2007	Sept.17, 2012	2.0
2	Sept. 4	August 27, 2013	Sept.19, 2010	3.1	Sept.11	August 27, 2008	Oct. 2, 2009	4.3	Sept.7	August 25, 2007	Sept.25, 2009	4.2



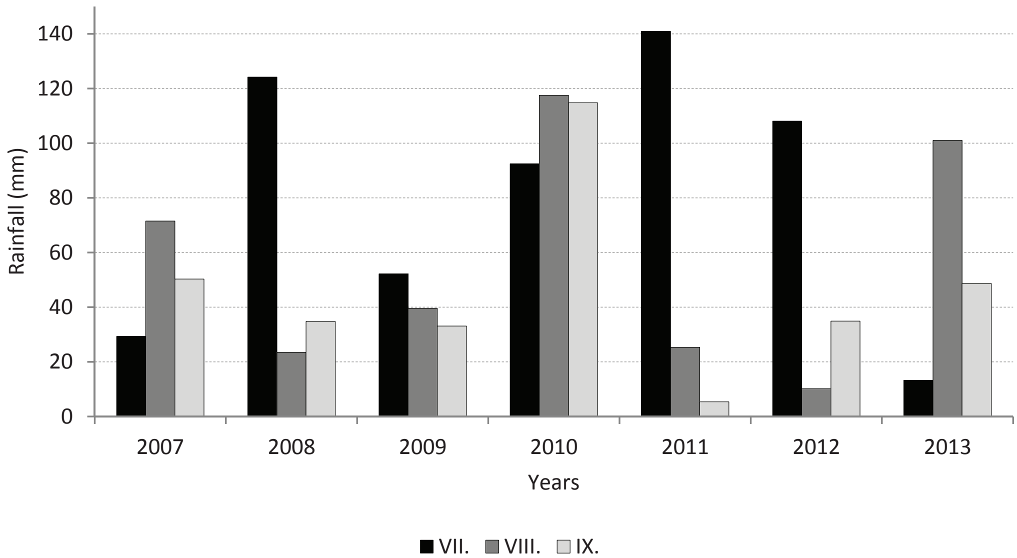
4: *Colouring of leaves of tree species at Zvolen (1) and Boky (2) locations in the years 2007–2013*



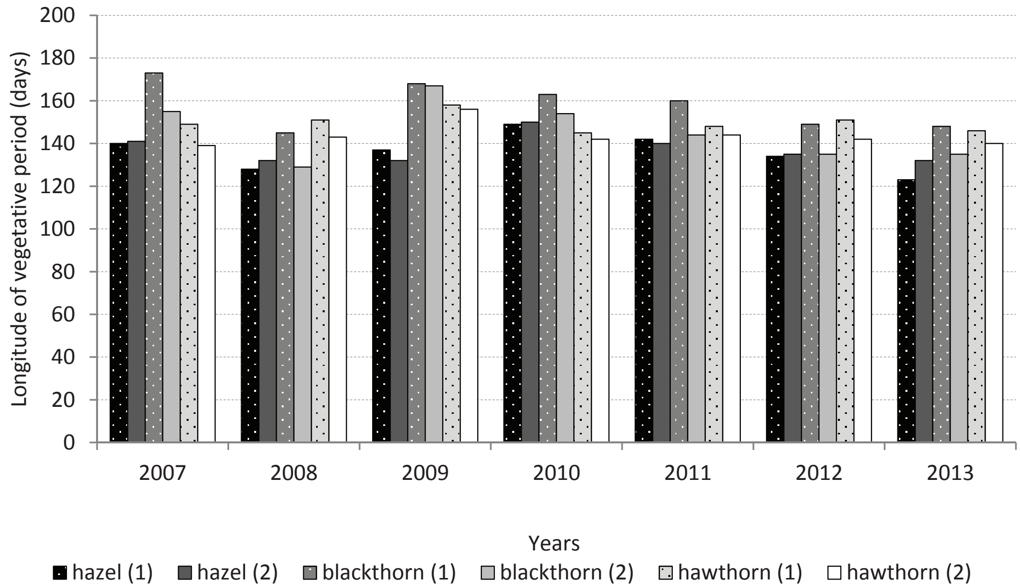
5: *Average monthly air temperatures in August and September at Sliač weather station in the years 2007–2013*

(140.9 mm), due to which sufficient moisture was ensured for the subsequent dry and hot period.

Apart from the onset of both phenological phases we also observed the length of the growing season of the selected tree species. The growing season begins with first leaves and finishes with the onset of beginning of colouring of leaves, when the physiological activity of leaves is stopped. In the temperate region, the length of the growing season reflects the air temperature development. Its prolongation is a signal of changes in climate conditions of the site. The course of the length



6: *Average monthly precipitation totals in July, August and at Sliač weather station in the years 2007–2013*



7: *Average length of the growing season of selected species at Zvolen (1) and Boky (2) locations in the years 2007–2013*

of the growing season in the years 2007–2013 is presented in Fig. 7. In the conditions of central Slovakia, the average length of the growing season of hazel, blackthorn and hawthorn was 136, 152 and 147 days, respectively. In spite of the fact that in the Zvolenská valley the growing season of blackthorn and hawthorn shows positive trends of its prolongation (Škvareninová, 2013), at Boky location we observed a shorter period by 12 and 5 days in the case of blackthorn and hawthorn, respectively, in comparison to Zvolen location. This is due to more extreme temperature and moisture conditions.

Bauer, Bartošová *et al.* (2014) found that in the Czech Republic, the average air temperature in spring (March to May) increased by 0.5 °C during the years 2001–2010. This affected the onset of hawthorn flowering that was shifted by almost 13 days to the earlier period. The presented results confirmed that the onset of spring phenological phases will probably occur earlier in the future, which prolongs the growing season of this species.

CONCLUSION

In the years 2007–2013 we performed phenological observations of common hazel (*Corylus avellana* L.), blackthorn (*Prunus spinosa* L.), and hawthorn (*Crataegus oxyacantha* L.) at two locations of central Slovakia called Zvolen and Boky. At Zvolen location, the phenophase of first leaves started first on hawthorn, on April 17th on average, followed by hazel and blackthorn on April 21st and 22nd, respectively. At Boky site, first leaves of individual species occurred in the same order, but by 4 to 7 days earlier than at Zvolen in spite of the higher elevation. This is caused by extreme site conditions. The progress of this phenophase was influenced by the average daily air temperature above 0 °C. Temperature sums TS0 for the examined tree species ranged from 283.3 to 488.5 °C at Zvolen location, and from 224.3 to 473.2 °C at Boky, while at both locations the highest temperature sum was needed for first leaves of blackthorn.

At Zvolen, the phenological phase colouring of leaves occurred first on hazel on September 10th, followed by hawthorn on September 13th, and blackthorn on September 27th, on average. At Boky, we observed earlier colouring of leaves by 6 days in the case of hazel and hawthorn, and by 16 days in the case blackthorn due to the overheated slope with southern aspect. The onset of colouring of leaves was more stable during the assessed period, which was confirmed by lower values of coefficients of variation. The onset of both phenophases in the individual years was influenced by air temperature and precipitation. Extreme values of meteorological factors and of the onset of phenological phases were observed in the years 2007, 2011 and 2013.

The development of the growing season reflected the course of air temperature. In the conditions of central Slovakia, its average length was 136, 152, and 147 days for hazel, blackthorn, and hawthorn, respectively. During the last 7 years, the growing season at Boky was shorter than at Zvolen by 12 days in the case of blackthorn and by 5 days in the case of hawthorn due to more extreme temperature and moisture.

The presented results showed that site extremes can cause the earlier onset of the phenological phases, and the shortening of the growing season even at the sites situated at higher elevations.

SUMMARY

In the years 2007–2013 we performed phenological observations of common hazel (*Corylus avellana* L.), blackthorn (*Prunus spinosa* L.), and hawthorn (*Crataegus oxyacantha* L.) at two locations of central Slovakia situated at elevations of 300 m (Zvolen) and 530 m (Boky) a.s.l. The species are native for these locations. We observed the phenological phases of first leaves and colouring of leaves, which had to occur on at least 10% of the observed individuals. We evaluated the onset of first leaves in relationship to temperature sum. From both phenological phases we could determine the length of the growing season, which can indicate the changes of climate conditions, and also site extremes. At both locations, first leaves of the species occurred in the same order. Nevertheless, at the location situated at a higher elevation it occurred by 4 to 7 days earlier. The average daily temperature above 0 °C affected the progress of first leaves. Temperature sums TS0 for tree species ranged from 283.3 to 488.5 °C at Zvolen location, and from 224.3 to 473.2 °C at Boky, while the highest temperature sum was needed for first leaves of blackthorn at both locations.

Colouring of leaves occurred earlier at the location situated at higher elevation, by 6 days in the case of hazel and hawthorn, and by 16 days in the case of blackthorn due to the overheated slope with southern aspect. The stable onset was also confirmed by low coefficients of variation (2.0–3.4%). The beginning of both phenophases in the individual years was influenced by air temperature and precipitation. Extreme values of meteorological factors and of the onset of phenological phases were recorded in the years 2007, 2011 and 2013.

In the conditions of central Slovakia, the average length of the growing season was 136, 152, and 147 days for hazel, blackthorn, and hawthorn, respectively. At an elevation of 530 m a.s.l. at Boky, the growing season was shorter by 12 days in the case of blackthorn and by 5 days in the case of hawthorn during the last 7 years due to more extreme temperature and moisture conditions. The results indicate that site extremes and elevation have an impact on the earlier onset of phenological phases of tree species in native forest ecosystems.

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