JOURNAL OF FOREST SCIENCE, *62*, 2016 (2): 47–52

doi: 10.17221/55/2015-JFS

Impact of climatic conditions on the reproductive phenological phases of European hazel (*Corylus avellana* L.) in Slovakia

J. Škvareninová

Faculty of Ecology and Environmental Science, Technical University in Zvolen, Zvolen, Slovak Republic

ABSTRACT: The work presents the results of phenological observations of flowering and fruit ripeness of the European hazel (*Corylus avellana* L.) in Slovakia in two time periods: 1964–1983, and 1994–2013. The phenological stations at elevations from 100 to 875 m a.s.l. were grouped to 7 elevation zones, each 100 m wide. In the first studied period, flowering started on 19 March on average, while in the second period it started 5 days earlier. The average duration of flowering equal to 7–9 days did not depend on the elevation, but on the air temperature and weather patterns in the different elevation zones. During the first period, the average elevation gradient of flowering was 5.6 days per 100 elevation meters, while in the second period it was reduced to 3.5 days in the entire elevation profile. In the elevation zones between 300 and 500 m, a high correlation ($P < 0.01$) between the onset of flowering and elevation was reduced to a moderate level of correlation due to changing environmental conditions. In 1994–2013, the ripeness of hazel nuts started on average on 30 August in Slovakia, showed low variability and moderate correlation with elevation. The phenological elevation gradient was 2.9 days per 100 m of elevation.

Keywords: phenology; forest ecosystems; climate change; weather extremes

Currently, climate change is often in the centre of attention of both the experts and the general public. In Slovakia, we can see more frequent climate changes in the form of extreme weather events with adverse consequences such as floods, long-lasting periods of drought, and increasing risk of fires. Variations in air temperature, precipitation totals and other environmental factors cause changes in the time course of signs of plant life, i.e. onsets of phenological phases, length of their duration and length of the entire growing period. Lengthening of the growing season and the shift of its beginning to earlier spring dates imply an increase of the risk of their damage by early spring frosts. Due to an earlier beginning of the growing season, some tree species seem to have a greater variability of spring phenological phases (Schieber 2007; Škvareninová et al. 2008). In our geographical zone, air temperature is a primary driving parameter that determines the course and the length of the growing season. This is reflected in its highly significant relation to the onset of spring phenological phases (Bednářová et al. 2012; Škvareninová 2013). The reaction of the flowering phenophase was also distinct, since in the case of some tree species it has shifted by 14 days earlier over a long-term period (Roetzer et al. 2000). In several parts of Europe, it has been observed that an average beginning of the growing season of forest tree species has shifted by 8 days earlier (Chmielewski, Rötzer 2001). These changes cause changes in the species composition and changes in the original ranges of species. Higher average air temperatures in the winter months significantly influence those species which for their successful budburst in spring need to be exposed to low temperatures over a certain period.

Supported by the Ministry of Education of the Slovak Republic, Project No. 1/0463/14.

Phenological observations contribute to the explanation of climate change in several ways (Schwartz 1999). Long-term phenological records at a species level may explain its biological responses to climate change. Suitable phenological models in combination with climate scenarios enable predicting future development of communities, competition and relationships between species, and population density (Chuine 2000; Schaber, Badeck 2003).

MATERIAL AND METHODS

The European hazel belongs to tree species that start their phenological activity first with flowering in early spring. It is a reliable bioindicator of changes in climatic conditions along its elevation gradient in Slovakia, especially during the spring season. The data from 50 Slovak phenological stations representing the onset of flowering were processed in two 20–year periods: 1964–1983, and 1994–2013. The phenological stations were situated at elevations from 100 to 875 m above sea level, and were grouped to 7 elevation zones, each 100 m wide. The data on the beginning of fruit ripening were available only for the period 1994–2013, therefore it was not possible to reveal any changes by comparing the data with the older ones. Changes in the development of phenological phases with the increasing elevation can be expressed using so called elevation phenological gradient. The gradient is quantified as the difference in the onset of the phenological phase between the lowest and the highest site converted to 100 elevation meters.

Phenological observations were carried out in the forest stands of Slovakia, where hazel was in the undergrowth of mixed deciduous forests or created separate groups at forest edges. Phenological phases were determined following the valid methodology of the Slovak hydro-meteorological institute (Braslavská, Kamenský 1996). Each phenological phase was assessed on a set of 10 individuals. The onset of flowering occurred when male flowers of at least half of the individuals started to shed pollen. The ripeness of hazel nuts became evident by gradual colouring and hardening of nuts. In statistical data processing, we used the Julian calendar, in which the date of the phenological phase is represented by a serial number of the day of the year. Older data were transformed to create a uniform database. The data were processed in Microsoft Excel. The type of linear correlation was specified according to Šmelko and Wolf (1977).

RESULTS AND DISCUSSION

In the period 1964–1983, the onset of hazel flowering in Slovakia started on 19 March on average. The earliest date during this period was recorded on February 14, 1966 in the first elevation zone, and the latest onset was recorded on May 10, 1970 in the seventh elevation zone. In the second period 1994–2013, the average onset of flowering was on 14 March. The earliest date of the onset of flowering occurred on January 15, 2007 in the first elevation zone. The latest flowering was on April 27 in 1997 and 2006. According to the presented data, the average date of hazel flowering has been shifted by 5 days earlier over the last 20 years. The earliest dates of average flowering were shifted by 3–19 days earlier in the second period than in the first period. The greatest differences of 12 and 19 days occurred in the 4th and 5th elevation zones. Despite the fact that only few older phenological records were available, the given phenological data indicate the changes of temperature conditions in Slovakia at the end of the winter and in the spring time. If we compared the average onset of flowering of the European hazel in Slovakia in the period 1994–2013 with the values representing a similar period in the Czech Republic (1991–2010) (Hájková et al. 2012), we revealed a shift of the phenophase by 8–13 days to later periods with the increasing elevation. These distinct time differences resulted from the geographic conditions of Slovakia and the increase of continentality toward the east.

From trend analyses we can detect whether the onset of flowering changes in time due to different climatic conditions (Figs 1, 2). In both examined periods we found a trend of earlier flowering by 2–6 days, however the trend was not significant. In the years 1994–2013, the trend of flowering decreased to 2 days. The results of Roetzer et al. (2000) are consistent with our findings, as they showed that

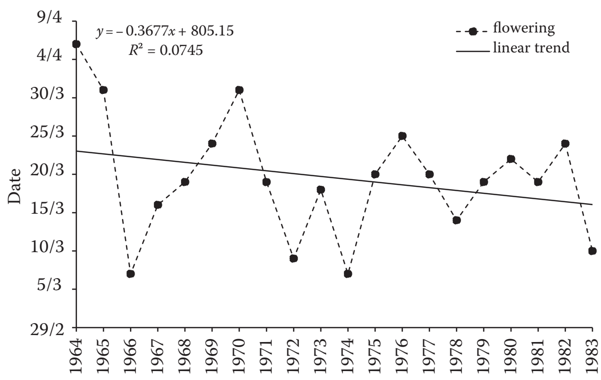

Fig. 1. The average onset of European hazel flowering in 1964–1983

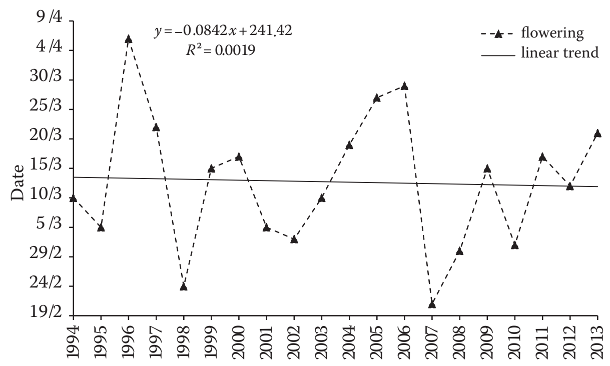

Fig. 2. The average onset of European hazel flowering in 1994–2013

over 40 years the onset of spring phenological phases of forest tree species in central Europe shifted by 13–15 days earlier. A longer time series of data is needed to confirm statistical significance of the earlier onset of flowering as a result of climate change.

High variability of flowering in the second period in all elevation zones (s_x = 2.4–34.5%) is a signal of the hazel response to temperature extremes at the end of winter and in early spring. The signals are more pronounced in the earlier periods of the year. Schieber (2007) also confirmed that higher variability of spring phenological phases is a result of climate change.

Elevation is a surrogate of a set of meteorological elements (temperature, precipitation), which cause changes in the course of plant phenological phases. With the increasing elevation, flowering in the elevation zones was unevenly delayed by 1 to 15 days in the first period, and by 1–10 days in the second period (Table 1). A comparison of the average onset of flowering in the individual elevation zones showed that in the second period the onset in the first four elevation zones was almost the same due to similar weather conditions. A higher coefficient of variation (R_{s_x} (%)) in the second period indicates more frequent alternation of warmer and cooler periods during the spring in Slovakia.

The analysis of a correlation between the average onset of flowering and elevation (Fig. 3) confirmed the significance of their relationship ($P < 0.01$). In the first period, the value of the coefficient of determination was 0.88 and thus it showed high dependence, while in the second period the correlation was moderate (R^2 = 0.79) due to the similar average onset of flowering in the first five elevation zones. The results of the phenological analyses of hazel flowering in northeastern Slovenia also confirmed its significant dependence on maximum air temperature with a high level of correlation (R^2 = 0.64 to 0.98) (Črepinšek et al. 2012). High correlations were determined between the mean air temperature and the start of spring phenological phases in trees of a mixed stand in the Drahanská vrchovina Upland region (Merklová, Bednářová 2008). Correlation coefficients were statistically significant. To evaluate the relationships by means of the sum of effective temperatures > 5°C, the stage of budbreak was most important in all studied species.

A phenological elevation gradient is a simpler way of expressing the change of environmental conditions in the vertical profile. In the first period, flowering was on average delayed by 5.6 days per 100 el-

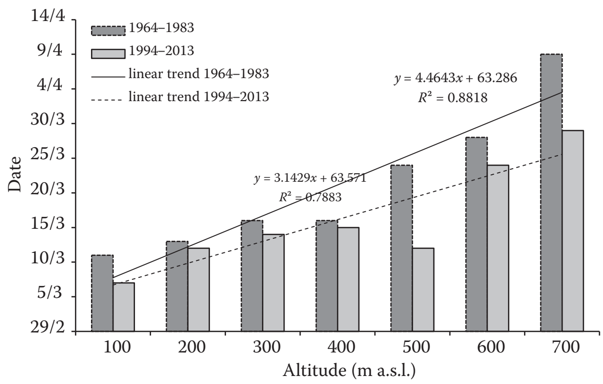

Fig. 3. The relationship between the average onset of European hazel flowering and elevation in the monitored periods

Table 1. Statistical characteristics of the onset of European hazel flowering in two different time periods

Elevation zone (m a.s.l.)	1964–1983					1994–2013				
	Ø	min	max	s_x (%)	R_{s_x} (%)	Ø	min	max	s_x (%)	R_{s_x} (%)
100	66	53	87	3.0–21.6	18.6	71	50	86	4.5–29.8	25.3
200	72	58	93	3.5–23.7	20.2	72	51	96	3.3–22.2	18.9
300	76	58	91	10.1–32.1	22.0	74	47	98	7.2–29.9	22.7
400	76	65	94	3.6–16.8	13.2	75	53	103	10.0–30.1	20.1
500	84	71	99	4.8–16.0	11.2	73	52	100	4.6–34.5	29.9
600	85	76	108	3.1–19.0	15.9	83	68	104	2.4–22.5	20.1
> 700	100	81	111	5.0–26.0	21.0	90	73	107	2.4–24.3	21.9

Ø – arithmetic mean (Julian day), min – the earliest start, max – the latest start, s_x – coefficient of variation, R – variation range

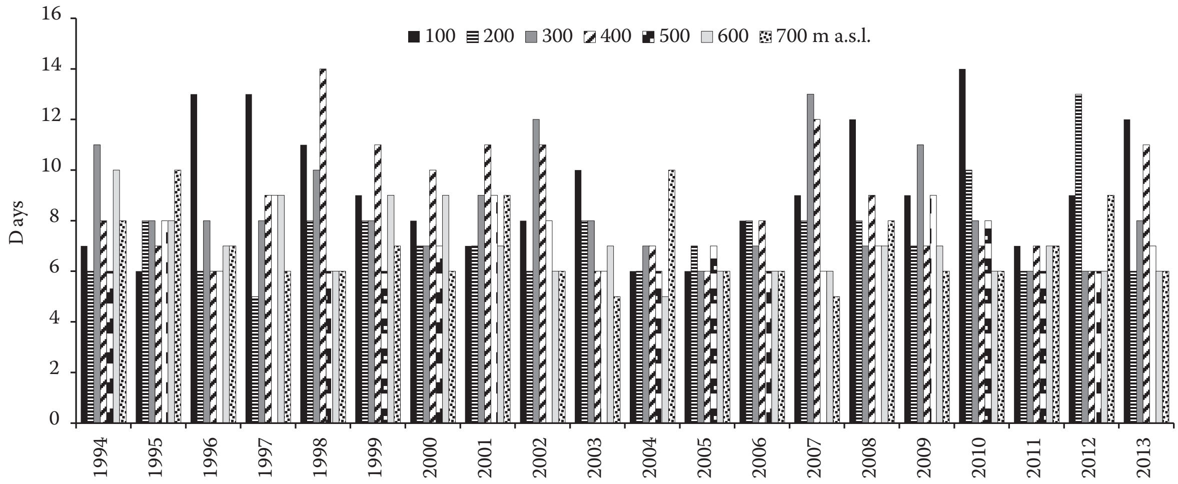

Fig. 4. Duration of European hazel flowering in the period 1994–2013 in individual elevation zones

evation meters, while in the second period the delay was reduced to 3.5 days per 100 elevation meters in the entire elevation profile. On the basis of these data we can predict climate changes in the form of increasing air temperature in the entire elevation profile. In Slovakia, elevation gradients in the flowering of shrubby tree species (*Sambucus nigra*, *Prunus spinosa*) were 3–4.3 days/100 m of elevation during the period 2007–2011 (Schieber 2014).

An interesting comparison of the data representing hazel flowering in the period 1991–2004 from the coastal area in the north of Italy (10 m a.s.l.) and Slovakia (700 m a.s.l.) revealed the effect of continental climate on the phenological elevation gradient of flowering. In Italy, the average onset of flowering was on 19 January (Longo, Sauli 2010), while at the highest sites of hazel natural occurrence in Slovakia the onset was on 13 March. The average delay of flowering was 53 days, and the elevation gradient was 7.6 days/100 m. The presented values of flowering onset were affected by large differences (6.7–9°C) in the average monthly air temperature from January to March 1991–2004

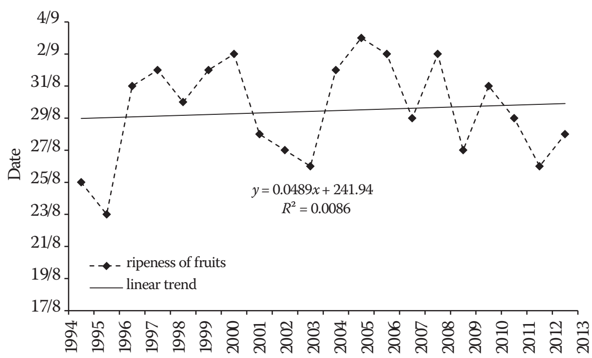

Fig. 5. The onset of average ripeness of European hazel nuts in 1994–2013

between the sites due to elevation differences and continental climate in Slovakia.

Over long periods, tree species can react to changes of climatic conditions by changing the duration of their phenological phases. The duration of the phase is affected by long-term development of air temperature, but also by sudden changes of weather. In the years 1994–2013 (Fig. 4) flowering lasted from 7 to 9 days on average, the minimum and maximum duration was 5 and 14 days, respectively. The shortest duration of flowering was in 2005 and 2011 in all elevation zones. We can see from the figure that the duration of flowering is independent of elevation, and probably depends on weather patterns, which may vary in individual elevation zones even during one year.

In the years 1994–2013, the ripeness of hazel nuts started on 30 August on average in Slovakia. The earliest onset occurred in 1995, when the nuts started to be ripe on August24, while the latest average onset of ripeness was recorded on September 4, 2005. This phenological phase was characterised by a balanced course with low variability (s_x = 2.9 to 5.4%). This is caused by stable weather conditions in late summer, when the temperature fluctuations and precipitation totals are minimal. Unlike the spring phenophase, the ripeness of nuts is mainly influenced by the onset of heat waves in early summer. The trend analysis (Fig. 5) confirmed the balanced course without a significant shift of the onset of ripeness over time. The shift of the phenophase to later periods was observed with the increasing elevation (Fig. 6). The shift was most pronounced between the first and second elevation zones (11 days) and between the sixth and seventh elevation zones (13 days). From the second to the fifth elevation zones, the onset was similar. A significant correlation at a moderate level was confirmed between the

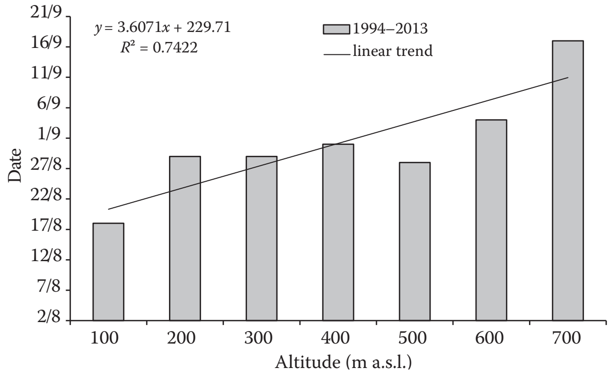

Fig. 6. The relationship between the average onset of ripeness of European hazel nuts and elevation in 1994–2013

ripening of nuts and elevation. The phenological elevation gradient of nut ripeness reached 2.9 days per 100 elevation meters, which confirms that differences between the sites are considerably smaller than in the case of the spring phenological phase. Similar results were also presented by Schieber et al. (2013), who showed that the site differences in average onsets of autumn vegetative phenophases of common beech were significantly lower (1–1.78 day/100 m) than those of spring phenophases.

CONCLUSION

The analysis of the onset of European hazel flowering in the territory of Slovakia was aimed at revealing the impact of changes in environmental conditions caused by climate change on this phenophase in two periods 1964–1983, and 1994–2013. In the years 1964–1983, the average onset of flowering was on 19 March, while in the years 1994–2013, the onset was shifted by 5 days earlier. Despite the fact that the trend of an earlier onset of flowering by 2–6 days was not significant, the variability of the onset was greater in the second period. Due to climate change, warming at high elevations occurs, which was reflected in the decrease of the phenological elevation gradient between the two examined periods by 2 days per 100 elevation meters. In the second period, the average onset at elevations between 300 and 500 m occurred on 15 March. The changes of environmental conditions were also confirmed by a significant correlation between the onset of flowering and elevation at a high level (R^2 = 0.88) in the first period. The reduction of the correlation to a moderate level in the second period (R^2 = 0.79) was caused by similar average values of the onset of flowering in the first five elevation zones. The changes were also reflected in earlier average onsets of flowering in almost every elevation zone in the second period compared to the first period. The average duration of flowering equal to 7–9 days did not depend on the elevation, but on the air temperature and weather patterns in the different elevation zones.

In 1994–2013, the ripeness of hazel nuts started in Slovakia on 30 August on average, and its variability was low (s_x %=2.9–5.4). The course of this phenological phase over time was balanced with no temporal shifts of the ripeness. The determined elevation profile confirmed the significance of correlation between the ripening of nuts and elevation at a moderate level (R^2=0.74). The phenological elevation gradient was 2.9 days per 100 m of elevation.

The results of the phenological observations of reproductive phenological phases of the European hazel revealed differences in several evaluated parameters that indicate climate warming and changes in the environmental conditions as a result of expected climate change.

References

Bednářová E., Truparová L., Merklová L. (2012): Monitoring the spring phenological stages in a spruce monoculture in the Drahanska vrchovina upland in 2005–2011. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 60: 15–20.

Braslavská O., Kamenský L. (1996): Fenologické Pozorovanie Lesných Rastlín. Bratislava, Slovenský Hydrometeorologický Ústav: 22.

Chmielewski F.M., Rötzer T. (2001): Response of tree phenology to climate change across Europe. Agricultural and Forest Meteorology, 108: 101–112.

Chuine I. (2000): A unified model for budburst of trees. Journal of Theoretical Biology, 207: 337–347.

Črepinšek Z., Štampar F., Bogataj L.K., Solar A. (2012): The response of *Corylus avellana* L. phenology to rising temperature in north-eastern Slovenia. International Journal of Biometeorology, 56: 681–694.

Hájková L., Voženílek V., Tolasz R., Kohut M., Možný M., Nekovář J., Novák M., Reitschläger D.J., Schmiedová V., Skokanová Z., Šedivý J., Škvareninová J. (2012): Atlas fenologických poměrů Česka. Praha, Olomouc, Český hydrometeorologický ústav Praha, Univerzita Palackého Olomouc: 311.

Longo L.R., Sauli M.P. (2010): Flowering phenology and airborne pollen occurrence of *Corylus* and *Castanea* in Trieste (Italy), 1991–2004. Acta Botanica Croatica, 69: 199–214.

Merklová L., Bednářová E. (2008): Results of a phenological study of the tree layer of a mixed stand in the region of the Drahanská vrchovina Upland. Journal of Forest Science, 54: 294–305.

Roetzer T., Wittenzeller M., Haeckel H., Nekovař J. (2000): Phenology in central Europe – differences and trends of spring phenophases in urban and rural areas. International Journal of Biometeorology, 44: 60–66.
Schaber J., Badeck F.W. (2003): Physiology-based phenology models for forest tree species in Germany. International Journal of Biometeorology, 47: 193–201.
Schieber B. (2007): Changes of flowering phenology of six herbal species in a beech forest (Central Slovakia) a decade analysis. Polish Journal of Ecology, 55: 233–244.
Schieber B., Janík R., Snopková Z. (2013): Phenology of common beech (*Fagus sylvatica* L.) along the altitudinal gradient in Slovak Republic (Inner Western Carpathians). Journal of Forest Science, 59: 176–184.
Schieber B. (2014): Effect of altitude on phenology of selected forest plant species in Slovakia (Western Carpathians). Folia Oecologica, 41: 75–81.
Schwartz M.D. (1999): Advancing to full bloom: planning phenological research for the 21st century. International Journal of Biometeorology, 42: 113–118.
Škvareninová J. (2013): Vplyv zmeny klimatických podmienok na fenologickú odozvu ekosystémov. Zvolen, Technická univerzita vo Zvolene: 132.
Škvareninová J., Domčeková D., Snopková Z., Škvarenina J., Šiška B. (2008): Phenology of pedunculate oak (*Quercus robur* L.) in the Zvolen basin, in dependence on biometeorological factors. Folia Oecologica, 35: 40–47.
Šmelko Š., Wolf J. (1977): Štatistické metódy v lesníctve. Bratislava, Príroda: 330.

Received for publication June 5, 2015
Accepted after corrections January 11, 2016

Corresponding author:
doc. Jana Škvareninová, PhD., Technical University in Zvolen, Faculty of Ecology and Environmental Science, T.G. Masaryka 24, 960 53 Zvolen, Slovak Republic; e-mail: skvareninova@tuzvo.sk