# Effect of altitude on phenology of selected forest plant species in Slovakia (Western Carpathians)

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**Abstract**

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Phenological response of selected forest plant species to different ecological conditions along the altitudinal gradient were studied during the period of 5 years (2007–2011). Leafing as well as flowering phenophases were investigated within two herb species (*Dentaria bulbifera and Galium odoratum*) and three shrubs (*Prunus spinosa, Rubus idaeus* and *Sambucus nigra*), respectively. Altitudinal gradient was expressed by different altitude sites situated in Burda Mts (200 m a.s.l.), in Kremnické vrchy Mts (500 m a.s.l.) and in Poľana Mts (≥900 m a.s.l.) belonging to Western Carpathians. On average, the earliest onset of the phenophases was found in the low-lying sites and vice versa. For vegetative phenophases, phenological gradient expressing the shift in onset of the phenophases along the gradient reached the mean values from +2.7 to +3.6 days per 100 m. In the case of generative phases (flowering) within the species, the gradient moved from +3.0 to +4.3 days per 100 m of an altitude increase. Interannual variability in onsets of phenophases was also determined.

**Keywords**

*Dentaria bulbifera*, *Galium odoratum*, flowering, leafing, *Prunus spinosa*, *Rubus idaeus*, *Sambucus nigra*, vertical phenological gradient

## Introduction

Recently, the phenology standing at the edge of ecology and meteorology has been a dynamically developing science. The current changes (local and global) in the environment influence the life processes of the individuals as well as entire ecosystems. In terms of phenology, these changes are observed at the species level – species-level phenology, and at the ecosystem level – ecosystem- and global-scale phenology (Maak and Storch, 1997; Totland and Alatalo, 2002; Zhang et al., 2003; Badeck, 2004; Bednářová and Merklová, 2007; Inouye, 2008; Škvareninová et al., 2008; McEwan et al., 2011). In addition to exogenous factors such as increase in average air temperature, precipitation regime change, the increase of $CO_2$ concentration, also internal – biological factors, e.g. genetic variability, play an important role in the phenological response of the species (Chesnoiu et al., 2009). The initial development of the plants in spring is related to the development of the assimilation system. This period is crucial for its subsequent successful growth. Late frosts often damage leaves and plant must expend more energy to regenerate itself again. If such events occurred frequently, fatal consequences for populations of several species would be observed (Hufkens et al., 2012). Flowering is a part of plant life, when the preconditions for its generative reproduction are created. This is the basis of genetic diversity, which plays an important role in the adaptation of species to changing environmental conditions. It is known that in areas of the temperate zone most of the plant species blooms in spring or in early-summer. The beginning of flowering signalises the onset of some daily mean temperature (DMT), which can be defined as the onset of growing season, e.g. flowering of blackthorn and linden signalises the onset of DMT 10 °C and DMT 15 °C, respectively. Weather course varies considerably during the year at the temperate zone (Fitter et al., 1995; Tyler, 2001; Lu et al., 2006). This variability is related to variability in the onset and course of the phenophases. It can be found at particular species during the year. The reason for the variability may be the different phytoclimate within the same stand, or the different bioclimatic conditions along the vertical gradient (Schieber, 1996, 2008, 2013). Shift (positive or negative) in the onset of phenophases along the gradient indicates indirectly the differences in environmental conditions.

There is relatively little information concerning plant phenology along the altitudinal gradient in the literature (Levesque et al., 1997; Blionis et al., 2001; Dittmar and Elling, 2006; Giménez-Benavides et al., 2007; Ziello et al., 2009; Schieber, 2013; Schuster et al., 2013). However, the results of these studies can be used in prognosis of the physiological responses of plants to changing environmental conditions due to ongoing climate change, which can already interfere significantly with the functioning of forest ecosystems.

Therefore the aim of this paper is to assess the variability in the onset and course of selected vegetative and generative phenological phases – leafing and flowering of five widespread species in forest ecosystems along the altitudinal gradient in South and Middle Slovakia.

## Material and methods

Phenological research was conducted on five species (*Dentaria bulbifera* L., *Galium odoratum* (L.) Scop., *Prunus spinosa* L., *Rubus idaeus* L. and *Sambucus nigra* L.) in forest ecosystems in three neo-volcanic mountains located south of the main line of the climate in Slovakia – Burda Mts, Kremnické vrchy Mts and Poľana Mts (Fig. 1). The Burda Mts. lie in the south-eastern corner of the lower Danube Plain between the rivers Danube, Hron and Ipeľ and their height is relatively little differentiated (113–405 m a.s.l.). The area belongs to the warm climate, dry district with mild winter. Observations were done at site located north of the village of Chľaba (Helemba). The locality is situated at the beginning of the Veľká dolina valley (200 m a.s.l.). The Kremnické vrchy Mts are situated in the central part of Slovak Republic. Phenological observations were carried out on an Experimental Ecological Stationary Kremnické vrchy Mts (500 m a.s.l.), which is located in the SE part of the above orographic unit. The locality belongs to the temperate climate zone, slightly damp to wet district. The Poľana Mts are the highest volcanic mountain range in Slovak Republic. Southern foothills of the Poľana Mts belong to the temperate climate, humid district. The other mountain territory is classified into a cold climate zone, slightly cool to cold mountain district (Lapin et al., 2002). Observations were done at five localities. The lowest-lying area, within this mountain chain, is situated above the village of Priehalina (900 m a.s.l.), the second location is Javorinka (1,000 m a.s.l.). The other sites are located at Huklová (1,200 m a.s.l.), Predná Poľana (1,300 m a.s.l.) and Zadná Poľana (1,400 m a.s.l.). Supplemental characteristics of research sites are given in Table 1.

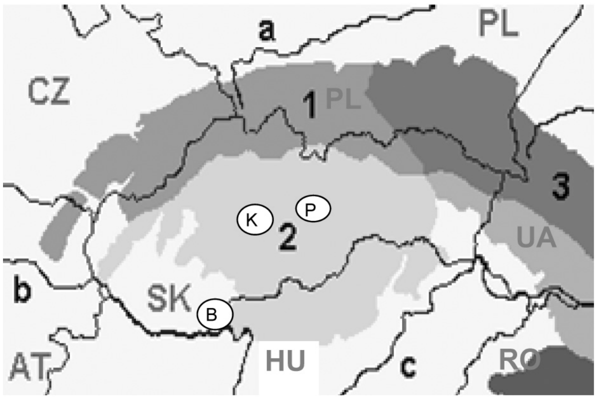


Fig. 1. Location of the research plots in Slovak Republic (B, Burda Mts; K, Kremnické vrchy Mts; P, Poľana Mts; 1, Outer Western Carpathians; 2, Inner Western Carpathians; 3, Outer Eastern Carpathians; a, Vistula River; b, Danube River; c, Tisza River).

Methodology of observations is based on the methodological prescription for phenological observation used in phenological monitoring by Slovak Hydrometeorological Institute (SHMI) Bratislava (Braslavská and Kamenský, 1996). Phenophases were defined according to the BBCH scale (Hess et al., 1997). Observations were conducted weekly during the growing season for five years (2007–2011). For herbaceous species, there were observed vegetative and generative phenophases: germination (BBCH 09), first leaves (BBCH11), first flowers (BBCH60) and flowering 50% (BBCH65). In the case of (semi-)shrubs the following phenophases were evaluated: first leaves (BBCH11), three leaves (BBCH13), first flowers (BBCH60) and flowering 50% (BBCH65). The onset of phenophases was expressed as a sequence of days counted from 1$^{st}$ January – day of year (DOY). Climate data were taken from the databases of SHMI and Hungarian National Meteorological Service and supplemented by own measurements (smart sensor Minikin, Mini32 software, EMS Brno, Czech Republic).

## Results

### Vegetative phenophases

Onset of vegetative phenological phases for all species along the altitudinal gradient in the period 2007–2011 is described in Tables 2–3. As for herb species *Dentaria bulbifera*, the average onset of the both BBCH09 and BBCH11 phenophases was recorded on 75th and 81st day of the year (DOY), i.e. 15th March and 21st March at the lowermost site (200 m a.s.l.), respectively. Onset of the phenophases delayed progressively with increasing altitude, the 39 days delay (i.e. 24th April and 30th April) was recorded at the highest altitude (1,300 m a.s.l.). Phenological response of *Galium odoratum* species was similar, the average onset of both BBCH09 and BBCH11 phenophases was recorded on 102nd and 110th DOY, i.e. 12th April and 20th April at the altitude of 500 m a.s.l., respectively. The 22–23 days delay (i.e. 4th May and 13th May) was recorded at the highest altitude (1,300 m a.s.l.). The average length of the interval between both BBCH09 and BBCH11 phenophases varied within the range of 4.8–6.0 days and 7.4–9.4 days for *Dentaria bulbifera* and *Galium odoratum*, respectively.

Table 1. Characteristics of research sites along the altitudinal gradient

| Localities | Burda Mts | Kremnické vrchy Mts | Poľana Mts | | | | |
|---|---|---|---|---|---|---|---|
| Altitude [m a.s.l.] | 200 | 500 | 900 | 1,000 | 1,200 | 1,300 | 1,400 |
| Exposition | NE | WSW | SE | SE | E | SE | SW |
| AAT $_{1951–1980}$ [°C] | 9.3 | 6.9 | 5.6 | 5.1 | 4.0 | 3.4 | 2.9 |
| $AT_{IV.-IX.1951–1980}$ [°C] | 15.9 | 13.6 | 11.6 | 11.0 | 10.1 | 9.5 | 8.8 |
| $AAP_{1951–1980}$ [mm] | 600 | 780 | 890 | 930 | 1,040 | 1,100 | 1,160 |
| $AP_{IV.-IX.1951–1980}$ [mm] | 355 | 420 | 500 | 530 | 575 | 610 | 640 |

AAT, average annual air temperature; $AT_{IV.–IX.}$, average air temperature IV.–IX.; AAP, average annual precipitation; $AP_{IV.–IX.}$, average precipitation IV.–IX.

Table 2. The onset of vegetative phenophases of herb species at different altitudes

| Altitude [m a.s.l.] | | 200 | | 500 | | 900 | | 1,000 | | 1,200 | | 1,300 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phenophase (BBCH) | | 09 | 11 | 09 | 11 | 09 | 11 | 09 | 11 | 09 | 11 | 09 | 11 |
| $Mean_{2007–2011}$ [DOY] | *Dentaria bulbifera* | 75 | 801 | 87 | 92 | 96 | 101 | 100 | 105 | 109 | 115 | 114 | 120 |
| | *Galium odoratum* | – | – | 102 | 110 | 110 | 118 | 114 | 121 | 119 | 128 | 124 | 133 |
| SD [± days] | *Dentaria bulbifera* | 3.9 | 4.8 | 5.9 | 5.8 | 4.4 | 4.3 | 4.7 | 4.7 | 4.2 | 3.5 | 3.8 | 3.4 |
| | *Galium odoratum* | – | – | 5.0 | 4.4 | 3.9 | 4.3 | 4.4 | 5.2 | 2.9 | 4.3 | 4.2 | 4.2 |
| CV [%] | *Dentaria bulbifera* | 5.2 | 6.0 | 6.8 | 6.3 | 4.6 | 4.2 | 4.7 | 4.5 | 3.8 | 3.1 | 3.3 | 2.9 |
| | *Galium odoratum* | – | – | 4.9 | 4.0 | 3.6 | 3.6 | 3.9 | 4.3 | 2.4 | 3.4 | 1.5 | 3.2 |

DOY, day of year; SD, standard deviation; CV, coefficient of variation; BBCH09, emergence: shoot/leaf breaks through soil surface; BBCH11, first true leaf / leaf pair of whorl unfolded.

Table 3. The onset of vegetative phenophases of shrub species at different altitudes

| Altitude [m a.s.l.] | | 200 | | 500 | | 900 | | 1,000 | | 1,200 | | 1,300 | | 1,400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phenophase (BBCH) | | 11 | 13 | 11 | 13 | 11 | 13 | 11 | 13 | 11 | 13 | 11 | 13 | 11 | 13 |
| $Mean_{2007–2011}$ [DOY] | *Prunus spinosa* | 105 | 113 | 121 | 126 | – | – | – | 128 | 136 | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 103 | 117 | 115 | 127 | 118 | 130 | 127 | 138 | 132 | 143 | 140 | 149 |
| | *Sambucus nigra* | – | – | 103 | 130 | 118 | 140 | 122 | 145 | – | – | – | – | – | – |
| SD [± days] | *Prunus spinosa* | 1.9 | 2.3 | 5.7 | 3.6 | – | – | 6.2 | 5.9 | – | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 1.9 | 1.7 | 2.0 | 2.3 | 1.7 | 2.1 | 2.8 | 4.3 | 3.7 | 5.1 | 4.0 | 5.4 |
| | *Sambucus nigra* | – | – | 2.3 | 6.7 | 4.0 | 5.5 | 4.7 | 6.0 | – | – | – | – | – | – |
| CV [%] | *Prunus spinosa* | 1.8 | 2.1 | 4.7 | 2.9 | – | – | 4.9 | 4.3 | – | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 1.8 | 1.5 | 1.7 | 1.8 | 1.5 | 1.6 | 2.2 | 3.1 | 2.8 | 3.6 | 2.9 | 3.6 |
| | *Sambucus nigra* | – | – | 2.2 | 5.1 | 3.4 | 3.9 | 3.9 | 4.1 | – | – | – | – | – | – |

DOY, day of year; SD, standard deviation; CV, coefficient of variation; BBCH 11, first true leaf unfolded; BBCH 13, three true leaves.

Vertical phenological gradient, which reflects the difference in onset of the phenophases among the sites calculated to 100 meters of altitude increase, reached the values of 3.5 (for BBCH09) and 3.6 (for BBCH11) in the case of *Dentaria bulbifera*. As for *Galium odoratum*, the gradient reached the values of 2.7 and 2.9 days per 100 m, respectively (Fig. 2).

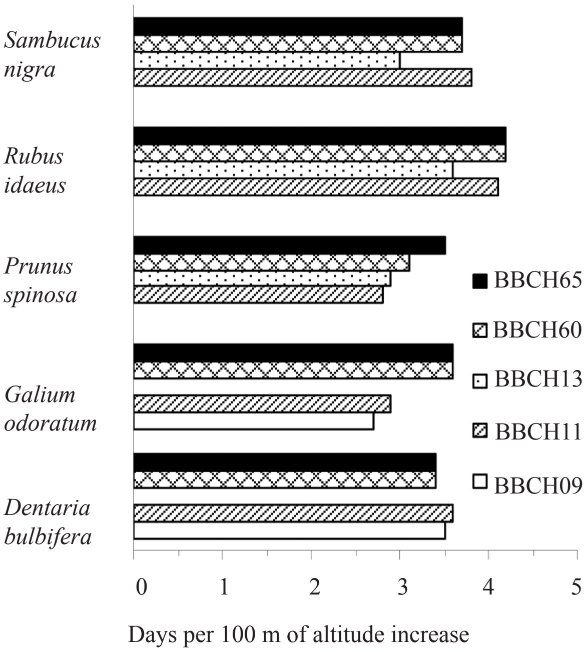


Fig. 2. Average shifts of the onset of phenophases along the altitudinal gradient during the years 2007–2011. BBCH09–BBCH65, see Tables 2–5.

On average, the onset of both BBCH11 and BBCH13 phenophases of *Prunus spinosa* was recorded on 105th and 113rd DOY (i.e. 15th April and 23rd April) at the lowermost site (200 m a.s.l.), respectively. Onset of these phenophases delayed with increasing altitude along the altitudinal gradient, the 23 days delay (i.e. 8th May and 16th May) was recorded at the altitude of 1,000 m a.s.l. As for the other shrub species, the onset of vegetative phenophases for *Rubus idaeus* was observed on 103rd and 117th DOY, for *Sambucus nigra* it was on 103rd and 130th DOY, respectively. The average length of the interval between onset of both BBCH11 and BBCH13 phenophases varied within the range of 5.4–8.0 days and 22.2–26.6 days for *Prunus spinosa* and *Sambucus nigra*, respectively. Vertical phenological gradient for shrub species moved from 2.8–2.9 days (*Prunus spinosa*) to 3.6–4.1 days (*Rubus idaeus*) per 100 m of altitude increase (Fig. 2).

Dating the vegetative phenophases varied not only depending on the altitude, but also between the compared years. For herb species, the smallest year to year variability in the onset of phenophases was found out within the higher mountain ranges (>1,200 m a.s.l.), on the other hand, higher variability was observed at the lower sites (<500 m a.s.l.). As for shrub species, the variability increased with the altitude increasing in the case of *Prunus spinosa*. The variability in onset of phenophases of the other shrubs was relatively stable along the gradient, only for *Rubus idaeus* higher variability at the altitudes >1,200 m a.s.l. was recorded.

**Generative phenophases – flowering**

Onset and course of generative phenophases (flowering) of the species along the gradient is described in Tables 4–5. The average onset of both BBCH60 and BBCH65 phenophases of *Dentaria bulbifera* was recorded on 108th and 114th day of the year (DOY), i.e. 18th April and 24th April at the lowermost site (200 m a.s.l.), respectively. Increasing altitude caused the delay of the onset of the phenophases, the 37–38 days delay (i.e. 26th May and 31st May) was recorded at the highest altitude (1,300 m a.s.l.). As for *Galium odoratum* species, the average onset of the phenophases was recorded on 125th and 132nd DOY, i.e. 5th May and 12th May at the altitude of 500 m a.s.l., respectively. The 28–29 days delay (i.e. 2nd June and 10th June) was recorded at the highest altitude (1,300 m a.s.l.). The average length of the interval between both BBCH60 and BBCH65 phenophases, which represents the dynamics of flowering of plants along the gradient, varied within the range of 4.8–6.0 days and 6.6–8.2 days for *Dentaria bulbifera* and *Galium odoratum*, respectively.

In the case of *Dentaria bulbifera*, vertical phenological gradient reached the same values of 3.4 days for both BBCH60 and BBCH65 phenophases, for *Galium odoratum* it was similar, the gradient reached the values of 3.6 days per 100 m (Fig. 2).

On average, the onset of both BBCH60 and BBCH65 phenophases of *Prunus spinosa* was recorded on 96th and 100th DOY (i.e. 6th April and 10th April) at the altitude 200 m a.s.l., respectively. The shift in onset along the gradient was 24–28 days (i.e. 1st May and 7th May) at the altitude of 1,000 m a.s.l. The onset of generative phenophases for *Rubus idaeus* was observed on 145th and 151st DOY, for *Sambucus nigra* it was on 145th and 157th DOY, respectively. The average length of the interval between both BBCH60 and BBCH65 phenophases varied within the range of 3.4–6.6 days and 11.4 days for *Prunus spinosa* and *Sambucus nigra*, respectively. Vertical phenological gradient for shrub species moved from 3.0–3.5 days (*Prunus spinosa*) to 4.2–4.3 days (*Rubus idaeus*) per 100 m of altitude increase (Fig. 2). Interannual variability in onset of generative phenophases was also found. As for herb species, the smallest year to year variability in onset of generative phenophases was found out within the lowest site (200 m a.s.l.) with tendency of its increasing to the altitude 900 m a.s.l. Variability at higher altitudes was

Table 4. The onset of generative phenophases of herb species along the altitudinal gradient

| Altitude [m a.s.l.] Phenophase (BBCH) | | 200 | | 500 | | 900 | | 1,000 | | 1,200 | | 1,300 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 |
| Mean$_{2007–2011}$ [DOY] | *Dentaria bulbifera* | 108 | 114 | 115 | 120 | 129 | 135 | 138 | 144 | 143 | 148 | 146 | 151 |
| | *Galium odoratum* | – | – | 125 | 132 | 135 | 144 | 143 | 149 | 150 | 157 | 153 | 161 |
| SD [± days] | *Dentaria bulbifera* | 2.3 | 3.7 | 3.9 | 4.3 | 5.9 | 6.7 | 5.0 | 5.1 | 5.3 | 5.3 | 6.3 | 5.6 |
| | *Galium odoratum* | – | – | 4.8 | 3.3 | 5.1 | 6.2 | 5.7 | 6.4 | 5.4 | 5.3 | 5.4 | 6.1 |
| CV [%] | *Dentaria bulbifera* | 2.1 | 3.3 | 3.4 | 3.6 | 4.6 | 4.9 | 3.6 | 3.5 | 3.7 | 3.6 | 4.3 | 3.7 |
| | *Galium odoratum* | – | – | 3.8 | 2.5 | 3.8 | 4.3 | 4.0 | 4. | 3.6 | 3.4 | 3.5 | 3.8 |

DOY, day of year; SD, standard deviation; CV, coefficient of variation; BBCH60, first flowers open; BBCH65, full flowering: 50% of flowers open.

Table 5. The onset of generative phenophases of shrub species along the altitudinal gradient

| Altitude [m a.s.l.] Phenophase (BBCH) | | 200 | | 500 | | 900 | | 1,000 | | 1,200 | | 1,300 | | 1,400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 | 60 | 65 |
| Mean$_{2007–2011}$ [DOY] | *Prunus spinosa* | 96 | 100 | 110 | 114 | | 121 | 127 | – | – | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 145 | 151 | 159 | 167 | 164 | 171 | 172 | 178 | 176 | 182 | 183 | 189 |
| | *Sambucus nigra* | – | – | 145 | 157 | 158 | 170 | 164 | 175 | – | – | – | – | – | – |
| SD [± days] | *Prunus spinosa* | 4.0 | 3.7 | 5.3 | 5.0 | – | – | 6.5 | 7.1 | – | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 5.3 | 5.2 | 5.3 | 5.7 | 4.8 | 4.5 | 6.0 | 4.5 | 5.9 | 4.3 | 4.0 | 3.4 |
| | *Sambucus nigra* | – | – | 4.7 | 5.8 | 4.3 | 3.9 | 5.4 | 3.5 | – | – | – | – | – | – |
| CV [%] | *Prunus spinosa* | 4.1 | 3.7 | 4.8 | 4.4 | – | – | 5.4 | 5.5 | – | – | – | – | – | – |
| | *Rubus idaeus* | – | – | 3.6 | 3.4 | 3.4 | 3.4 | 2.9 | 2.6 | 3.5 | 2.5 | 3.4 | 2.3 | 2.2 | 1.8 |
| | *Sambucus nigra* | – | – | 3.2 | 3.7 | 2.7 | 2.3 | 3.3 | 2.0 | – | – | – | – | – | – |

DOY, day of year; SD, standard deviation; CV, coefficient of variation; BBCH60, first flowers open; BBCH65, full flowering: 50% of flowers open.

relatively stable. Interannual variability in flowering of *Prunus spinosa* increased with the altitude increasing, but the other shrubs flowered relatively stable along the gradient.

## Discussion

Onsets of phenophases varied depending on the altitude, but also between the compared years. It is known that the temperature is the main factor affecting the dynamics of the plant development. Our investigations revealed that the earliest onset of all phenophases was observed in the lowest altitudes and vice versa. This fact was affected by decreasing in temperature due to the increasing altitude. Considering that the vertical temperature gradient in spring reached –0.6 °C per 100 m of altitude increase (Fig. 3), the drop in temperature of 1 °C was associated with delayed onset of 5.7–6.0 days and 4.5–6.0 days for *Dentaria bulbifera* and *Galium odoratum*, respectively. The delay in onset of vegetative and generative phenophases within the shrubs reached the following values: 4.6–5.8 days for *Prunus spinosa*, 5.0–6.3 days for *Sambucus nigra* and 6.0–7.2 days for *Rubus idaeus* per 1 °C of temperature decrease. These results correspond to those reported by Vitasse et al. (2009) or Cornelius et al. (2013). Kurpelová (1972) stated phenological gradient of 3 days and 5 days per 100 m along the elevation gradient in central Slovakia within the blackthorn and elder phenophases, respectively.

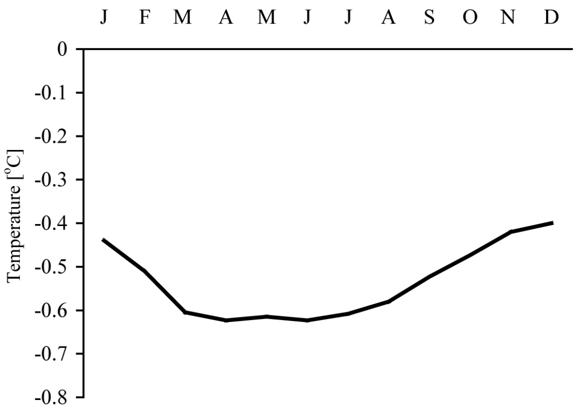


Fig. 3. Average temperature gradient (per each 100 m) throughout the year in the period 2007–2011.

Blionis et al. (2001) found a shift from 2 to 3 days per 100 m of altitude increase in flowering of different species of the genus *Campanula* along the vertical gradient in the mountain areas. Melo (2006) reported that blossoming of lime tree was delayed on average of 4.1 days per 100 m of altitude increase in various localities in Slovakia. Remišová and Vinceová (2007) evaluated the first flowering of European hazel during the period of 20 years in Slovakia. They found the delay of 3 days per 100 of altitude increase. Pellerin et al. (2012) determined for the trees in the Alps the delays of spring phenophases ranging from 2.4 to 3.4 days per 100 m.

Interannual variability in onset of vegetative phenophases for herb species was the smallest within the higher mountain ranges (>1,200 m a.s.l.), on the other hand, higher variability was observed at the lower sites (<500 m a.s.l.). As for shrub species, the variability in onset of vegetative phenophases increased with the altitude increasing. Interannual variability in onset of generative phenophases was slightly different. As for herb species, the smallest year to year variability in onset of generative phenophases was found out within the lowest site (200 m a.s.l.) with tendency of its increasing to the altitude of 900 m a.s.l. Variability at higher altitudes was relatively stable. Interannual variability in flowering of *Prunus spinosa* increased with the altitude increasing, but the other shrubs flowered relatively similarly along the gradient. Based on the above findings, it seems that climate variability did not affect onsets of the phenophases of herbal species so significantly at high-altitude environments (>1,200 m a.s.l) compared to low-lying sites. Likewise, the onset of generative phenophases for *Rubus idaeus* was associated with the lowest variability at the highest altitude (1,400 m a.s.l.).

Increased attention is devoted to study how changes in environmental conditions are caused by global changes, which are classified as climate changes. Impact of the increasing volatility of the main climatic elements running throughout the year occurs subsequently to different phenological response. For a more objective understanding of these processes, it is therefore important to know the response of plants on the edges of their existence, for example along the vertical gradient. The results of phenological studies on plants may contribute to the expansion of knowledge regarding their phenological responses as bio-indicators of changing environmental conditions.

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