

## PHENOLOGY OF LEAF DEVELOPMENT IN EUROPEAN BEECH (*FAGUS SYLVATICA*) ON A SITE IN LJUBLJANA, SLOVENIA IN 2020

### FENOLOGIJA RAZVOJA LISTOV NAVADNE BUKVE (*FAGUS SYLVATICA*) NA RASTIŠČU V LJUBLJANI V LETU 2020

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#### Abstract / Izvleček

**Abstract:** In spring of 2020 we observed leaf phenology in mature European beech (*Fagus sylvatica*) trees in Tivoli, Rožnik and Šišenski hrib Landscape Park in Ljubljana, Slovenia (46.05°N, 14.49°E, 310 m a. s. l.). A group of 11 trees was selected for daily monitoring of leaf development. We recorded seven phases from dormant buds, through leaf unfolding till development of mature leaves. At the same time, photos were taken to illustrate the leaf development. First developing leaves were observed on 4 April in one tree. General leaf unfolding, as defined by International Phenological Gardens (IPG), was observed in different trees between 7 and 25 April 2020. The occurrence and duration of individual phases of leaf development showed great variation within and between trees. General leaf unfolding of the tree included in the long-term monitoring program of the Environmental Agency of the Republic of Slovenia (ARSO) occurred on DOY 105 (14 April 2020), which is 4 days earlier than long-term average of the same tree/location, and this is ascribed to above average temperatures in the winter of 2019/2020.

**Keywords:** phenology, leaf development, variability, European beech (*Fagus sylvatica*), Slovenia

**Izvleček:** V Krajinskem parku Tivoli, Rožnik in Šišenski hrib v Ljubljani (46,05°S, 14,49°V, 310 m n. m.) smo spomladi leta 2020 opazovali fenologijo razvoja listov odraslih dreves navadne bukve (*Fagus sylvatica*). Izbrali smo skupino enajstih dreves za dnevno opazovanje, beleženje in fotografiranje razvoja listov. Razlikovali smo sedem faz od mirujočih brstov, preko različnih faz olistanja do zrelih listov. Prve razvijajoče se liste smo na enem drevesu opazili 4. aprila 2020. Fazo splošnega olistanja, kot jo določa metodologija Mednarodnih fenoloških vrtov, smo pri različnih drevesih beležili od 7. do 25. aprila 2020. Pri nastopu in trajanju različnih faz razvoja listov smo zabeležili velike razlike znotraj posameznega drevesa in med drevesi. Splošno olistanje pri drevesu, ki ga dolgotrajno opazuje Agencija RS za okolje (ARSO), je nastopilo na zaporedni dan 105 (14. aprila 2020), kar je 4 dni prej kot kaže dolgoletno povprečje za isto drevo/lokacijo. Slednje pripisujemo nadpovprečno visokim temperaturam v zimi 2019/2020.

**Ključne besede:** fenologija, razvoj listov, variabilnost, bukev (*Fagus sylvatica*), Slovenija

## 1 INTRODUCTION

### 1 UVOD

Phenology is the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant (or animal) life. In forest trees, we often observe the phenology of leaf development, wood and phloem production, cambium activity, or a combination of these (e.g. Prislán et al., 2013b; Žust, 2015; Gričar et al., 2017). Leaf phenology of forest trees is often studied in European beech (*Fagus sylvatica*) (e.g., Dittmar & Elling 2006; Donnelly et

al., 2006; Vitasse et al., 2011; 2013; Wenden et al., 2019). It can be basically divided into early or spring phenology and autumn phenology. Spring phenology involves processes related to the interruption of winter dormancy and phases of leaf development from the dormant bud to fully developed and functional mature leaves (Meier, 1997). Leaf unfolding is one of the most visible signs of the reactivation of a tree's physiological activity after the winter dormancy (Žust, 2015). It is synchronised with reactivation of cambium and onset of wood and phloem formation, which are not visible unless we extract tissues from the tree for monitoring under a microscope (Čufar et al., 2008; Prislán et al., 2013a; 2013b).

Common beech is the most common tree species in Slovenia and represents one third (32.6% in

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2018) of the growing stock in the country (Poročilo Zavoda..., 2018). A recent national forest inventory by the Slovenian Forestry Institute showed that 208 million beech trees grow in Slovenia (Inventura gozda, 2018).

Beech is one of twelve tree species included in the Slovenian National Phenological Network of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning, which has conducted systematic monitoring since 1951 (Žust, 2015). The Slovenian National Phenological Network is also a part of the International Phenological Gardens (IPG), which has monitored genetically identical trees (clones) on ca. 90 localities all over Europe since 1957, with large latitudinal gradient, from Portugal ~41°N to Norway ~63°N (The international..., 2020; Chmielewski et al., 2013). Observation of genetically identical trees limits the bias in leaf phenology caused by possible genetic variation, which is known to affect this (Kraj & Sztorc, 2009). Long-term phenological data are a rich source of information on the response of trees to climate change (e.g., Menzel et al., 2006; Fu et al., 2019).

The leaf phenology monitoring of beech by ARSO records general leaf unfolding, defined as the phase BBCH11 when 50% of the leaves have unfolded completely (Meier, 1997; ARSO, 2020). In Slovenia it is considered that the leafing of beech marks the real beginning of spring, while the ripened fruits indicate the beginning of true autumn (Žust, 2015). General leaf yellowing (BBCH94), which occurs when more than half of the leaves turn yellow in autumn, and leaf fall (BBCH93-10% of leaves fell down from trees to the ground to BBCH97-100% of leaves fell down from trees to the ground) are also monitored (Žust, 2015; Lukasova et al., 2019).

Spring phenology and the mechanisms driving leaf development are generally better understood than the autumn ones. Beech has thinly pointed leaf buds that are already visible on the tree in the autumn before the tree enters winter dormancy, when growth is inhibited even if seemingly favourable environmental conditions (a warm winter) occur. Leaf development can start in spring when the buds are able to respond to warmer forcing temperatures (Caffarra & Donnelly, 2011; Wenden et al., 2020). However, this is only possible if the tree previously experienced adequate chilling and if the

photoperiod is sufficiently long (Vitasse & Basler, 2013; Dantec et al., 2014). Such requirements are species and site specific (Wenden et al., 2020).

A study based on the leaf unfolding and leaf colouring data for beech obtained by ARSO from 47 localities all over Slovenia (altitudes 55 to 1,050 m a.s.l.), in the period 1955-2007 showed that the average day of the year (DOY) of the leaf unfolding varied from 14 April (DOY 104) to 13 May (DOY 133) (Čufar et al., 2012), and was delayed for 2.6 days as the altitude rose 100 m. Year-to-year variation of leaf unfolding was mainly driven by March and April temperatures, whereas the temperatures in March had greater effect at lower elevations and those in the April at higher elevations. During 1955-2007, March and April temperatures showed a slightly positive trend and leaf unfolding occurred 1.52 days earlier per decade at 1,000 m a.s.l. and 0.67 days earlier at 500 m a.s.l., which showed that climate change particularly affects phenological behaviour at higher altitudes. However, leaf colouring occurred from 2 October till 29 October and was earlier at higher altitudes (1.9 days earlier for every 100 m). Colouring proved to be positively correlated to August and September temperatures, whereas the long-term trends and relation to altitude were not statistically significant (Čufar et al., 2012). It was also shown that leaf unfolding approximately agrees with the onset of wood production by the cambium, although the climatic drivers of both processes are different (Čufar et al., 2008). Variability in leaf phenology generally cannot be directly correlated with variations in radial tree-ring growth (Čufar et al., 2015), and the extension of the growing season due to climate change does not necessarily increase tree-ring width (Kolar et al., 2016).

As organization and implementation of ground observations is demanding, it has been discussed whether ground monitoring of leaf phenology and the condition of leaves could be replaced by other techniques, like modelling (e.g., Vilhar et al., 2018) or satellite imagery (e.g., Allevato et al., 2019; Lukasova et al., 2019). Research into beech canopy parameters all over Slovenia between 2001 and 2017 based on analyses of crown features derived from the satellite Moderate Resolution Imaging Spectroradiometer (MODIS) and calculating the remotely sensed Enhanced Vegetation Index (EVI) shows that the resolution and frequency of satellite

images hamper the precise reconstruction of leaf phenology. However, it is possible to reconstruct spatio-temporal leaf and canopy damage due to extreme weather events like heat waves, ice storms and spring frosts recorded in changes of the EVI (Decuyper et al., 2020).

Any of the abovementioned methodologies needs to take into account the great variability of phenology, which varies within and among trees and sites. However, this is relatively difficult as we lack precise observations on representative numbers of trees on a daily scale (e.g., Lukasova et al., 2019).

The aim of this study was to select beech trees on a site in Ljubljana, Slovenia, and in the spring of 2020 monitor different phases of their leaf development daily, from dormant buds to the development of mature leaves, to establish a photo-gallery of temporal variability of leaf development, and to relate the leaf development to air temperature and precipitation. Finally, general leaf unfolding in individual trees in 2020 was compared with long-term data (1951-2020) for beech in Ljubljana collected by ARSO.

## 2 MATERIALS AND METHODS

### 2 MATERIAL IN METODE

#### 2.1 STUDY SITE AND TREES

##### 2.1 OPAZOVANA PLOŠEV IN DREVEŠA

The selected study area was Tivoli, Rožnik and Šiška Hill Landscape Park in Ljubljana which was declared a Natural Site of Special Interest in 1984 (Odlok o razglasitvi..., 2020). Forest management is allowed in the park. The stand with selected trees has 428 m<sup>3</sup>/ha of average growing stock, and the predominant forest community is *Blechno – Fagetum clamagrostidetosum*. These forests are site-silvicultural class suburban forests on acidic beech habitats. The prevailing tree species is beech (*Fagus sylvatica*) (49%), followed by sessile oak (*Quercus petraea*) (20%), spruce (*Picea abies*) (11%), large-leaved lime (*Tilia platyphyllos*) (11%) and other deciduous trees (Pregledovalnik ..., 2020).

At the forest foothills, along a transect of about 1.6 km (Figure 1), we selected adult dominant or codominant beech trees with diameters at breast height of 50 – 100 cm and heights over 30 m. We observed the trees on three locations: (1) trees 11-19 (where the first number indicates the location and the second the tree number) growing

on the slope, along the pathway Pod Turnom, near the water reservoir, (2) one tree number 20 growing in the vicinity of trees 11-19 with the earliest leaf unfolding, and (3) one beech number 30, which grows near the Cekin Mansion (National Museum of Contemporary History) (Figure 1, Table 1).

Trees 11-20 grow in the abovementioned beech habitats, while the beech 30 grows in the park and is included in the long-term monitoring of the Slovenian National Phenological Network (*Fagus sylvatica* Hardegsen, identification number of the plant 221, year of planting 1969, origin Germany) of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning as a part of the International Phenological Gardens of Europe.

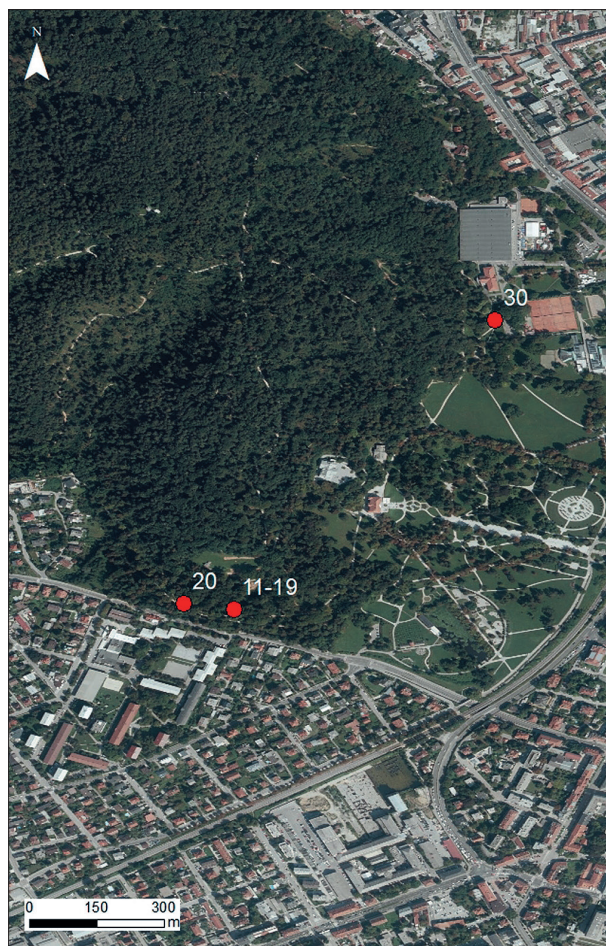


Figure 1. Locations of selected trees (red dots) in Tivoli, Rožnik and Šišenski hrib Landscape Park in Ljubljana, Slovenia.

Slika 1. Lokacije izbranih dreves (rdeče pike) v Krajin-skem parku Tivoli, Rožnik in Šišenski hrib v Ljubljani.



Table 1. Geographical coordinates of the observed trees

Preglednica 1. Geografske koordinate opazovanih dreves

| Tree numbers    | Latitude           | Longitude           | Altitude         |
|-----------------|--------------------|---------------------|------------------|
| Številke dreves | Zemljepisna širina | Zemljepisna dolžina | Nadmorska višina |
| 11-19           | 46.052585°         | 14.490125°          | 316 m            |
| 20              | 46.052697°         | 14.489115°          | 315 m            |
| 30              | 46.058247°         | 14.495366°          | 307 m            |

## 2.2 FIELD OBSERVATIONS OF LEAF PHENOLOGY

### 2.2 TERENSKA OPAZOVANJA RAZVOJA LISTOV

In the period from 4 till 27 April 2020, we visited and photographed the selected trees and recorded the phenological phases daily (Figure 2, Table 2), which indicated the progress of leaf development. In May 2020, we visited the trees at weekly intervals, because significant changes related to phenological phases were no longer happening on a daily basis. The observations were carried out in agreement with the criteria of the World Meteorological Organization (Guidelines ..., 2009).

Table 2. Descriptions of the main phenological phases of leaf development in beech.

Preglednica 2. Opis glavnih fenoloških faz razvoja listov pri bukvi.

| Phase / Faza |   | Description  | Opis faze  |
|--------------|---|--|--|
| BBCH00       | A | buds dormant   | speči popki  |
| BBCH02       | B | buds swollen   | popki napeti (nabrekli)  |
| BBCH07       | C | buds swollen, brown scales open, and the green colour of the developing leaves appears                 | popki nabrekli, rjave luske se razprejo in pojavi se zelena barva razvijajočih se listov   |
| BBCH09       | D | buds swollen and open  | popki nabrekli in odprti   |
| BBCH10       | E | leaves partly unfolded, the petiole is not visible   | listi delno razviti, vidna listna ploskev, listni pecelj ni viden  |
| BBCH11       | F | leaves unfolded, 10% of leaves have final shape, but not final size and colour, the petiole is visible | listi razviti, listna ploskev je odprta, 10 % listov je značilne oblike, ni še končne velikosti in barve, viden je listni pecelj |
| BBCH19       | G | mature leaves, final size and colour   | zreli listi, končne velikosti in barve   |

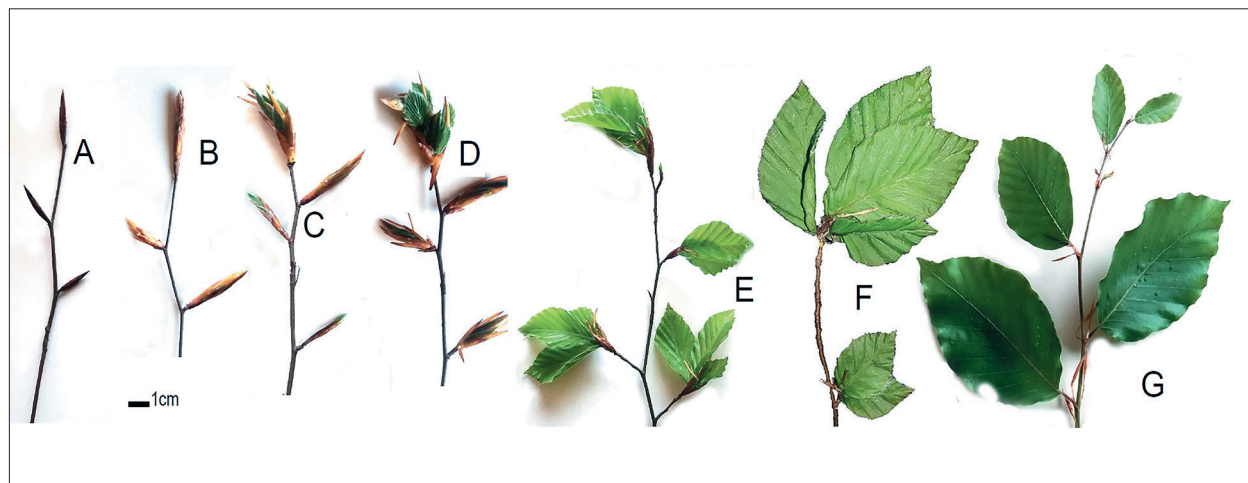


Figure 2. Phenological phases of leaf development in beech from (A) dormant bud to (G) mature leaves.

Slika 2. Fenološke faze razvoja listov bukve od (A) spečih popkov do (G) zrelih listov.



## 2.3 CLIMATIC AND PHENOLOGICAL DATA FOR COMPARISON

### 2.3 KLIMATSKI IN FENOLOŠKI PODATKI ZA PRIMERJAVO

To study the weather conditions during the observed leaf development we used the daily climatic data, minimum and maximum temperatures and sums of precipitation for Ljubljana for the period 1951-2020 obtained from the on-line meteorological archive ARSO METEO.

Current leaf development was compared with long-term phenological data, i.e. the data of general leaf unfolding for Ljubljana for the period 1951-2019 obtained from the database of the Slovenian National Phenological Network of ARSO (Žust, 2015).

## 3 RESULTS AND DISCUSSION 3 REZULTATI IN RAZPRAVA

### 3.1 DYNAMICS OF LEAF DEVELOPMENT IN SPRING 2020

#### 3.1 DINAMIKA RAZVOJA LISTOV SPOMLADI 2020

On the first day of observation, 4 April 2020 (DOY 95), we inspected all mature dominant and co-dominant beech trees along the 1.6 km long pathway to select the trees for observation (Figure 1, 3). Tree number 20 already had partly unfolded leaves (phase E), whereas all other trees had dormant or swelling buds (phases A, B) and showed no leaf emergence yet (Figures 4, 5, 6). The crown of tree 30 (included in the IPG) still had abundant dry leaves from the previous year.



Figure 3. Study site and trees: (A) Tivoli, Rožnik forest as seen from Ljubljana Castle on 3 May 2020 (DOY 124) with the locations of the monitored trees, and (B) the observed trees before general leaf unfolding. Trees 11-20 belong to a beech forest site, while tree 30 grows in the park and is a clone (*Fagus sylvatica* Hardeggen) included in the International Phenological Gardens.

Slika 3. Opazovano območje in drevesa: (A) gozd Tivoli Rožnik, fotografiran z Ljubljanskega gradu 3. maja 2020 (DOY 124) z mesti opazovanih dreves in (B) drevesa pred splošnim olistanjem. Drevesa 11–20 rastejo v pretežno bukovem gozdu, drevo 30 pa v parkovnem delu in je kot klon (*Fagus sylvatica* Hardeggen) vključeno v Mednarodni fenološki vrt.

| Date             | Datum | 4    | 5    | 6    | 7  | 8  | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  | 25  | 26  | 27  |   |
|------------------|-------|------|------|------|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|
| DOY              | Dan   | 95   | 96   | 97   | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 |   |
| Tree No. / Drevo | 20    | E    | E    | F    | F* | F  | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | G   | G   | G   | G   |   |
|                  | 12    | A, B | C    | E    | E  | F  | F*  | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   |   |
|                  | 13    | A    | A    | B    | B  | B  | B   | C   | C   | D   | E   | E   | F   | F*  | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F |
|                  | 14    | A    | A    | A    | A  | B  | B   | B   | B   | B   | B   | B   | B   | C   | C   | C   | C   | C   | E   | E   | E   | E   | F   | F*  | F   | F |
|                  | 19    | A    | A    | A    | A  | B  | B   | B   | C   | C   | D   | D   | D   | E   | E   | E   | E   | E   | F   | F*  | F   | F   | F   | F   | F   | F |
|                  | 30    | A    | A, B | A, B | C  | D  | D   | D   | D   | E   | F   | F*  | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F   | F |

Legend / Legenda

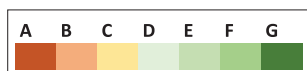


Figure 4. Phenological phases of most typical trees, showing different timing and dynamics of leaf development; A-G indicate leaf development phases (see Figure 2). Phase F\* in the frame indicates the day of general leaf unfolding when 50% of the leaves have unfolded completely. "Date" indicates the day in April 2020 and DOY indicates the day of the year.

Slika 4. Fenološke faze najbolj tipičnih dreves, ki prikazujejo različne čase nastopa posameznih faz in različno dinamiko razvoja listov; oznake A-G označujejo faze razvoja listov (glej sliko 2). Faza F\* v okviru nakazuje dan splošnega olistanja za opazovano drevo, ko je bilo 50 % listov popolnoma razvitih. Datum predstavlja dan v aprilu 2020 in DOY predstavlja zaporedni dan v letu.

Tree 12 already showed numerous buds which started to open (phase C) on 5 April 2020 (DOY 96); phase C was observed in tree 30 on 7 April 2020 (DOY 98), and in trees 13, 19, and 14 on 10, 11 and 16 April (DOY 101, 102, 107), respectively. Phase C was quickly followed by the first leaf emergence (phase E) and unfolding (F). General leaf unfolding (F\*), as defined by IPG (when 50% of the leaves have unfolded completely) was first observed in tree 20 (7 April, DOY 98), slightly later in tree 12 (9 April, DOY 100), and in tree 30 on 14 April (DOY 105). In tree 19 general leaf unfolding appeared much later, on 22 April (DOY 113), and in tree 14 on 25 April (DOY 116). The first mature leaves, phase G, were observed on 24 April (DOY 115) in tree 20. In all other trees the leaves remained light green and soft till 27 April 2020, the last day of daily monitoring. However, monitoring of the trees on 3 May (DOY 124) showed that the colour of the leaves was dark green in most of the trees (Figure 3A). The described phases were documented on photos of the entire trees that were taken every day (Figures 5, 6).

Besides tree 20, which had the earliest leaf development (Figures 5, 6), it is worth mentioning tree 30, which is included in the long-term monitoring within IPG (Figures 5, 6, 7), and for which ARSO has long-term data on leaf unfolding (Figure 9). In this tree general leaf unfolding occurred on 14 April (DOY 105) (Figure 7).

The latest leaf unfolding was observed in trees 14 and 19 (Figure 3B, 5, 6, 8). As tree 14 grows in the group, it was difficult to follow its leaf development after the neighbouring trees unfolded their leaves. Therefore, we put special attention to the nearby tree 19 which is solitary and also showed late leaf unfolding, with a general leaf unfolding date of 22 April (DOY 113) (Figure 8). The upper part of the crown also developed numerous male flowers, which possibly affected late leaf flushing.

### 3.3 WEATHER SITUATION BEFORE AND DURING LEAF UNFOLDING

#### 3.3 VREMENSKE RAZMERE PRED IN MED OLISTANJEM

Weather situation after the leaf fall of previous season was characterized by a warm winter 2019/2020 in Slovenia and Ljubljana with above average temperatures and smaller amount of precipitation compared to long-term data (Cegnar 2019; 2020a; b and Figure 9).

In winter 2019/2020 there were no days with maximum daily temperatures below 0°C. January and February 2020 were also very dry (Figure 9). The warm winter was followed by a warm early spring. The average March temperature in Ljubljana was 7.2°C, the average minimum daily temperature was 2.3°C, and the amount of precipitation





Figure 5. Phenology of leaf development of observed beech trees on chosen days of the year (DOY) - dates.  
Slika 5. Fenologija razvoja listov opazovanih bukev na izbrane zaporedne dneve v letu (DOY) - datume.





Figure 6. Phenology of leaf development of observed beech trees on chosen days of the year (DOY) - dates.  
Slika 6. Fenologija razvoja listov opazovanih bukev na izbrane zaporedne dneve v letu (DOY) - datume.



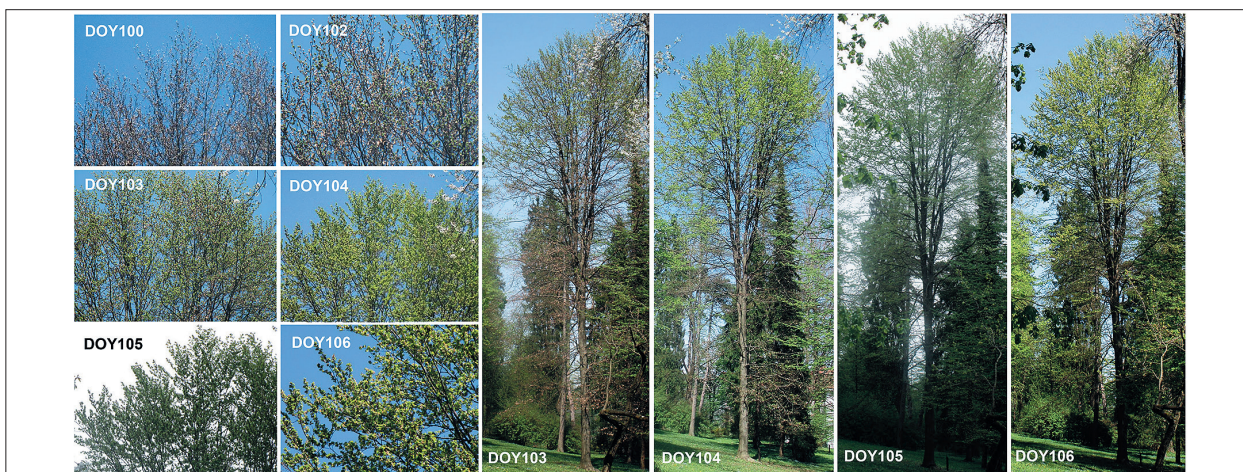


Figure 7. Tree 30, included in the International Phenological Gardens: leaf development between 9 April (DOY 100) and 15 April (DOY 106), with 14 April 2020 (DOY 105) considered as the day of general leaf unfolding (for detailed daily photos see Supplement <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807>).  
 Slika 7. Drevo 30, vključeno v Mednarodne fenološke vrtove: razvoj listov med 9. aprilom (DOY 100) in 15. aprilom 2020 (DOY 106); 14. april 2020 (DOY 105) je dan splošnega olistanja za to drevo (za podrobne dnevne slike glej Dodatek <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807>).

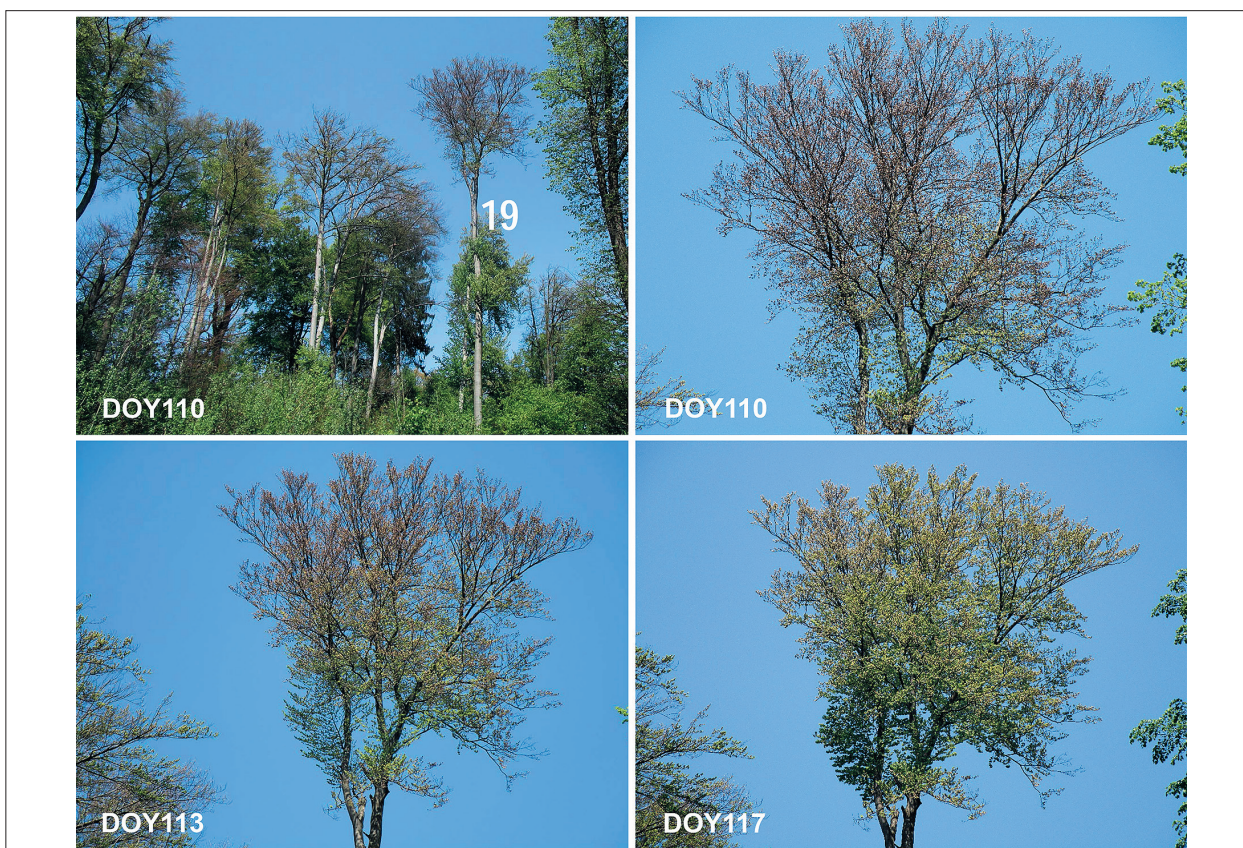


Figure 8. Tree 19 with late leaf unfolding: its position on the site, and detailed views of the crown on 19, 22 and 26 April 2020 (DOY 110, 113 and 117) (see Figure 4).  
 Slika 8. Drevo 19 s poznim olistanjem - položaj drevesa in podroben pogled na krošnjo 19., 22. in 26. aprila 2020 (DOY 110, 113 in 117) (glej sliko 4).



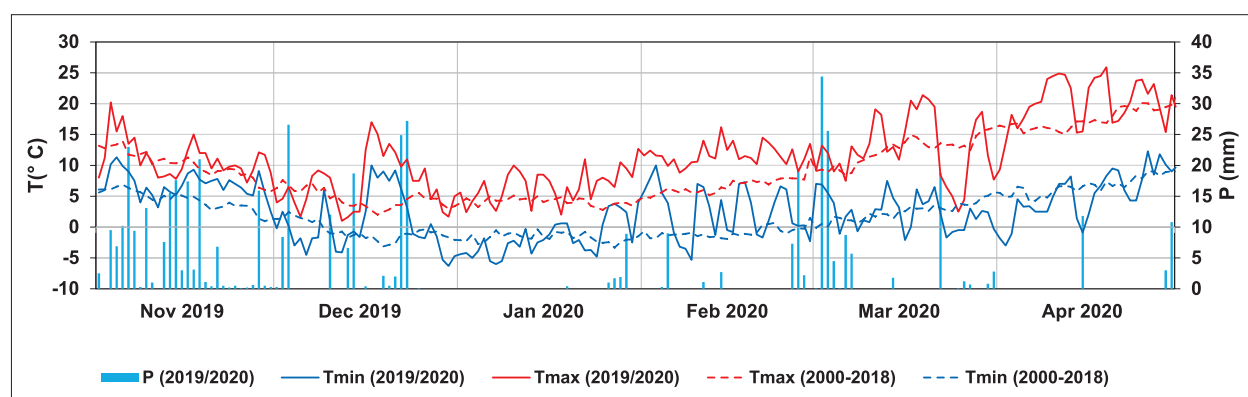


Figure 9. Minimum and maximum daily temperatures ( $T$ ) and precipitation ( $P$ ) in winter 2019/2020 and average minimum and maximum temperatures for the period 2000–2018.

Slika 9. Minimalne in maksimalne dnevne temperature ( $T$ ) ter padavine ( $P$ ) v zimi 2019/20 in povprečne minimalne ter maksimalne temperature za obdobje 2000–2018.

was 105 mm. Compared to the long-term average, March 2020 was generally warmer and had less precipitation, only in the period between 22 and 26 March was the weather cold and temperatures below the long-term average. In total, Ljubljana had eight frost days in March, when the minimum daily temperature was below  $0^{\circ}\text{C}$ . Agrometeorological conditions in March were characterised by premature flowering of early stone fruit trees, while the frost between 22 and 26 March caused damage to apricots and peaches throughout Slovenia. The lack of rainfall in winter and early spring caused drought conditions, which at the end of March affected the growth of plants in the area of Ljubljana (Žust, 2020).

April, when the leaf development was observed, was characterised by warm, sunny and dry weather. The average monthly temperature in Ljubljana in April was  $12.9^{\circ}\text{C}$ , and the minimum daily temperatures ranged between  $-3^{\circ}\text{C}$  and  $12.3^{\circ}\text{C}$ . The maximum daily temperatures were between  $9.3^{\circ}\text{C}$  and  $25.9^{\circ}\text{C}$ . The amount of precipitation was only 25.6 mm, with just three rainy days (Figure 9).

Compared to the long-term average April 2020 was  $2.1^{\circ}\text{C}$  warmer and had only 26% of the long-term average amount of precipitation. April had four cold days and 292 hours (70% more than the long-term average) of sunshine. Agrometeorological conditions in April were characterised by a long drought period which had a negative impact on agriculture.

### 3.4 LEAF DEVELOPMENT PHENOLOGY IN THE LIGHT OF LONG-TERM OBSERVATIONS

#### 3.4 FENOLOGIJA RAZVOJA LISTOV V LUČI DOLGOLETNIH OPAZOVANJ

As mentioned before, tree 30 (the number 30 is assigned to this tree only for the purpose of this study) is a clone (*Fagus sylvatica* Hardegsen) which is a reference tree for Ljubljana monitored in the framework of the Slovenian National Phenological Network included in the IPG and is one of a series of genetically identical trees that are planted all over Europe (The International..., 2020). Leaf unfolding in Ljubljana has varied over time, with the long-term (1951–2019) average day of leaf unfolding being DOY 109 (19 April when note a leap year). The earliest leaf unfolding was observed on DOY 95 (5 April 1990), and the latest on DOY 125 (5 May 1958) (Figure 10). In Ljubljana we can observe a trend towards an earlier general leaf unfolding date (Figure 10), which is however not statistically significant (Čufar et al., 2012). General leaf unfolding of tree 30 was observed on DOY 105 (14 April 2020), and this is thus four days earlier than the long-term average and can be ascribed to the generally warm winter.



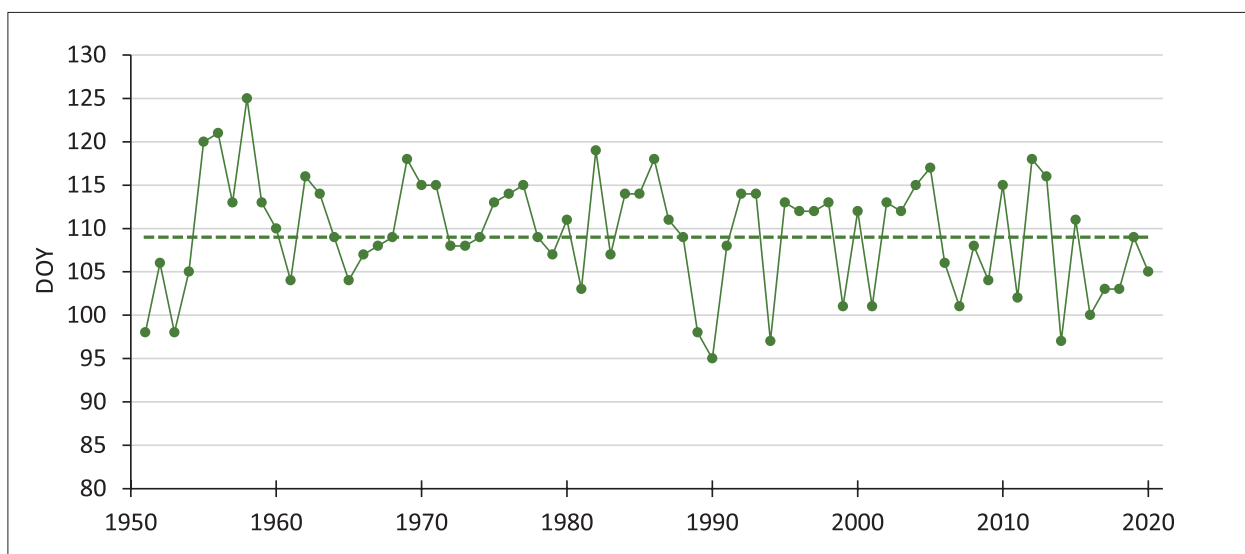


Figure 10. General leaf unfolding of beech in Ljubljana observed by ARSO in the period 1951-2020 and the corresponding average (dotted line). DOY - day of the year.

Slika 10. Dan olistanja bukke v Ljubljani, ki ga je spremljal ARSO v obdobju 1951-2020 in pripadajoče povprečje (črtkana črta). DOY – zaporedni dan v letu.

#### 4 CONCLUSIONS

##### 4 ZAKLJUČKI

Long-term phenological observations of beech carried out by ARSO throughout Slovenia provide a date for general leaf unfolding for an individual location. For beech in Ljubljana, the 70-year (1951-2020) set of leaf unfolding data shows that it occurs on average on DOY 109 (19 April when not a leap year), with a 30-day range between DOY 95 and DOY 125.

In this study, we investigated seven spring phenological phases of beech leaf development in one location in Ljubljana. We observed the trees with the earliest and latest leaf unfolding (on a 1.6 km long transect) and obtained information on the variability of the occurrence of individual phenological phases among the trees. The observed trees showed general leaf unfolding between 7 and 25 April 2020. There were large differences among the trees even if they grow very close to each other. In the reference beech, for which we have long-term data, general leaf unfolding occurred on DOY 105 (14 April). This is four days earlier than the long-term (1951-2020) average of the data collected by ARSO for the same tree/location. Earlier leaf unfolding of beech is in line with observations of ARSO in other plant species, which in spring of 2020 generally showed up to one week earlier phenolog-

ical phases than the long-term average, which is ascribed to the above-average warm winter and early spring (Cegnar, 2020c; Žust, 2020).

This study helped us to obtain basic information on phenological variability among the trees on the same microsite, which is, among other things, important to better understand tree physiology and cambial activity with wood and phloem formation.

#### 5 SUMMARY

##### 5 POVZETEK

Fenologija (iz grške besede φαίνομαι, *phainomai* - pojaviti se) je veja ekologije, ki proučuje zakonitosti periodičnih pojavov v razvojnem ciklu rastlin in živali ter ugotavlja njihovo odvisnost od sezonskih in letnih nihanj podnebnih dejavnikov okolja. Primera tega sta čas razvoja listov in cvetov pri rastlinah ter prvega opaženega prihoda ptic selivk na določenem območju.

Pri gozdnih drevesih najpogosteje opazujemo fenologijo razvoja listov in iglic. Med najbolj raziskovanimi gozdnimi drevesi je navadna bukev (*Fagus sylvatica*). Posebej zanimiva je zgodnja (spomladanska) fenologija, ki proučuje faze razvoja listov od listnih brstov (popkov) v mirujočem stanju do nastanka zrelega, polno delujočega lista (slika 2, preglednica 2). Olistanje je med najbolj očitni-

mi zunanji znaki fiziološke aktivnosti drevesa po zimskem mirovanju. Povezano je tudi s procesi reaktivacije kambija ter nastajanja lesa in skorje, ki na zunaj niso vidni in jih lahko spremljamo samo, če iz drevesa odvzamemo tkiva in jih ustrezno pripravimo za proučevanje pod mikroskopom (Čufar et al., 2008; Prisljan et al., 2013a; 2013b).

Navadna bukev je v Sloveniji najbolj zastopana drevesna vrsta in predstavlja tretjino (32,6 %) lesne zaloge (Poročilo Zavoda ..., 2018). Ob nedavni inventuri gozda so ugotovili, da v Sloveniji raste 208 milijonov bukovih dreves (Inventura gozda, 2018). Olistanje bukve naj bi označevalo začetek prave pomladi, cvetenje, ki je nekoliko kasnejše, pa glavno obdobje prave pomladi; dozoreli plodovi nato označajo začetek prave jeseni (Žust, 2015).

Listno fenologijo bukve že od leta 1951 sistematično spremlja Agencija Republike Slovenije za okolje (ARSO). Na reprezentativnih drevesih po Sloveniji spremljajo naslednje faze: (1) olistanje (BBCH11), ki nastopi, ko se prvi listi izvijajo iz ovojne zaščitne luske, listna ploskev je odprta, značilne oblike, ni pa še prave velikosti, viden je listni pecelj. Mladi listi so porasli s številnimi dlačicami, ki kasneje odpadejo, (2) splošno rumenenje listja (BBCH94), ki nastopi, ko je več kot polovica listov jesensko porumenelih ter (3) odpadanje listov. ARSO je vključen tudi v aktivnosti mednarodne mreže fenoloških vrtov (The International ..., 2020; Chmielewski et al., 2013; Žust, 2015) in v tem okviru spremlja fenologijo bukovih klonov, ki so nasajeni po botaničnih vrtovih Evrope, primer tega klona (*Fagus sylvatica* Hardegsen) raste tudi v Ljubljani na območju parka Tivoli (drevo 30 v naši raziskavi).

Dragoceni dolgoletni podatki listne fenologije bukve so med drugim tudi bogat vir informacij pri spremljanju odziva dreves na podnebne spremembe. Študija splošnega olistanja in rumenjenja bukve na osnovi podatkov ARSO iz 47 krajev po vsej Sloveniji (nadmorske višine od 55 do 1.050 m), je za obdobje 1955–2007 pokazala, da olistanje nastopi od 13. aprila do 13. maja (Čufar et al., 2012) in se zakasni za 2,6 dni, če se nadmorska višina poveča za 100 m. Na olistanje vplivajo predvsem temperature v marcu (na nižjih nadmorskih višinah) in v aprilu (na višjih legah). V času 1955–2007 so temperature v marcu in aprilu naraščale, kar je vplivalo na vedno zgodnejše olistanje, to je za 1,52 dni na desetletje na 1000 m n. m. in za 0,67 dni na 500 m n. m.

Slednje kaže, da podnebne spremembe vplivajo na fenološko vedenje bukve predvsem na višjih nadmorskih višinah. Splošno obarvanje listov je v istem obdobju nastopilo od 2. do 29. oktobra in se prej pojavi na višjih nadmorskih višinah (1,9 dni prej za vsakih 100 m). Rumenenje listov je pozitivno povezano s temperaturami v avgustu in septembru, vendar dolgoročni trendi in spreminjanje z nadmorsko višino tu niso statistično značilni (Čufar et al., 2012). Pokazalo se je tudi, da se čas olistanja približno ujema z začetkom delovanja kambija in nastajanja lesa, čeprav omenjene procese vodijo različne klimatske spremenljivke (Čufar et al., 2008). Fenologije listov na splošno niso mogli povezati z variiranjem širin branik (Čufar et al., 2015), prav tako se podaljšanje rastne sezone v splošnem ne odraža v širinah branik (Kolar et al., 2015).

Zaradi zahtevne organizacije fenoloških opazovanj se v zadnjem času razpravlja, kako bi jih lahko nadgradili z modeliranjem (Vilhar et al., 2018) ali s pomočjo satelitskih posnetkov (npr., Allevato et al., 2019; Lukasova et al., 2019). Nedavne raziskave bukve v Sloveniji, kjer so med leti 2001 in 2017 z analizo multispektralnih posnetkov satelitov MODIS in z izračunom vegetacijskega indeksa EVI spremljali spremembe zelene biomase v krošnjah dreves, so pokazale, da ločljivost satelitskih slik praviloma še ne omogoča spremljanja fenologije listov, zabeležiti pa je bilo mogoče poškodbe listov/krošenj zaradi izjemnih vremenskih dogodkov in ujem, kot so vročinski valovi, žledolomi in pozebe (Decuyper et al., 2020).

Na rezultate omenjenih raziskav vpliva velika variabilnost fenoloških faz istega drevesa, med drevesi in med rastišči, različne metode, kot so terensko opazovanje ali slikanje, pa na različne načine obvladujejo problem variabilnosti (Lukasova et al., 2019). Zato smo se odločili, da v času razvoja listov v aprilu 2020 vsakodnevno fotografsko spremljamo razvoj listov pri skupini dreves na območju Krajinskega parka Tivoli, Rožnik in Šišenski hrib v Ljubljani v Sloveniji (slika 1) ter predstavimo časovno variabilnost razvoja listov za posamezno drevo in med drevesi.

Ob 1,6 km dolgi poti ob vznožju hriba smo pregledali bukova drevesa in izbrali najzgodnejše drevo (drevo 20), skupino dreves z različno dinamično olistanja (drevesa 11-19) in drevo 30 (klon *Fagus sylvatica* Hardegsen), ki ga ARSO spremlja v okviru

mednarodne mreže fenoloških vrtov IPG ob podpori Mestne občine Ljubljana (Identifikacijska številka rastline: 221, leto sajenja: 1969, izvor: Nemčija) (sliki 1, 3). V času od 4. do 27. aprila 2020 smo dnevno fotografirali izbrana drevesa in popisali najbolj značilno fenološko fazo razvoja listov (slika 2). V maju 2020 smo drevesa obiskovali v tedenskih intervalih. Opazovanja so potekala po kriterijih, ki jih je izdala agrometeorološka komisija pri WMO (Guidelines ..., 2009) (slika 2, preglednica 2).

Pridobljene podatke smo ovrednotili tudi z vidika dolgoletnih meteoroloških podatkov in fenoloških opazovanj bukve v Ljubljani.

Prvi dan opazovanja, 4. aprila 2020 (dan v letu=DOY 95) je drevo 20 že imelo liste v fazi razpiranja (faza E), medtem ko so bili brsti pri vseh drugih drevesih v mirujočem stanju ali v fazi nabrekanja (fazi A, B), listi pa še niso pogledali iz lusk (slike 3, 4, 5). Krošnja drevesa 30 je imela brste v mirujočem stanju, na vejah pa še veliko suhega listja iz prejšnjega leta.

Že 5. aprila 2020 (DOY 96) so se brsti na drevesu 12 začeli odpirati (faza C), medtem ko je bila faza C pri drevesu 30 opažena 7. aprila 2020 (DOY 98), pri drevesih 13, 19 in 14 pa po vrsti 10., 11. in 16. aprila (DOY 101, 102, 107). Faza C je hitro sledil prvi razvoj listov (faza E) in olistanje (F), ko so bili listi popolnoma razprti. Splošno olistanje (F\*) po definiciji Mednarodnih fenoloških vrtov, ko je olistane 50 % krošnje, smo najprej opazili pri drevesu 20 (7. aprila, DOY 98), nekoliko kasneje pri drevesu 12 (9. aprila, DOY 100), pri drevesu 30 pa 14. aprila (DOY 105). Pri drevesu 19 se je faza F\* pojavila veliko kasneje, 22. aprila (DOY 113), pri drevesu 14 pa 25. aprila (DOY 116). Prve zrele temno zelene in čvrste liste, ki so značilni za fazo G, smo opazili 24. aprila (DOY 115) na drevesu 20. Na vseh drugih drevesih so listi ostali svetlo zeleni in mehki do 27. aprila 2020, ko smo zaključili vsakodnevno opazovanje. Ob naslednjem obhodu, 3. maja (DOY 124), pa je bila barva listov pri večini dreves temno zelena (slika 2A). Opisane faze so bile dokumentirane na fotografijah celotnih dreves, posnetih vsak dan (sliki 5, 6).

Poleg drevesa 20, ki je imelo najzgodnejši razvoj listov (sliki 5, 6), smo fotografsko predstavili tudi drevo 30, za katerega ima ARSO dolgoletne podatke (slike 5, 6, 7) in je v letu 2020 olistalo 14. aprila (DOY 105) (slika 7).

Nazadnje sta se olistali drevesi 14 in 19 (slike 3B, 5, 6, 8). Ker drevo 14 raste v skupini, je bilo po olistanju sosednjih dreves pri njem težko slediti razvoju listov, zato smo bolj podrobno predstavili olistanje drevesa 19, ki raste v neposredni bližini in ni utesnjeno. Drevo 19 je olistalo 22. aprila (DOY 113) (slika 8). Zgornji del krošnje je razvil številne moške cvetove, kar je morda dodatno vplivalo na pozno olistanje.

V prispevku diskutiramo tudi o vremenskih razmerah pred in med olistanjem (slika 9). Cikel razvoja listov se začne že v letu pred olistanjem, saj se tipični zašiljeni brsti oblikujejo že do zaključka predhodne sezone, za olistanje spomladi pa mora drevo skozi ustrezno dolgo obdobje mrzlega vremena, dovolj dolgo dolžino dneva in ustrezno toplo vreme pred olistanjem (Vitasse & Basler, 2013; Dantec et al., 2014; Wenden et al., 2020). Zima 2019/2020 je bila nadpovprečno topla, kar je veljalo tako za november in december 2019, ter januar in februar 2020 (Cegnar 2019; 2020a; 2020b). Razen novembra, ki je bil nadpovprečno moker, so bili ostali zimski meseci nadpovprečno suhi (Cegnar, 2019; 2020a; 2020b). Tudi marec je bil toplejši in bolj suh kot dolgoletno povprečje 1981–2010, v času od 22. do 26. marca pa se je močno ohladilo. V Ljubljani je bila povprečna marčevska temperatura 7,2 °C, povprečna najnižja dnevna temperatura pa je bila 2,3 °C, kar je 0,7 oz. 0,5 °C nad dolgoletnim povprečjem. V Ljubljani je bilo v marcu 8 hladnih dni, ko se najnižja dnevna temperatura spusti pod ledišče (Cegnar, 2020c). Fenološki razvoj pri večini rastlin je bil na začetku pomladi 2020 bolj zgođen kot običajno. V marcu je po Sloveniji predčasno zacvetelo koščičasto sadje, v hladnem obdobju med 22. in 26. marcem pa je prišlo do obsežne pozebe. Dve pozebi so po Sloveniji zabeležili tudi 8. in 15. aprila (ARSO, 2020). Temperature v Ljubljani so bile v obeh hladnih obdobjih v aprilu 2020 nekoliko višje kot po Sloveniji, zato učinkov obeh pozeb na bukev (v občutljivi fazi razvoja listov) v Ljubljani nismo zabeležili.

V tej študiji smo spremljali sedem faz razvoja listov pri bukvah na eni lokaciji, pri čemer smo skušali zajeti tudi drevesi z najzgodnejšim in najpoznejšim olistanjem in s tem pridobiti informacije o variabilnosti pojava posameznih faz med drevesi. Splošno olistanje je pri različnih drevesih nastopilo med 7. in 25. aprilom 2020, olistanje pri bukvi, za katero imamo dolgoletne podatke o datumu olistanja, pa je nastopilo 14. aprila (DOY 105), kar je 4



dni prej od dolgoletnega povprečja (DOY 109) (slika 10). Pri najzgodnejši bukvi na opazovanem transektu, za katero nimamo dolgoletnih podatkov, pa je olistanje nastopilo že 7. aprila (DOY 98). K zgodnjemu pojavu fenoloških faz pri bukvi je pripomogla nadpovprečno topla zima in zgodnja pomlad, kar je bilo opazno tudi pri drugih rastlinah, ki jih spremlja ARSO (Žust, 2020). V tej študiji smo pridobili informacije o variabilnosti listne fenologije, kar nam bo med drugim pomagalo bolje razumeti fiziologijo gozdnega drevja, vključno z delovanjem kambija ter nastajanjem lesa in skorje.

## SUPPLEMENT DODATEK

The supplement related to this article is available online in the Repository of the University of Ljubljana (RUL) and can be accessed through <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807>, and cited as Škrk et al. (2020).

It contains daily photos (period 5 - 27 April and 2 May 2020) of leaf development in European beech (*Fagus sylvatica*) (tree 30 in this study) which is as a plant number 221 included in the long-term monitoring of the Slovenian National Phenological Network of the Environmental Agency of the Republic of Slovenia (ARSO) within the Ministry of the Environment and Spatial Planning as a part of the International Phenological Gardens of Europe.

Dodatek, povezan s tem člankom, je prosto dostopen na spletu v Repozitoriju Univerze v Ljubljani (RUL). Dostop do njega je možen preko povezave <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116807> in se ga citira kot Škrk et al. (2020). Dodatek vsebuje dnevne fotografije (obdobje od 5. do 27. aprila in 2. maja 2020) razvoja listov pri navadni bukvi *Fagus sylvatica* (drevo številka 30 v tej študiji), ki je kot drevo z identifikacijsko številko 221 vključeno v dolgoletno spremljanje v okviru Slovenske nacionalne fenološke mreže Agencije Republike Slovenije za okolje (ARSO) Ministrstva za okolje in prostor Republike Slovenije, ki je vključen v aktivnosti Mednarodnih fenoloških vrtov Evrope.

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