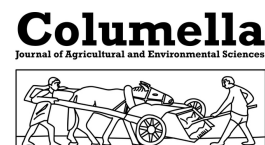# Comparative study of flowering phenology of selected plant life forms in urban and rural environments. Preliminary results

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Abstract: Global climate change has unforeseeable ramifications for the ecosystem of our home planet. In Europe, more than half of the vascular plant flora may become endangered by the year 2080 as a result of climatic changes. Urban climate conditions are considered similar to the changing global climate conditions. The concept of our study is based on the Space for Time Substitution method, utilizing its advantage of saving time and resources compared to long-term monitoring. To find out how excess heat in urban environments affects the phenological flowering patterns of species we planted specimens representing 6 different life-forms of the Raunkiær system (phanerophytes, chamaephytes, hemicryptophytes, geophytes, hemitherophytes, therophytes). Each category was represented by at least 5 species and each species by 5-5 specimens in Budapest, Füvészkert and in the MATE Botanical Garden of Gödöllő. All the species in the experiment averaged at 7.62 days earlier flowering onset in Budapest. The peak of the flowering had 12.94 days of difference, while the end of flowering had 2.9 days of difference, with the earlier being Budapest. There is a strong significant difference ($P < 0.001$) in the onset of the flowering of *Globularia cordifolia* between the locations, regarding the peaks of flowering there is a strong significance ($P < 0.001$) for *Inula ensifolia*, regarding the end of flowering there is a strong significance ($P < 0.001$) for *Polygonatum multiflorum*. To clarify other driving forces and the role of abiotic parameters in the flowering phenology patterns, further study is required.

Keywords: Reproductive phenology, plant life forms, climate change, heat island, botanical garden

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Introduction

United Nations 1992 Framework Convention on Climate Change (UNFCCC) – referencing prior research results – clearly states that the mean temperature of the planet Earth is rising (http1). By today the theory of global warming is widely supported by multi-disciplinary research, including the 2007 IPCC report (IPCC 2007). According to the World Meteorological Organisation's study, compared to the average mean temperature between 1961 and 1990 by 2015 the difference reached 1 °C, and by 2020 Global Mean Surface Temperature was around 1.2°C warmer than the pre-industrial baseline (1850–1900) (http1, http2). The last decade (2011–2020), is the warmest on record (http2). Another 2–4°C rise is expected during the next century (MEA 2005). This change has unforeseeable ramifications for the ecosystem of our home planet. In Europe, more than half of the vascular plant flora may become endangered by the year 2080 as a result of climatic changes (Thuiller et al. 2005).

Unfortunately, this significant environmental crisis is unsolved to this day (IPCC 2007, Hufnagel & Sipkay 2012). Based on current research it seems that climate change can no longer be stopped. Therefore, it is crucial to investigate possible adaptations (Li et al. 2019).

Urban climate conditions are considered similar to the changing global climate conditions; therefore, many researchers study urbanized areas as small-scale experiments,

or models, of global climate change (Ziska et al., 2003). Thus the urban environment is suitable for the application of the Space for Time substitution method. Which method encompasses analyses in which contemporary spatial phenomena are used to understand and model temporal processes that are otherwise unobservable, most notably past and future events. This method is used to predict the effects of climate change on biodiversity, identifying general trends, therefore its application saves time and money compared to long-term studies. (Pickett 1989, Blous et al. 2013)

Thus, it is key to examine the patterns and shifts in the patterns of flowering phenology in urban areas compared with rural ones. Cities are strongly affected by climate change.

Fifty years of data from the Copernicus Program on more than 100 000 European municipalities confirm that the continent is heating up at every latitude. In a third of these municipalities, the average temperature has risen by more than 2°C between the 1960s and the last decade (http3, http4). The survey compared the mean temperatures of the municipalities of the period between 1961–1970 with the period between 2009–2018. According to the report of this program mean temperature of Budapest increased from 8.04°C to 12.04°C, and in Gödöllő from 7.56°C to 10.76°C. According to this change (4°C and 3.2°C), both cities belong to the top third of the data. The increase in the capital city Budapest was 0,8°C bigger than that of Gödöllő, which is a small town with more green areas. According to the report, it is clear, that capitals and their suburbs are affected most significantly, especially in central-eastern Europe. Riga and Budapest are the two European capitals that have warmed most of all.

Phenology is the study of the timing of recurrent biological events, the causes of their timing with regards to biotic and abiotic forces, and the interrelation among phases of the same or different species (Lieth 1974). Many research shows that temperature change significantly affects the life cycle of plants (e.g. Scheifinger et al. 2003, Kunkel et al. 2004, Hansen et al. 2006, Lehoczky et al. 2016).

Towards the end of the last century, phenological observations were recognized for their capability to visually and quantitatively assess climate change effects on ecosystems. Several studies demonstrate significant shifts in phenological phases of plants across Europe (e.g., Menzel and Fabian 1999; Menzel 2000, Chmielewski and Roetzer 2001, Schleip et al. 2009). Shifts in phenological events in the Carpathian Basin are particularly poorly documented, with a few exceptions coming from the works of Keresztes (1984), Walkovszky (1998), Schieber et al. (2009), Eppich et al. (2009), Molnár et al. (2012), Varga et al. (2012), Lehoczky et al. (2016), and Szabó et al. (2016). Keresztes (1984), Walkovszky (1998), and Varga et al. (2012) are focusing on their study on *Robinia pseudoacacia*, a non-native species for the Carpathian Basin, however, there is a lack of studies with emphasis on native species' phenology in Hungary. There is less available phenological data on wild-growing plants, then from cultivated species (Walkovszky 1998, Hunkár 2012). Szabó et al. (2016) showed in their study based on the long-term data from the Hungarian Meteorological Service recorded between 1952 and 2000, that native plant species advanced their flowering time (1952–2000) by 1.9–4.4 days per decade.

In the last few years, more and more researches use remote sensing to detect changes in phenological patterns between urban and rural areas (Yao et al. 2017, Luo et al. 2020, Jia et al. 2021). In Northeast China, the start of the growing season in old urban areas had become earlier and the differences of the start of the growing season between urbanized areas and the ru-

ral area changed greatly during 2001–2015 (−0.79 days/year, $P < 0.01$). Meanwhile, the length of the growing season in urban areas had become increasingly longer than in rural areas (0.92 days/year, $P < 0.01$) (Yao et al. 2017). In China, the time of the start of the growing season of inland cities of Liaoning Province had negative correlations with urban size. Specifically, when the urban size increased 10-fold, the start of the growing season advanced by 10.03 days (Luo et al. 2020). Other research, based on MODIS data, claims that overall in China, the phenology shifted earlier by 8.6 ± 0.54 days for the start of the growing season in urban core areas compared with their rural counterparts. (Jia et al. 2021). A comprehensive understanding of species phenological responses to global warming requires observations that are both long-term and spatially extensive. Long-term data series deriving from the same place are rare (Hunkár et al. 2012). It is also very important to choose the correct methodology for the research. Primack (1985) described the methodology of collecting flowering phenology data. For the observation of individual plants, he suggests counting every flower open on the entire plant on every day that the plant is in bloom, to note the date of first flowering, the date of the last flowering, and the date on which the most flowers are open (date of maximum flowering). According to him the duration of flowering may be an appropriate statistic for comparative purposes for species that begin and stop flowering abruptly and have about the same number of flowers open per day.

Previous research on the Carpathian Basin (Keresztes 1984, Walkovszky 1998, Schieber et al. 2009, Eppich et al. 2009, Molnár et al. 2012, Varga et al. 2012, Lehoczky et al. 2016, and Szabó et al. 2016) did not follow Primack's method but still provided important data. Several previous studies (e.g., Menzel 2000, Roetzer et al. 2000,

Walkovszky 1998, Eppich 2009) confirmed that flowering phases advanced during the 20th century, which is connected with the increasing temperature. Szabó et al. (2016) examined flowering phenological records for six species (*Convallaria majalis*, *Taraxacum officinale*, *Syringa vulgaris*, *Sambucus nigra*, *Robinia pseudoacacia*, *Tilia cordata*) based on phenological observations from the Hungarian Meteorological Service recorded between 1952 and 2000. Altogether, four from the six examined plant species showed a significant advancement in flowering onset with an average rate of 1.9–4.4 days per decade. The examined species showed a difference where flowering occurred on the Great Hungarian Plain before West-Hungary. Using a long-term data series of 144 years (1851–1994) Walkovszky (1998) showed 3–8 days advancement in the flowering date of *Robinia pseudoacacia*, relating the event to the mean temperature of March–May. Templ et al. (2017) examined the flowering phenology of plant species a 3000-km-long, North-South transect from northern to eastern Central Europe over the period 1970–2010 to identify the spatio-temporal patterns biogeographical regions of Europe. The results show that Continental, Alpine and Boreal regions have a greater shift in flowering phenology (2.2–9.6 days per decades) than in Pannonian and Mediterranean regions.

Strategy for Plant Conservation (GSPC; Secretariat of the CBD 2002, Convention of Biological Diversity 2010) define the role of botanic gardens, so they have responsibilities in research, teaching, and public education in the field of botany and in conservation both in *ex situ* conservation and in *in situ* conservation serving resources for restoration projects. Botanic gardens are contributing to climate change-related research. The project of International Phenological Gardens (IPG) started in 1957 and now encompasses 50 botanical gardens across Europe and collected 65 000 observations of

23 plant species during the decades (Primack & Miller-Rushing 2009). This project used clonal plant material to reduce the amount of genetic variation, so that variation in phenology reflects the influence of environmental factors rather than genetic differences among individuals (Primack & Miller-Rushing 2009).

This study aims to find out how excess heat in urban environments affect the phenological flowering patterns of species belonging to different life forms, and how different the effect is in colder rural mesoclimactic environments. To observe this, we planted plants representing six different life forms in two distinct locations. One was in downtown Budapest in ELTE Botanical Garden (Füvészkert), and the other in MATE Botanical Garden of Gödöllő. The flowering of the plants was recorded between the 1st of March and 25th of December in 2020. We hypothesized locations with higher mean temperatures would result (i) in an earlier onset and (ii) and an earlier end of flowering, compared to colder locations.

The following abbreviations were used: Phanerophytes (Ph), Chamaephytes (Ch), Geophytes (Ge), Hemicryptophytes (He), Hemitherophytes (HT), Therophytes (Th).

Materials and Methods

Study area

Examination covering the entire vegetation cycle of species have been implemented in the Experimental Site of Hungarian University of Agriculture and Life Sciences Gödöllő Botanical Garden (47°35'36.2"N 19°22'06.2"E, 250 m elevation, mean annual temperature is 9.7°C; the average amount of precipitation is 560 mm) (Dövényi et al. 2008, Szirmai et al. 2014) and the Eötvös Loránd University Botanical Garden Füvészkert (Budapest 47°29'05.6"N 19°05'05.7"E, 114 m elevation, mean annual temperature is 10.4°C; the average amount

of precipitation is 514 mm) (Dövényi et al. 2008, Orlóci et al. 2019). Within a radius of 250 m around the two botanical gardens, the following local climate zones (LCZ) are present. In Budapest: LCZ 5 - Open mid-rise 60%, LCZ 6 - Open low rise 20% LCZ 2 - Compact mid-rise 20%. In Gödöllő: LCZ A - dense trees 40%, LCZ D - low plants 50%, LCZ 6 - Open low-rise 10% (Stewart & Oke 2012, http5). In the text, we refer to the experiment locations as Gödöllő and Budapest.

For the 34 species, 34 homogenous row shaped patches have been created within the two selected areas with 5 repetitions by species and by location.

Ex situ phenological experiment

We planted specimens representing 6 different life-forms of the Raunkiær system (phanerophytes, chamaephytes, hemicryptophytes, geophytes, hemitherophytes, therophytes). Each category was represented by at least 5 species (Table 1) and each species by 5–5 specimens in both locations.

The observation units were put in standard-sized flowerpots with a diameter of 27 cm for phanerophytes, and 14 cm for the rest, containing at least one specimen from the given species. We tried to maximize genetic conformity in each species. This was achieved by using clones in phanerophytes, obtained from the Hungarian University of Agriculture and Life Sciences Soroksári Botanical Garden. In the case of seed-sown species, the propagating material was collected from one specimen per species in the Gödöllő Botanical Garden and the Eötvös Loránd University Botanical Garden Füvészkert, while in the case of other species we obtained specimens propagated from the horticulture of Beretvás és Társai Kft. We collected and planted the specimens to the experimental patches during December of 2019.

To minimize external factors, we used a standard soil mix and we put the plants in the patches of similar characteristics and fol-

Table 1. The species included in the experiment grouped by life-forms

Ph	Ch	He
Cornus sanguinea	*Dianthus plumarius*	*Euphorbia polychroma*
Prunus spinosa	*Sedum album*	*Ajuga reptans*
Ligustrum vulgare	*Vinca minor*	*Inula ensifolia*
Prunus fruticosa	*Thymus vulgaris*	*Sedum acre*
Cotinus coggygria	*Cerastium tomentosum*	*Briza media*
Prunus tenella	*Globularia cordiflora*	
Rosa spinosissima		

Ge	HT	Th
Iris pumila	*Daucus carota***	*Hibiscus trionum*
Polygonatum multiflorum	*Dipsacus pilosus***	*Solanum nigrum*
Convallaria majalis	*Dipsacus lacinatus***	*Silene latifolia*
Galanthus nivalis*	*Capsella bursa-pastoris*	*Portulaca oleracea*
Eranthis hyemalis*	*Malva sylvestris***	*Consolida regalis*
		Papaver rhoeas

* the species were introduced after the start of the growing season, therefore were not included in the record
** resulting from their life-form, flowering in the first year is not expected (Krumbiegel, 2008)

lowed the same protocol during their observation. In practice, this meant frequent weeding and regular irrigation during the summer months. Observations were realized weekly on the same day of the week from March to December of 2020, on both locations, collecting flowering phenological data. For the study of the flowering phenological data, we used Primack's (1985) method. The timing of the start, peak, and end of flowering was recorded in an Excel sheet. We recorded the end of flowering when there was no more flower on any of the specimens. The peak was the first day from all the dates when the specimen had the maximum number of flowers noticed. In case of solitary flower we recorded the number of flowers, while in case of *Briza media (He), Capsella bursa-pastoris (HT), Sedum album (Ch)* and *Thymus vulgaris (Ch)* we recorded the number of inflorescences for each observation unit. During the growing season specimens of *Cornus sanguiena (Ph),*

Ligustrum vulgare (Ph), Prunus tenella (Ph), Rosa spinosissima (Ph), Dianthus plumarius (Ch), Sedum album (Ch), Vinca minor (Ch), Thymus vulgaris (Ch), Cerastium tomentosum (Ch), Ajuga reptans (He), Inula ensifolia (He), Sedum acre (He), Briza media (He), Iris pumila (Ge), Polygonatum multiflorum (Ge), Capsella bursa-pastoris (HT), Hibiscus trionum (Th), Solanum nigrum (Th), Silene latifolia (Th), Portulaca oleracea (Th), Consolida regalis (Th), Papaver rhoeas (Th) flowered. In case of *Portulaca oleracea (Th)* we could only infer the flowering from the fruiting because there was no flower detected at the times of observation. The flowering of the *Papaver rhoeas (Th)* could only be detected on one of the locations, on the other a short flowering period could be inferred from the buds and fruits. Therefore, these two species were excluded from the evaluation of the flowering data. On both observation locations only *Prunus tenella (Ph), Dianthus plumarius (Ch), Se-*

dum album (Ch), Vinca minor (Ch), Thymus vulgaris (Ch), Cerastium tomentosum (Ch), Ajuga reptans (He), Inula ensifolia (He), Sedum acre (He), Briza media (He), Iris pumila (Ge), Polygonatum multiflorum (Ge), Capsella bursa-pastoris (HT), Hibiscus trionum (Th), Solanum nigrum (Th), Silene latifolia (Th) flowered. All species – except *Iris pumila (Ge)* – produced enough flowers for statistical analysis of the data.

Statistical analysis

Figures were created with Sigma Plot 12.0. For statistical analysis, we used Windows Excel 2016, while we calculated the two-tailed t-test to show the difference between locations. The results shown in the figures are the averages and standard deviations for each species in both locations.

Results

From the 16 species flowering on both locations 12 species *Globularia cordiflolia (Ch)* (Figure 1), *Briza media (He)* (Figure 2), *Hibiscus trionum (Th)* (Figure 3), *Silene latifolia subsp. alba (Th), Inula ensifolia (He), Polygonatum multiflorum (Ge), Dianthus plumarius (Ch), Sedum album (Ch), Vinca minor (Ch), Thymus vulgaris (Ch), Cerastium tomentosum (Ch)* and *Capsella bursa-pastoris (HT)* confirmed our hypothesis, by flowering earlier in Budapest than in Gödöllő. From the listed species the average difference in the onset of flowering was 10.66 days. *Solanum nigrum (Th), Sedum acre (He)* started the flowering on the same week on both locations. *Prunus tenella (Ph), Ajuga reptans (He)* and *Iris pumila (Ge)* started to flower earlier in Gödöllő, contradicting our hypothesis. Species with the earlier onset of flowering happening in Gödöllő had an average difference of 2.2 days. All the species in the experiment averaged at 7.62 days earlier flowering onset in Budapest. The peak of the flowering had 12.94 days of dif-ference, while the end of flowering had 2.9 days of difference, with the earlier being Budapest.

Globularia cordifolia (Ch), Inula ensifolia (He), Polygonatum multiflorum (Ge), Dianthus plumarius (Ch), Thymus vulgaris (Ch), Cerastium tomentosum (Ch) and *Capsella bursa-pastoris (HT)* had an earlier onset as well as an earlier end of flowering in Budapest compared to Gödöllőn. The flowering of *Sedum album (Ch)* had an earlier onset in Budapest and a simultaneous end on both locations. The flowering of *Hibiscus trionum (Th)* and *Vinca minor (Ch)* started earlier and ended later in Budapest. The flowering of *Ajuga reptans (He)* and *Iris pumila (Ge)* started later and ended later in Budapest. The flowering of *Prunus tenella (Ph)* started later in Budapest and ended at the same time. The flowering of *Solanum nigrum (Th)* and *Sedum album (Ch)* started in the same week and ended earlier in Budapest. The flowering of *Silene latifolia subsp. alba (Th)* started in the same week in both locations, but in contrast to the former two ended later in Budapest. The average duration of the flowering of all species was 4.72 days longer in Budapest compared to Gödöllő. Flowering duration of *Hibiscus trionum (Th), Silene latifolia subsp. alba (Th), Globularia cordifolia (Ch), Briza media (He), Sedum album (Ch), Vinca minor (Ch), Capsella bursa-pastoris (HT), Ajuga reptans (He)* and *Iris pumila (Ge)* was longer in Budapest, compared to Gödöllő.

According to the statistical analysis, there is a strong significant difference ($P < 0.001$) in the onset of the flowering of *Globularia cordifolia (Ch)* between the locations. *Polygonatum multiflorum (Ge), Cerastium tomentosum (Ch)* and *Capsella bursa-pastoris (HT)* showed a medium significance ($P < 0.01$). There was a still significant but weaker connection ($P < 0.05$) for the onset of flowering of *Thymus vulgaris (Ch)* between the two locations.
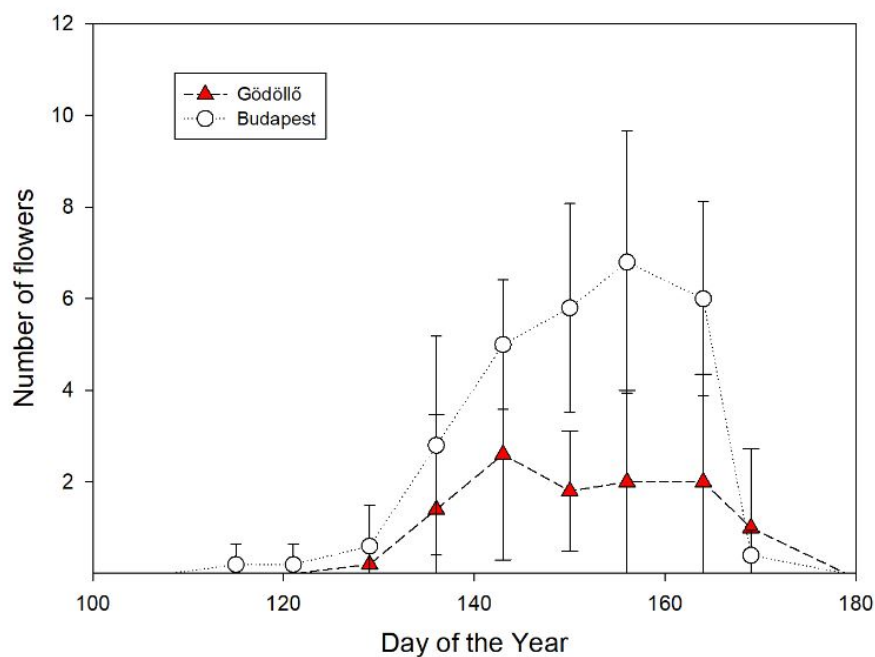
Regarding the peaks of flowering there was

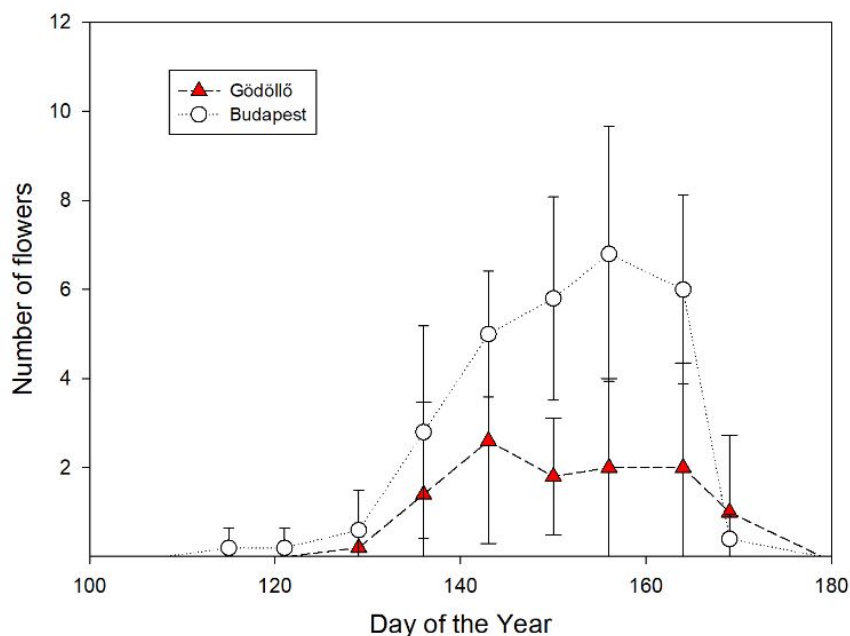Figure 1. The flowering period and pattern of *Globularia cordifolia*.

Figure 2. The flowering period and pattern of *Briza media*.

a strong significance ($P < 0.001$) for *Inula ensifolia (He)* medium significance ($P < 0.01$) for *Globularia cordifolia (Ch)*, *Dianthus plumarius (Ch)*, *Thymus vulgaris (Ch)*, *Cerastium tomentosum (Ch)*, *Capsella bursa-pastoris (HT)* and a weaker significance ($P < 0.05$) for *Polygonatum multiflorum (Ge)*.
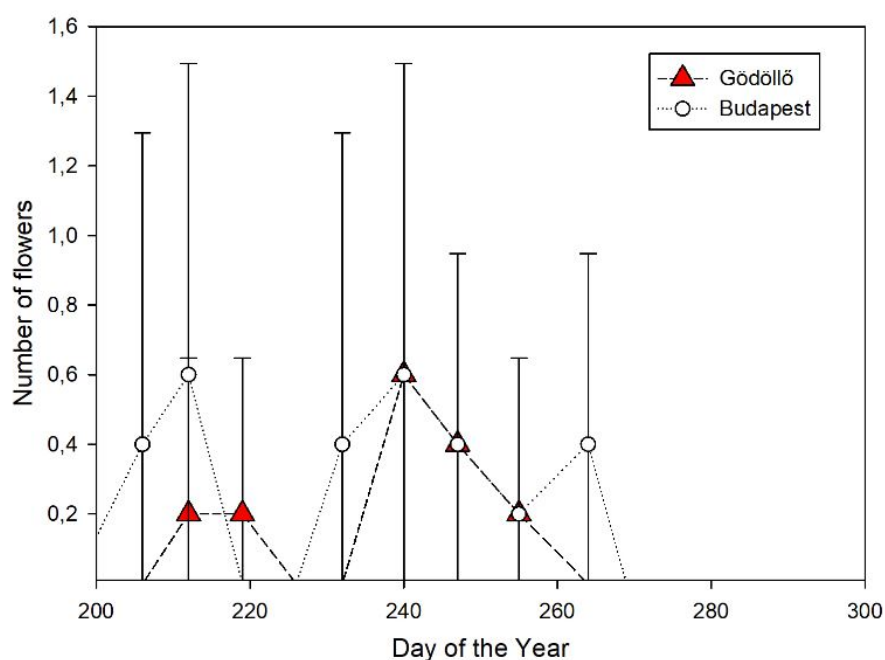
Figure 3. The flowering period and pattern of *Hibiscus trionum*.

Regarding the end of flowering there is a strong significance ($P < 0.001$) for *Polygonatum multiflorum (Ge)*, medium siginificance ($P < 0.01$) for *Globularia cordifolia (Ch), Thymus vulgaris (Ch)* and a weaker significance ($P < 0.05$) for *Sedum acre (He), Dianthus plumarius (Ch)* and *Cerastium tomentosum (Ch)*.

Discussion

Our results show that the onset and end of flowering occurred earlier in the capital city with a higher mean temperature than in the lower mean temperature rural area. However, the flowering period lasted longer in Budapest than the rural area with a 3°C lower mean temperature. Only a few studies (e.g., Roetzer et al. 2000, Ziska et al. 2003, Neil & Wu 2006, Jochner et al. 2012) focused on the difference in phenological patterns between urban and rural areas. Roetzer et al. (2000) analyzed data for four spring-blooming plants from 10 central European

observation stations between 1951 and 1995. At almost all stations, the plants tended to bloom earlier in urban areas than in surrounding rural areas by about 2–4 days. Jochner et al. (2012) investigated the role of elevation and urbanization in the shift of flowering phases of tree species, and an advance of 2.6–7.6 days was observed between an entirely rural area and an entirely urban one. Roetzer et al. (2000) showed, that in European cities with strong urban climate effects e.g., Munich, Vienna and Hamburg, phenophases are beginning 3–16 days earlier. His results are in agreement with our results as the plants grown in Budapest have on average 7.62 days earlier onset of flowering compared to Gödöllő. This result could mean that downtown Budapest is strongly affected by the urban climate effect. Researchers attribute advanced flowering in urban environments to the Heat Island Effect (Neil & Wu 2006), which is clearly noticeable in our results as well.

Extension of growing periods in urban habitats has also been reported in the northern

hemisphere (e.g., Zhang et al. 2004, Neil and Wu 2006) while possible protracted flowering periods within urban landscapes are poorly studied, especially in Europe. Davis et al. (2016) examined eucalyptus trees in streets in Sidney, Australia, and observed, that 3 tree species from the family Myrtaceae showed a significantly longer flowering period on the streets of the city than in their natural habitats. Our results are consistent with this study, as the species participating in the experiment had a 4.72 days longer flowering period in Budapest compared to Gödöllő.

Compared to the onset of flowering there are significantly fewer studies regarding the end of flowering and the possible advancement of it. Masetti et al. (2015) studied *Tilia × europea* in Florence, Italy, and concluded that both the start and end of flowering advanced by 1.4 days in urban areas. In our experiment *Globularia cordifolia (Ch), Inula ensifolia (He), Polygonatum multiflorum (Ge), Dianthus plumarius (Ch), Thymus vulgaris (Ch), Cerastium tomentosum (Ch)*, and *Capsella bursa-pastoris (HT)* started to flower earlier in Budapest compared to Gödöllő. All the species in the experiment had an average of 2.9 days advancement at the end of flowering in Budapest compared to Gödöllő, which is in agreement with the observation of Masetti et al. (2015).

Nail and Wu (2006) observed the phenomenon that early spring bloomers in these environments tend to be more sensitive than mid- or late-spring bloomers. For the future investigation of this conclusion, we will introduce 2 early spring bloomers *Eranthis hyemalis (Ge)* and *Galantus nivalis (Ge)* from 2021.

Is there a significant difference between the years? Exactly with which abiotic parameters do the flowering phenology correllate? These are questions to be addressed in future studies.

Based on our result, not all of these questions can be answered. Peñuelas and Filella (2001) showed that the advancements of phenological events were significantly correlated, with temperature increase over the 30 years before then, however, the significance of other factors is unclear. According to Rathcke and Lacey (1985) and Neil and Wu (2006) photoperiod, temperature, and soil moisture have been recognized as the main environmental triggers for leafing and flowering. Zhang et al. (2004) claim that it is the interaction between temperature and photoperiod that is responsible for initiating flowering Szabó et al. (2016) claim that the flowering phenophase shows the strongest correlation with the average air temperature of a few months preceding the event, while Eppich et al. (2009) came to the conclusion that the average of the daily temperature fluctuation in the given period and the number of frosty days are the most important triggers for flowering phenology. To clarify the driving forces of flowering phenology patterns we installed micrometeorological equipment to continuously measure abiotic parameters on both locations.

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