

Flowering phenological changes in relation to climate change in Hungary

Barbara Szabó^{1,2} · Enikő Vincze³ · Bálint Czúcz²

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Abstract The importance of long-term plant phenological time series is growing in monitoring of climate change impacts worldwide. To detect trends and assess possible influences of climate in Hungary, we studied 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 significant advancement in flowering onset with an average rate of 1.9–4.4 days per decade. We found that it was the mean temperature of the 2–3 months immediately preceding the mean flowering date, which most prominently influenced its timing. In addition, several species were affected by the late winter (January–March) values of the North Atlantic Oscillation (NAO) index. We also detected sporadic long-term effects for all species, where climatic variables from earlier months exerted influence with varying sign and little recognizable pattern: the temperature/NAO of the previous autumn (August–December) seems to influence *Convallaria*, and the

temperature/precipitation of the previous spring (February–April) has some effect on *Tilia* flowering.

Keywords Beginning of flowering · Spring phenology · Long-term effects · North Atlantic Oscillation · Precipitation · Central Europe

Introduction

There is a worldwide increase in the number of studies, which call attention to the ecological consequences of global climate change. These effects appear at population, community, as well as ecosystem levels by modifying species composition, spatial patterns, and ecosystem functioning (Parmesan 2006; Root et al. 2003; Rosenzweig et al. 2008). Shifts in the timing of recurring life history events (phenophases) of species constitute a major component of the ecological impacts of climate change (Parmesan and Yohe 2003; Walther et al. 2002). Diverging phenological shifts in communities may lead to a breakdown of synchronous species interactions (Buse et al. 2002; Stenseth et al. 2002), which eventually can result in increased risk of extinctions (Memmott et al. 2007). Several studies warn about potentially detrimental impacts of these processes (Both et al. 2009; Visser and Both 2005). Furthermore, phenology also exerts control over many potential feedbacks from vegetation to the climate system by influencing the seasonality of albedo, canopy conductance, fluxes of water and energy, CO₂, and biogenic volatile organic compounds (Richardson et al. 2013).

The analysis of long-term plant phenological time series have been in the focus of climate impact research since the early 1990s (Schwartz 1999). Several studies have demonstrated significant advancements in spring phenophases of plants across the northern hemisphere (Menzel et al. 2006; Schleip et al. 2009; Schwartz et al. 2006). Similar tendencies can be seen across

✉ Barbara Szabó
barbara.szabo.elte@gmail.com

¹ Department of Plant Systematics, Ecology and Theoretical Biology, Institute of Biology, Eötvös Loránd University, Pázmány Péter sétány 1/C, 1117 Budapest, Hungary

² Institute of Ecology and Botany, Centre for Ecological Research, Hungarian Academy of Sciences, Alkotmány út 2-4, 2163 Vácrátót, Hungary

³ Hungarian Meteorological Service, Kitaibel Pál u. 1, 1024 Budapest, Hungary

several other taxonomical groups, including, e.g., fungi (Kausserud et al. 2010), insects (Robinet and Roques 2010), amphibians (Beebe 2002), and birds (Gordo 2007). These changes are not limited to terrestrial ecosystems but can also be observed in freshwater and marine systems (Thackeray et al. 2010).

Induction of different phenophases along the life cycle of individuals is governed by species-specific environmental thresholds. Alterations in CO₂ level, temperature, photoperiod, solar radiation, precipitation, snowmelt, and frost effects exert influence together on plants' physiological processes (Körner and Basler 2010; Nord and Lynch 2009). There are several conflicting reports in the literature about the relative roles of different drivers and/or explanatory variables of the phenological development (Migliavacca et al. 2012). The best predictors of plant phenology within the temperate zone are local meteorological variables, like air temperature and precipitation, but macroclimatic circulation patterns, such as the North Atlantic Oscillation (NAO) index are also frequently considered as predictors. It is also well known that NAO-induced local weather conditions can affect phenology and this relationship can be different in different parts of Europe (Gordo and Sanz 2010; Scheifinger et al. 2002; Stenseth et al. 2003), as it is expected from this impact system (Hurrell and van Loon 1997; Pauling et al. 2006; Trigo et al. 2002).

Strongly connected to the problem of identifying the appropriate predictor variables is the problem of finding the effective time period, the weather of which most strongly influences the subsequent phenological events. The timing of flowering is controlled by complex mechanisms, which act to ensure that flower emergence occurs in suitable conditions attuned to seasons (Tooke and Battey 2010). Most studies report that the flowering phenophase shows the strongest correlation with the average air temperature of a few months preceding the event, but focusing only on spring temperatures can lead to inaccurate interpretations and predictions for species, because photoperiod and vernalization plays also major

roles in spring phenological events (Cook et al. 2012; Körner and Basler 2010; Tooke and Battey 2010).

The aim of our study is to evaluate the shift in the flowering phenologies of six spring-flowering plant species in Hungary during the second half of the last century (1952–2000). In spite of the number of phenological time series available, Hungary is a relatively unexplored country in central Europe in terms of phenological studies. Similarly to other parts of western and central Europe, Hungary is relatively warm and springs tend to be drier during positive NAO periods, while wetter than average during negative NAO periods (Bartholy et al. 2009a). In this study, we have set two main goals: (i) to test whether trends similar to those observed in other parts of Europe can also be detected within Hungarian spring phenological changes, and (ii) to determine which month's climate exerts the greatest effect on the flowering onset of different species.

Materials and methods

Phenological data

To seek for potential shifts in spring phenological events, we studied the beginning of flowering (BF) of six angiosperm species: lily of the valley (*Convallaria majalis* L.), common dandelion (*Taraxacum officinale* (L.) Weber), common lilac (*Syringa vulgaris* L.), black elder (*Sambucus nigra* L.), black locust (*Robinia pseudoacacia* L.), and small-leaved lime (*Tilia cordata* Mill.) during the period 1952–2000 in Hungary. Historical data on plant phenological observations were obtained from the Hungarian Meteorological Service (Table 1). Our selection of species and observing stations was seriously limited by the extreme fluctuation in the number of stations, observers, and observed species which characterized the phenology observations of the Hungarian Meteorological Service

Table 1 An overview of the phenological observations by the Hungarian Meteorological Service (HMS) for the studied species

Species	BF (#61) a (b, c)	FL (#11) a (b, c)	BR (#86) a (b, c)	LF (#97) a (b, c)
<i>Taraxacum officinale</i>	2012 (62, 20)			
<i>Syringa vulgaris</i>	2339 (71, 19)		1304 (45, 0)	1719 (65, 0)
<i>Convallaria majalis</i>	2039 (64, 19)			
<i>Robinia pseudoacacia</i>	2330 (72, 20)	1689 (66, 0)	1336 (45, 0)	1850 (67, 0)
<i>Sambucus nigra</i>	2167 (64, 20)		1716 (62, 0)	1631 (61, 0)
<i>Tilia cordata</i>	1729 (51, 20)	597 (22, 0)	1113 (38, 0)	1381 (54, 0)

For each species and phenophase, the following three numbers are given: a—the total number of records between 1952–2000; b—the number of stations with at least 10 years of observations before 1982 (the reorganization of the HMS phenology network); and c—the number of stations with at least 10 years of observations after 1982. For each phenophase the corresponding BBCH code (Meier, 1997) is also given in parentheses. The datasets used in our study are marked in bold

BF beginning of flowering, FL appearance of first leaves, BR beginning of ripening, LF leaf falling

(Dunay 1984; Szalai et al. 2008). During 1952–1961, the observation network of the Meteorological Service consisted of ~100 stations performing phenological observations on ~100 phenological events of 37 plant species. The number of stations decreased to ~60 with an increasingly uneven geographical coverage during 1961–1981 (Table 1). After a 1-year disruption in 1982, the network was reorganized with a drastically reduced list of observed species and phenological events (shifting from wild plant species to crops), and a reduced number of stations with a more even coverage (Dunay 1984; Szalai et al. 2008). This reorganized network, which was hosted by the regional Pest Control and Agrochemistry stations of the Agriculture and Food Ministry, operated in consistent and reliable way from 1983 until 2000, when the entire network fell apart due to lack of funding. As a consequence of these recurrent reorganizations phenological time series long enough for climate impact analysis can only be studied for a few phenological events, which were observed both prior to and after 1982, and even for these events the number of complete time series is very limited (Table 1). Luckily, the definition of phenological events did not change during the reorganizations, so the beginning of flowering phenological event was consequently defined as “the appearance of the first flowers producing pollens on at least 50 % of the observed plants” (Dunay 1984), which equals the event 61, according to the BBCH scale (Meier 1997).

We converted all dates given in months and days to day of the year (DOY) values. To exclude potential coding and typing mistakes we first checked for outliers using the *extremevalues* R package (van der Loo 2010) assuming a normal distribution. In order to cope with the fluctuations and inhomogeneity in the distribution of stations, we grouped the observations according to the six geographical macroregions of Hungary (Dövényi 2010). For each region, we only kept observation time series of at least 10 years of continuous data. As an additional criterion, we only analyzed data for those regions where there were at least two stations with at least 10 years of continuous data both before and after the reorganization of 1982. This way, we compiled regional datasets for three geographical macroregions (*Alföld*—Great Hungarian Plain, r1; *Nyugatmagyarországi peremvidék*—West Hungary, r3; and *Dunántúli-középhegység*—Transdanubian Mountains, r5) consisting altogether of 133 local data series of the studied species (see Fig. 1). To deal with uneven data coverage, we used linear mixed models to derive single homogenized time series as described by Shaber and Badeck (2002). Accordingly, for each species and region, we created time series using a fixed effect of year, with a station-level random effect with the help of the *pheno* R package (Schaber 2012). Accordingly, the analyses were carried out on 18 homogenized time series for the six species and the three regions (r1, r3, r5).

Climate data

To determine any correlations between the macroclimatic conditions and the flowering phenology of the selected species, we generated a large number of climatic variables based on air temperature, precipitation, and NAO index data. As a starting point for generating air temperature and precipitation variables, we used monthly records from the Hungarian Meteorological Service. After check for outliers similar to what was done in case of the phenological data, we used the same linear mixed model procedure (Shaber and Badeck 2002) to generate a single homogenized macroclimatic signal for each region (see Fig. 1).

To identify the combination of climatic variables and effective periods, which effectively influence the spring phenologies of the studied species, we used the methodology of Gordo and Sanz (2010). Accordingly, we defined a series of monthly, bi-monthly, and trimonthly means (temperature) and sums (precipitation) of climate variables, which could potentially influence the actual phenological event. We created 18 monthly mean temperature (T1) variables relative to the current year: from the previous year’s January (T101) to current year’s June (T118). Similarly, we defined seventeen bimonthly (T2) variables, with T201 meaning the mean temperature of previous year’s January–February, T202 being previous year’s February–March, and T217 being current year’s May–June. Trimonthly temperature data series (T3) were also created in a similar way, ranging from T301 (previous year’s January–March) to T316 (current year’s April–June). We defined precipitation variables the same way as T, namely 18 monthly (P101–P118), 17 bimonthly (P201–P217), and 16 trimonthly (P301–P316) precipitation sum variables were created.

To check for potential effects of large-scale circulation patterns on the timing of the studied phenological events, we also defined predictor variables based on the values of the NAO index. Based on the monthly NAO values taken from the NOAA Climatic Research Unit homepage (<http://www.cru.uea.ac.uk/cru/data/nao/>), we defined 18 variables for monthly (N101–N118), 17 variables for bimonthly (N201–N217), and 16 variables of trimonthly (N301–N316) mean NAO values, exactly following the structure of the other climatological variables. This way we created a set of 144 strongly correlated climatic predictors (51 for temperature, 51 for precipitation, and 51 for NAO). However, unlike mean temperature and sum of precipitation data (which were constructed for each individual region separately), there was a single common NAO data series for all of the studied regions.

Data analysis

We first computed linear regression coefficients for the time series to assess the magnitude and the significance of the trends in flowering date over time for each species and within each region (Sneyers 1990).

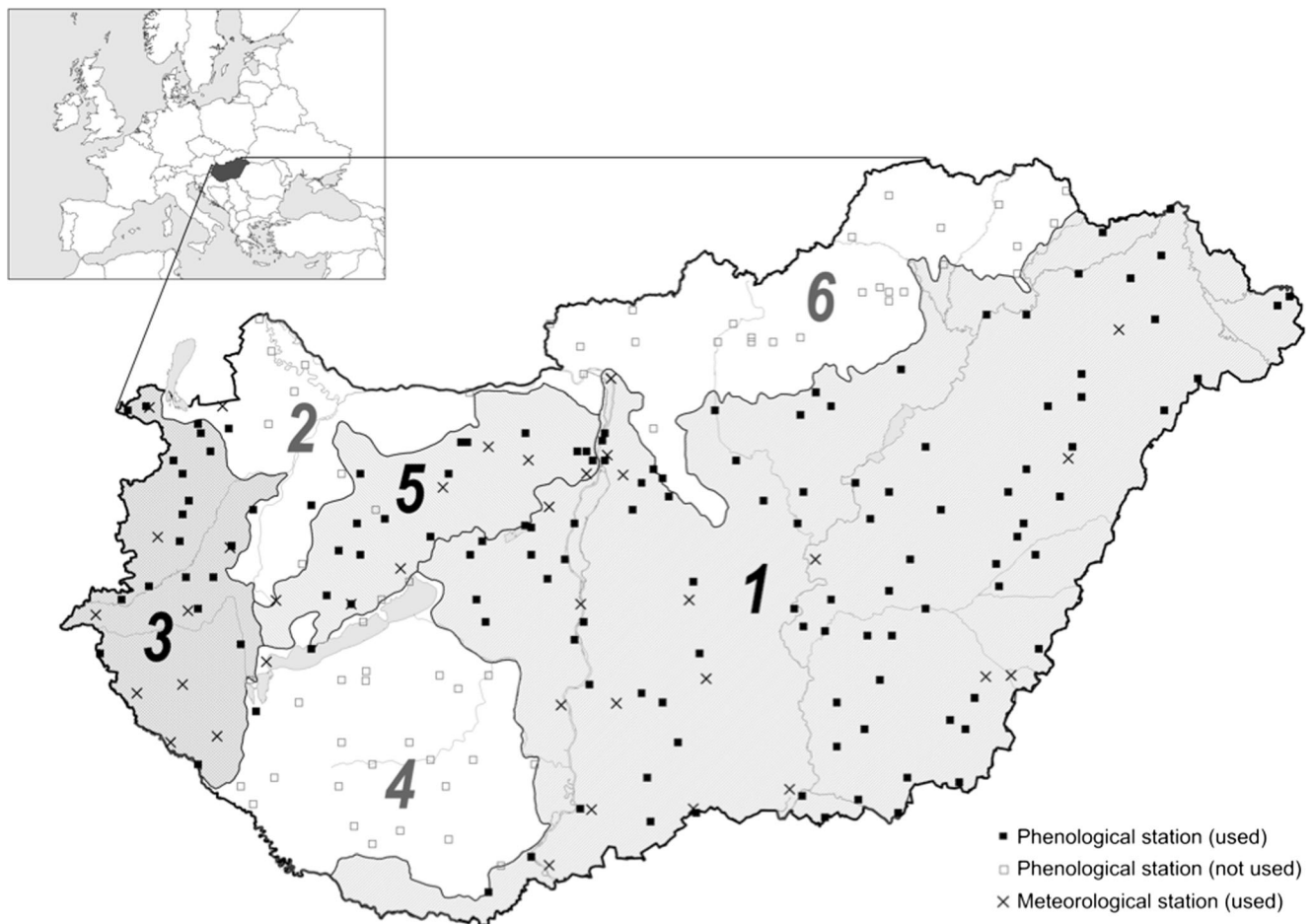


Fig. 1 The location of the study regions and the data sources. Local observational stations used in our analysis: *squares*: phenological stations; *crosses*: meteorological stations. *r1* Alföld (Great Hungarian Plain), *r3* Nyugat-magyarországi Peremvidék (West Hungary), *r5*

Dunántúli-középhegység (Transdanubian Mountains). Phenological stations outside the three study regions are also shown in this map, but they were not used in the analysis

As a next step, we looked for statistical relationships between the phenological data and the climatic variables. To this end, we first removed temporal trends from all of the time series, taking the residuals of the univariate linear regressions fitted in the previous step as “detrended” phenological variables. After this detrending step, we created separate linear regression models for each species and region. As the set of predictors was still highly intercorrelated, we used forward stepwise selection to sequentially add terms from the set of potential predictors until reaching minimal Akaike’s information criterion (AIC), a metric commonly applied to compare and rank multiple competing models (Johnson and Omland 2004). We checked the significance of the parameters from the best models with univariate F tests, adding the terms sequentially to the model in the same order they were found by the stepwise algorithm. We used Bonferroni correction to avoid a potential proliferation of type I errors (Abdi 2007). All data preparation and statistical analysis steps were performed in the R statistical environment (R Development Core Team 2013),

using the add-on packages *reshape2* (Wickham 2007), *extremvalues* (van der Loo 2010), and *pheno* (Schaber 2012).

Results

We found significant shifts in flowering onset dates for four species (lily of the valley, common dandelion, black elder, and small-leaved lime) in the examined period (1952–2000). All of the trends (even the nonsignificant ones) were negative (onset of flowering gradually shifting earlier). The strongest advancements (2.8–4.4 days per decade) were found for small-leaved lime. Two of the examined woody species (common lilac and black locust) did not show significant trends. Altogether, 7 of the 18 studied cases (species \times regions) showed significant advancement in their beginning of flowering (Table 2).

Altogether, we found 45 significant relationships between the timing of the flowering events and the meteorological variables studied (Table 3, Fig. 2). The majority (33) of these

Table 2 Mean dates (a), trends (b), and significance levels in the flowering of the studied species in three regions of Hungary

Species	r1: Great Hungarian Plain a (b)	r3: West Hungary a (b)	r5: Transdanubian Mountains a (b)
<i>Taraxacum officinale</i>	11 April (-0.275**)	12 April (-0.08)	11 April (-0.371***)
<i>Syringa vulgaris</i>	28 April (-0.103)	1 May (-0.05)	1 May (-0.043)
<i>Convallaria majalis</i>	29 April (-0.024)	2 May (-0.188*)	2 May (0.073)
<i>Robinia pseudoacacia</i>	17 May (0.011)	22 May (-0.014)	22 May (-0.084)
<i>Sambucus nigra</i>	19 May (-0.138*)	24 May (-0.188**)	21 May (-0.137)
<i>Tilia cordata</i>	10 June (-0.069)	16 June (-0.442***)	16 June (-0.279***)

Trends are expressed as linear regression coefficients (day/year, negative values mean advancement), significance level symbols: *** $0 < p < 0.001$; ** $0.001 < p < 0.01$; * $0.01 < p < 0.05$. Relationships found to be significant above $\alpha = 0.05$ are highlighted in bold

relationships were linked to temperature, whereas NAO and precipitation were found in 9 and 3 relationships, respectively. For almost all of the studied cases, the most influential predictor was the temperature of the 2 or 3 months immediately preceding the typical date of the phenological event studied (henceforward called “short-term” relationships, Table 3). We also found 15 significant “long-term” connections documenting delayed influence of past meteorological conditions. These long-term relationships were however much weaker, involving all three climatic elements (temperature, precipitation, and NAO) with very little pattern recognizable. The coefficients for “short-term” temperature and NAO variables were generally negative, indicating that warm years and positive NAO anomalies generally induced earlier flowering onset. On the other hand, coefficients for long-term effects greatly varied among species and seasons (Table 3, Fig. 2).

There were only 27 out of the 144 climatic predictors studied that were included in any of the significant relationships identified. The most influential meteorological predictors seemed to be March–April temperature (T215: dandelion, common lilac, lily of the valley), April–May temperature (T216: black locust, lime) and March–May temperature (T315: black locust, black elder). There is also a weak recurrent pattern in the case of NAO, with an effective period at the end of the winter (January–March, N313), which seems to influence several species (*Syringa*, *Convallaria*, *Robinia*). As for long-term relationships, the temperature/NAO of the previous autumn seems to influence lily-of-the valley, and the temperature/precipitation of the previous early spring (February–April) has some effect on lime flowering (Table 3, Fig. 2).

Table 3 The highest monthly/bi/trimonthly temperature, precipitation, and NAO values influencing flowering phenology according to the results of the forward stepwise variable selection

	NAO							Precipitation			Temperature																	
	N101	N109	N215	N216	N309	N310	N313	P104	P207	P302	T108	T111	T115	T117	T201	T202	T204	T206	T214	T215	T216	T302	T310	T313	T314	T315	T316	
<i>Taraxacum officinale</i> r1		++						-												---								
<i>Taraxacum officinale</i> r3			-										---														---	
<i>Taraxacum officinale</i> r5																				---								
<i>Syringa vulgaris</i> r1	--																			---								
<i>Syringa vulgaris</i> r3																				---								
<i>Syringa vulgaris</i> r5							--																					
<i>Convallaria majalis</i> r1											--									---				+				
<i>Convallaria majalis</i> r3													---				--			---								
<i>Convallaria majalis</i> r5												+								---								
<i>Robinia pseudoacacia</i> r1																				---								
<i>Robinia pseudoacacia</i> r3																				---								
<i>Robinia pseudoacacia</i> r5																				---								
<i>Sambucus nigra</i> r1																				---								
<i>Sambucus nigra</i> r3																				---								
<i>Sambucus nigra</i> r5							++													---								
<i>Tilia cordata</i> r1										+																		
<i>Tilia cordata</i> r3																												
<i>Tilia cordata</i> r5																					---							

Climatic variables follow the naming convention introduced and used in the text; the periods ending in the month of the mean flowering date are highlighted by shading. r1, r3, r5: the three study regions (Fig. 1); regions with significant trends are highlighted in bold; +/-, + +/- -, + + +/- --: significant positive/negative relationships at $\alpha = 0.05, 0.01, \text{ and } 0.001$, respectively

Discussion

Shifts in spring plant phenological events in the Carpathian Basin (Central Europe) are particularly poorly documented, with a few exceptions coming from the works of Keresztes (1984), Walkovszky (1998), Schieber et al. (2009), Molnár et al. (2012), Varga et al. (2012), and Lehoczky et al. (submitted). Based on datasets for these six plant species, the current paper presents the most in-depth study so far of phenological trends and their environmental drivers among Hungary.

Throughout Europe, the vast majority of spring phenological time series ending after 1988 reveal advancing trends (Dose and Menzel 2004). We also detected significantly advancing trends in 7 of the studied 18 cases for 4 of the 6 examined species during the second half of the twentieth century in Hungary. This ratio is considerably smaller than the findings of Parmesan and Yohe (2003) for the entire Northern Hemisphere, where 87 % of the terrestrial datasets exhibited responses coherent with global warming. Askeyev et al. (2010) pointed out that phenological changes have been less marked in the eastern part of Europe, than in western and central Europe. This can be one of the possible reasons for not finding significant flowering trends in all of the studied regions and species. Nevertheless, our results also show shifts very similar to the tendencies experienced in other parts of Europe (2.2–2.5-day advance per decade) (Chmielewski and Rötzer 2001; Menzel et al. 2006).

Similarly to most of the studies exploring the relationship between climatic variables and spring phenological events (IPCC 2007), we have found temperature to be the most influential determinant of the timing of flowering in Hungary. All of the most significant ($p < 0.001$) relationships found belong to temperature from the January–May period (Fig. 2). In most cases, the effective periods are the 2–3 months containing or immediately preceding the mean month of flowering. This observation is highly supported by other studies as well (e.g., Estrella et al. 2007; Fitter and Fitter 2002; Sparks et al. 2000).

Beyond question, there are no other meteorological variables and effective periods, which could match the significance of short-term air temperature in shaping the spring phenologies of the studied species. The only exception is NAO, with a weak effective period at the end of the winter (January–March, N313), which seems to influence a broad range of plants in Hungary, including earlier and later flowering species (*Syringa*, *Convallaria*, *Robinia*). In many parts of the world, teleconnection indices, like NAO, describing large-scale circulation patterns are considered as a useful proxy for precipitation anomalies (López-Moreno et al. 2011). In Hungary, winter NAO is known to be strongly correlated to both temperature (positively) and precipitation (negatively, Zsilinszki 2014). It is important to note, however, that being an abstract teleconnection index, NAO cannot directly influence plant physiological processes, probably just indirectly

Fig. 2 Periods of the climatic predictors significantly influencing the flowering onset of the studied species (*Taraxacum officinale*, *Syringa vulgaris*, *Convallaria majalis*, *Robinia pseudoacacia*, *Sambucus nigra*, *Tilia cordata*). Periods are grouped by species along the vertical axis and grouped by color according to climatic variable (a), the direction of the relationship (b), and significance level (c). Triangles indicate the mean date of the flowering onset in Hungary

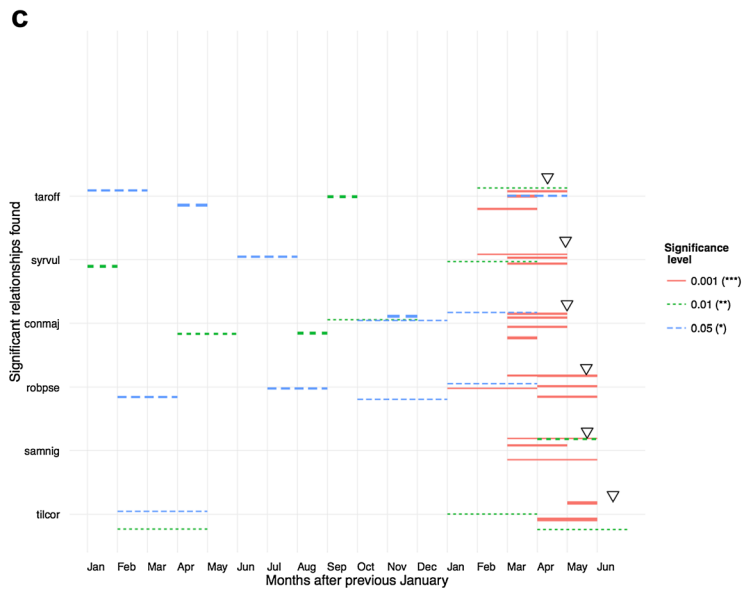
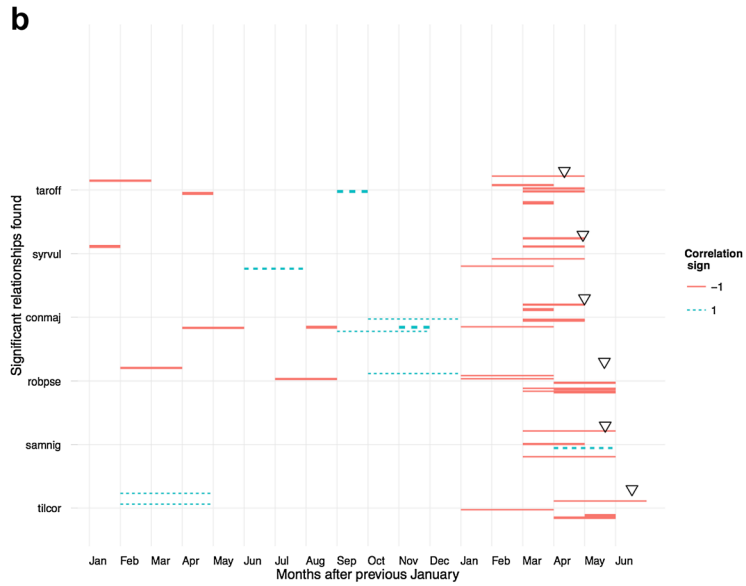
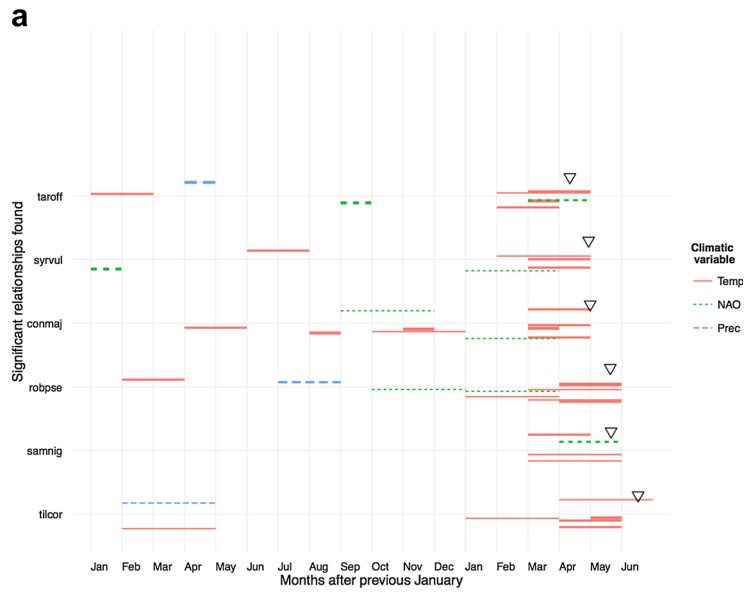
through further unidentified meteorological variables. As we have explicitly added, both mean temperature and precipitation to our set of predictors; thus, the significant influence of NAO cannot be attributed to either of them as an underlying factor in our case. Consequently, we can assume that there is still a significant, yet unknown meteorological factor (e.g., temperature or precipitation extremities, solar radiation, wind, etc.—see also Gordo and Sanz 2010) influencing the flowering phenologies of a broad range of taxa, for which January–March winter NAO values act as a proxy in Hungary.

Even though spring phenologies are known to be highly rainfall-sensitive in many parts of the world (Peñuelas et al. 2004), we could not find any clear relationships for precipitation. On the other hand, it is known (Fu et al. 2014) that at higher latitudes, the effect of GDD requirement, chilling, and precipitation influence the spring vegetation green-up in complex interaction. The simple linear modeling technique applied by us might not be appropriate for capturing such complex responses in general, whereas the few weak but significant long-term relationships involving precipitation (and NAO) might be seen as legacies testifying to the presence of such complex nonlinear relationships.

Common dandelion shows significant phenological trends in 2 of the 3 studied regions for the 1952–2000 period. Dandelion exhibits a strong response to the temperature (February–April) of the current year, with sporadic additional long-term effects (N109, P104, T201). At the European level, dandelion shows a stronger response to temperature in warmer than in colder countries (Menzel et al. 2006). We also documented a relatively high-speed advancement for this species in Hungary (−3.4 to −3.9 days per decade), which fits well into this broader European picture (Menzel et al. 2006; Jatzcak and Walawender 2009).

In the case of common lilac, we did not find any significant shifts, but we demonstrated a temperature (February–April, T314) and a NAO (January–March, N313) sensitivity of the flowering onset. There is a known temperature sensitivity of this species across Europe (−2 to −4 days/°C for the mean temperature of the previous months) exhibiting a stronger response to temperature in warmer than in colder countries (Menzel et al. 2006). There are several studies that documented significant shifts of 4–6 days per decade in the flowering of common lilac both in Europe (Sparks et al. 2011; Jatzcak and Walawender 2009) and in North America (Schwartz and Reiter 2000).

Lily of the valley is one of the species in Europe, which is not really well represented in phenological studies (Nekovář



et al. 2008). We have detected a significant trend for this species in West Hungary, and we also found that the temperature of the 60 days preceding flowering (March–April, T216) is strongly related to the timing of lily of the valley flowering. A similar relationship has already been demonstrated between the emergence of lily of the valley shoots and the February–April temperature by Sparks et al. (2011) in western Poland. Furthermore, we have also found a weak but noteworthy memory effect: several temperature and NAO variables from the previous autumn (T108, T111, T310, N309) seemed to influence the beginning of flowering of this species. Such impact of the previous autumn's weather has already been documented for other herbaceous species (Crimmins et al. 2010). At semi-arid environments, autumn conditions are more important to low-elevation species and spring variables found to play greater role in flowering of high-elevation species (Crimmins et al. 2010).

One of the most explored species in Hungary in terms of shifts in flowering phenology is black locust. Using a long-term data series of 144 years (1851–1994) Walkovszky (1998) showed 3–8-day advancement in the flowering date of black locust, relating the event to the mean temperature of March–May. Our results confirm the findings of temperature sensitivity of this species (with an effective period of (March–)April–May, T216 and T315), but we did not find any significant shifts in flowering during our study period (1952–2000). At the European level, the flowering of black locust shows stronger response to temperature in colder countries (Menzel et al. 2006). In contrast to the response of other species (Menzel et al. 2006), black locust has negative regression coefficients of the temperature sensitivity against flowering. In Poland, Jatzcak and Walawender (2009) has found an advancement of 2.7 days per decade for this species during the second half of the twentieth century.

Elder flowering in Europe is shifting in average ~2.8 days earlier per decade (Menzel 2000). There is also clear documented temperature sensitivity for this species: Sparks et al. (2000) have found a strong relationship with March and April mean temperatures. This influence of the spring temperatures are clearly supported also with our results showing an unambiguous and highly significant negative relationship between the timing of flowering and the trimonthly temperature of the current year's March–May period (T315). And additionally, we also documented a relatively clear influence of NAO for almost the same period (N216) in the only macroregion lacking a significant temporal trend (r_5).

Late spring temperature values (April–June, T117, T216, T316) were the most influential ones also in case of small-leaved lime, but we also documented a relatively clear long-term influence of previous year's early spring temperature and precipitation as well (February–April, T302, P302). Schleip et al. (2009) has also found that April–June temperatures influence the flowering of the closely related *Tilia platyphyllos*, even

though the strength of this relationship (temperature weights) was weaker than for most of the other studied tree species.

The connections between flowering phenologies and climate identified in this paper offer some insight into the future potential consequences of climate change in this region. As the temperature increase expected in Hungary (Krüzselyi et al. 2011) may considerably exceed the global rate of warming (Bartholy et al. 2009b; Pieczka et al. 2010), future advancement of spring flowering is to be expected. Further understanding of the relationship between plant phenologies and climate in Central and Eastern Europe may be gained from future studies on more species and phenophases. There is still a lot of data to analyze in Hungary, as well as in other European countries (Szabó et al. 2014). For detecting climate change impacts the best solution would be a coordinated renaissance of the national phenological observation networks in this region, supported by citizen science.

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