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ORIGINAL PAPER

The influence of altitude and urbanisation on trends and mean dates in phenology (1980–2009)

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Abstract Long-term studies on urban phenology using network data are commonly limited by the small number of observation sites within city centres. Moreover, cities are often located on major rivers and consequently at lower altitudes than their rural surroundings. For these reasons, it is important (1) to go beyond a plain urban–rural comparison by taking the degree of urbanisation into account, and (2) to evaluate urbanisation and altitudinal effects simultaneously. Temporal phenological trends (1980–2009) for nine phenological spring events centred on the German cities of Frankfurt, Cologne and Munich were analysed. Trends of phenological onset dates were negative (i.e. earlier onset in phenology) for 96% of the 808 time series and significantly negative for 56% of the total number. Mean trends for the nine phenological events ranged between −0.23 days year^{-1} for beech and −0.50 days year^{-1} for hazel. The dependence of these trends and of mean dates on altitude and on the degree of urbanisation was explored. For mean dates, we demonstrated an earlier phenological onset at lower altitude and with a higher degree of urbanisation: altitude effects were highly significant and ranged between 1.34 days (100 m)$^{-1}$ (beech) and 4.27 days (100 m)$^{-1}$ (hazel). Coefficients for the log-transformed urban index were statistically significant for five events and varied greatly between events (coefficients from −1.74 for spruce to −5.08 for hazel). For trends in phenology, altitude was only significant for Norway maple, and no urban effects were significant. Hence, trends in phenology did not change significantly with higher altitudes or urbanised areas.

Keywords Phenology · Urban index · Urban heat island · Altitude · Temporal trends · Land use

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Introduction

Phenology, the science of recurring natural events, has attracted increasing interest in recent years. Several studies have been published whose main focus is the impact of global climate change on biological systems (Intergovernmental Panel on Climate Change 2007a, b; Parmesan and Yohe 2003; Root et al. 2003).

With respect to the urban heat island effect, temperature in urban areas may serve as a proxy for future conditions and allow better prediction of future phenology from current information (Mimet et al. 2009; Neil and Wu 2006; Ziska et al. 2003). The urban climate is modified due to land use changes, such as the high amount of hard, sealed surfaces. This, together with the typical construction of urban buildings (e.g. skyscrapers), affects the radiation balance. Moreover, factors such as the lack of vegetation, heat waste and traffic contribute to higher temperatures (e.g. Kuttler 1998; Landsberg 1981; Matzarakis 2001; Oke 1987). Therefore, plants located in urban areas have to cope with warmer conditions compared to plants growing in rural areas. As a consequence, they tend to bloom earlier in spring. Terrestrial observational studies have been conducted in the German cities of Hamburg (Franken 1955), West Berlin (Zacharias 1972), Munich (Baumgartner et al. 1984) and Mannheim (Karsten 1986). These studies and those of other European cities, e.g. by Koch (1986), Bernhofer (1991), Defila and Clot (2003), Lakatos and Gulyás (2003) and Mimet et al. (2009), as well as studies in North America (e.g. White et al. 2002; Zhang et al. 2004) or Asia (e.g. Lu et al. 2006; Luo et al. 2007) confirm an earlier plant development in urban areas.

There are several ways to classify urban and rural sites. White et al. (2002) and Gazal et al. (2008) used satellite-derived land cover classification, Rötzer et al. 2000 utilised, inter alia, present day and historical topographic maps, and Zhang et al. (2004) not only employed MODIS NBAR spectral data but also nighttime light data and gridded population density data. Attempts to classify phenological sites by three levels of urbanisation were achieved by Pellissier et al. (2008) who used the proportion of six land use classes (surface water, woodland, cropland, grassland, roads, built-up areas) derived from digital orthophotos within 500 m × 500 m grid squares to obtain distinct urbanisation levels for the city of Rennes (France) by the use of principal components analysis (PCA). Their categorisation of urban, suburban and periurban sites was also adopted by Mimet et al. (2009) for the same study area.

However, the classification of urban stations within existing phenological networks is not trivial due to the generally lower numbers of sites in very densely urbanised areas. Therefore, and in order to overcome the limited validity of a plain urban-rural dichotomy (that may induce unexplainable and inconsistent results in differences of plant phenology), continuous variables describing the extent of urbanisation are desirable. Rötzer et al. (1997), for example, calculated a building index on the basis of digital land use information that comprised a summation of raster elements with densely developed areas within a radius of 2.5 km. A further estimate of the degree of urbanisation was achieved by Shustack et al. (2009) who used orthophotos to evaluate the proportion of different cover types (forest, agriculture, mowed, paved, road) and the number of buildings within a radius of 1 km by means of a PCA. The first component of the PCA was defined as the index of urbanisation, where positive values indicated urban and negative values rural sites.

Moreover, urban phenology is often affected by altitudinal influences on plant development since cities are frequently situated in major river valleys that feature lower altitudes than their rural surroundings. Therefore, it is reasonable to incorporate both urbanisation and altitudinal effects in phenological models.

In our study, we have decided not to use a classification based on the dichotomy “urban” and “rural”, but calculated a ratio scaled variable, the urban index (ui), which equates to the proportion of land associated with a high degree of impervious surfaces within a radius of 2 km. The phenological data used in this study are based on extensive, standardised, terrestrial, species-specific observations of the German Meteorological Service (DWD). We firstly described trends and mean dates of nine spring phenophases during 1980–2009 centred on the cities of Frankfurt, Cologne and Munich. Subsequently, multiple regression analyses were conducted in order to answer the main questions of this study:

1) Is the mean date of onset of a specific phase a function of altitude and urbanisation (urban index), i.e. mean date~f(altitude, ui)?
2) Is the temporal trend in phenology of a specific phase a function of altitude and urbanisation (urban index), i.e. trend~f(altitude, ui)?

Although the urban heat island effect seems to be well documented by phenological data in the temperate zone, the pattern of urban–rural phenology deserves further investigation and principally, our urban index may better quantify the effects of land use changes on biological systems.

Materials and methods

Study area

Areas selected for this study were centred within 50 km of three of the largest cities in Germany: Frankfurt, Cologne and Munich (Fig. 1; Table 1).

Urban index

We calculated an urban index (ui) based on CORINE Land Cover 2000 data (European Environment Agency 2000) using ArcGIS 9.3. This index reflects the proportion of predefined built up areas (e.g. continuous and discontinuous urban fabric, industrial or commercial units) within a radius of 2 km and thus can vary from 0 to 1; i.e. from a low (0) to a high (1) degree of urbanisation. The 2-km radius was selected to ensure that mesoclimatic effects are covered by the index and extensive/thinly urbanised areas are identified as such. Therefore, the estimate for each phenological station concerning the degree of urbanisation could be obtained. Moreover, the geographical location of observed plants in the phenological dataset of the DWD is not exactly recorded, since the coordinates, specified in degrees and minutes, only indicate the centre of the observation area and phenological observers can search for individual plants of the respective species within a radius of 1.5–2 km around the coordinates of the phenological station.

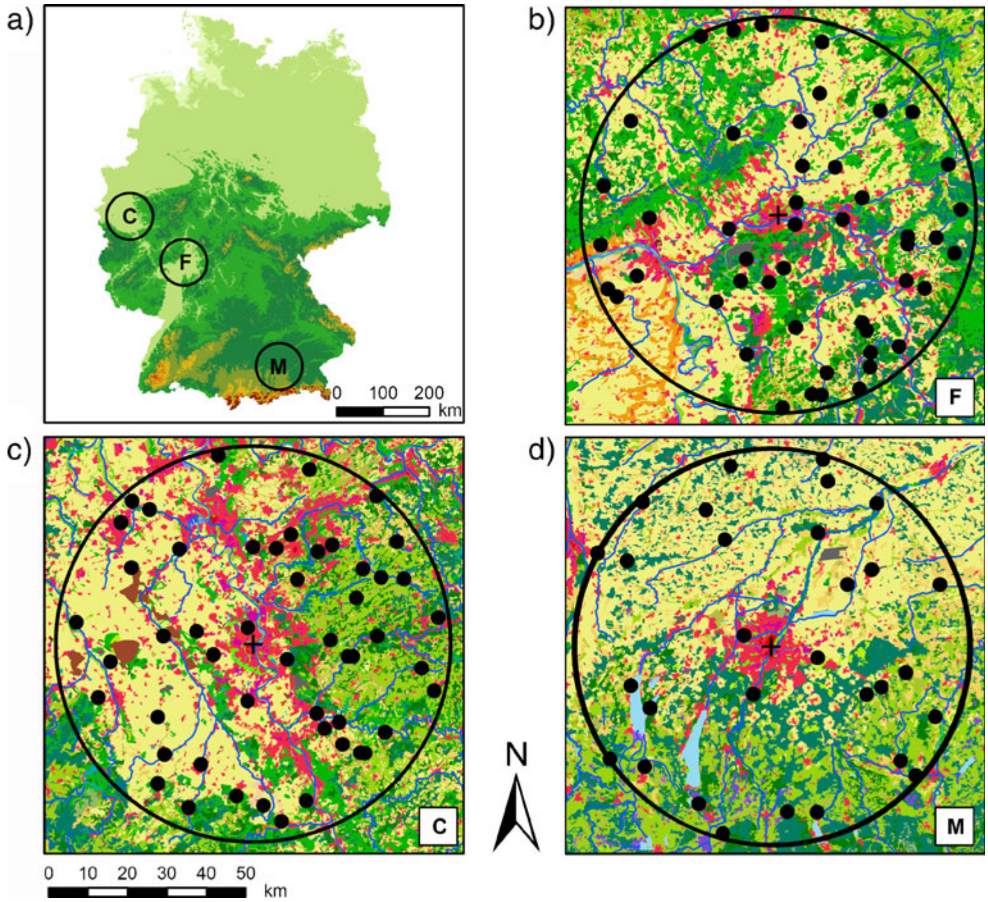

Fig. 1 **a** Locations of the three selected cities in Germany: *C* Cologne, *F* Frankfurt, *M* Munich; *background* digital elevation model (SRTM; Jarvis et al. 2006, see http://srtm.csi.cgiar.org/). **b–d** Survey area extending to 50 km: *black dots* phenological stations (DWD), *cross* city centres; *background* landcover (CORINE landcover 2000, EEA 2000); major classes: *red* urban fabric, *green* forest and pasture, *yellow* arable land, *blue* rivers and lakes; for complete legend, see http://dataservice.eea.europe.eu/dataservice/metadetails.asp?id=667

Phenological data

Data for nine spring phenophases obtained from the phenological network of the DWD were selected: beginning of flowering of hazel (*Corylus avellana* L.), snowdrop (*Galanthus nivalis* L.), goat willow (*Salix caprea* L.), forsythia (*Forsythia suspensa* (Thunb.) Vahl), Norway maple (*Acer platanoides* L.), leaf unfolding of beech (*Fagus sylvatica* L.), flowering of apple (*Malus domestica* Borkh.), May sprout of spruce (*Picea abies* (L.) Karst.) and flowering of lilac (*Syringa vulgaris* L.).

These observations covered the 30-year period from 1980 to 2009 during which most of the recent temperature increase could be observed (Intergovernmental Panel on Climate Change 2007a). For inclusion, the only criterion was that phenological series had to contain more than 20 years of data. The number of stations per city differed according to the plants observed for each site. We could obtain a maximum number of 41 stations for Frankfurt, 45 for Cologne and 27 for Munich. The spatial distribution of the phenological stations is displayed in Fig. 1b–d. In total, 808 phenological time series were obtained.

Mean onset dates and linear temporal trends (1980–2009)

Mean onset dates were calculated for each phenological time series (n=808) within the study period 1980–2009. Trends in phenological time series (1980–2009) were

Table 1 Location of the centres of Frankfurt, Cologne and Munich, population size (2007) and characteristics of the phenological stations included: altitude (m a.s.l.), urban index, numbers of phenological time series (1980–2009)

City	Location of the city centre			Population size	Altitude			Urban index			Number of time series
	Latitude	Longitude	Altitude		Mean	Min	Max	Mean	Min	Max	
Frankfurt	50.12°N	8.69°E	112	652,610	167	35	380	0.27	0	0.84	314
Cologne	50.95°N	6.96°E	55	989,766	192	90	460	0.22	0	0.65	300
Munich	48.14°N	11.58°E	528	1,294,608	526	420	730	0.19	0	0.76	194

calculated by linear regression of date of onset on year for each series. Negative coefficients reflect an advance of the phenophase in days/year; positive values reflect a delay.

Multiple regression analyses

For each phenophase, mean onset dates were regarded as a function of altitude and urban index; i.e. mean date~f(altitude, ui) and submitted to a multiple regression analysis. The mean date of onset of the respective phenological phase was regressed on altitude and urban index; regression coefficients then equate to delays or advances expressed in days $(100\ m)^{-1}$ or days ui^{-1} for altitude and urban index, respectively.

Phenological trends (dependent variable) were also considered as a function of altitude and urban index (independent variables), i.e. trend ~f(altitude, ui). Multiple regressions and interpretation of regression coefficients were as for mean date regressions in the previous paragraph.

The cities do not differ significantly in their urban index values (P=0.17). Consequently the use of the "altitude" term in our model incorporates both within- and between-city altitude effects. Thus, urban effects are assessed only after adjusting for both these effects.

All statistical analyses were conducted using SAS 9.2.

Transformation

Significant deviations from the normal distribution were found by the Kolmogorov–Smirnov test for the residuals resulting from the multiple regression analysis of flowering of *Salix caprea*. Therefore, the values of the urban index (which was also non-normally distributed) were converted using a $\log_{10}$-transformation for substantially positively skewed distributions (Tabachnick and Fidell 1989). Since values of the urban index can be zero, a constant was added that was calculated from the actual distribution of the data. According to Stahel (2008), we used the square of the first quantile of all values greater than zero divided by the third quantile (c=0.03363). The transformation was Lui = $\log_{10}$(ui + 0.03363). All multiple regressions were recalculated using the transformed urban index (Lui) and none failed normality testing of residuals. These regression results are reported below.

Results

Linear temporal trends in phenology (1980–2009)

Table 2 comprises the linear temporal trends in phenology during the study period 1980–2009. Of 808 trends, 96% were negative, and 56% were significantly negative, pointing toward a clear and obvious advancement of phenological spring phases. The remaining positive trends (n=34) with two exceptions were not significant.

The mean trends varied between −0.50 days $year^{-1}$ for *Corylus avellana* and −0.23 days $year^{-1}$ for *Fagus sylvatica*. The trends of each phase are plotted against their mean onset dates (1980–2009) in Fig. 2 and show that the more pronounced trends were generally detected for early phenophases and vice versa. However, the relationship between mean timing in spring and the respective advancement seems to be highly variable.

Table 2 Number of temporal linear trends in phenology (1980–2009) classified by direction and significance

Phase	Number of trends					Mean trend days $year^{-1}$ ± SD	Mean DOY ± SD
	Total	Negative trends (n=774)		Positive trends (n=34)			
		Sig	NS	Sig	NS		
Corylus avellana FFD	102	42 (41%)	53	1	6	−0.50±0.36	46.7±10.8
Galanthus nivalis FFD	111	53 (48%)	49	0	9	−0.36±0.29	50.3±7.8
Salix caprea FFD	105	36 (34%)	63	0	6	−0.29±0.24	76.4±5.8
Forsythia suspensa FFD	112	67 (60%)	45	0	0	−0.44±0.22	83.4±7.3
Acer platanoides FFD	71	52 (73%)	18	0	1	−0.43±0.26	100.8±6.2
Fagus sylvatica FLD	78	47 (60%)	26	1	4	−0.23±0.17	115.5±4.2
Malus domestica FFD	55	37 (67%)	18	0	0	−0.31±0.21	117.0±5.2
Picea abies MS	78	51 (65%)	23	0	4	−0.28±0.18	123.6±4.8
Syringa vulgaris FFD	96	68 (71%)	26	0	2	−0.31±0.20	125.4±5.1
Total	808	453 (56%)	321	2	32	−0.35	93.2

sig $P \leq 0.05$, *NS* $P > 0.05$ for all phases with mean trend (days $year^{-1}$) and mean onset date (DOY), *SD* standard deviation, *FFD* first flowering date, *FLD* first leaf unfolding date, *MS* May sprout

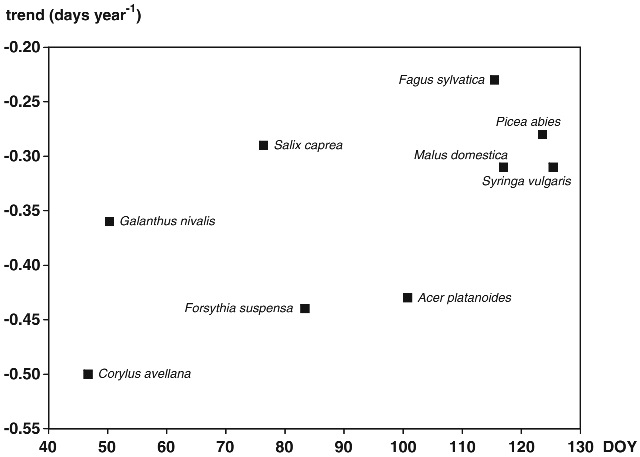

Fig. 2 Linear trends (days year^{-1}) for 1980–2009 versus mean onset dates (DOY) calculated for nine spring phenophases in the greater areas of three German cities (Frankfurt, Cologne and Munich)

Influence of altitude and urbanisation on mean onset dates

Mean onset dates, regressed on altitude and urbanisation are reported in Table 3. The model fits (R^2) ranged from 0.332 for *Salix caprea* to 0.710 for *Forsythia suspensa* indicating a medium to high degree of model accuracy. Coefficients for altitude were positive throughout and highly significant (all $P<0.001$) indicating that mean onset dates are clearly influenced by the altitude of the stations. The highest coefficient was detected for *Corylus avellana* [4.27 days (100 m)$^{-1}$] and the lowest coefficient for *Fagus sylvatica* [1.34 days (100 m)$^{-1}$]. Coefficients for the transformed urban index were negative throughout, ranging from −5.08 days Lui^{-1} for *Corylus avellana* to −1.74 days Lui^{-1} for *Picea abies.* These coefficients suggest that a transition from completely rural (ui=0) to completely urban (ui=1) equates to approximately a 2.6- to 7.6-day advance in phenology. The coefficients were significant ($P\leq0.05$) in five out of nine cases, i.e. for flowering of *Corylus avellana, Acer platanoides, Forsythia suspensa, Malus domestica* and *Syringa vulgaris*. Leaf unfolding of *Fagus sylvatica* was marginally significant at $P\leq0.10$ and the remaining phases (flowering of *Galanthus nivalis*, *Salix caprea* and May sprout of *Picea abies*) slightly exceeded the 10% level. The consistency in the direction of both coefficients of the multiple regressions confirmed an earlier onset with (1) lower altitude, and (2) a higher degree of urbanisation.

Influence of altitude and urbanisation on linear trends

Table 4 shows the results of the multiple regression analyses for the nine selected spring phenophases of linear trends in phenology for each station (dependent variable) on altitude and urban index (independent variables). The models had small R^2 values ranging between 0.002 for *Galanthus nivalis* and 0.217 for *Acer platanoides*. The significance of most coefficients exceeded $P=0.05$. Trends were influenced by altitude ($P<0.001$) only for *Acer platanoides* and no urban index effects were significant ($P>0.05$). The magnitude of the altitudinal coefficients was too small to recognise a distinct pattern and coefficients were only negative in 3 out of 9 cases; the coefficients for the transformed variable urban index ranged from −0.094 (*Corylus avellana*) to 0.079 days year^{-1} (Lui)$^{-1}$ (*Salix caprea*).

Discussion

Linear temporal trends in phenology (1980–2009)

Our results showed remarkably clear trends towards earlier onset dates for all examined phenophases with 453 (56%) of the analysed 808 series becoming significantly earlier (Table 2). Hence, phenological phases appeared to be affected by major changes, ranging between −0.23 days year^{-1} for *Fagus sylvatica* and −0.50 days year^{-1} for *Corylus avellana*, regardless of (1) the location with respect

Table 3 Multiple regression analyses for nine spring phases in the greater area of Frankfurt, Cologne and Munich with mean onset date (1980–2009) as the dependent variable and altitude and (transformed) urban index as independent variables

Phase	*df*	R^2	Coefficient		*P* value	
			Altitude	Urban index	Altitude	Urban index
Corylus avellana FFD	99	0.537	4.27	−5.08	**<0.001**	0.026
Galanthus nivalis FFD	108	0.498	3.03	−2.37	**<0.001**	0.152
Salix caprea FFD	102	0.332	1.78	−2.36	**<0.001**	0.107
Forsythia suspensa FFD	109	0.710	3.29	−3.44	**<0.001**	0.003
Acer platanoides FFD	68	0.599	2.27	−3.49	**<0.001**	0.019
Fagus sylvatica FLD	75	0.436	1.34	−1.93	**<0.001**	*0.086*
Malus domestica FFD	52	0.697	2.13	−3.96	**<0.001**	0.003
Picea abies MS	75	0.490	1.73	−1.74	**<0.001**	0.154
Syringa vulgaris FFD	93	0.559	1.90	−3.84	**<0.001**	0.001

df Degrees of freedom, *FFD* first flowering date, *FLD* first leaf unfolding date, *MS* May sprout

P value: significant results ($P\leq0.05$) in bold, marginally significant ($P\leq0.1$) in italics

Table 4 Multiple regression analyses for nine spring phases in the greater area of Frankfurt, Cologne and Munich with linear trend in phenology (1980–2009) as the dependent variable and altitude and (transformed) urban index as independent variables

Phase	*df*	R^2	Coefficient		*P* value	
			Altitude	Urban index	Altitude	Urban index
Corylus avellana FFD	99	0.008	−0.014	−0.094	0.541	0.402
Galanthus nivalis FFD	108	0.002	0.004	0.037	0.809	0.667
Salix caprea FFD	102	0.013	0.011	0.079	0.476	0.277
Forsythia suspensa FFD	109	0.032	0.024	0.047	*0.060*	0.446
Acer platanoides FFD	68	0.217	0.066	0.007	**<0.001**	0.935
Fagus sylvatica FLD	75	0.029	−0.011	−0.082	0.333	0.162
Malus domestica FFD	52	0.018	0.015	0.073	0.407	0.427
Picea abies MS	75	0.021	−0.013	−0.063	0.285	0.316
Syringa vulgaris FFD	93	0.008	0.001	0.056	0.930	0.393

df Degrees of freedom, *FFD* first flowering date, *FLD* first leaf unfolding date, *MS* May sprout

P value: significant results ($P \leq 0.05$) in bold, marginally significant ($P \leq 0.1$) in italics

to altitude, and (2) the amount of urbanisation. On average, trends for early spring phenophases were largest and vice-versa (Fig. 2). This finding is in agreement with Fitter and Fitter (2002), Menzel et al. (2001), Rötzer et al. (2000) and Sparks and Menzel (2002) who also found more pronounced advances in early spring phases. Rötzer et al. (2000) attributed this to increases in temperature in central Europe from 1961–1990 for the months January–March and decreases for April. The less pronounced response of *Fagus sylvatica* is also confirmed by other studies (Kramer 1995; Menzel 1997; Menzel 2003) and attributed to its limited phenological plasticity (Vitasse et al. 2010).

Altitudinal and urbanisation gradients of phenological means and trends

Altitudinal gradients

Plant phenology can be monitored over a short distance along altitudinal and consequently thermal gradients (Defila and Clot 2005; Dittmar and Elling 2006; Guyon et al. 2010; Larcher 2006; Studer et al. 2005; Ziello et al. 2009). Therefore, mountainous regions are useful to describe wide-ranging characteristics in phenological behaviour. However, our study was not focused on mountainous regions and phenological sites only varied from 35 to 730 m a.s.l. (Table 1).

Trends for altitudinal dependence on phenological mean dates in our study were all significant and varied between 1.34 days $(100\ \mathrm{m})^{-1}$ for flowering of *Fagus sylvatica* and 4.27 days $(100\ \mathrm{m})^{-1}$ for flowering of *Corylus avellana* (Table 3). Taking an altitudinal gradient of temperature of −0.6°C $(100\ \mathrm{m})^{-1}$ and a temperature response in phenology of −1 to −5 days $°\mathrm{C}^{-1}$ for flowering phases in Europe (Menzel et al. 2006), we would anticipate smaller altitudinal responses of between 0.6 and 3.0 days $(100\ \mathrm{m})^{-1}$. In fact, altitudinal gradients calculated by Ziello et al. (2009) also exceeded these expectations by ranging between 0.9 days $(100\ \mathrm{m})^{-1}$ for *Picea abies* and 4.6 days $(100\ \mathrm{m})^{-1}$ for *Corylus avellana*. However, we could demonstrate that earlier phases, such as flowering of *Corylus avellana*, showed stronger altitudinal and therefore thermal responses. This is supported by Menzel et al. (2006) who found that early phases tended to have larger temperature responses.

Influences of altitude on trends were not significant with the exception of the altitude coefficient for *Acer platanoides* (Table 4). Studer et al. (2005) only found an altitudinal dependence of phenological trends in the northern, but not in the southern Alps. Our results are partly in agreement with the findings of Ziello et al. (2009) who demonstrated that trends from 7 of 10 phenological spring phases in the Alpine regions showed no statistical dependence on altitude and were associated with overall very low R^2 values. Nevertheless, the majority of altitudinal gradients calculated by Ziello et al. (2009) were negative, suggesting a more pronounced advancement in higher regions. Defila and Clot (2001) claimed that plants located at higher elevations were more sensitive and showed a stronger response to climate change since temperature is regarded as a limiting factor for plant growth and development. However, our study could not verify stronger trends for higher regions, although our sites were at considerably lower altitudes than those used by the authors cited above.

Urbanisation gradients

The dependency of mean dates on urbanisation, expressed by the (transformed) urban index, was significant for five of the nine selected phenophases and marginally significant for a further one (Table 3). Only for flowering of *Galanthus nivalis* and *Salix caprea* as well as May sprout of *Picea abies* were urban effects not proved statistically. However, coefficients for all phases were in the same direction. Land use changes from entirely rural (i.e. ui=0) to entirely urban (i.e. ui=1) imply, depending on the phenological phase, an advance of 2.6–7.6 days suggesting that urbanisation processes can lead to major changes in phenological onset dates. Our results confirm the findings of previous studies that showed cities generally having earlier phenological events than rural areas (e.g. Fukuoka and Matsumoto 2008; Lakatos and Gulyás 2003; Rötzer et al. 2000; White et al. 2002).

The spatial resolution of our response variables (i.e. phenological temporal trends and means), do not account for micro- but for mesoclimatic characteristics since the coordinates of the observation sites are not precise enough (recorded only in degrees and minutes) and observers are allowed to search for plants within a radius of 2 km. This might adversely affect the results for *Galanthus nivalis* since it is believed that herbaceous plants are more sensitive to microclimatic conditions (Mimet et al. 2009).

The fact that the largest differences in urban–rural phenology occur in early spring is well known. Ten European cites were analysed by Rötzer et al. (2000), who found stronger urban–rural differences for early spring phenophases than for full spring phases. However, in our study, there was no clear relationship between the urban index coefficient of nine events and their associated mean onset dates, though some early spring phenophases exhibited large differences (e.g. −5.08 days Lui^{-1} for flowering of *Corylus avellana*).

A more pronounced advancement in urbanised areas could not be shown by our analysis (Table 4). However, Defila (1999) and Rötzer and Sachweh (1995) detected stronger trends in urban phenological time series in Switzerland and Germany, respectively. In contrast, the majority of phenological trends (1980–1995) calculated by Rötzer et al. (2000) were larger in rural regions, and they argued that this fact was due to differences in urbanisation rates. Urban development, e.g. changes in hard surfaces (soil sealing), may determine if the trend is stronger or weaker in urban areas.

These examples prove that the definition of a dichotomous variable with the categories “urban” and “rural” cannot ultimately explain phenological behaviour. This may also be due to the fact that these studies used only a few phenological stations.

Besides the fact that urban phenology in general is limited by the number of phenological stations established in the city centre, the location of the city at lower altitude leads to difficulties in analysing and interpreting urban phenology. Hence, without taking phenological lapse rates into account, urban–rural differences in phenology may be related not only to the urban heat island but also to altitudinal differences. The selected cities for this study also show distinctive ranges of altitude within the study area (Table 1), with the urban centres at lower altitude. Therefore, the effect of the urban heat island might be enhanced due to the additional effect of altitude. Moreover, urban sprawl is not restricted to the adjacent areas of city cores. Figure 1 shows the pattern of continuous and discontinuous urban fabric (red colour). Consequently, the definition of urban as an area within a specified radius of the city centre seems to be inappropriate and justifies our approach to base comparisons on a variable that is derived from land use information-the urban index-simultaneously with altitude.

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