Comparison of Climate Warming Induced Changes in Silver Birch (*Betula pendula* Roth) and Lime (*Tilia cordata* Mill.) Phenology

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Abstract

The aim of the study is to compare the shift in timing of main spring (bud burst, leaf unfolding) and autumn (leaf colouring, leaf fall) phenophases and changes in rate of seasonal development for tree species with different ecological requirements – birch (*Betula pendula* Roth) and lime (*Tilia cordata* Mill.). Long term dataset of phenological observations (1956-2010) from the Kaunas Botanical garden of Vytautas Magnus University (central Lithuania) was used for this study. Increased temperature was detected to be as a strong driver of spring phenology for both species. Higher sensitivity to the rise in temperature was characteristic of early season birch species. Length of the period between bud burst and leaf unfolding of birch has become shorter almost by 6 days during the study period, indicating acceleration of seasonal development during spring period for this early season species. Changes in the timing of autumn phenophases of lime and birch demonstrated opposite character. Leaf colouring and fall of lime were delayed, while advancement of these phases was detected for birch. Presumption is made that lower soil moisture caused by a rise in temperature and decrease in precipitation is one of the most important factors leading to the advancement of birch leaf senescence. Despite very different changes in autumn phenology of birch and lime, duration of the period between leaf colouring and leaf fall, has become longer almost by 2 days for both species, indicating deceleration of seasonal development during phenological autumn.

Key words: climate warming, bud burst, leaf unfolding, leaf colouring, leaf fall, growing season, birch, lime.

Introduction

Phenological studies have traditionally investigated annual sequence of key events in plant seasonal development, i.e. bud burst, leaf unfolding, flowering, leaf fall etc. A remarkable renewal of phenology is connected with climate change, and particularly with climate warming studies (Ahas et al. 2000, Kramer et al. 2000, Garcķa-Mozo et al. 2010). Changes in plant phenology are considered as one of the most appropriate bio-indicators and are able to provide important information on the impact of ongoing climate changes in plant development (Roetzer et al. 2000, Walter 2010).

Numerous phenological studies have indicated advanced biological spring (bud burst, leaf unfolding) and delayed biological autumn (leaf colouring, leaf fall) related to climate warming (Chmielewski and Rötzer 2001, Peńuelas et al. 2002, Menzel et al. 2006, Bareika and Ozolinčius 2008). Some species are favoured under warming climate conditions while others remained unaffected (Primack et al. 2009, Vitasse et al. 2009, McEwan et al. 2011). These differences in direction and/or rate of changes create ecological imbalances between interacting species or between species and their abiotic environment (Ibáñez et al. 2010). As a consequence such changes could alter the functioning and composition of ecosystems (Walther 2010) and may cause essential consequences for different ecological processes, agriculture and forestry (Cleland et al. 2007, Peńuelas et al. 2009).

Most pheno-climatic studies detected significant correlations between early spring phenology (bud burst, leaf unfolding) and rising temperature, but impact of climate warming on autumn events (leaf colouring, leaf fall) is not so consistent and in some cases an earlier end of growing season was detected (Cleland et al. 2007; Vitasse et al. 2009). In temperate regions precipitation was detected to be a much less influencing factor (Kramer et al. 2000, Wielgolaski 2003).

The shift in phenophases in most cases causes extension of the growing season and leads to an increase in primary productivity, and also determines water content in the atmosphere due to changes in evapotranspiration, carbon and nutrient balance (Menzel and Fabian 1999). As plant species have different ecological requirements, distinct phenological responses are also expected among species. The available data on the impact of climate warming to tree phenology confirmed that various tree species react differently to climate changes (Ahas et al. 2000, Wielgolaski et al. 2003, Menzel et al. 2006, Primack et al. 2009).

This study attempts to compare the shift in timing of main spring (bud burst, leaf unfolding) and autumn (leaf colouring, leaf fall) phenophases and changes in the rate of seasonal development for tree species with different ecological requirements – birch (*Betula pendula* Roth) and lime (*Tilia cordata* Mill.).

Materials and methods

Data and site desciption

Long term time-series of the phenological observations (1956-2010) at Vytautas Magnus University Botanical Garden were used for this study. The Botanical Garden (54°5'N, 23°5'E, altitude 84 m) occupies an area of 62.5 ha and it is located 3.3 km from Kaunas city centre, remote from heavy traffic, industry and high-density multi-storey urban buildings. Any local city climate effects (heat island) were not detected in the botanical garden and surroundings.

Silver birch (*Betula pendula* Roth) and small-leaved lime (*Tilia cordata* Mill.) were chosen for this study. These species were selected to have contrasting ecological requirements (Heremy et al. 2010). Silver birch is a boreal fast growing, light demanding pioneer species, preferring well-drained sandy soils. In contrast, small-leaved lime is warmth-demanding, shade tolerant and drought resistant tree. Lime is considered as a late-season species because its flushing is later than that of birch. Observation size was 12 individuals of *B. pendula* and 10 individuals of *T. cordata*. The same individuals were observed during the entire study period.

Changes in spring (bud burst, leaf unfolding) and autumn (leaf colouring and the end of leaf fall) phenological events were analyzed. Leaf unfolding is considered to be an indicator for the beginning of the growing season and the end of leaf fall indicates the end of the growing season. The difference (number of days) between the end and the beginning of the growing season is defined as the length of the growing season. Phenological observations were performed according to standard procedures described in the Methodological Guidelines for Phenological Observation (Gavenauskas and Lamdosienė 2004). Observations were made with binoculars twice a week.

Monthly temperature and precipitation data were obtained from Kaunas Meteorological Station (Lithuanian Hydrometeorological Service under the Ministry of Environment), located 3.6 km away from the botanical garden (54°9'N, 23°8'E, altitude 76 m).

Data analysis

Dates of phenological phases occurrence were transformed to day number from the beginning of year (day of the year (DOY), i.e. January 1 is considered as day 1) for further analysis. Linear regression was used for approximation of the phenophase occurrence dependence on temperature of 3 months prior to a given phenophase. The slope of the linear regression indicates the shift of the phenophase as a function of temperature (days per 1°C) and provided measures for the temperature sensitivity. Statistical significance of slope was evaluated according to the F-test.

Linear trends of the onset dates against year were calculated for evaluation temporal trends. In this case slope of a linear trend (coefficient b) indicates annual shift of the phenophase (days per year). Negative and positive slopes indicate advanced and delayed phenophases, respectively. Shift of the onset of a phenophase during the study period was calculated as a product of coefficient b and duration of investigated period (55 years).

Significance of difference between linear regression slopes for different species was evaluated according to Z-test (Clogg et al. 1995):

$$Z = \frac{b_1 - b_2}{\sqrt{SEb_1^{\,2} + SEb_2^{\,2}}}, \qquad (1)$$

where b_1 and b_2 are the slopes of linear regression for different species; SEb – standard error of b coefficients.

Null hypothesis on equality of slopes is rejected and a difference between slopes are considered as statistically significant ($p < 0.05$) when Z-test exceeds the critical value of 1.96.

All statistical analyses were performed with STATISTICA Software.

Results

Phenological sensitivity to changes in temperature and precipitation

Bud burst and leaf unfolding dates for both species were negatively correlated to mean monthly temperature (Table 1). In the case of bud burst, statistically significant correlation coefficients were detected with mean February and March temperatures; however, rather high values of coefficients are characteristic of January temperatures as well. Correlation of leaf unfolding timing with mean monthly temperatures of the three preceding months (February, March, April) was statistically significant in all cases and a statistically significant correlation with mean January temperature was detected.

For the autumn phenophases, the correlation between mean monthly air temperature and timing of phenophases was weaker and in most cases statistically insignificant. Occurrence of the end of leaf fall of *T. cordata* was only significantly ($p < 0.05$) positively related with mean September and October temperature. Because the correlations between the timing of phenophases and air temperature were mostly remarkable only for the 3 months preceding phenophases, only mean temperatures of these months were considered for further analysis of species sensitivity to temperature change.

days per 1 °C for *B. pendula* and 1.9 days for *T. cordata* (Fig. 1), though the difference between the slopes was also statistically insignificant (Z= 0.776).

Autumn phenophases showed more diverse relationships with temperature than spring phenophases and the slopes of the linear regression on temperature of preceding three months occurred to be much more species dependent and the difference between these slopes was statistically significant (Z = 1.99, Fig.1). Remarkable differences in the advancement rates of leaf colouring for the two species were detected. Autumnal coloration of *B. pendula* demonstrated much higher sensitivity to autumn temperature changes than *T. cordata* – the slope of linear regression between the timing of leaf colouring of *B. pendula* and average temperature of the preceding three months was 3.23 days/°C ($p = 0.05$) as compared with 0.32 days/°C ($p = 0.86$) for *T. cordata*.

The observed relationships between timing of leaf fall and autumn temperature were even more species

Table 1. Correlation between mean monthly air temperature and amount of precipitation and timing of different phenophases (significant correlations ($p < 0.05$) are marked in bold) for the period 1956-2010

Phenophase	Species	T_{12}	T_1*	T_2	T_3	T_4	P_{12}	P_1	P_2	P_3	P_4
Bud burst	*Betula pendula*	-0.14	-0.24	**-0.49**	**-0.48**		-0.10	0.11	**-0.41**	-0.11	
	Tilia cordata	-0.26	-0.26	**-0.46**	**-0.46**		-0.16	0.06	**-0.40**	-0.12	
Leaf unfolding	*Betula pendula*		**-0.45**	**-0.39**	**-0.57**	**-0.51**		-0.27	-0.09	-0.23	0.01
	Tilia cordata		-0.20	**-0.38**	**-0.45**	**-0.61**		-0.22	-0.13	-0.19	-0.04

		T_6	T_7	T_8	T_9	T_{10}	P_6	P_7	P_8	P_9	P_{10}
Leaf colouring	*Betula pendula*	-0.17	-0.24	-0.17	-0.24		-0.01	0.05	-0.07	0.11	
	Tilia cordata	-0.12	-0.10	-0.17	0.25		-0.06	0.02	0.10	0.04	
Leaf fall	*Betula pendula*		-0.15	-0.22	-0.11	-0.01		-0.21	0.25	-0.15	-0.21
	Tilia cordata		-0.02	0.14	**0.30**	**0.32**		-0.18	-0.20	0.01	-0.22

* Number beside the T (temperature) and P (precipitation) are values corresponding to number of month (i.e., T_1 means temperature of January)

The correlation between precipitation and timing of the investigated phenophases was much weaker (Table 1). For spring phenophases, significant negative relationships were detected between February precipitation and timing of bud burst for both species ($p < 0.05$), indicating that increased amount of snow at the very end of winter delays the beginning of phenological spring. For autumn phenophases, there were no statistically significant relationships of phase occurrence with the amount of precipitation preceding months ($p > 0.05$). It is necessary to note that the autumn phenophases of birch (leaf colouring and fall) were neither significantly related with temperature nor with precipitation ($p > 0.05$).

Advancement of bud burst was 2.2 days per 1 °C for lime and 2.3 days for birch (Fig. 1). The difference between the slopes of linear regressions was statistically insignificant (Z = 0.09). Advancement of leaf unfolding differed between species more markedly – 2.5

specific (Fig. 1). Leaf fall of lime was delayed by 4.45 days per 1°C increase in autumn air temperature ($p < 0.01$). Unlike the lime, slope of birch leaf fall response to temperature increase was negative and resulted in advancement of this phenophase by 2.2 days per 1°C increase. Difference between these slopes was highly significant (Z = 3.03).

Temporal trends of phenophase occurrence

The occurrence of bud burst advanced from 1956 to 2010 but negative trends for both species were not significant ($p > 0.05$). The shift of bud burst date was more pronounced for *T. cordata* - 2.1 days per decade, corresponding to 11.3 days during the study period, in comparison with *B. pendula* - 1.7 days per decade (9.2 days through investigation period) (Fig. 2). Difference between these slopes was not significant as well (Z = 0.23).

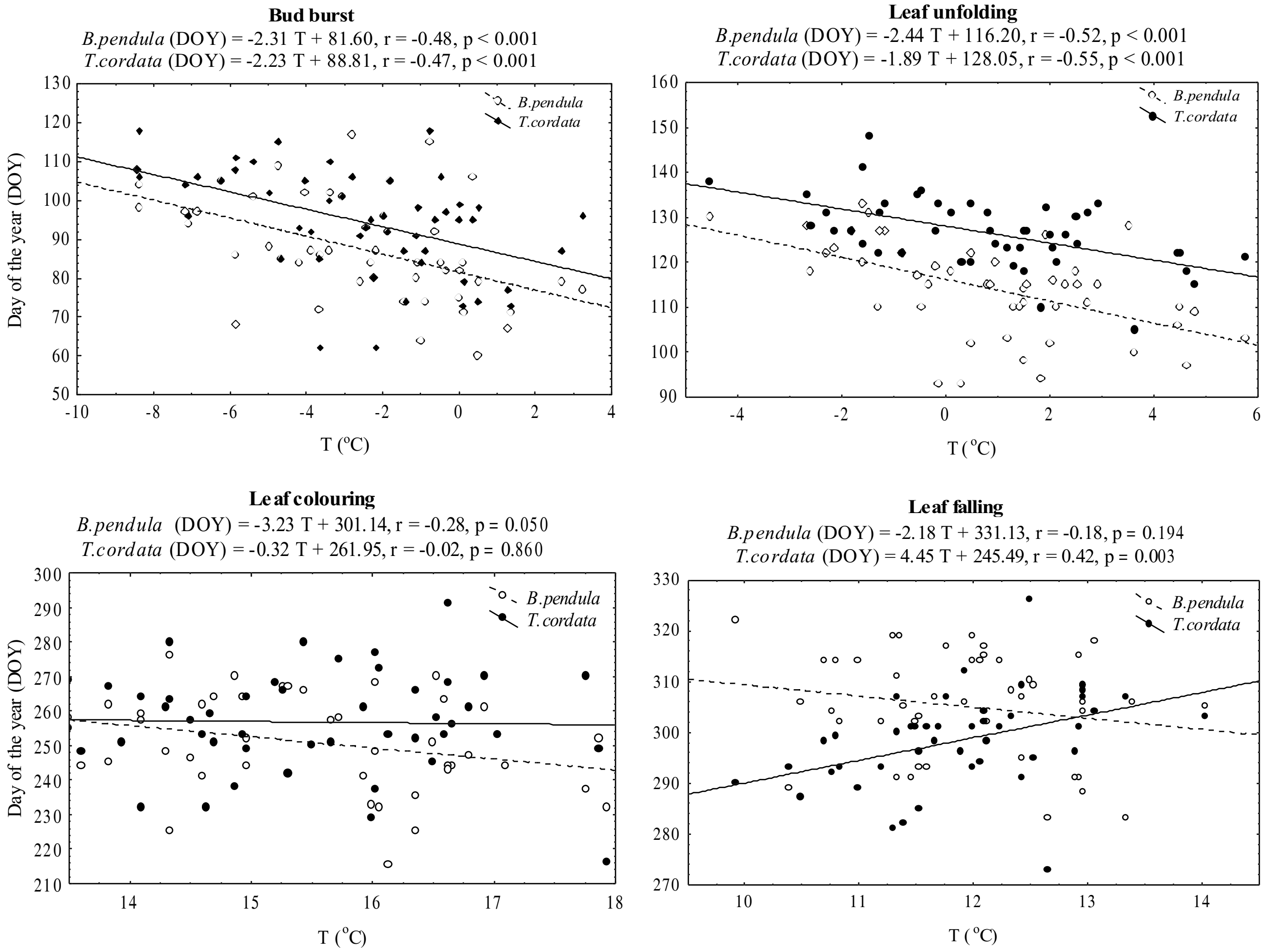

Figure 1. Relationship between phenophase timing and average temperature over 3 month's period before the occurrence of the phenophase date (1956-2010)

Regression analyses of the dates of leaf unfolding against time showed statistically significant ($p < 0.05$) trends towards earlier spring phenology (Fig. 2). Changes in leaf unfolding were more notable for *B. pendula* - 2.7 days advancement per decade (14.9 days during the study period). The advancement in the leaf unfolding of *T.cordata* was 1.7 days per decade (9.6 days during the study period). The difference between linear regression slopes of birch and lime leaf unfolding occurrence against time were not statistically significant ($Z = 0.89$).

Observed changes in the timing of autumn phenophases were very species specific and demonstrated the different character of changes (Fig. 2). Leaf colouring of *B. pendula* and the successive leaf fall displayed a specific pattern of advance during the study period. Shift in leaf colouring of *B. pendula* was 2.4 days per decade and leaf fall – 2.1 days per decade (13.0 and 11.5 days during the study period, respectively). Contrary to this advancement in autumn phenophases of *B. pendula*, the timing of leaf colouring and fall of *T. cordata* were delayed (Fig. 2). During the study period delay in leaf colouring and leaf fall of lime was 10.1 and 11.5 days, respectively. Statistically significant changes were detected only in the case of leaf fall ($p < 0.05$).

Considering the opposite trends in timing of autumnal phenophases (Fig.2), statistically significant difference between the slopes of linear regression for birch and lime was detected for both – leaf colouring ($Z = 2.28$) and leaf fall ($Z = 3.49$).

Changes in the length of growing season

The average length of growing season in the beginning of the study period for birch was 191 days as compared with 159 days for lime, resulting in the difference of 32 days. Considering species specific differences in shifts of leaf unfolding and particularly in leaf fall, changes in the length of growing season for birch and lime occurred to be statistically significantly different ($Z = 3.68$, Fig. 3).

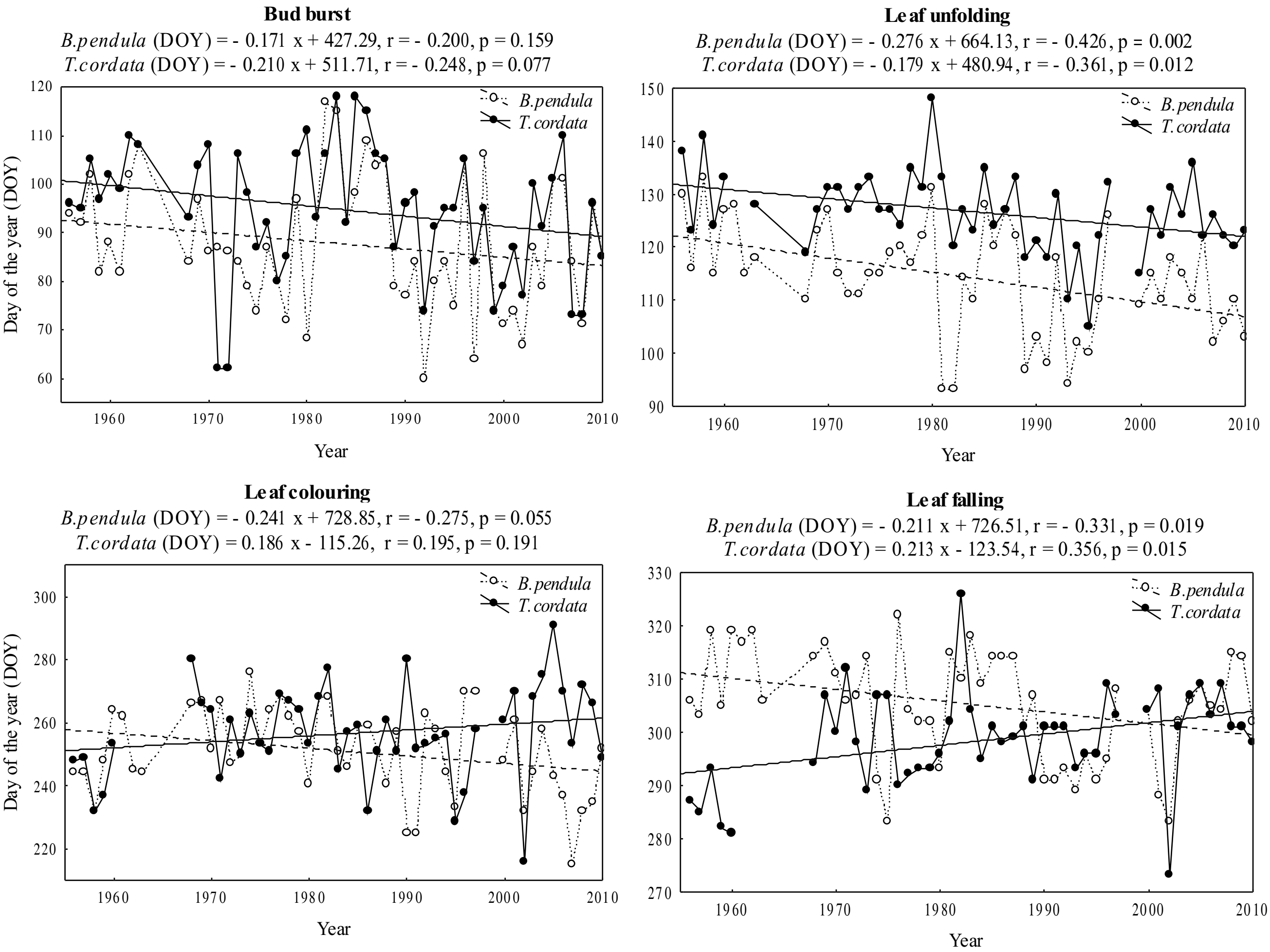

Figure 2. Shift in spring (bud burst, leaf unfolding) and autumn (leaf colouring, leaf fall) phenophases for *B.pendula* and *T.cordata* during the period 1956-2010

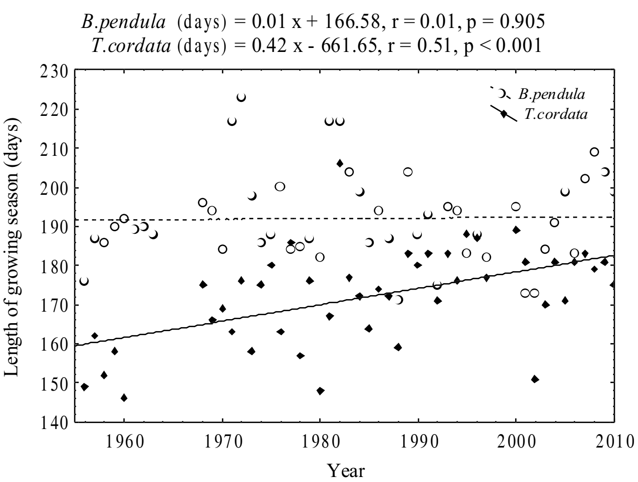

Figure 3. Changes in the length of the growing season for birch and lime during 1956-2010

Within the study period, the length of the growing season for *T.cordata* was extended by 22.7 days due to an earlier leaf unfolding and later leaf fall. Taking into account advanced both spring and autumn phenophases of birch, the length of the growing season did not experience any statistically significant changes and the entire growing period was shifted earlier almost for two weeks during the study period. Difference in the length of the two species growing season decreased considerably during the study period and currently the length of the birch growing season exceeds the growing season of lime only by 9.4 days instead of 32 days at the beginning of the study period.

Discussion

On the basis of a 55 year phenological data set for *Tilia cordata* and *Betula pendula* marked changes in their phenology were detected during the study period. Spring phenophases (bud burst and leaf unfolding) of *B. pendula* showed greater response to temperature rise than *T. cordata*. These results indicated a stronger effect of temperature on birch, as an earlier season species, flushing almost 11 days earlier than lime at the beginning of investigated period. Since birch exhibited a more remarked change than late season lime over time, the advancement rate in leaf unfolding of birch was higher almost by 1 day per decade in comparison with lime resulting 15 days earlier than lime flushing at the end of investigated period. These results support findings of other authors that early season species are more sensitive and responding more to climate warming than later season species (Menzel and Fabian 1999, Fitter and Fitter 2002, Walther et al. 2002, Menzel et al. 2003, 2006, McEwan et al. 2011).

As a result of different changes in the timing of spring phenophases, length of the period between bud burst and leaf unfolding of birch has become shorter along with increased temperature, indicating acceleration of seasonal development during spring period for this early season species. The data showed that the duration of the period between bud burst and leaf unfolding was 29.5 days in the beginning of the study period and was reduced by 5.7 days by the end of the study period. In the case of lime, advancement of both spring phenophases was similar and no changes of spring development rate were detected for this later season species.

Temporal changes of autumnal phenophases were much more different between two species. Leaf senescence of birch tended towards earlier dates. Such trend was also detected in north-western Russia for mountain birch (Kozlov and Berlina 2002, Shutova et al. 2006). Early leaf fall or even complete defoliation is a phenomenon regularly observed in drought stressed silver birch trees in pots under increased temperature and in the field (Fort et al. 1998; Kozlov and Berlina 2002; Shutova et al. 2006). Earlier shedding of leaves to reduce the transpiring area is considered as a morphological adaptation to climate change rather than inability to cope with it (Aspelmeier 2001). According to modelling results, M. Broadmeadow et al. (1996) suggested that birch is likely to be the most sensitive species to climate change because of their sensitivity to drought along with increased temperature. Analysis of long-term changes in temperature and precipitation has shown that simultaneous increase in temperature and decrease in precipitation was characteristic namely of August and September (Juknys et al. 2011). It is suggested that lower soil moisture caused by increase in temperature and decrease in precipitation is one of the most important factors leading to the advancement of birch leaf senescence.

In contrast, warmer temperatures in autumn triggered a delay in lime leaf senescence. Lime as a warmth-demanding and one of the most drought-resistant species was able to take advantage of a longer growing season: an increase of 1°C in temperature in autumn delayed leaf fall by 4.45 days (Fig. 1). Such a trend was characteristic of many other species and delay in the development of autumn coloration has been attributed to global warming in a meta-analysis covering several hundred plant species (Menzel and Fabian 1999, Menzel et al. 2006). Ground observation data averaged across Europe suggested a delayed autumn senescence by 1.3 days per decade (Menzel et al. 2006), whereas the results of our study showed a slightly higher delay for *T.cordata* (1.8 days per decade for leaf colouring and 2.1 days per decade for leaf fall). Although there is no the only explanation about the determinants of delayed autumnal senescence and most other studies have shown that autumnal phenological events are little affected by temperature (Menzel 2000, Chmielewski and Rētzer 2001), our results showed that delayed leaf fall of lime was mainly driven by temperature.

Considering autumnal phenology (leaf colouring and leaf fall) it is necessary to note that the correlation of their timing with temperature is much weaker of that for spring phenophases (Fig.1). As it was noticed by F.M. Chmielewski and T. Rötzer (2001), autumn phenology is a more complex process and it is impossible to explain the beginning of biological autumn only by temperature or other climatic indicators. Negative correlation of temperature with timing of birch leaf fall and contrary - positive correlation with timing of lime leaf fall, illustrates this complexity very evidently.

The opposite trends of lime and birch autumn phenology resulted in the reversal occurrence of these phenophases. At the beginning of study period leaf colouring of lime occurred 6.4 days earlier than birch and at the end of study period the opposite result was detected – leaf colouring of birch occurred 16.7 days earlier than leaf colouring of lime. Exchange in the occurrence of the last autumnal phenophase – leaf fall was even more remarkable. At the beginning of the investigation period leaf fall of lime occurred 18.5 days earlier of that of birch, and at the end of the investigation period leaf fall of birch occurred 4.4 days earlier of that of lime.

Our results showed that species-specific changes due to climate warming may lead to contrasting changes in the length of the growing season. *T. cordata* as a warmth-demanding and one of the most drought resistant species has been favoured by a warmer climate and due to an earlier leaf unfolding and later leaf fall its growing season was extended by 22.6 days during the study period. In contrast, the length of *B. pendula* growing season did not experience any statistically significant changes due to advancement in spring and autumn phenophases. As it was stated by different authors, disparities between tree species in changes of their seasonal development along warmed climate could lead to very different responses in community dynamics and ecosystems processes (Cleland et al 2007, Richardson et al. 2010).

In general, our results suggest that different tree species might have a particular sensitivity to climate warming and differences in their response can induce essential changes in competitive ability and distribution range. Considering that growing season of *T. cordata* was extended significantly during the study period, lime would be expected to use a growing season more efficiently and its competitive ability should increase along with climate warming. At the same time birch, as a more boreal species, did not gain any priorities along with warmed climate and in some latitudes could be replaced by more warmth-demanding species.

Conclusions

Increased temperature in late winter and early spring (February, March and April) was detected to be as a significant factor inducing advancement of spring phenology (bud burst and leaf unfolding) for both species – *B. pendula* and *T. cordata*. Higher sensitivity to temperature increase was characteristic of the early season species birch as compared with lime as the late season species.

As a result of different changes in the timing of spring phenology, length of the period between bud burst and leaf unfolding of birch has become shorter along with increased temperature, indicating acceleration of seasonal development during spring period for this early season species. In the case of lime, advancement of both spring phenophases was similar and any changes of spring development rate were not detected for this later season species.

Autumn phenophases (leaf colouring and leaf fall) occurred to be much less and more diverse related with temperature than spring phenophases and even negative correlation of temperature was detected for birch autumn phenophases, resulting in the advancement of birch leaf senescence along with climate warming. It was suggested that a decrease in soil moisture caused by simultaneous rise in temperature and decrease in precipitation was one of the most important factors leading to the advancement of birch leaf senescence.

Despite very different changes in autumn phenology of birch and lime, duration of the period between leaf colouring and leaf fall, has become longer almost by 2 days for both species, indicating deceleration of seasonal development during phenological autumn.

Lime as a warmth-demanding and one of the most drought resistant species has been favoured by a warmer climate and due to earlier leaf unfolding and later leaf fall its growing season was extended more than for three weeks during the study period. In contrast, the length of birch growing season did not experience any statistically significant changes due to advancement in both - spring and autumn phenophases.

Regarding to significantly elongated growing season lime would be expected to use a growing season more efficiently and its competitive ability should increase along climate warming. Birch, as a more boreal species, did not gain any priorities along with warmed climate and in some latitudes could be replaced by more warmth-demanding species.

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СРАВНЕНИЕ ПОТЕПЛЕНИЕМ КЛИМАТА ОБУСЛОВНЕННЫХ ИЗМЕНЕНИЙ ФЕНОЛОГИИ БЕРЁЗЫ (*BETULA PENDULA* ROTH) И ЛИПЫ (*TILIA CORDATA* MILL.)

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Резюме

Основная цель исследований – сравнить временные сдвиги основных весенних (разбухание почек и возникновение листвы) и осенних (пожелтение листвы, листопад) фенофаз и темпов сезонного развития берёзы и липы. Установлено, что изменения фенологии деревьев вследствии потепления климата зависят от вида деревьев. Разбухание почек за изученный 55-летний период (1956-2010) стало более ранним у липы, а возникновение листвы у берёзы. Выявлено ускорение весеннего развития (сокращение периода между разбуханием почек и возникновением листвы) у берёзы на 6 дней за изучаемый период. Различия в имениях осенней фенологии берёзы и липы оказались ещё более очевидными. Пожелтение листвы и листопад липы стали более поздними, а берёзы наоборот – более ранними. Несмотря на эти различия, у обоих видов установлено замедление осеннего развития и период между пожелтением листвы и листопадом сократился примерно на 2 суток в течение изучаемого периода. Различия в изменениях сезонного развития различных видов деревьев, могут обусловить существенные изменения в породном составе и продуктивности древостоев.

Ключевые слова: потепление климата, разбухание почек, возникновение листвы, пожелтение листвы, листопад, берёза, липа