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EFFECTS OF CLIMATE WARMING ON TIMING OF LIME (*Tilia cordata* L.) PHENOLOGY

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Abstract. This study is aimed to investigate impact of climate warming on timing of lime phenological spring (bud burst and leaf unfolding) and phenological autumn (leaf colouring and fall). An essential shift in timing of all investigated phenological phases is detected. The most significant advancing was detected in the case of earliest phenological phase. Shift of bud burst dates during investigated period (1956-2010) consisted 13.5 days. Shift in timing of leaf unfolding was detected to be not so essential and consisted 9.7 days during the same period. The leaf colouring of lime has been delayed by 10 days and leaf fall approximately by 12 days during the study period. As a consequence of observed changes in spring and autumn phenology, growing season of lime has been extended by 22.6 days during 1956 -2010 period. Occurrence of lime leaf unfolding is best correlated with late winter (January, February) and early spring (March) temperature, i.e. with temperature of most warmed during last decade's months. Relationship of leaf colouring and fall timing with temperature is much weaker and in most cases statistically insignificant, indicating that timing of phenological autumn is more complex process and can't be explained only by changes in temperature.

Keywords: climate warming, phenology, lime, temperature, precipitation.

1. Introduction

The effects of global climate warming on species and ecosystems are becoming progressively apparent during last decades (Menzel 2000; Wielgolaski 2003; Yang and Rudolph 2009). Phenological studies have traditionally investigated the timing of key events of plant seasonal development, i.e. bud burst, leaf unfolding, flowering, leaf fall etc. An essential renovation of phenology, is connected with climate change, and particularly with climate warming studies (Kramer *et al.* 2000; García-Mozo *et al.* 2010). Long-term observations of plant phenology are considered as one of the most sensitive instruments to detect and quantify the impact of climate change on vegetation (Roetzer *et al.* 2000; Walter 2010)

Most current phenological studies has showed that climate warming has an essentially advanced the biological spring including such phenological phases of plants as bud burst, leaf unfolding, and delayed biological autumn, i.e. leaf coloring and leaf fall (Menzel *et al.* 2006; Tailor *et al.* 2008). The shift of plant phenological phases and lengthening of vegetation period may cause essential consequences for different ecological processes, agriculture and forestry (Cleland *et al.* 2007; Peñuelas *et al.* 2009).

In temperate climate conditions changes in timing of tree phenology are detected to be mainly dependent on temperature while precipitation is much less influencing factor (Wielgolaski 1999; Kramer *et al.* 2000). Most of pheno-climatic studies detected significant correlation between early spring phenology (bud burst, leaf unfolding) and rising temperature, but impact of climate warming to autumn events (leaf coloring, leaf fall) is not so consistent and in some cases even advanced end of growing season was detected (Cleland *et al.* 2007; Vitasse *et al.* 2009).

Data of different studies on the impact of climate warming to tree phenology have showed that various tree species react differently to various climatic factors (Wielgolasky 2003; Primac and Ibanes 2009; Šimatonytė and Žeimavičius 2009). At the same time it was detected that the same species in different regions react differently to climate warming (Kozlov and Berlina 2002; Sparks *et al.* 2010).

This study is aimed to investigate changes in timing of phenological spring and phenological autumn of *Tilia cordata* L. along to climate changes.

2. Methods and material

Data of long term (1956–2010) phenological observations in Vytautas Magnus University botanical garden were used for this study. Botanical Garden (latitude 54°5'N, longitude 23°5'E, altitude 84 m) occupies the area of 62.5 ha and is located 3.3 km from Kaunas city centre, remotely from intensive traffic, industry and high concentration of multistorey houses.

Phenological observations were performed according to standard procedures described in the Methodological Guidelines for Phenological Observation (Gavenauskas and Lamsodienė 2004). Bud burst and leaf unfolding are chosen as indicators of phenological spring, leaf colouring and leaf fall – as indicators of phenological autumn. The length of growing season was determined as period from *Tilia cordata* leaf unfolding to the end of leaf fall.

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 (latitude 54°9'N, longitude 23°8'E, altitude 76 m).

Linear trends for investigated climate data (mean of annual temperature and annual amount of precipitation) were detected and their statistical significance was evaluated. Dates of phenological phases occurrence were transformed to day number from the beginning of year (DOY – day of the year) where 1= 1 January, etc. Slope of linear trend is considered as indicator of changes in timing (days per year) of investigated phenological phases.

3. Results

3.1. Trends in temperature and precipitation from 1956 to 2010

The values and linear trend of mean annual temperature are presented in Fig 1. The mean annual temperature increased significantly ($p < 0.05$) at rate 0.03°C annually, corresponding to total change of 1.62 °C for 1956-2010 year, period.

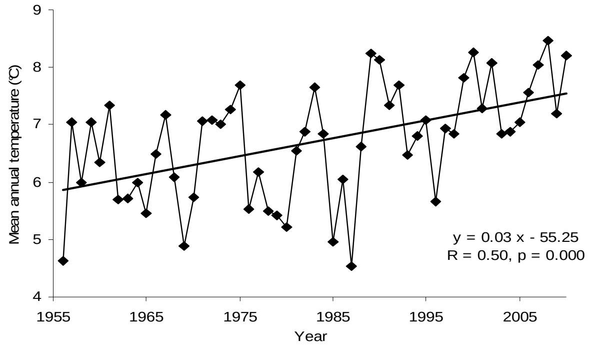

Fig 1. Linear trend of mean annual air temperature in Kaunas region from 1956 to 2010

Precipitation (Fig 2) increased by 65.88 mm over the same period i.e. 1.22 mm per year on average but the increase was not statistically significant ($p = 0.07$).

3.2. Changes in spring and autumn phenophases

In Fig 3 the dates of appearance of lime spring phenophase – bud burst throughout the study period (1956–2010) are presented. A significant trend toward an earlier occurrence of bud burst was determined and this phenophase has advanced 13.5 days during investigated period (0.25 days per year, R = 0.34, $p = 0.01$). It is necessary to note that most of the earliest dates of bud burst occurred in the last two decades (Fig 3).

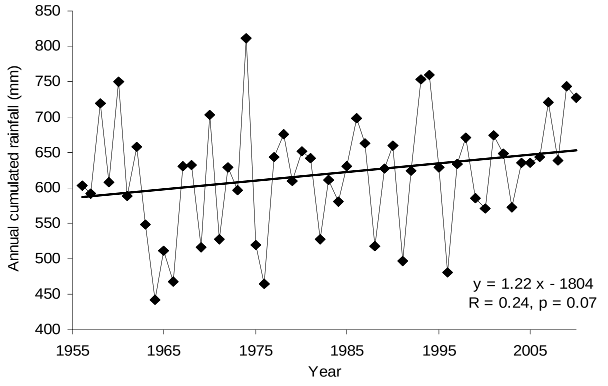

Fig 2. Linear trend of annual precipitation in Kaunas region from 1956 to 2010

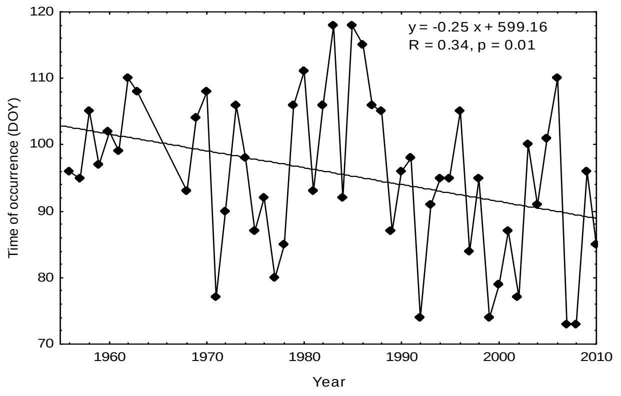

Fig 3. Appearance date of bud burst of lime, 1956–2010

The appearance dates of lime leaf unfolding are shown in Fig 4. A significant changes in timing of leaf unfolding (0.18 per year, R = 0.36, $p = 0.01$) can be seen as well, however advancing of leaf unfolding was not so essential as bud burst and consisted 9.72 days during 1956-2010 period.

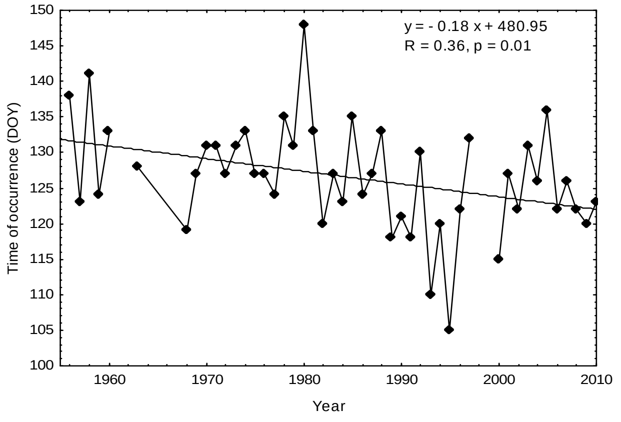

Fig 4. Appearance date of leaf unfolding of lime, 1956–2010

Changes in the occurrence of autumn phenophases over the study period showed opposite trends (Fig 5 and 6). The occurrence of the coloring of leaves was delayed 10.1 days during investigated period though the trend toward later coloring of leaves was not statistically significant (R = 0.19, *p* = 0.19).

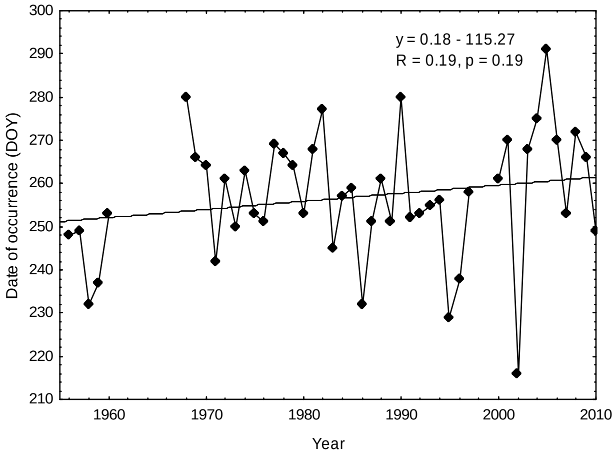

Fig 5. Appearance date of leaf coloring of lime, 1956–2010

Delay of leaf fall was more essential (R = 0.35, *p* = 0.01) as compared to delay of leaf coloring and occurred 11.5 days later in 2010 than in 1956 (Fig 6).

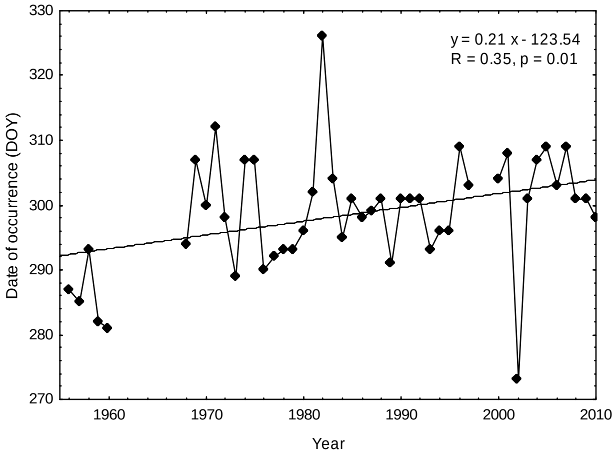

Fig 6. Appearance date of leaf falling of lime, 1956–2010

As a consequence of observed changes in spring and autumn phenology, growing season of lime has been extended by 22.6 days during 1956 -2010 period (0.42 days per year).

3.3. Relationship between climatic indicators and occurrence of lime phenophases

Data on correlation of timing of investigated phenological phases and climatic indicators (temperature and precipitation) are presented in Table 1. Response in the timing of spring and autumn phenophases was closer related with air temperature than with precipitation. Mean monthly temperature regimes prior to phenophase onset had a strong and significant impact on the timing of spring phenophases. Bud burst and leaf unfolding was negatively correlated with the temperature of the months previous to the phenophase ($p < 0.01$). The average air temperature had no significant influence on the timing of leaf coloring ($p > 0.05$). The leaf fall was positively related with temperature also with month's temperature prior to this phenophase (Table 1).

Table 1. Correlation between mean monthly temperatures and precipitation and the timing of investigated phenological phases

Climatic indicator	Phenological phase	
	Bud burst	Leaf unfolding
T_1*	**-0.41**	
T_2	**-0.51**	**-0.38**
T_3	**-0.49**	**-0.46**
T_4		**-0.60**
P_1	0.02	
P_2	**-0.42**	-0.12
P_3	-0.14	-0.19
P_4		-0.03
	Leaf coloring	End of leaf falling
T_8	-0.15	0.16
T_9	-0.25	**0.30**
T_{10}	0.10	**0.33**
P_8	0.13	-0.21
P_9	0.05	0.02
P_{10}	-0.09	-0.22

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

As it was already mentioned, relationship between precipitation values and timing of investigated phenophases was much weaker. A significant negative relationship was detected between the February precipitation and bud burst of lime ($p > 0.05$) indicating that less precipitation, thick snow layer promote advancement of bud burst.

4. Discussion

On the basis of 54 year phenological data set for *Tilia cordata* an essential impact of climate warming on it's phenology was detected. The changing phenology was reflected as advancing in spring events (bud burst and leaf unfolding) and delay in autumn events (leaf coloring and fall). The most significant advancing was detected for bud burst dates and during investigated period (1956–2010) consisted 13.5 days. A significant change in timing of leaf unfolding was detected as well, however, advancing of leaf unfolding was not so essential as bud burst and consisted 9.7 days during the same period. In our study determined mean advancing of bud burst and leaf unfolding (2.5 and 1.8 days per decade) matches previous results concerning the Europe-wide and regional trends where the mean advance of spring phenological phases was 2.5 days per decade (Menzel and Fabian, 1999; Defila and Clot 2001; Menzel 2003). In Lithuania the analysis of trends of various species changes in phenology also shows that the onset of spring events is becoming earlier (Romanovska and Bakšienė 2007; Kalvāne *et al.* 2009; Veriankaitė *et al.* 2010).

According to the most investigations impact of climate warming to autumn events (leaf coloring, leaf fall) is not so consistent and in some cases even advanced end of growing season was detected (Chmielevski and Rotzer, 2001; Cleland *et al.* 2007; Vitasse *et al.* 2009). However, in our study shift of phenological autumn was not less essential than shift in phonological spring. Leaf colouring of lime has been delayed by 10 days and leaf fall approximately by 12 days during the study period. Taking into account that *Tilia cordata* is a warmth-demanding tree species (Hemery *et al.* 2010), growth of lime is favored by higher temperature during the warmer autumn.

Analysis of correlation between temperature and occurrence of investigated phenophases has confirmed a significant influence of climate warming on timing of spring phenological events. Shift in spring phenological phase was significantly correlated with temperature changes, especially with temperature of 2–3 months previous to the phenophase (p < 0.01). Negative relationship between spring phenophases (bud burst and leaf unfolding) and mean temperature of months proceeding to the onset of the phenophase indicated advancement of biological spring along with it warming.

While spring phenological changes were significantly correlated with temperature, the correlation between timing of autumn phenophases and temperature was detected to be much weaker. However, lime leaf fall was significantly (p < 0.05) correlated with mean temperature of September and October (Table 1).

Leaf colouring was not significantly related with temperature neither with precipitation. As it was stated by Chmielewski and Rötzer (2001), autumn phenology is more complex process and it is impossible to explain the beginning of biological autumn only by mean temperature. Further investigations are needed to define the relative importance of other autumn climatic indicators such as wind, sunshine and photoperiodic factors on leaf colouring which are reported to regulate autumn phenophases more strongly than temperature (Menzel 2002).

Influence of precipitation to timing of seasonal development was much weaker as compared with temperature. Weak correlation of precipitation with analyzed phenophases was also determined by other authors (Wielgolaski 1999; Kramer *et al.* 2000; Peñuelas *et al.* 2002). A significant negative relationship was detected only between the February precipitation and bud burst of lime (p > 0.05) indicating that increased air humidity at the time of high light intensities in late winter promotes advanced bursting of lime buds. Such growth conditions were proved to cause advanced greening of trees (Wielgolaski 2001).

According to our study, advanced phenological spring and delayed phenological autumn for *T.cordata* resulted in the essential changes in the duration of growing season. The mean trends in duration of growing season indicated a lengthening with the rate of 0.42 days per year (22.6 days during 1956–2010 period). Longer growing season is likely to contribute to prolonged tree growth and increased biomass formation. This lengthening of the growing season allows trees to remove more carbon dioxide from the atmosphere each year and this phenomenon, in turn, reduces the annual rate of rise of the air's CO_2 content (White *et al*. 1999). However, warmer and drier summers in recent years are able to offset the expected increase in productivity of forest ecosystems (Cleland *et al.* 2007). More deep investigations on relations between longer growth season and climatic changes needed to be performed.

5. Conclusions

1. An essential shift in timing of investigated phenological phases is characteristic feature of lime response to climate warming. .The changing phenology was reflected as advanced phonological spring (bud burst and leaf unfolding) and delayed phenological autumn (leaf coloring and fall).
2. The most significant advancing was detected in the case of earliest phenological phase. Shift of bud burst dates during investigated period (1956–2010) consisted 13.5 days. Shift in timing of leaf unfolding was detected to be not so essential and consisted 9.7 days during the same period.
3. The leaf colouring of lime has been delayed by 10 days and leaf fall approximately by 12 days during the study period.
4. Occurrence of lime leaf unfolding is best correlated with late winter (January, February) and early spring (March) temperature, i.e. with temperature of most warmed during last decade's months. This means that temperature in this period is most decisive for the annual timing of spring.
5. Relationship of leaf colouring and fall timing with temperature is much weaker and in most cases statistically insignificant, indicating that timing of phenological autumn is more complex process and can‘t be explained only by increased temperature.

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