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Climate Change Impact on Duration of Vegetative Period of Five Deciduous Tree Species

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The air temperature is directly linked to the plant growth season, affecting the timing of the start and the end of the vegetative period and its duration. The aim of this study was to analyse the impact of changing climatic parameters on the duration of the vegetation period in 1956-2008 of five deciduous tree species (oak – *Quercus robur* L., maple – *Acer platanoides* L., lime – *Tilia x vulgaris* Hayne, birch - *Betula pendula* Roth. and ash - *Fraxinus excelsior* L.) growing in Kaunas Botanical Garden of Vytautas Magnus University. The duration of the vegetative period (number of days) was calculated between the dates of the beginning of bud swell and the end of leaf fall phenophases. Mean length of the vegetative period in 1956–2008 of observed tree species varied from 186 for ash to 214 days for birch. The beginning of the bud swelling phenophase advanced on average from 1 (oak) to 14 days (ash) in 1956–2008. The beginning of the bud swelling phenophase was significantly related to the temperature of February (for lime, birch and ash) and March (for all species). The end of the leave fall phenophase was delayed on average from 3 (birch) to 25 days (maple) in 1956–2008. In most cases, the end of a leave fall phenophase was not significantly related to climatic parameters, however the temperature of September had a significant positive impact (higher temperature determining later leave fall date) on maple, lime and ash. The duration of the vegetative period of deciduous tree species depended mostly on the warming late winter – early spring temperature (February–April) and for some species - on the warming late summer temperature (in August), while changes in the amount of precipitation had little effect. Among the observed species the duration of the maple vegetative period was the most and that of oak was the least sensitive to climate warming.

Key words: *bud swelling phenophase, leave fall phenophase, vegetative period, climatic parameters.*

1. Introduction

Plant phenology based on variation in the annual course of the elements is one of the most responsive and easily observable traits in nature that change in response to climate (Menzel 2002, Badeck et al. 2004, Cleland et al. 2007). Analysis of phenological observation data reflecting climate changes enables researchers to make precise evaluation of an impact of these changes on the surrounding environment and forecast future climate and nature changes (Walkovszky 1998, Baronienė& Romanovskaja 2004).

The mean air temperature is directly linked to the plant growth season, while the sum of the temperatures (degree–days) influences plant phenology linearly (Theurillat&Guisan 2001). For some phenophases, e.g. leaf bud break in spring, the temperature during the night or the minimum temperature is found to be of great importance, whereas further development from leaf bud break to flowering, for example, is mainly dependent on the day or maximum temperature (Wielgolaski 2003). As a result of an increase in the mean air temperature since early 1960, the average annual plant growing season has lengthened by 10.8 days (six in spring, 4.8 in autumn) in Europe (Menzel&Fabian 1999).

The phenology of boreal forests is mainly driven by the temperature, affecting the timing of the start and the end of the vegetative period and thereby its duration (Kramer et al. 2000). The results obtained from the data set of 542 plant species in 21 European countries (1971–2000) showed that 78 % of all leafing, flowering and fruiting records advanced (30%

significantly) and only 3 % notably were delayed, whereas the signal of leaf colouring/fall was ambiguous (Menzel et al. 2006b). Temperature warming in the early spring (February–April) by 1°C caused an advance at the beginning of the growing season of 7 days, while an increase in the mean annual air temperature by 1°C led to an extension of 5 days (Chmielewski&Rotzer 2001). Early phenological events (in spring) are more variable than the later ones, both in time and in space (Menzel et al. 2006a).

Woody plants display less phenological sensitivity to climatic variability than herbaceous species (Post&Stenseth 1999). There is a wide range of phenological alterations among the different species, which may alter their competitive ability, ecology and conservation, structure and functioning of ecosystems (Penuelas et al. 2002).

In Lithuania the plant growth season lengthened by 8–16 days in 1974–2003 (Baronienė& Romanovskaja 2004). The plant growing season differs slightly from the vegetative period: it starts with the dates of early flowering plant phenophases and ends with the beginning of autumn tree leave colouring dates (thus it is shorter than the vegetative period). The beginning of bud burst and flowering phenophases became significantly advanced (Baronienė&Romanovskaja 2004). During the last 4 decades the duration of phenological spring changed (lengthened on average by 8–16 days) more than that of phenological summer (lengthened on average by 1 day) (Romanovskaja 2004). Similar findings are reported from Estonia (Ahas 1999) where springs have advanced 8 days over the last 80-year period; the last 40-year period has warmed even faster. Forecasts predict that in future thermal and humidity conditions of the plant vegetative period and also the winter period will change, which may have a negative impact on plant growth (Baronienė& Romanovskaja 2004).

Climate simulation models, using different emission scenarios, predict the global temperature rise of 1.4–5.8 ^{o}C in 1990–2100. In the Baltic region considerable climate warming will determine an increase in the duration of the vegetation period (the mean daily temperature being >5 ^{o}C): up to 20–50 days in the northern part and up to 30–90 days in the southern part of the region (Rimkus 2007). Temperature rise by 1–3 ^{o}C will accelerate leaf formation of many plant species in spring by several weeks earlier (Kutorga&Rukšėnienė 2007). Depending on species, the average timing of leafing or flowering could be advanced by 3–27 days by 2050 (Chmielevski et al. 2005).

There are findings (Roetzer et al. 2000, Defila&Clot 2001, Rotzer&Chmielewski 2001) indicating that plant species flowered earlier in urbanised areas than in rural areas in central Europe. The forcing in urban areas was about 2–5 days for pre-spring phenophases and about 2 days for full-spring phenophases, while autumn phenophases delayed 3–4 days. This phenomenon can be attributed to the city effect (warmth islands) (Min 2000, Roetzer et al. 2000, Zhongkui 2007).

The aim of this study was to analyse the impact of the change in climatic parameters in 1956–2008 on the duration of the vegetation period of five deciduous tree species (*Quercus robur* L., *Acer platanoides* L., *Tilia x vulgaris* Hayne, *Betula pendula* Roth., *Fraxinus excelsior* L.) growing in Kaunas Botanical Garden of Vytautas Magnus University.

2. Methods

Phenological observations of five deciduous tree species (oak – *Quercus robur* L., maple – *Acer platanoides* L., lime – *Tilia x vulgaris* Hayne, birch – *Betula pendula* Roth., ash – *Fraxinus excelsior* L.) were made in Kaunas Botanical Garden in 1956–2008. The impact of climate change on the duration of the vegetative period of these woody species was analysed. Since Kaunas Botanical Garden is located in a peripheral region of Kaunas city far from large urban settlements, there is no additional city effect (warmth islands) on the local microclimate.

There is a considerable inter-annual variation in the timing of phenological events (with standard deviation often = 5 to > 10 days between the earliest and latest dates of the occurrence spanning = 1 month) (Badeck et al. 2004). A possible error in that analysis in Kaunas Botanical Garden was ±5 days. The duration of the vegetative period (number of days) was calculated between the dates of the beginning of bud swell and the end of leaf fall phenophases. The date of bud swelling was considered the day when pea-green streaks appeared on bud squamae or the tops of bud squamae became green in their inner side, while the date of the end of leaf fall was the day when almost all leaves of the observed tree fell and its crown became bare.

Mean various months' temperature (^{o}C) and the amount of precipitation (mm) data (1956–2008) were obtained from Kaunas meteorological station archives. The data were used for correlation analysis (to estimate the relation between the deciduous tree species vegetative period duration and the climatic parameters). Descriptive parameters (mean, standard deviation, standard error, coefficients of variation) and Pearson correlation coefficients were calculated for statistical data analysis. Changes in the period of 1956–2008 were approximated by a linear trend method, taking the values in the beginning (start date) and at the end (end date).

3. Results and discussion

In Lithuania the period of 1961-1990 was by 0.1–0.3 ° C warmer than in 3 previous decades, except the southern part (there the temperature dropped by 0.1° C) (Bukantis&Rimkutė 1996). Changes in climatic parameters (temperature and precipitation amount of each month) in 1956–2008 in the region of Kaunas are presented in *Table 1*.

Table 1. Changes in climatic parameters in Kaunas region in 1956–2008

	Changes in mean temperature (°C)			Changes in mean precipitation amount (mm)		
	Start date (in 1956)	End date (in 2008)	Change (°C)	Start date (in 1956)	End date (in 2008)	Change (mm)
January	-5.5	-2.9	+2.6	32.6	45.6	+13.0
February	-5.5	-2.3	+3.2	27.4	34.2	+6.8
March	-1.7	0.9	+2.6	27.2	43.6	+16.4
April	+5.2	+7.6	+2.4	37.3	43.2	+5.9
May	+12.0	+12.9	+0.9	53.0	48.3	-4.7
June	+16.1	+15.5	-0.6	64.3	66.9	+2.6
July	+16.8	+18.1	+1.3	67.0	78.1	+11.1
August	+15.7	+17.5	+1.8	90.3	59.1	+31.2
September	+11.7	+12.3	+0.6	59.7	48.6	-11.1
October	+7.2	+7.0	-0.2	44.5	63.1	+18.6
November	+2.1	+1.7	-0.4	52.9	46.4	-6.5
December	-2.6	-2.2	+0.4	42.8	47.6	+4.8

Results (*Table 1*) show that even though the mean annual temperature increased in that period, dynamics of the temperature differed among various months: it rose (by 0.4–3.2 °C) in most of the cases, except a slight drop (by 0.2–0.6 °C) in June, October and November. The largest increase in temperature was estimated in February, the smallest change – in October (a drop of 0.2 degrees).

The mean annual precipitation amount increased in 1956–2008, but the changes between various months differed: the precipitation amount increased (by 2.6–31.2 mm) in most of the cases, except May, September and November, when it dropped (by 4.7–11.1 mm) (*Table 1*). The largest increase in the precipitation amount was estimated in August, the smallest change – in June (rise by 2.6 mm).

The duration of the vegetative period of observed species in Kaunas Botanical Garden of Vytautas Magnus University in 1956–2008 is presented in *Figs 1–5*.

A tendency of prolonged vegetative period in 1956–2008 was noticed (*Figs 1–5*) for all observed deciduous tree species, especially since 1986. The greatest prolongation is visible in curves for ash and maple, the least – in a curve for oak. Mean parameters of the vegetative period duration of 5 observed species are presented in *Table 2*.

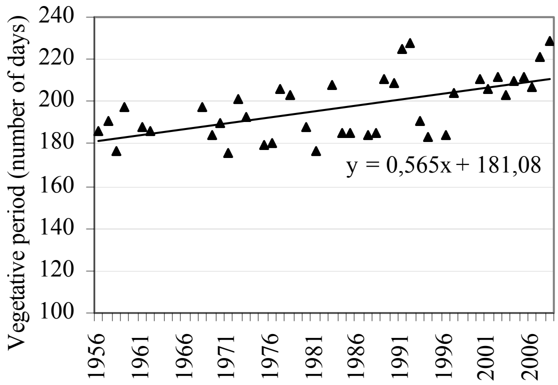

Fig. 1. Vegetative period (number of days) of Acer platanoides in 1956–2008

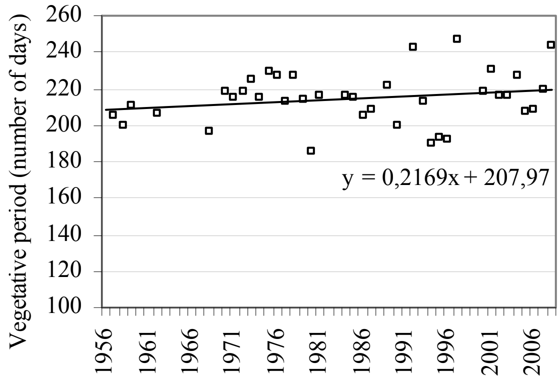

Fig. 2. Vegetative period (number of days) of Betula pendula in 1956–2008

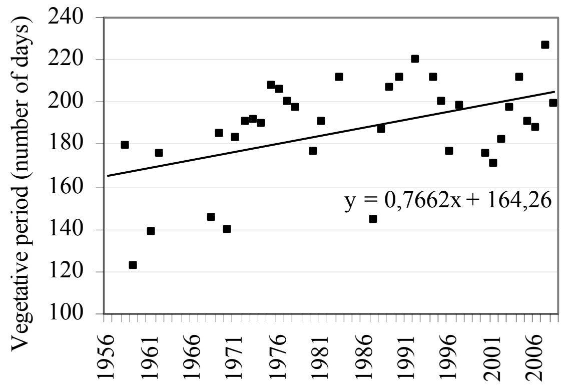

Fig. 3. Vegetative period (number of days) of Fraxinus excelsior in 1956–2008

In 1956-2008 the mean duration of the vegetative period of observed tree species varied from 186 for ash to 214 days for birch (*Table 2*). Results (variation coefficients) show that variation of the vegetative period duration (number of days) was greater for maple, birch and lime, and smaller for oak and ash.

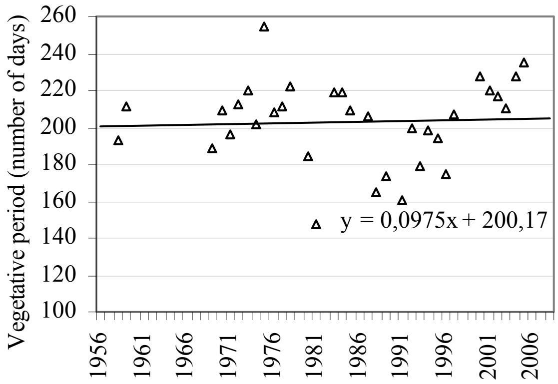

Fig. 4. *Vegetative period (number of days) of Quercus robur in 1956–2008*

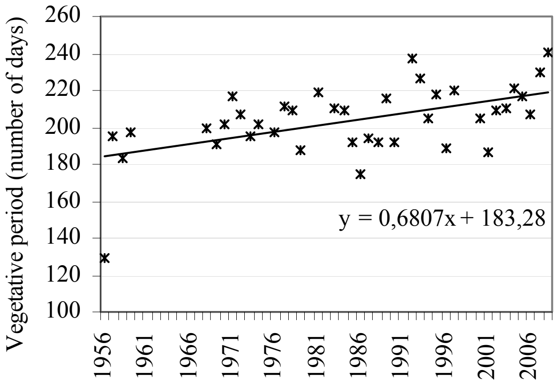

Fig. 5. *Vegetative period (number of days) of Tilia x vulgaris in 1956–2008*

Table 2. *Descriptive parameters of the vegetative period duration of 5 deciduous tree species in 1956–2008*

	Mean	Standard deviation	Standard error of mean	Coefficient of variation (V) %
Acer platanoides	196	13.66	2.22	14.34
Betula pendula	214	13.70	2.28	15.59
Fraxinus excelsior	186	23.67	4.06	7.84
Quercus robur	201	22.05	3.96	9.13
Tilia x vulgaris	202	18.09	2.97	11.17

Phenophases of all observed 5 deciduous species in Kaunas Botanical Garden reacted to the warming climate. Results of the changes in bud swelling and leave fall phenophases dates in 1956–2008 are presented in *Tables 3* and *5*, results of correlation analysis between these phenophases and climatic parameters are presented in *Tables 4* and *6*.

The beginning of a bud swelling phenophase advanced on average from 1 (oak) to 14 days (ash) in 1956–2008 (*Table 3*). Results of correlation analysis show that the beginning of the bud swelling phenophase was significantly ($p<0.05$) negatively related to the temperature of February (for lime, birch and ash) and March (for all species) (*Table 4*). The temperature of January was important only for the birch bud swelling phenophase, while the April temperature had no noticeable effect. No significant relation was estimated between the beginning of the bud swelling phenophase and the precipitation amount in January–April.

Table 3. *Changes in bud swelling phenophase dates in 1956–2008*

	Linear trend line function	Start date (in 1956)	End date (in 2008)	Change (number of days)
Acer platanoides	y=-0.1554x+6.1229	04.07	03.30	Advanced 8 d.
Betula pendula	y=-0.2209x+3.2305	04.04	03.24	Advanced 11 d
Fraxinus excelsior	y=-0.3067x+24.11	04.25	04.09	Advanced 14d.
Quercus robur	y=-0.0237x+11.326	04.12	04.11	Advanced 1 d.
Tilia x vulgaris	y=-0.2253x+9.3422	04.10	03.30	Advanced 9 d.

Table 4. *Correlation coefficients: between the beginning of bud swelling date and the temperature (T, oC), between the beginning of bud swelling date and the amount of precipitation (P, mm) in January–April*

	January		February		March		April	
	T (°C)	*P* (mm)	*T* (°C)	*P* (mm)	*T* (°C)	*P* (mm)	*T* (°C)	*P* (mm)
Acer platanoides	-0.22	-0.02	-0.41	-0.38	**-0.71**	-0.31	-0.21	-0.17
Betula pendula	**-0.43**	-0.07	**-0.63**	-0.30	**-0.76**	-0.10	-0.30	-0.08
Fraxinus excelsior	-0.25	0.10	**-0.47**	-0.34	**-0.45**	-0.01	-0.02	0.14
Quercus robur	-0.13	-0.06	-0.28	-0.02	**-0.45**	0.06	-0.25	-0.06
Tilia x vulgaris	-0.38	-0.02	**-0.51**	-0.38	**-0.55**	-0.07	-0.20	-0.07

Note: values in bold type are statistically significant ($p<0.05$).

The end of the leave fall phenophase was delayed on average from 3 (birch) to 25 days (maple) in 1956–2008 (*Table 5*). Results of the leave fall phenophase indicate that late phenological events of observed 5 deciduous species were more sensitive to the climate change than early spring events, which contradicted to some other findings (Menzel et al. 2006a). The reaction of the leave fall phenophase in comparison with the bud swelling phenophase differed between species: the bud swelling phenophase was more sensitive to climate warming than leave fall for birch, while it worked on the contrary for oak, maple and lime. Sensitivity of bud swelling and leave fall phenophases towards the warming climate was more or less the same for ash.

Table 5. Changes in leave fall phenophase dates in 1956–2008

	Linear trend line function	Start date (in 1956)	End date (in 2008)	Change (number of days)
Acer platanoides	y=0.4706x-2.7951	10.03	10.28	Delayed 25 d.
Betula pendula.	y=0.0749x+20.508	10.27	10.30	Delayed 3 d.
Fraxinus excelsior	y=0.2766x+9.1797	10.15	10.30	Delayed 15 d.
Quercus robur	y=0.1241x+20.1	10.26	11.01	Delayed 6 d.
Tilia x vulgaris	y=0.3614x+7.6922	10.14	11.01	Delayed 18 d.

In total, the duration of the vegetation period lengthened by 7 days for oak, 33 d. for maple, 27 d. for lime, 14 d. for birch and 29 d. for ash. These results do not contradict to the findings of many other studies (Chmielewski&Rotzer 2001, Baronienė& Romanovskaja 2004, Menzel et al. 2006a, 2006b). Maple was most and oak was least sensitive to climate warming. This could be explained by a wide range of phenological alterations determined by morphological and genetic features among the different species (Penuelas et al. 2002).

Table 6. Correlation coefficients: between the end of leaf fall date and the temperature (T, oC), between the end of leaf fall date and the amount of precipitation (P, mm) in September–December

	September		October		November		December	
	T (°C)	*P* (mm)	*T* (°C)	*P* (mm)	*T* (°C)	*P* (mm)	*T* (°C)	*P* (mm)
Acer platanoides	**0.50**	-0.01	0.07	0.03	0.06	-0.29	0.16	-0.33
Betula pendula	0.08	0.29	0.05	-0.22	0.10	0.05	-0.05	0.06
Fraxinus excelsior	**0.48**	0.01	-0.27	-0.03	-0.25	-0.09	**0.44**	**0.48**
Quercus robur	0.15	0.23	-0.07	-0.16	-0.04	-0.35	0.27	-0.35
Tilia x vulgaris	**0.52**	0.14	-0.18	0.07	-0.14	-0.01	0.39	0.14

Note: values in bold type are statistically significant ($p<0.05$).

Results of correlation analysis show that the end of the leave fall phenophase was not statistically significant in most cases. However, the temperature of September had a significant positive effect (the higher temperature determining the later leave fall date) for maple, lime and ash (*Table 6*). A higher plus temperature and a greater amount of precipitation in December had a significant effect on the later ash leave fall date.

Pearson correlation coefficients were calculated for the analysis of the relation between the duration of the vegetative period and the climatic parameters (various months' temperature and precipitation amount) in 1956–2008.

Results of the correlation analysis show that the length of the vegetative period of deciduous tree species depended mostly on the increasing late winter – early spring temperature (mean statistically significant r for February, March and April was equal to0.47, 0.44 and 0.37, $p<0.05$, respectively), for some species (maple and lime) the warming late summer temperature in August (mean statistically significant $r=0.38$, $p<0.05$), while changes in the amount of precipitation had little effect (the majority of correlation coefficients were statistically insignificant $p>0.05$). A higher temperature in October had a tendency of a negative effect on the duration of the vegetative period of deciduous tree species. Significant negative correlation was estimated only between the precipitation amount in January and the vegetative period duration of birch ($r=-0.33$, $p<0.05$), also between the precipitation amount in June and the vegetative period duration of ash ($r=-0.34$, $p<0.05$). Results show a tendency that in most cases the higher precipitation amount in April–August had a negative effect on the duration of the deciduous tree species vegetative period.

Possible consequences of the lengthened vegetative period include increased biomass production, CO_2 uptake, demand for nutrient substances, etc., but it does not always lead to the better tree growth. Sensitivity of the vegetative period duration to the warming climate varied among species, which may be of great importance in adaptation processes and retaining the structure of boreal ecosystems in future, as forecasts predict the further temperature rise.

4. Conclusions

1. Mean duration of the vegetative period of observed tree species (*Quercus robur* L., *Acer platanoides* L., *Tilia x vulgaris* Hayne, *Betula pendula* Roth., *Fraxinus excelsior* L.) varied

from 186 for ash to 214 days for birch in 1956-2008.

2. The beginning of the bud swelling phenophase advanced on average from 1 for oak to 14 days for ash mainly due to the warming temperature of February (for lime, birch and ash) and March (for all species) in 1956–2008.
3. The end of the leave fall phenophase was delayed on average from 3 (birch) to 25 days (maple) in 1956–2008. That phenomenon was closely related to the increasing temperature in September (for maple, lime and ash), while the temperature rise in other months did not have any significant effect.
4. In total, the duration of the vegetative period lengthened by 7 days for oak, 33 d. for maple, 27 d. for lime, 14 d. for birch and 29 d. for ash. The vegetative period duration of deciduous tree species depended mostly on the warming late winter – early spring temperature (February–April), for some species – on the warming late summer temperature (in August), while changes in the amount of precipitation had little effect.

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Klimato kaitos poveikis penkių lapuočių medžių rūšių vegetacijos periodo trukmei

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Oro temperatūra, veikdama vegetacijos periodo pradžią, pabaigą ir šio laikotarpio trukmę, yra tiesiogiai susijusi su augalų augimo sezonu. Šio tyrimo tikslas buvo ištirti 1956–2008 m. kintančių klimato sąlygų poveikį penkių lapuočių medžių rūšių (ąžuolo – *Quercus robur* L., klevo – *Acer platanoides* L., liepos – *Tilia x vulgaris* Hayne, beržo – *Betula pendula* Roth. ir uosio – *Fraxinus excelsior* L.), augančių Kauno botanikos sode, vegetacijos periodo trukmei. Vegetacijos periodo trukmė (dienų skaičius) buvo skaičiuojama tarp fenologinių fazių, pumpurų brinkimo pradžios ir lapų kritimo pabaigos datų. Vidutinė tirtų rūšių vegetacijos periodo trukmė 1956–2008 m. svyravo nuo 186 (uosio) iki 214 (beržo) dienų. Pumpurų brinkimo fenologinės fazės pradžia vidutiniškai paankstėjo nuo 1 d. (ąžuolo) iki 14 d. (uosio). Pumpurų brinkimo fenologinės fazės pradžia buvo reikšmingai neigiamai veikiama aukštesnės vasario (liepos, beržo ir uosio) ir kovo (visų tirtų rūšių) mėnesių temperatūros. Lapų kritimo fenologinės fazės pabaiga 1956–2008 m. vidutiniškai vėlavo nuo 3 (beržo) iki 25 (klevo) dienų. Rezultatai parodė, kad lapų kritimo fenologinės fazės pabaigos ir klimato rodiklių ryšys buvo daugeliu atvejų nereikšmingas, tačiau aukštesnė rugsėjo temperatūra galėjo lemti vėlesnę klevo, liepos ir uosio lapų kritimo pabaigą (ryšys statistiškai patikimas). Lapuočių medžių vegetacijos periodo trukmę daugiausiai lėmė šiltėjanti vėlyvos žiemos ir ankstyvo pavasario (vasario–balandžio) temperatūra, kai kurioms rūšims ir šiltėjanti vėlyvos vasaros (rugpjūčio) temperatūra, o kritulių kiekio pokyčiai turėjo mažai įtakos. Iš tirtų rūšių klevo vegetacijos periodo trukmė buvo daugiausiai, o ąžuolo mažiausiai jautri klimato pokyčiams.