The 9th International Conference "ENVIRONMENTAL ENGINEERING"
22–23 May 2014, Vilnius, Lithuania
SELECTED PAPERS
eISSN 2029-7092 / eISBN 978-609-457-640-9
Available online at *http://enviro.vgtu.lt*

Section: Environmental protection

Effects of Climate Warming on Timing of Native and Non-Native Tree Species Phenology

Gintarė Sujetovienė, Irma Šveikauskaitė

Vytautas Magnus University, Vileikos st. 8, LT-44404 Kaunas, Lithuania

Abstract

The aim of the study was to investigate impact of climate warming on timing of deciduous tree species spring (leaf unfolding) and autumn (leaf falling) phenology and to compare seasonal development and growing season changes of native (*Quercus robur* L.) and non-native (*Quercus rubra* L.) tree species. Long-term dataset of phenological observations (1980–2013) from Kaunas Botanical Garden of Vytautas Magnus University (central Lithuania) were used for this study. Increased temperature was detected to be a strong driver of spring phenology for both species. It was detected that red oak had a greater response in leaf unfolding 9.5 days comparing with common oak which displayed advance by 8 days during the investigated period. Leaf fall was delayed for common oak by 13.5 days, for red oak – by 1.9 days. An advance of leaf unfolding and delay of leaf fall extended the growing season of investigated tree species. Native tree species responded more than non-native species in response of changes in temperature and the growing season for *Q. robur* extended by 21.6 days, while for *Q. rubra* – 11.4 days.

Keywords: climate warming; phenology; temperature; native species; non-native species.

1. Introduction

The climate change all over the world is unquestionable [1]. The last three decades of the 20th century can be characterized as the period of extremely rapid air temperature rise in the Northern Hemisphere [2]. These increased temperature changes can drastically affect the hydrological cycle, ocean circulation and can have serious impacts on all biota. Many studies analyzing the influence of global warming on terrestrial ecosystem reveal a consistent pattern of change and the response of phenological events to temperature fluctuations is very well investigated across the Northern Hemisphere [2, 3, 4, 5].

Trees are long lived, but not versatile organisms, so it experiences a range of environmental conditions over their lifetimes. In order to handle with various environmental conditions, trees express phenotypic plasticity in their phenology and physiology. Phenological studies is connected with climate change and usually determines the impact of seasonal and interannual variations in climate to plants life cycle events such as bud burst, leaf unfolding, leaf coloring, leaf fall etc. Warming climate has dramatically altered plant phenology worldwide. Researchers provide various comprehension and interpretation of the temperature impact on the timing of phenological phases [6, 7]. Many scientists determined that spring and summer phenophases correlate with temperatures in the preceding 1 to 3 month [8, 9, 10], whereas impact of increased temperature on autumn phenophases is not so consistent and in some cases an earlier end of growing season is detected [11, 12].

Among the factors which greatly influence plant growth activity are temperature, photoperiod, and quantity of light, temperature during the light and dark periods, nutritive conditions and water supply. Temperature and photoperiod is considered to be a major factor determining the phenology of temperate tree species [13]. Because the phenology of trees is strongly driven by environmental factors such as temperature, climate change has already altered the vegetative and reproductive phenology of many species, especially in the temperate zone. Many studies of increased temperature impact on tree phenology showed that various tree species react differently to increased temperature [12, 14]. Changes in growth or reproductive phenology have major consequences on species interactions which affect the dynamics of plant communities [15, 16]. If non-native species are better able to respond to climate changes than native species, than climate change may exacerbate species invasions across communities. Therefore, it is very important to know more about the timing of

Corresponding author: Irma Šveikauskaitė. E-mail address: i.sveikauskaite@gmf.vdu.lt
http://dx.doi.org/10.3846/enviro.2014.059

phenological events of different species respond to inter-annual variation in temperature and the general trend toward a warming climate.

Global climate models showed that future temperature during the period 1990–2100 will increase 1.4–5.8 °C depending on Emissions scenarios [1]. This rapid upturn of temperature will certainly have influence on the elongation of growing season. Some scientists determined that till the end of 2050 the leaf unfolding and the beginning of flowering depending on tree species will advance about 3–27 days [17]. Phenological observation data help us to predict the changes of plant response to climate warming. Various phenological dataset is used to show climate fluctuations. To forecast future plants development and evolutionary changes in warming climate conditions is necessary to analyze long-term phenological observation data and to evaluate the impact of climate change on the timing of plant phenological events.

There is not many studies comparing native and non-native species phenologal changes as related to climate change. The purpose of this study was to investigate native (*Quercus robur* L.) and non-native (*Quercus rubra* L.) tree species response in timing of spring (leaf unfolding) and autumn (leaf falling) phenological events to climate change.

2. Materials and methods

The analysis is based on 30 years' historical phenological observations data of Vytautas Magnus University Botanical Garden. The Botanical Garden (latitude 54 °5'N, longitude 23 °5'E, altitude 84 m) is located 3.3 km from Kaunas city center and occupies an area of 62.5 ha. The garden is remote from heavy traffic, industry and high density multi-storey urban buildings.

Long-term phenological observations were performed according standard procedures described in the Methodological Guidelines for Phenological Observation [18]. The phenological data during 1980–2013 were analyzed. This period was chosen because of the situation that continuous data series for *Q. rubra* were formed only from 1980. Earlier periods have lots of gaps in observations.

For the long-term analysis and impact of climate change (temperature) on the timing of spring and autumn phenophases two tree species: native (*Q. robur* L.) and non-native (*Q. rubra* L.) were chosen. Common oak (*Quercus robur* L.) is native to most of Europe, occurs from southern Scandinavia to the Mediterranean, and from Ireland to the Ural Mountains in Russia. *Quercus robur* is described as sun-loving and according to Elenberg H. *et al.* 1991 [19] is assigned to 7th group – exclusively sun-loving tree and are known to occur in the places more than 30% of spot lights. Common oak is soil demanding tree and grows in loam and sandy loam averaged fertility soil. The northern red oak (*Quercus rubra* L.) is a tree native to southeastern Canada and the northeastern United States, and it was introduced in the 18th and 19th centuries in central Europe. Red oak is less soil demanding compared with common oak. *Quercus rubra* as non-native species is quite common all around Lithuania. Both oak species are long lived trees: common oak lives until 600 years (rarely till 1500), red oak – until 300 (rarely till 400). Red oak is frost resistant tree, whereas common oak is more sensitive to late spring frost and sometimes is damaged by spring frost. Vulnerability to frost damage depends in part on trees sensitivity to temperature fluctuations in early spring and the timing in phenology.

In this research changes in spring (leaf unfolding) and autumn (the end of leaf fall) phenological events were analyzed. The length of the growing season is defined as the difference (number of days) between the end (leaf falling) and the beginning (leaf unfolding) of the growing season.

In the analysis of past conditions the monthly temperature data of the 1980–2013 period were used, which was provided by Kaunas Meteorological Station (Lithuanian Hydrometeorological Service under the Ministry of Environment). The Meteorological Station (latitude 54°9'N, longitude 23°8'E, altitude 76 m) is located 3.6 km away from Botanical Garden of Vytautas Magnus University.

Dates of phenophases occurrence were transformed to the number of days from beginning of the year (from 1st January). Slope of linear trend is considered as indicator of changes in timing (days per year) of investigated phenological phases. Coefficient b in a slope of linear trend indicates annual shift in phenophase (days per year). Positive slope indicates delay, whereas negative – advancement of phenophases. In order to determine the impact of mean monthly temperature on timing of investigated phenophases, correlation analysis was performed against 4 (in case of autumn phenophases) and 5 (in case of spring phenophases) previous to the phenophases months. The spring and autumn phenophases changes over the time were analyzed using linear regression. All statistical analyses were performed with STATISTICA Software.

3. Results

3.1. Temperature changes during the period 1980-2013

Fluctuation in mean year temperature observed in Kaunas Meteorological Station is presented in Figure 1. Slope of linear trend is considered as indicator of temperature changes per year (°C per year). A significant trend toward temperature increase was determined during the period 1980-2013. Throughout the study period temperature has increased by 1.49 °C (0.045 °C per year, $r = 0.47$, $p = 0{,}005$).

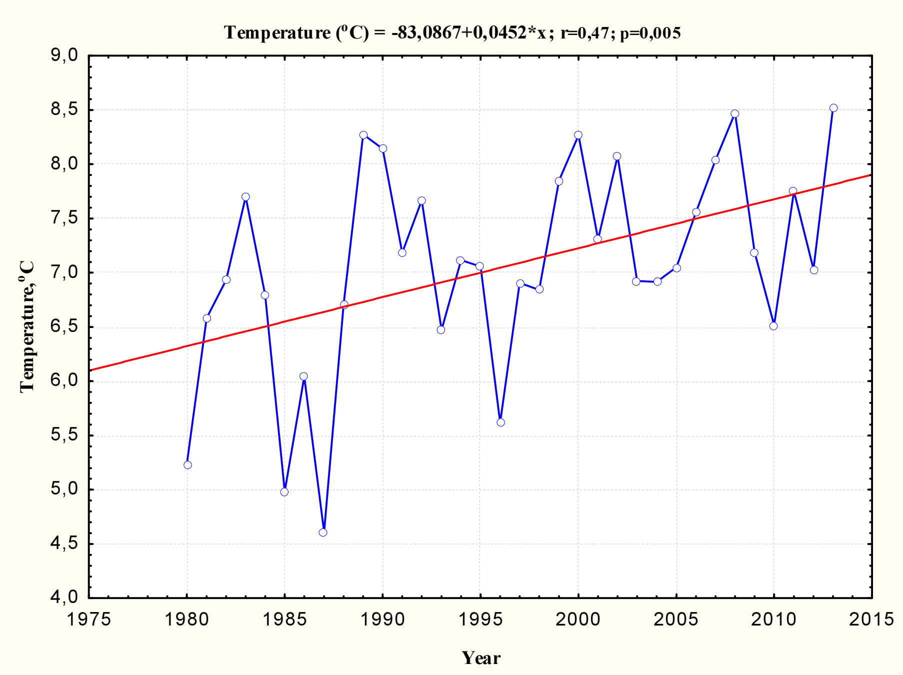

Fig. 1. Mean year temperature changes during the period 1980-2013

3.2. Relationship between temperature and occurrence of Q. robur and Q. rubra phenophases

Data on correlation of timing of spring and autumn phenophases and temperature are presented in Table 1. Leaf unfolding for native and non-native tree species was negatively correlated to mean monthly temperature prior the phenophase (Table 1.). Mean monthly temperature of April had a strong and significant ($p<0.05$) impact on timing of leaf unfolding for *Q. robur.* Correlation of leaf unfolding timing with mean monthly temperatures of two preceding months – April and May was statistically significant for *Q. rubra.*

For the autumn phenophases, leaf falling for both tree species was positively correlated with air temperature of the months previous to the phenophases. The correlation between mean monthly air temperature of September and timing of the end of leaf fall was statistically significant ($p>0.05$) for native and non-native oaks and showed medium strong influence of temperature on shift of leaf fall. The temperature rise in other months did not have any significant effect on timing of autumn phenophase.

Table 1. Correlation between mean monthly air temperature and timing of spring and autumn phenophases for the period 1980–2013 (significant correlations ($p<0,05$) are marked in bold)

Phenophase	Species	T_1*	T_2	T_3	T_4	T_5
Leaf unfolding	Q. robur	–0.1627	–0.0462	–0.2293	**–0.4970**	–0.1030
	Q. rubra	–0.2877	–0.2341	–0.3796	**–0.5760**	**–0.5223**
		T_7	T_8	T_9	T_{10}	
Leaf falling	Q. robur	0.2322	0.2509	**0.4420**	0.3830	-
	Q. rubra	0.3302	0.2498	**0.4490**	–0.1308	-

* Numbers beside the T (temperature) are values corresponding to number of month (i.e. T_1 means temperature of January)

3.3. Changes in spring and autumn phenophases

To evaluate spring and autumn phenological changes over the time linear regression was performed. Figure 2 presents data on timing of native and non-native tree species spring phenology – leaf unfolding during the period 1980–2013. Both oak species showed the advancement in leaf unfolding during the study period. The advancement of spring phenophase of *Q. robur* was 8 days during the investigated period, but this advancement was statistically insignificant ($p = 0.075$). A significant trend toward an earlier appearance of leaf unfolding was determined for *Q. rubra* and this phenophase has advanced 9.5 days throughout the study period (0.29 days per year, $r = –0.46$, $p = 0.01$).

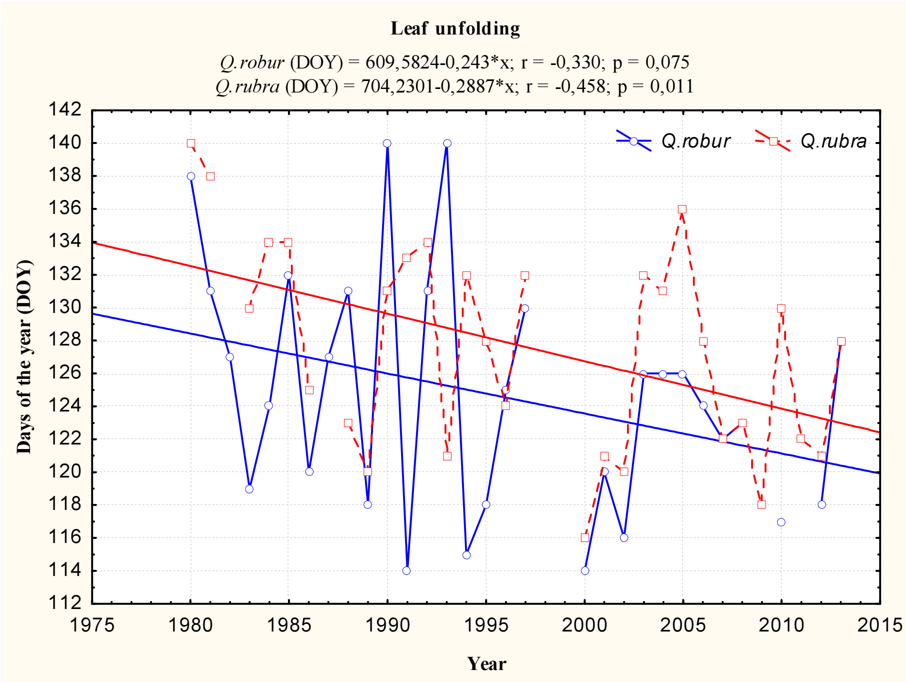

Fig. 2. Shift in spring (leaf unfolding) phenophases for *Quercus robur* L. and *Quercus rubra* L. during 1980–2013

Changes in the occurrence of both oaks species autumn phenophases (leaf falling) during the year 1980–2013 showed opposite trends compared with spring phenophases (Fig. 3). Native tree species indicated statistically significant ($p<0.05$) delay of leaf falling. The date of leaf falling of common oak delayed 0.41 day per year and 13.5 days during the investigated period ($p<0.05$). Statistically insignificant phenological changes were detected for non-native tree species. The delay of red oak was 1.9 day during 1980–2013.

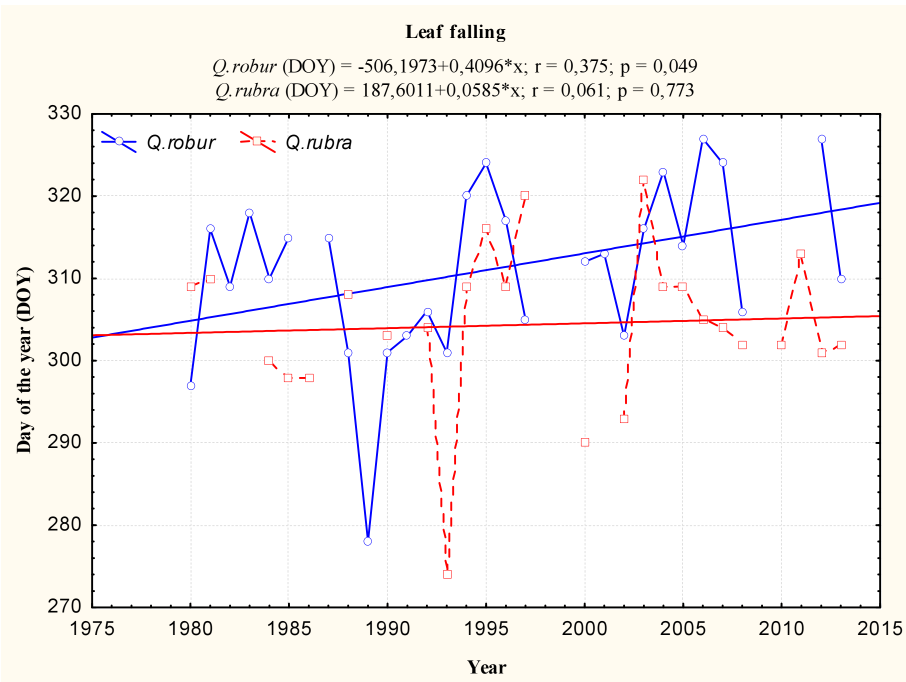

Fig. 3. Shift in autumn (leaf falling) phenophases for *Quercus robur* L. and *Quercus rubra* L. during the period 1980–2013

3.4. Changes in the length of growing season

The length of the growing season for native and non-native oak species was extended significantly due to an earlier leaf unfolding and later leaf fall. Vegetation period of *Q. robur* during the study period extended 21.6 days and the growing season for *Q. rubra* increased 11.4 days. The advancement in timing of leaf unfolding and the delay of leaf fall resulted in an annual increase in the length of the growing season by 0.65 days per year for native oak and by 0.35 days per year for non-native oak (Fig. 4).

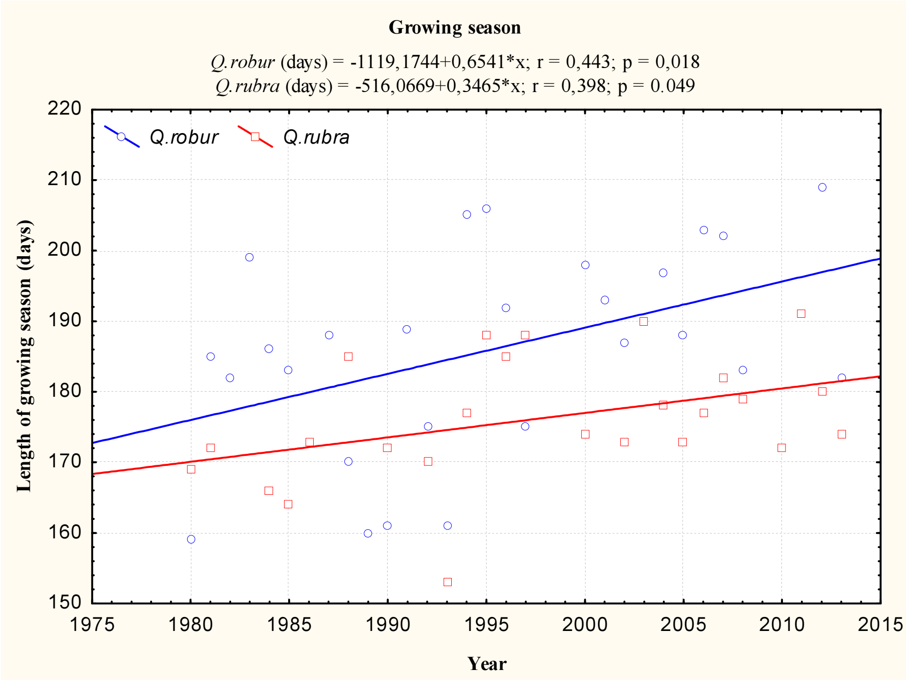

Fig. 4. Changes in the length of growing season for *Quercus robur* L. and *Quercus rubra* L. during the period 1980–2013

4. Discussion

Long-term phenological observations data of native and non-native oak species in Kaunas Botanical Garden showed different response to increased temperature. Whereas accomplished correlation analysis revealed that leaf unfolding of *Q. rubra* had a strong and significant link with temperature of two preceding months – April and May. For *Q. robur* temperature of April correlated with the date of leaf unfolding. The correlation for both species was negative and indicated that increased temperature in spring determines the earlier date of phenological events. Other researcher also investigated that variation of temperature of two or three previous to the spring phenophases months has impact on flowering and leaf unfolding time [8, 12, 20, 21].

For the autumn phenophases, leaf falling for both species was positively correlated with air temperature of the months previous to the phenophases. The correlation between mean monthly air temperature of September and timing of the end of leaf fall was statistically significant ($p>0.05$) for native and non-native oaks and showed medium strong influence of temperature on shift of leaf fall. The positive correlation indicated that decreased temperature in September has influenced the earlier timing of leaf falling. The studies of European phenological response to climate change also detected that species phenology was undoubtedly responsive to temperature of the previous to the phenophase month [14].

In this study marked changes in phenology of native and non-native oak species were detected during the study period (1980–2013). The spring and autumn phenophases changes over the time were analyzed using linear regression. Spring phenophase – leaf unfolding of non-native oak showed a greater response to temperature rise than native species. The advancement of leaf unfolding for *Q. rubra* was 9.5 and for *Q. robur* – 8 days ($p>0.05$). Since non-native oak showed more appreciable change than native oak over time, the advancement in leaf unfolding of red oak was 0.29 days per year, whereas common oak advanced 0.24 days per year. These results indicated a higher non-native oak response to increased temperature at the beginning of the growing season. Species which react faster in a warmed temperature during the early spring (in our case it is red oak), develops their buds, shoots and leaves. Some researchers results demonstrate that non-native species have been far better able to respond to recent climate change by adjusting their flowering time [22]. Advanced response to earlier, warmer spring, increases tree probability of being exposed to a spring frost [23]. Frost damage to the tree differs and depends on the stage of phenophase. It is detected that greater damage is at later phases [24].

Autumn phenophases – leaf falling were much more different and the leaf falling delay for native oak was 13.5 days and for non-native oak 1.9 day during the investigated period. The delay per year of common oak was 0.41 day and of red oak much less – only 0.06 days. Since both oak species demonstrate medium strong correlation between timing in leaf fall and September temperature, the shorter delay of non-native oak might be explained as higher sensitivity to short-term decreased temperature. This coincide the findings of other researchers, who found that non-natives are significantly better able to track seasonal temperatures than native species [22]. However, the end of the growing season – leaf fall is less well understood, because there is no united opinion about main factors influencing autumn phenophases. Scientists pay special attention to air temperature in August and September [25] and affirm that temperature predicts more of the change in the timing of visible senescence than photoperiod [25, 26].

The length of the growing season for both oak species was extended significantly due to an earlier leaf unfolding and later leaf fall. Vegetation period of common oak during the study period extended 21.6 days and the growing season for red oak increased 11.4 days. Since non-native species – red oak demonstrate higher response to temperature in early spring, the growing season extended less compared with native species. Shorter growing season of red oak depended mainly on earlier leaf fall. Common oak showed very long delay in autumn phenology. The annual increase in the length of the growing season for native species was 0.65 days and for non-native oak – only 0.35 days, much less compared with natives. Prolongation of growing season of common oak can induce essential changes in competitive ability, while higher response to temperature fluctuations of red oak might have importance on tree distribution. However, advancement of red oak in spring phenology might have importance on higher tree vulnerability of late spring frost. But it is more probable that the trees which are longer growing in fall, will suffer more from early fall frost than those that finished their growth.

In general our results suggest that native and non-native oak species will have a higher response to warming climate. However native tree species responded to increased temperature more than non-native species and the growing season for native oak extended almost double compared with non-native.

5. Conclusions

A significant trend toward temperature increase was determined during the period 1980–2013. Mean year temperature has increased 1.49^{o}C throughout the study period. Our analysis showed that there is close relationship between mean monthly temperature and phenological events. Increased temperature in early spring (April) was detected to be as a significant factor inducing advancement of spring phenology – leaf unfolding for both native and non-native species. The early autumn (September) temperature showed positive and statistically significant correlation with occurrence of the end of leaf fall for both oak species and indicated that increased temperature in early autumn determined delay of leaf fall.

Increased temperature (0.045 °C per year) determined native and non-native tree species advancement in spring phenology and delay in autumn phenology. A significant trend toward an earlier appearance of leaf unfolding was determined for non-native oak (*Q. rubra* L.) and this phenophase has advanced 9.5 days throughout the study period, whereas native oak (*Q. robur L.*) showed 8 days advancement of leaf unfolding, which was statistically insignificant ($p>0.05$). For the autumn phenophase (leaf falling) native oak showed much longer – 13.5 days delay ($p<0.05$) comparing with non-native – 1.9 days ($p>0.05$).

According to the increased temperature growing season for native and non-native oak species significantly lengthened by 21.6 days for *Q. robur* and 11.4 days for *Q. rubra*. The vegetative period duration of native oak mostly depended on the delayed leaf fall, while growing season of non-native oak – on the advanced leaf unfolding. Higher response to temperature increase was determined for native (*Q. robur*) compared with non-native (*Q. rubra*) oak species.

References

[1] *IPCC Fourth Assessment Report: Climate Change 2007* (AR4). 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 976 p.

[2] Bukantis, A.; Rimkus, E. 2005. Climate variability and change in Lithuania, *Acta Zoologica Lituanica* 15(2): 100–104. http://dx.doi.org/10.1080/13921657.2005.10512382

[3] *IPCC. 2001. Climatic Change 2001: Synthesis Report.* Summary for Policy makers. Intergovernmental Panel on Climate Change, Geneva.

[4] Walther, G. R.; Post, E.; Convey, P.; Menzel, A.; Parmesan, C.; Beebee, T. J. C.; Fromentin, J. M.; Guldberg, O. H.; Bairlein, F. 2002. Ecological responses to recent climate change, *Nature* 416: 389–395. http://dx.doi.org/10.1038/416389a

[5] Root, T. L.; Price J. T.; Hall K. R.; Schneider, S. H.; Rosenzweig, C.; Pounds, A. 2003. Fingerprints of global warming on wild animals and plants, *Nature* 421: 57–60. http://dx.doi.org/10.1038/nature01333

[6] Carroll, E.; Sparks, T.; Donnelly, A.; Cooney, T. 2009. Irish phenological observations from the early 20th century reveal a strong response to temperature, *Biology and Environment: Proceedings of the Royal Irish Academy* 109B: 116–126.

[7] Orlandi, F.; Ruga, L.; Romano, B.; Fornaciari, M. 2005. Olive flowering as an indicator of local climatic changes, *Theoretical and Applied Climatology* 81: 169–176. http://dx.doi.org/10.1007/s00704-004-0120-1

[8] Juknys, R.; Sujetovienė, G.; Žeimavičius, K.; Šveikauskaitė, I. 2012. Comparison of climate warming induced changes in silver birch (*Betula pendula* Roth) and lime (*Tilia cordata* Mill.) phenology, *Baltic Forestry* 18(1): 25–32http://dx.doi.org/10.1002/joc.821.

[9] Sparks, T. H.; Menzel, A. 2002. Observed changes in the seasons: an overview, *International Journal on Climatology* 22: 1715–1725.

[10] Menzel, A. 2003. Plant phenological anomalies in Germany and their relation to air temperature and NAO, *Climatic Change* 57: 243–263. http://dx.doi.org/10.1023/A:1022880418362

[11] Cleland, E. E.; Hiune, I.; Menzel, A.; Mooney, H. A.; Schwarz, M. D. 2007. Shifting plant phenology in response to global change, *Trends in Ecology and Evolution* 22(7): 357–365. http://dx.doi.org/10.1016/j.tree.2007.04.003

[12] Vitasse, Y.; Porte, A. J.; Kremer, A.; Michalet, R.; Delzon, S. 2009. Responses of canopy duration to temperature changes in four temperate tree species: relative contributions of spring and autumn leaf phenology, *Oecologia* 161(1): 187–198. http://dx.doi.org/10.1007/s00442-009-1363-4

[13] Sarvas, R. 1974. Investigations on the annual cycle of development of forest trees. II. Autumn dormancy and winter dormancy, *Communicationes Instituti Forestalis Fenniae* 84: 1–101.

[14] Menzel, A.; Sparks, T. H.; Estrella, N.; Koch, E.; Aasa, A.; Ahas, R.; Alm-Kubler, K.; Bissolli, P.; Braslavska, O.; Briede, A.; Chmielewski, F. M.; Crepinsek, Z.; Curnel, Y.; Dahl, A.; Defila, C.; Donnelly, A.; Fitella, Y.; Jatczak, K.; Mage, F.; Mestre, A.; Nordli, O.; Penuelas, J.; Pirinen, P.; Remišova, V.; Scheifinger, H.; Striz, M.; Susnik, A.; van Vliet A. J. H.; Wielgolaski, F. E.; Zach, S.; Zust, A. 2006. European phenological response to climate change matches the warming pattern, *Global Change Biology* 12(10): 1969–1976. http://dx.doi.org/10.1111/j.1365-2486.2006.01193.x

[15] Edwards, M.; Richardson, A. J. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch, *Nature* 430(7002): 881–884. http://dx.doi.org/10.1038/nature02808

[16] Sherry, R. A.; Zhou, X.; Gu, Sh.; Arnone, J. A.; Schimmel, D. S.; Verburg, P. S.; Wallace, L .L.; Luo, Y. 2007. Divergence of reproductive phenology under climate warming, *Proceedings of the National Academy of Sciences of the United States of America* 104(1): 198–202. http://dx.doi.org/10.1073/pnas.0605642104

[17] Chmielewski, F. M.; Muller, A.; Kuchler, W. 2005. Possible impacts of climate change on natural vegetation in Saxony (Germany), *International Journal of Biometeorology* 50: 96–104. http://dx.doi.org/10.1007/s00484-005-0275-1

[18] Gavenauskas, A.; Lamsodiene, I. 2004. *Methodical recommendation for observation of phenology.* Lithuanian University of Agriculture, 25 p.

[19] Ellenberg H.; Weber, H. E.; Düll, R.; Wirth, V.; Werner, W.; Paulissen, D. 1991. Zeigerwerte von Pflanzen in Miteleuropa, *Scripta Geobotanica* 18: 1–248.

[20] Miller-Rushing, A. J.; Katsuki, T.; Primack, R. B.; Ishii, Y.; Lee, S. D.; Higuchi, H. 2007. Impact of global warming on a group of related species and their hybrids: Cherry tree (*Rosaceae*) flowering at Mt. Takao, Japan, *American Journal of Botany* 94(9): 1470–1478. http://dx.doi.org/10.3732/ajb.94.9.1470

[21] Wielgolaski, F. E.; Nordli, O.; Karlsen, S. R.; O'Neil, B. 2011. Plant phenological variation related to temperature in Norway during the period 1928-1977, *International Journal of Biometeorology* 55: 819–830. http://dx.doi.org/10.1007/s00484-011-0467-9

[22] Willis, C. H. G.; Ruhfel, B. R.; Primack, R. B.; Miller-Rushing, A.; Losos, B. J.; Davis, C. C. 2010. Favorable climate change response explains non-native species' success in Thoreau's Woods, *PLoS ONE* 5(1): e8878. http://dx.doi.org/10.1371/journal.pone.0008878

[23] Augspurger, C. K. 2009. Spring 2007 warmth and frost: phenology damage and refoliation in a temperate deciduous forest, *Functional Ecology* 23: 1031–1039. http://dx.doi.org/10.1111/j.1365-2435.2009.01587.x

[24] Sakai, A.; Larcher, W. 1987. *Frost survival of plants: responses and adaptation to freezing stress*. Springer: Verlag, New York. http://dx.doi.org/10.1007/978-3-642-71745-1

[25] Gunderson, E. A.; Ramirez, G.; Beilock, S. L.; Levine, S. C. 2012. The relation between spatial skill and early number knowledge: The role of the linear number line, *Developmental Psychology* 48(5): 1229–1241. http://dx.doi.org/10.1037/a0027433

[26] Kramer, K. 1995. Modelling comparison to evaluate the importance of phenology for the effects of climate change on growth of temperate-zone deciduous trees, *Climate Research* 5: 119–130. http://dx.doi.org/10.3354/cr005119