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The modelling of climate change influence on plant flowering shift in Lithuania

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Abstract

The plant flowering timing is an essential tool in agrometeorology, agriculture and climatology. The flowering shift evaluation enables us to reveal the changes of plant development because of climate change. In this research we used 30 years' phenological (hazel, silver birch and small-leaved lime tree) observation data, air temperature data and output data of two different climate models (HadCM3 and ECHAM5) based on three (A1B, A2, B1) emission scenarios. By using long-term data it was shown that air temperature has impact on the beginning of selected plants' flowering, especially on that of early flowering plants. Observations of the beginning of hazel and birch flowering are an essential tool not only for agriculture. These anemophilous plants produce a huge amount of pollen and observation of the beginning of flowering is important due to the fact that increasingly more people become sensitive to the airborne pollen. Phenological and modelling data indicated that in 21st century the biggest differences are predicted for hazel. It was clearly showed that the possibility to have earlier flowering of silver birch is in the second half of 21st century and that of small-leaved lime tree – from the fourth decade.

Key words: phenology, temperature, *Corylus*, *Betula*, *Tilia*, climate models.

Introduction

The agrometeorology as a tool for successful agriculture covers classical meteorological and phenological data. However, meteorological and phenological observations are not carried out all over the world. The concern about plant development problems resulting from climate change makes us view the interactions between phenophases and meteorological factors in a different light. The climate change all over the world is unquestionable (IPCC, 2007). Climate change problems are frequently discussed by Lithuanian scientists in different scientific fields: from climatology to agriculture (Bukantis et al., 2001; Lazauskas et al., 2008). The extreme droughts and rising temperature change the development of plants and these are the reasons why agricultural productivity can decrease (Reidsma et al., 2007; Sakalauskienė et al., 2009). At the same time, the discussions about the chilling impact on vegetation season became more active (Orlandi et al., 2002; Ruiz et al., 2007). For example, Swedish scientists determined that each birch tree constantly maximizes reproductive effort, according to its capacity, but is impeded by unfavourable weather in certain years (Dahl, Strandhede, 1996). It is evident that the temperature is important for plant development. Researchers provide different comprehension and interpretation of the temperature impact on the duration of phenological phases (Orlandi et al., 2005; Carroll et al., 2009). Consequently, scientists use various base temperatures and different calculations of temperature impact on plants (Wielgolaski, 1999; Črepinšek et al., 2006).

Phenological observation data help us to forecast the dynamics of plant response to climate change. Various phenological data are used to show climate fluctuations. As a result, flowering is one of the indicators of changes occurring in plant development. For example the shift of flowering season can be related with problems in pollination (Memmott et al., 2007), plant or animal life cycle duration (Neilson et al., 2005; Dukes et al., 2009) and increasing incidence of allergy in the population (D'Amato et al., 2007). The analysis of historical data allows adjusting the climate models to modelling potential differences in plant and animal onthogenesis. A number of researches show the results of modelling by using universally accepted global climate models (Van Vliet et al., 2002; Jones et al., 2006). These models demonstrate the climate change in Lithuania (Rimkus et al., 2007).

Due to the rapid alterations in plant development it is necessary to analyse the impact of climate change on these processes. The evaluation of a possible plant response to the rise of temperature is mandatory. The modelling of the response of natural processes to the climate change makes us analyse the situation displayed by the long-term data of the research object. In this investigation we had a possibility to choose two types of phenological data because of the two phenological networks in Lithuania. One of them was initiated by prof. Nacevičius the founder of Lithuanian phenology (1975), the other was based on volunteers' observations. Phytophenological data of this network are regularly analysed by different scientists of the Lithuanian Institute of Agriculture (Kulienė, Tomkus, 1990; Romanovskaja, 2003; Romanovskaja, 2004; Kalvāne et al., 2009). Another network is under the Ministry of Environment of the Republic of Lithuania. In our study we used the long-term data stored at the Lithuanian Hydrometeorological Service (LHMS).

The aim of our research is to show the potentiality of flowering shift due to the impact of climate change by using the outputs of climate models.

Materials and methods

The research is based on 30 years' historical phytophenological data of Lithuania. For long-term analysis and impact of climate change modelling on the shift of flowering we chose *Corylus avellana* L., *Betula pendula* Roth. and *Tilia cordata* Mill. The phenological data from the 1970–1999 period were provided by the Lithuanian Hydrometeorological Service (LHMS). This period was chosen because of the situation that continuous data series were formed only from 1970. Other periods have lots of gaps in observations. Plant species for observation or sites were changed from time to time. In 2000, the observations were suspended and restarted in 2003. Phytophenological information was collected from 14 agrometeorological stations and subdivisions for hazel, from 15 for silver birch and 13 for small-leaved lime tree. In this study we used the data of the onset of flowering which is essential for analysis and interpretation of pollen dispersal in the air. Due to the fact that LHMS had some gaps in observations we had to make reconstruction in phenological data. For this reason to maintain the continuity of 30 years data and to complete the lack of the spatial distribution of flowering beginning it was necessary to reconstruct essential flowering dates according to the station similarities and location or the flowering data from Romanovskaja (2003) article (data averaged over 1961–2000). The phenological data gaps in 30 years' period were eliminated by using the data similarities of observation in the nearest stations. Due to the lack of spatial distribution (for example there was no phenological observation in costal region) the data were interpolated according to local thermal regime and the data from the stations where flowering data had been observed. Thereby for the investigation of climate change impact on flowering shift during the next 90 years we used additional data in such order: for hazel the flowering data for Klaipėda were reconstructed and for Telšiai used from published data, for silver birch for Klaipėda, Telšiai, Vilnius, Kaunas the data were reconstructed and for small-leaved lime tree for Klaipėda, Kaunas the data were reconstructed and for Vilnius were used from published data.

In the analysis of past conditions we used temperature data of the 1970–1999 period provided by LHMS from different meteorological stations. The temperature threshold was used in different level because of physiological peculiarities of plants. The first day of the year was chosen as the initial point for temperature regime analysis for plant flowering. Our decision was based on Romanovskaja and Bakšienė (2007) and Črepinšek et al. (2006). This exactly meets the requirements for hazel analysis. The estimation of temperature impact on silver birch and small-leaved lime tree flowering was started from 0°C. According to agrometeorology and phenology the threshold temperature for vegetation to start in Lithuania is +5ºC (Taikomoji fenologija…, 1983; Bagdonas, Karalevičienė, 1987). However, for the start of data analysis we chose the beginning of spring when the air temperature had reached 0ºC (Bagdonas, Karalevičienė, 1987) because we sought to find out the influence of positive temperature on the beginning of flowering of silver birch and small-leaved lime tree. *ArcView GIS 9.1* software was the main tool to display spatial view of averaged flowering dates in Lithuania during 1970–1999.

For the modelling of flowering shift during the next 90 years we used the calculation of effective temperature sum based on the different base temperatures adjusted to plant species considering accumulated heat requirements for species (0°C for hazel, +5°C for silver birch and +15°C for small-leaved lime tree). The outputs of HadCM3 and ECHAM5 climate models based on 3 different emission scenarios (A1B, A2, B1), were used for calculations of shift of phytophenological variables. A2 scenario was entitled as the most pessimistic because of the slow growth of economics and the forecast that the new technologies can be applied only in the most developed regions. If B1 scenario comes true, the climate changes will be moderate. A1B is in the middle between the two but is closer to the A2 scenario. The data for these scenarios are General Circulation Model input data usually used by world climate research centres for modelling the future climate change. Data outputs were adapted to the territory of Lithuania by using the linear and multiple regression downscaling procedure (Rimkus et al., 2007).

Results and discussion

Data analysis (based on the results of phenological observations covering 1970–1999) provides the grounds for understanding the shift of beginning of flowering of hazel, birch and lime tree all over Lithuania. The averaged dates of the beginning of flowering are presented in Figure 1.

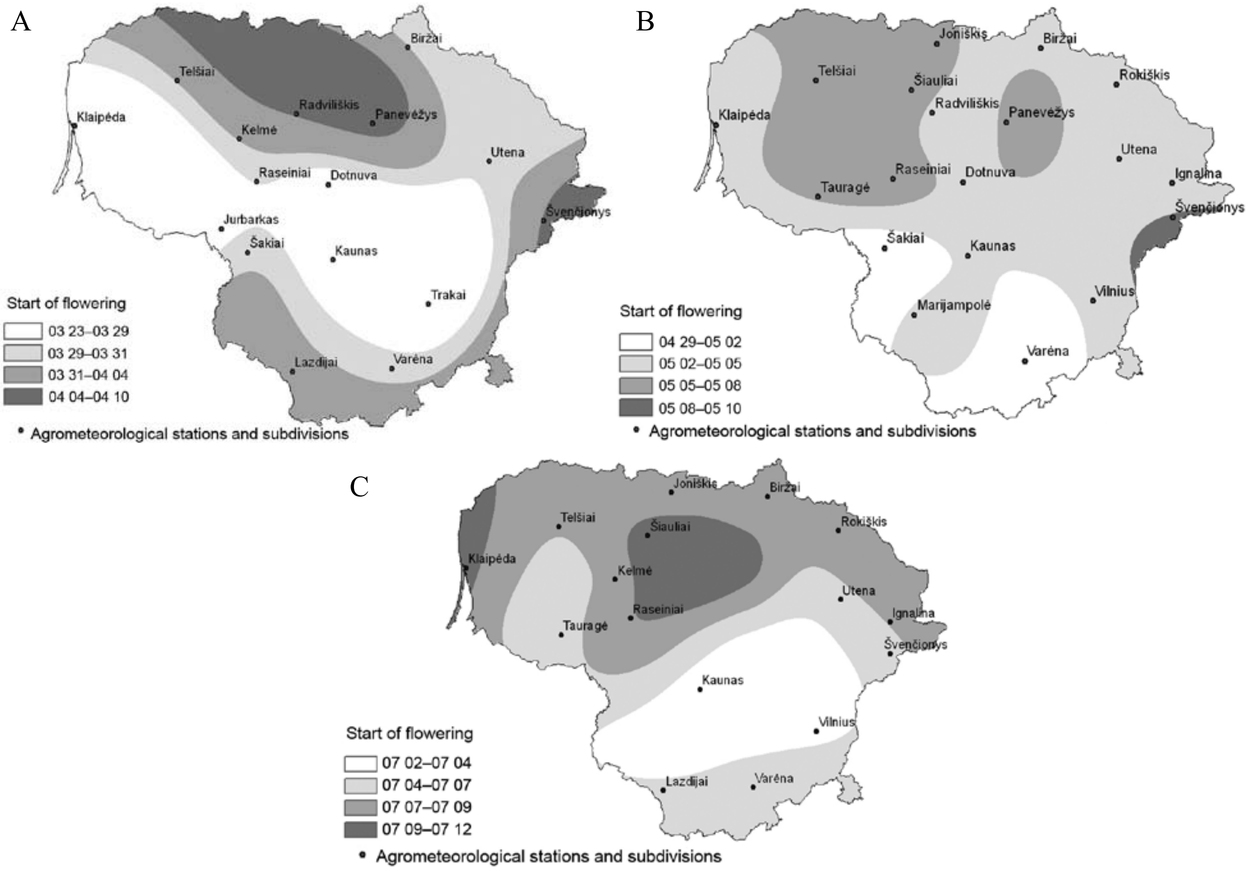

Figure 1. The averaged dates of the beginning of plant flowering during 1970–1999: A – *Corylus avellana*, B – *Betula pendula*, C – *Tilia cordata*

The onset of plant vegetation season is affected by atmospheric and soil thermal regime. Hazel, which is a phenological indicator of spring, is the plant that frequently starts flowering the earliest in Lithuania. Naturally, the beginning of hazel flowering proceeds from the South to the North of the country (Figure 1 A). Comparison of the long-term data shows marked fluctuations in the start of hazel flowering in Lithuania between years (Romanovskaja, 2004). The average derived from the 1970–1999 data of the start of hazel flowering varies slightly: approximately 10 days from the earliest to the latest date. The computed data averages reduce the possibility of analysis, but the highlighted trends are important for the modelling of plant development in the climate change conditions.

More even distribution of the beginning of flowering was established for birch: the difference between the earliest and the latest dates was 8 days. The spatial view (Figure 1 B) made of the long-term data indicates a consistent pattern that birch begins to flower in southern-central part of Lithuania. Observation of the hazel and birch flowering onset nowadays is of special relevance due to the increasing sensitivity of the population to the airborne pollen. This is a valid reason to ensure the phenological observation of *Betulaceae* family and to provide timely information on pollen count to allergy sufferers.

To explore how plant flowering and other development phases are affected by temperature variation (due to climate changes as well) we simulated the shift of the lime tree flowering beginning across Lithuania (Figure 1 C). Lime trees flower in midsummer and this phenophase is less dependent on temperature fluctuation. This is really obvious after estimation of the historical long-term data on phenological observations. Based on the LMHS data for the period 1970–1999 it was revealed that lime tree flowering in Lithuania started almost at the same time and the difference between the earliest and the latest date was determined to be 5 days. However, the analysis of the phenological observation data collected by volunteers showed this difference to be up to 9 days (Romanovskaja, 2003).

Despite the fluctuations in the dates of the beginning of plant flowering (Kulienė, Tomkus, 1990; Van Vliet et al., 2002; Romanovskaja, 2003; Menzel et al., 2006), the averaged data suggest that climate change influences the onset of plant flowering. The estimation of the averaged beginning of plant flowering based on the historical data enables us to simulate the flowering pattern under the load of the climate change.

In 1990, the problems of climate change were first analyzed on the international level (IPCC, 2007) and attention was drawn to the anthropogenic load impact on the environment with plants being one of the most significant indicators. The phenological observation data grouped according to decades exhibited the influence of climate change on the flowering shift in Lithuania. The research findings showed (Figure 2) that in the 9th decade the beginning of hazel flowering was observed in February. Compared with the oldest available records (Nacevičius, 1975), this is the earliest flowering time ever recorded. It is interesting to note, that the number of cases with early flowering of hazel doubled during the last decade of the 20th century. The analysis of the beginning of silver birch flowering evidenced the shift of flowering. Figure 2 shows that during the period from 1970 to 1979, only few events of birch beginning of flowering in April were observed. However, during the 1990–1999 period the opening of flowers in this month was more frequent (100 cases/period). For lime tree the differences were lesser under the influence of the temperature regime. Due to the fact that winter temperature rose more than summer temperature during the analyzed period (Bukantis et al., 1998), the temperature could cause the differences in the beginning of flowering of investigated plants.

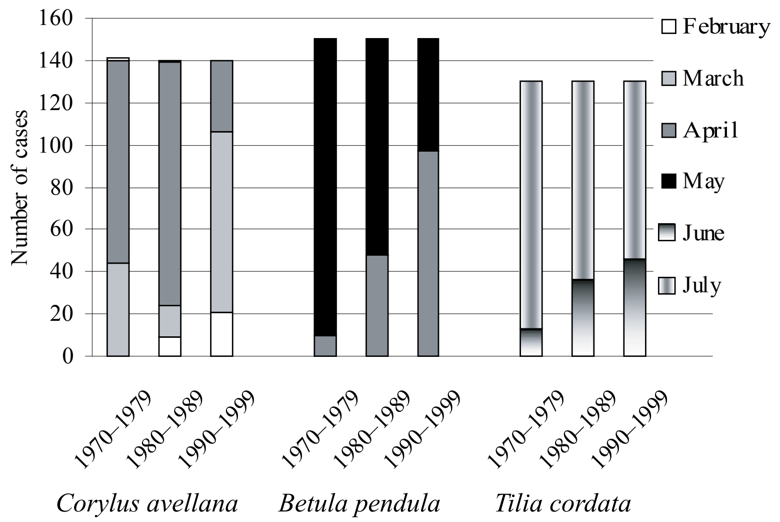

Figure 2. Plant flowering frequency by decades according to the month of the beginning of flowering during 1970–1999

Hazel as one of the earliest flowering vernal plant is definitely sensitive to the temperature variation (Menzel et al., 2006). The influence of climate change on earlier flowering, displayed through the change in temperature regime, stood out under assessment of hazel phenological data. The data presented in Figure 3 show the relationship between temperature and beginning of flowering: the more events of negative temperatures occurred before the beginning of flowering, the later was the onset of hazel flowering. The influence of negative temperatures on hazel flowering as an important parameter was noted by scientists from different countries. Slovenian scientists established that about −3°C is the lower temperature threshold (biological minimum of temperature) for investigation of the beginning of hazel flowering (Črepinšek et al., 2006). In Lithuania, the temperature regime of February and March exerts a stronger impact on the annual fluctuations of the beginning of flowering of hazel (Romanovskaja, Bakšienė, 2007). According to the long-term meteorological observation data (1961–2003), the mean monthly temperature in February was below zero and around zero in March (Galvonaitė et al., 2007), although Kulienė and Tomkus (1990) indicate that the beginning of hazel flowering is determined by temperature +4.8°C.

Analysis of 420 cases (30-year period) revealed the trend that the hazel began to flower in the middle of February only when positive temperatures prevailed from the beginning of January. This confirms the fact that the recorded extremely low temperatures (−30–−20°C) influenced the beginning of flowering. The comparison of late flowering cases and temperature regime exposed the significance of positive temperatures for flowering. Analysis of flowering data of the investigated period showed that essential temperature for birch and lime flowering was within the range 0–+5°C. It is obvious that the beginning of small-leaved lime tree flowering varied due to the temperature fluctuation from +5°C to +20°C. Therefore we can propose that lime trees require high air temperature for the vegetation. The influence of temperature on the shift of plant vegetation should not be as rapid as forecasted temperature, which, as a climate factor, will rise within the next 90 years. Due to this fact the modelling of plant flowering is based on a speedy increase of the air temperature in the end of winter. The largest increase will be observed in winter seasons (4–8°C), and not so strong in summer (1.5–3.5°C) but regional differences in temperature change would not be very high, only in winter season reaching more than 2°C (Rimkus et al., 2007).

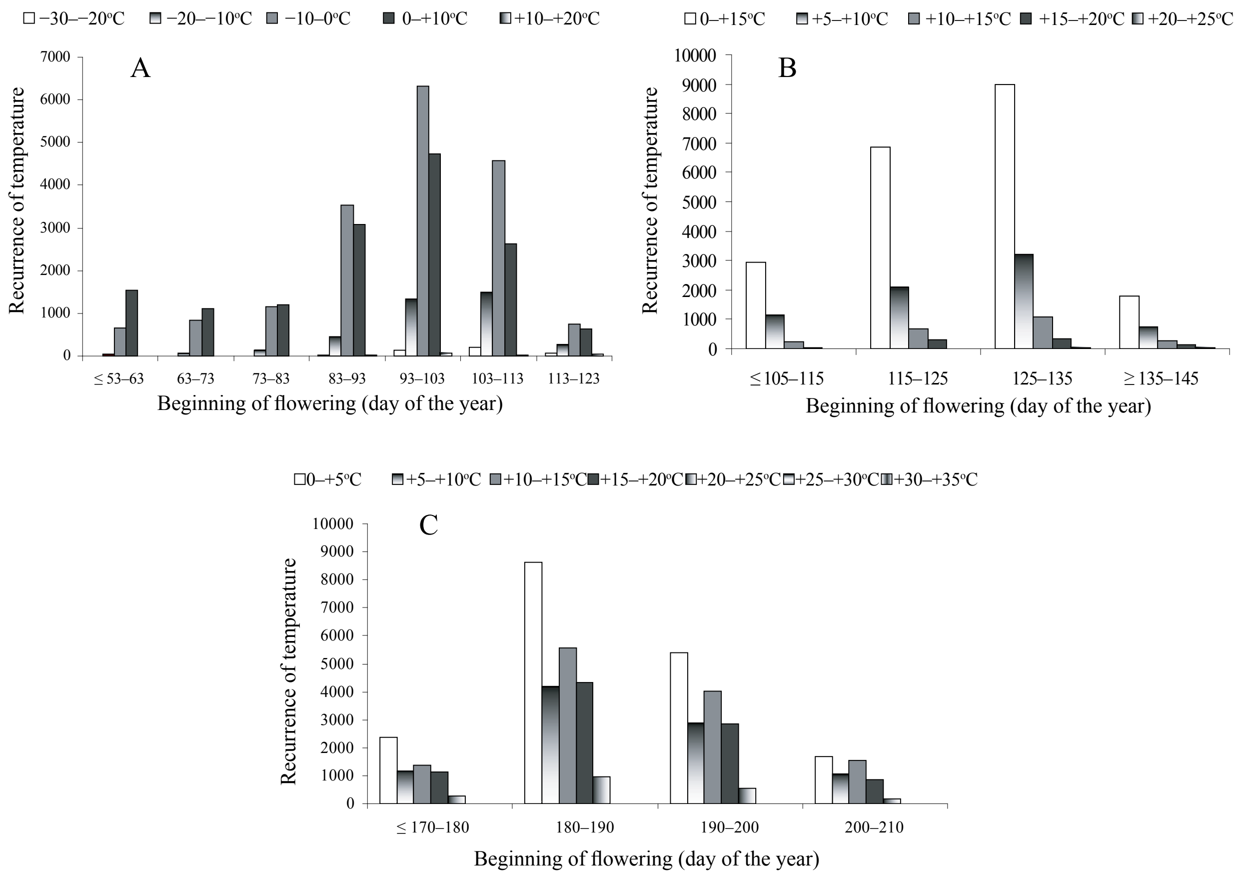

Figure 3. The influence of daily mean air temperature on the beginning of flowering during 1970–1999: A – *Corylus avellana*, B – *Betula pendula*, C – *Tilia cordata*

The modelling of climate change impact on the beginning of flowering based on the differences between historical observed and modelled data is presented in Figure 4.

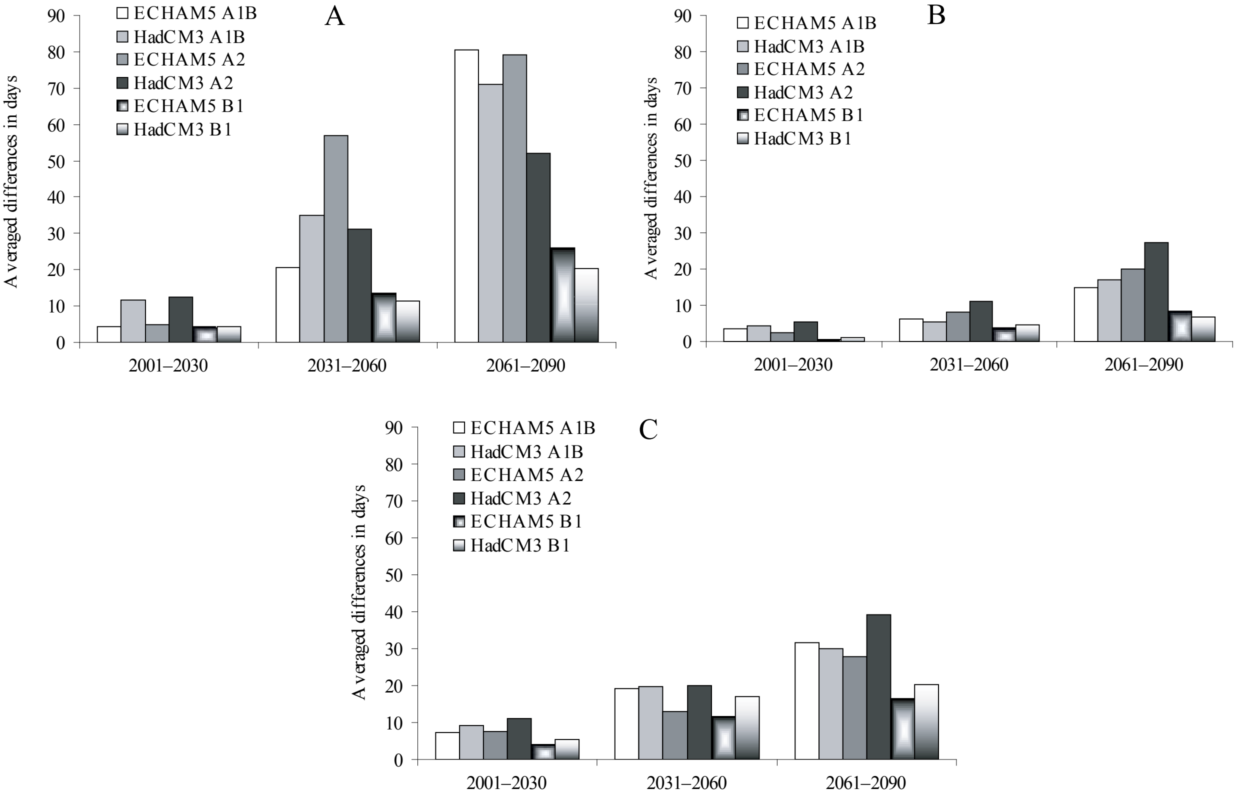

Figure 4. The changes in averaged dates of plant flowering beginning in Lithuania according to different climate models and emission scenarios: *A – Corylus avellana*, B – *Betula pendula*, C – *Tilia cordata*

The biggest differences between the long-term phenological and modelled data were established for hazel in all periods (Figure 4 A). According to the pessimistic scenarios the beginning of hazel flowering can be observed about two months earlier at the end of this century. However, if the situation develops according to B1 scenario, the changes will be lesser, but relating to the increasing of the winter temperature (Rimkus et al., 2007) the changes are unavoidable. Despite the forecast that the spring temperature will not change so rapidly, the beginning of birch flowering determined by positive temperature will not shift as significantly as for hazel (Figure 4 B). The modelling showed that the changes should be minor in the first half of the century, however according to the pessimistic scenarios; they will grow at the end of the period. The beginning of flowering can be about 25 days' earlier but the optimistic scenarios irrespective of the model used showed that the beginning of the birch flowering could shift only 8 days. Van Vliet et al. (2002) analysed the birch flower opening and obtained medium result compared with ours. They used the HadCM2 model output data based on Sa1 scenario and established that birch flowering will be about 13 days earlier. The differences between the results prevent us from managing the future events only on the basis of the forecast performed by one scenario.

At first sight, the situation with significant shift of lime tree flowering beginning seems curious (Figure 4 C) but research done by climatologists provides an explanation. The changes in summer temperatures are not less than those in winter temperatures (Rimkus et al., 2007). For this reason it is likely that during such a short time the lime tree ecophysiological characteristics will not change, but flowering time will be earlier. Our investigation shows that within the next 90 years, irrespective of the model or scenarios used, the situation can change so much that lime tree will start to flower 25 days earlier in comparison with the long-term phenological observation data.

The influence of temperature changes is only one of the factors determining the processes described in our study. To get a full view it is necessary to estimate the impact of other climate factors (precipitation, duration of sunlight etc.) on flowering.

Conclusions

1. According to the LHMS long-term phenological observations the beginning of flowering advanced by 10 days for hazel, 8 days for silver birch and 5 days for small-leaved lime tree. The changes in the date of the beginning of flowering were the most appreciable during the last decade of 20th century when the start of hazel and silver birch flowering shifted towards the beginning of the year more than that of small-leaved lime tree.

2. Estimation of the impact of the air temperature on the shift of plant flowering suggested that the more events of negative temperatures occurred before the beginning of flowering, the later was the onset of hazel flowering. The essential temperature for silver birch and small-leaved lime tree flowering is between 0°C and +5°C.

3. The B1 scenario indicated that the shift of flowering could be expected to be the least. It showed that the shift of flowering all over Lithuania in the 21st century would not change more than approximately 20 days in comparison with the long-term (1970–1999) flowering data. The pessimistic scenario (A2) demonstrated that the shift in the beginning of flowering can reach nearly two months.

4. The climate models and scenarios used in our study evidenced that during the 21st century the flowering of hazel will advance significantly. The silver birch will flower earlier in the second half of 21st century and small-leaved lime tree from the fourth decade.

Acknowledgments

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Klimato kaitos poveikio augalų žydėjimo laikui modeliavimas Lietuvoje

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Santrauka

Augalų žydėjimo laiko apskaičiavimas yra svarbus agrometeorologijos, žemės ūkio ir klimatologijos mokslų metodas. Žydėjimo datų analizė leidžia įvertinti augalų vystymosi ypatumus, atsiradusius dėl klimato pokyčių. Šio tyrimo metu buvo panaudoti 30-ies metų fenologiniai (paprastojo lazdyno, karpotojo beržo, mažalapės liepos) bei oro temperatūros ir dviejų klimato kaitos modelių (HadCM3 bei ECHAM5) išvesties duomenys, pagrįsti trimis dujų emisijos scenarijais (A1B, A2 bei B1). Panaudojus daugiamečius duomenis atskleista, kad oro temperatūra lemia pasirinktų augalų, ypač anksti pražystančių, žydėjimo pradžią. Lazdyno ir beržo žydėjimo pradžios stebėjimas būtinas ne tik žemės ūkyje, bet yra svarbus ir dėl didėjančio žmonių jautrumo oru plintančioms žiedadulkėms. Remiantis fenologiniais ir modeliavimo duomenimis nustatyta, kad XXI a. didžiausi žydėjimo datų pokyčiai bus būdingi paprastajam lazdynui. Be to, nuo ketvirtojo dešimtmečio tikėtinas ankstyvesnis mažalapės liepos, o XXI a. antrojoje pusėje – ir karpotojo beržo žydėjimas.

Reikšminiai žodžiai: fenologija, temperatūra, *Corylus*, *Betula*, *Tilia*, klimato modeliai.