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POLLEN CONCENTRATION IN THE AIR: CIRCULATING AND PHENOLOGICAL ASPECTS

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VILNIAUS UNIVERSITETAS

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ŽIEDADULKIŲ KONCENTRACIJA ORE: CIRKULIACINIAI IR FENOLOGINIAI ASPEKTAI

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Introduction

The rapid technical advance, constantly changing environmental conditions and fast scientific progress constitute an integral part of the contemporary social development. The vast scientific knowledge accrued enables an adequate estimation of the effects of the processes occurring in nature not only on the quality of natural environment but also on human activity. The connection between the welfare of the contemporary society and future changes in the context of climate change is based on the basis of evidence having a long data sequence.

Regular atmospheric pollen surveys are conducted on the basis of aerobiological data. Due to the scientific applicability and relevance of the research done, determination of the regularities of pollen dispersal in the atmosphere is increasingly attracting the attention of researchers. With joint initiative and efforts of researchers working in the fields of biomedical and physical sciences, a new interdisciplinary science is being developed.

The studies on pollen dispersal in the atmosphere are closely linked with the science of phenology. Based on the data of the long-term phenological observations, explanation of the chronological course of seasonal events has been started, various models for the assessment of changes in phenological events are being employed. In the changing climate conditions, the data of phenological observations are relevant not only for agriculture but also for the ascertainment of trends of anemophilous plants' pollen transport in the atmosphere and main dispersion principles.

One of the most relevant scientific applications of phytophenology is forecasting of pollen dispersion in the atmosphere. Research into airborne pollen is highly pertinent since part of the human population is sensitive to specific proteins that cause allergic reactions in a human body. Pollen allergens not only cause unpleasant sensations, allergy outbreaks, aggravate pulmonary conditions, but also deteriorate quality of life. As a result, these are the main aspects on which practical application of aeropalynological data analysis is validated. Another aspect of applied science about pollen dispersion is that, based on the pollen dispersion modelling and forecasting results it is possible to inform the public about the marginal values of different plants' pollen concentrations reached and the projected pollen variation trends. Establishment of flowering periods is not a less relevant part of research for forecasting, since airborne are dependent on plant flowering period. The long-term phenological observations are important for defining aeropalynological situation and assessment of climate change effects on plant vegetation. Changes in pollen dispersion are also weighty indicators of climate change, and complex analysis of aeropalynological and phytophenological data enables determination of presumptive changes for the coming century.

Objective of the research work

The study was designed to establish the variations of pollen concentration in the atmosphere and to estimate the effects of circulating and meteorological factors on pollen dispersion in the air under the changing climate conditions.

Research tasks

1. To establish the changes in airborne pollen counts in the atmosphere.
2. To compare pollen seasons with plant flowering periods.
3. To estimate atmospheric circulation and long-range air mass transport effects on pollen concentration.
4. To study the impact of meteorological factors on the variation of pollen concentration.
5. To estimate the effect of thermal regime on the start of plant flowering and, based on the long-term plant phenological data, to identify climate change effects on flowering start in the 21st century.

Propositions to be defended

1. During the vegetation season, bioaerosol pollen present in Lithuania's air is of indigenous and advective origin.
2. Air mass transport is one of the factors determining airborne pollen concentration in Lithuania.
3. Air temperature and relative humidity are major meteorological factors determining the variation of pollen concentration in the air.
4. Climate warming will advance the start of flowering dates in the 21st century.

Originality of research work

In his work, it is the first time in Lithuania: 1) based on the data from aeropalynological stations, pollen types, characterised by large counts of atmospheric pollen, have been discriminated in Lithuania; 2) relationships between the data of aeropalynological and phytophenological observations have been identified; 3) based on SILAM and HYSPLIT models, pollen dispersion in the atmosphere and long-range transport have been assessed in Lithuania; 4) the effects of air temperature, relative air humidity, amount of precipitation, wind velocity on pollen dispersion in the atmosphere have been established; 5) based on climate change forecasting data, forecasts have been made for flowering start dates in the 21st century at three-decade periods (2001–2030; 2031–2060 and 2061–2090).

Relevance and applicability of the research work

Research on pollen dispersion is relevant with respect to various aspects and provides valuable information, for example: in medicine – about the peculiarities of natural allergens' dispersal in the atmosphere; in biology – on the level of genetic information exchange; in ecology – by preliminary establishing distribution areas of certain species. The valuable data obtained can be used in the development and refinement of pollen dispersal models, which are of special relevance for people suffering from pollen – induced allergies. The regularities established in this work are important in predicting pollen concentrations in the air and are indispensable for life quality securing. The studies of pollen dispersal will form a solid basis for aeropalynological research in Lithuania, which is highly beneficial for pollen allergy sufferers and will enable evaluation of future changes related to climate change.

Plant flowering stages are significant not only for agricultural research but also for the rapidly developing aerobiology on the global scale. For a long time phenological information has been used for the determination of phytoindicators' development regularities and for the description of agricultural crops' phenophases. With the development of new interdisciplinary research trends, phytophenology has gained a new application area. Long-term and continuous plant flowering data enable assessment of the regularities related to climate change aspects and provide a basis for pollen dispersal modelling in the changing climate conditions.

Structure

The dissertation consists of the following sections - an introduction, literature review, methods and data, results, conclusions, a list of references including 242 references and annexes. The dissertation presents 14 tables and 80 figures.

Approval of results

The research findings have been presented in 8 international and 1 national conferences: the 4th International Conference "Research and conservation of biological diversity in Baltic region" (Daugpilis, Latvia, April 25–27, 2007); the 8th European Pollen Symposium (Bad Lippspringe, Germany, March 29–30); the 50th International Scientific Conference of Daugavpils University (Daugpilis, Latvia, May 15–17, 2008); the 4th European Symposium on Aerobiology (Turku, Finland, August 12–16, 2008); the 51st International Scientific Conference of Daugavpils University, (Daugavpils, Latvia, April 15–17, 2009); the 5th International Conference "Research and Conservation of Biological diversity in Baltic Region" (Daugavpils, Latvia, April 22–24); the 7th International Meeting. Pollen Monitoring Programme (Chalkidiki, Greece, April 22–27, 2009), Nordisk Aerobiologisk Förening (NAF) Symposium XII, (Copenhagen, Denmark, August 28–30, 2009); the 12th Young Researchers' Conference "Science – Lithuania's Future" (VGTU, Lithuania, April 2, 2009).

Publications

A total of five articles have been published in the publications included in the database of Institute of Scientific Information (ISI; Thomson Reuters Master Journal List), three of which in the publications, included in the ISI Web of Science database.

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Methods and data

Direct pollen measurement data (Vilnius, Klaipėda, and Šiauliai, 2004–2009), provided by Šiauliai University's Faculty of Natural Sciences, Department of Environmental Research were used for the study of aeropalynological situation in Lithuania. Airborne pollen was collected using Hirst-type volumetric spore traps sited at a height of 18–20 m above ground. To determine the aeropalynological situation in Lithuania, prevailing airborne pollen types were discriminated. Daily pollen concentration data of 37 pollen types were used to establish pollen dispersal. To define pollen seasons, a criterion of 2.5% was applied. A term of pollen index is used to describe a total pollen count in period.

The comparison of airborne pollen season and plant flowering start was based on the data of pollen concentration obtained from the three aerobiological stations and flowering start data obtained from the Lithuanian Hydrometeorological Service (LHMS), covering a period of 2004–2009. Pollen types of *Corylus* L., *Betula* L. and *Tilia* L. were chosen for the conduct of comparative analysis. Average pollen seasons were compared with the flowering start of *Corylus avellana* L., *Betula pendula* Roth, *Tilia cordata* Mill. and *Tilia platyphyllos* Scop.

Backward trajectories illustrating air mass movement were drafted using HYSPLIT 4 (HYbrid Single-Particle Lagrangian Integrated Trajectory Model) model developed by The National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL). To estimate the variation of pollen concentration (2004-2009) in the aerobiological stations, Europe was divided into 5 regions, taking into account the principles of backward trajectory representation (Fig. 1).

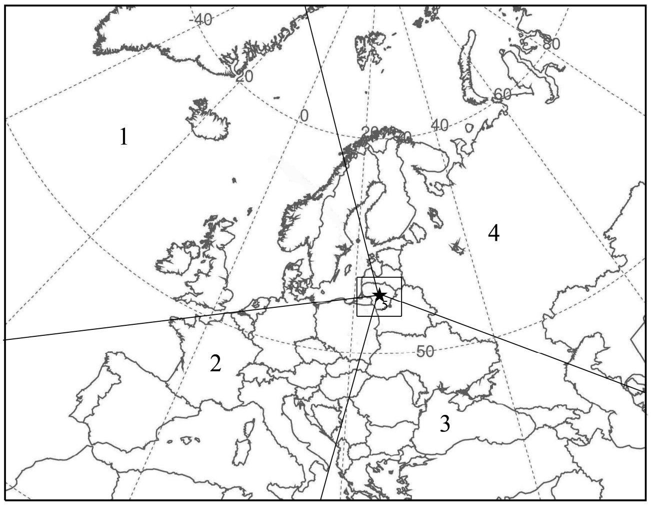

Fig. 1. Division of Europe into regions with respect to backward air mass transport trajectories

To analyse long-range transport of pollen in Lithuania were chosen pollen of *Ambrosia* and *Betula* genera. Two different models were employed to describe the possibilities of long-range transport. HYSPLIT 4 model was used to establish the long-range transport of pollen of plants belonging to *Betula* and *Ambrosia*. The Finnish Institute of Meteorology's SILAM model (Euler and Lagrange versions) was used to determine the long-range transport of pollen of *Betula* genera plants (2004-2007).

The relationship between pollen dispersal and meteorological conditions was studied using daily average meteorological data (air temperature, relative air humidity, amount of precipitation and wind velocity) for the period 2004–2009, provided by the LHMS. The data of pollen concentration and meteorological parameters were statistically processed (STATISTICA package). Using the Kolmogorov-Smirnov test were established the correspondence of pollen season data to the normal distribution. Correlation coefficients of meteorological parameters and pollen concentrations were calculated using the Spearman rank correlation method. The effects of meteorological conditions on the atmospheric pollen counts were estimated using the multiple regression analysis. In order to apply linear methods, pollen concentration data were standardised.

When examining meteorological parameters and pollen dispersal, air temperature, relative humidity, amount of rainfall and wind velocity were divided into intervals considering the values defining the variation of pollen concentrations for each pollen type. Identification of the similarities between the different pollen types was based on cluster analysis (dendograms – Euclidean distances, complete linkage method), taking into account the intervals of specific meteorological parameters expressed in percent.

Long-term phenological data (flowering start), indispensable for the establishment of plant flowering regularities, were collected from the LHMS archive. A 30-year period (1970–1999) was chosen for the analysis of climate change impact on the start of plant flowering. Taking into account data discontinuity and abundance of stations, for the analysis of flowering regularities were chosen the three plant species observed, whose data gaps is not bigger than 7 years, namely – *C. avellana* (the earliest to start flowering), *B. pendula* (later) and *T. cordata* (the latest). The gaps present in plant flowering data were reconstructed using the information from the adjacent stations, taking into account the thermal regime. For some plant species their flowering data were supplemented by the published data.

For the analysis of past conditions we used the data of flowering start and temperature data from different meteorological stations, provided by the LHMS.

Standard deviation for flowering start, mean long-term value, median, mode, mode frequency were calculated. To assess the shift of the start of plant flowering over the 1970–2009 period, linear trends were established whose significance was estimated using Student's criterion (t). To assess the temperature effect on flowering advancement were distinguished warm and anomalously warm months in Biržai (according climate norm 1961–1990) over the period 1970-1999.

For the establishment of air temperature effects on phytophenological stages were used methodologies refer to Bagdonas, Karalevičienė (1987), McMaster, Wilhelm (1997), Snyder et al. (1999) and V. Jato et al. (2004). Calculation of active temperature was based on the following equations:

$T_a = T_{mean}$, if $T_{mean} \geq T_b$ [1]

$T_a = 0$, if $T_{mean} < T_b$ [2]

where: T_a – active temperature (°C), T_{mean} – mean daily air temperature (°C) and T_b – biological temperature minimum or threshold temperature (°C).

Based on equations 1 and 2 were calculated period's active temperature sum (T_{sum}), which is illustrated as $T_{sum} = \sum_{i=1}^{n} T_{ai}$.

T_{ai} describes active temperature for i-th case.

Effective temperature (T_e) was calculated using the following equations:

$T_e = T_{mean} - T_b$, if $T_{mean} > T_b$ [3]

$T_e = 0$, if $T_{mean} \leq T_b$ [4]

There were calculated the study period's effective temperature sum.

One of the calculations indicating active temperature sum (GDD_1), is based on minimal and maximal daily air temperature values ($T_{i,\min}$, $T_{i,\max}$):

$$GDD_1 = \sum \left(\left(\frac{T_{i,\max} + T_{i,\min}}{2} \right) - T_b \right) \qquad [5]$$

If the calculated part $[(T_{i,\max} + T_{i,\min}) \times 0{,}5] < T_b$, then $[(T_{i,\max} + T_{i,\min}) \times 0{,}5] = T_b$.

Also, using equation 5 it is possible to develop the fourth active temperature calculation methodology (GDD_2), which was used in this work. In this case, other conditions are met: if $T_{i,\max} < T_b$, then $T_{i,\max} = T_b$ and if $T_{i,\min} < T_b$, then $T_{i,\min} = T_b$.

When detailing the above-described methods were applied also a single triangle calculation method, which is composed of three separately calculated equations:

$$^{o}D = 0 \text{, when } T_b \geq T_{max} \quad [6]$$

$$^{o}D = \left(\frac{T_{max} - T_b}{2}\right)\left(\frac{T_{max} - T_b}{T_{max} - T_{min}}\right) \text{, when } T_{min} < T_b < T_{max} \quad [7]$$

$$^{o}D = \left(\frac{T_{max} + T_{min}}{2}\right) - T_b \text{, when } T_b \leq T_{min} \quad [8]$$

Based only on maximal daily air temperature were calculated heat requirement (HR):

$$HR = \sum (T_{max} - T_b) \text{, when } T_{max} \geq T_b \quad [9]$$

$$HR = 0 \text{, when } T_{max} \leq T_b \quad [10]$$

Air temperature analysis was chosen for the assessment of the effects of future climate changes on the beginning of plant vegetation. Different active and effective temperature calculations were used which define the thermal regime necessary for vegetation. Temperature sums were calculated: in the case of *C. avellana* at 0°C, *B. pendula* at 5°C and *T. cordata* at 15°C.

For the establishment of climate change impact on flowering stages were used prognostic air temperature output data from ECHAM5 and HadCM3 climate models. When establishing the flowering period of *C. avellana*, *B. pendula* and *T. cordata* for the 21st century were used several greenhouse gas emission scenarios (A1B, A2 and B1). Aiming to better reveal climate change effects on the onset of flowering of different plant species in Lithuania, the 21st century was divided into 30-year periods (2001–2030, 2031–2060, 2061–2090). The difference of the predicted dates of the start of flowering from the long-term average (1970–1999) first flowering date was calculated.

To illustrate the spatial distribution of average first flowering dates (1970–1999) in the territory of Lithuania were used an ArcView GIS 9.1 software package. Maps of the first flowering date difference of the three different periods of *C. avellana*, *B. pendula* and *T. cordata* were made.

Analysis of atmospheric pollen dispersion

Based on the pollen counts recorded at the aerobiological stations, several dominating (2004–2009) pollen types in Lithuania were discriminated. It was found that high concentrations of *Betula* L., *Pinaceae* Lindl., *Urticaceae* Juss., *Alnus* Mill., *Poaceae* R. Br. Bernhart, *Artemisia* L. pollen are identified in the air. The highest diversity of pollen types (13 out of 37 observed) according to the abundance of pollen was noted in Vilnius environs, while as few as 9 pollen types were recorded in Klaipėda.

The length of the average pollen season in Lithuania ranges from 28 to 83 days. The shortest average pollen season (16 days) was identified in Klaipėda during the flowering of plants of *Secale* L., while the longest (97 days) during the flowering of plants of *Cupressaceae* Rich. Ex Bartl. In Vilnius, the shortest pollen season (25 days) was recorded for *Betula*, the longest (90 days) for *Poaceae* plants; in Šiauliai the shortest pollen season (25 days) was recorded for *Acer* L., the longest (91 days) for *Plantago* L. The pollen season was found to vary within the same plant genus or family depending on the locality/site.

In Lithuania, the highest pollen counts in the air are generally recorded during the period from April to August. Each month, different pollen counts are recorded at the aerobiological stations. In April, during the 2004–2009 period, the average pollen concentration in Vilnius was 292 grains/m^3, in Klaipėda – 152 grains/m^3, and in Šiauliai – 173 grains/m^3. The average pollen concentration in May in Vilnius amounted to 502 grains/m^3, in Klaipėda – 368 grains/m^3, and in Šiauliai – 250 grains/m^3. In terms of years and months, the highest pollen concentrations were recorded in May 2006, which exceeded the annual average pollen concentration of May by 2–3 times in the aerobiological stations. This sharp change was determined by the pollen of pants of *Betula* genus.

Aerobiolgical data suggest that atmospheric pollen counts in April during the 2005-2009 period were formed by the pollen of *Betula*, *Alnus*, *Populus* L., *Salix* L., *Fraxinus* L. and *Corylus*. In May, the highest atmospheric pollen counts come from the plants of *Betula*, *Pinaceae*, *Quercus* L., *Salix* and in some cases – *Acer*, *Alnus* genera and families. In June, pollen counts rather variable in pollen types were recorded in all aerobiological stations. In Lithuania, in general rather considerable pollen counts are recorded for *Poaceae* and *Urticaceae* plants. Compared with May – June months, lower pollen concentrations are recorded in July – August. The atmospheric pollen counts during this period are determined by late-flowering plants' pollination. In July–August, the highest atmospheric pollen counts come from grass family plants (*Urticaceae*, *Poaceae*, *Artemisia*, *Rumex* L., *Chenopodiaceae* Vent., *Solidago* L).

The data of aerobiological stations show pollen concentration variations not only between years but also between stations. Compared with other stations, the highest pollen counts of *Betula* genus plants (pollen index 35 804) were recorded in Klaipėda station in 2006. The data from Vilnius aerobiolgical station indicate that high *Betula* pollen concentrations are recorded annually. Vilnius is distinguished by high pollen concentrations from *Pinaceae* family plants (pollen index 5 684–11 431). The variations of atmospheric pollen counts in different localities of Lithuania can be determined by the distribution of plants and meteorological conditions during pollination period. Compared with other years, 2006 was characterised by high air temperature (13.1–13.4°C during pollen season), low rainfall rate (1.2–2.3 mm) and relative air humidity (42.5–57.2%) which resulted in high *Betula* pollen counts in the air.

Considering the various pollen types, the highest daily pollen concentrations are very diverse. The maximal pollen concentrations in Lithuania over the 2004–2009 period were found to range from 2 grains/m^3 (for plants of *Humulus* L. genus) to 4680 grains/m^3 (for plants of *Betula* genus).

Betula pollen levels that cause conjunctivitis and rhinitis (81–252 grains/m^3) are often exceeded in Lithuania. During the 2005–2009 period, in Vilnius there were 91 days when the pollen concentrations causing unpleasant sensations (35 grains/m^3) were exceeded. During 2004–2009, in Klaipėda this concentration was exceeded for 88 days, in Šiauliai for 105 days. Different pollen counts of *Poaceae* family plants can cause hay fever symptoms. A pollen count of 50 grains/m^3 can inflict negative sensations for allergic people. Based on the data from the aerobiological stations, the highest daily pollen concentrations often exceed this value by nearly 4–6 times in Lithuania.

Analysis of airborne pollen season and flowering start dates

When estimating atmospheric pollen dispersal it is important to identify the phenological aspect, i.e. the importance of flowering regularities for the pollen season of certain plant genera and families. Having compared the flowering of *C. avellana* and the length of pollen season of the plants of *Corylus* genus it was ascertained that the data of phenological observations cannot represent the pollen season of *Corylus* genus.

Flowering start of *C. avellana* is established earlier than the maximal pollen concentrations are recorded in the anaerobiological stations. Only *C. avellana* occurs spontaneously in Lithuania, consequently, adequate phenological observations of this species are relevant for the analysis of pollen dispersal of *Corylus* genus. Comparison of pollen season and flowering start dates revealed that the LHMS phenological observations network for 2004–2009 was insufficient and non-representative.

Comparative analysis between the atmospheric pollen concentration of *Betula* genus and phenological information indicated that for the plants of *Betula* genus the average pollen season partly coincides with the flowering start of *B. pendula* in Lithuania. However, some cases were established when pollen season started prior to the start of plant flowering in Lithuania. This is one of the long-range transport examples. In Lithuania, the length of the pollen season of the plants of *Betula* genus varied by several days' interval between the three aerobiological stations. This means that like for *Corylus* genus plants, for *Betula* it is not possible to choose one phenological station, which would represent the pollen data of one aerobiological station. Compared with the phenological network of *C. avellana*, the network of LHMS phenological stations of *B. pendula* is representative and can be used when estimating the pollen dispersal of *Betula* genus plants.

In Lithuania, only small pollen concentrations of *Tilia* genus are recorded since the pollen of this genus is not adapted to being carried by wind. Irrespective of this, pollen concentration and phenological data comparative analysis showed that the pollen seasons of *Tilia* genus does not coincide with flowering start in Lithuania. One of the reasons why pollen season and flowering start do not coincide in Lithuania could be limited application of the 2.5% criterion. Yet, the phenological network of *T. cordata* and *T. platyphyllos* observed by LHMS, can illustrate, with some exceptions, the variation of recorded pollen of *Tilia* genus in Lithuania.

The evaluation of air mass and long-range transport effect on pollen dispersion

The results (January – September) of backward air mass trajectory modelling evidence that Lithuania is reached mostly by the air masses (Europe region 1), that most frequently form above Iceland and travel over the Atlantic Ocean through Great Britain, the Norwegian Sea, Denmark, Norway, Sweden and the Baltic Sea (35–45 %) (Fig. 1). A lower percentage (26–28 %) accounts for the air masses moving through Central Europe (Europe region 2). The systemised data from 6 years showed that quite a fair cases are established when backward trajectories illustrate air mass transport over the continent, i.e. over Europe's territories in which communities of different plants, potential sources of pollen, prevail.

The general regularities of pollen dispersal in the air were defined considering the Europe's region over which air masses travelled and air transport directions with respect to the aerobiological station. When linking the highest pollen concentrations with air masses we can see a very similar picture between the air masses that had arrived and the air masses that determined higher monthly pollen index values. More than half of the cases established are linked with transport from Europe region 1 and 2: up to 78% account for backward air mass trajectories that reached the aerobiological stations and up to 83% of pollen is recorded when backward air mass trajectories indicate air mass transport direction from the mentioned regions.

In some cases it occurs that an increase in atmospheric pollen counts depends on the spread of different air masses and the highest concentration recorded in the case of non-prevailing air mass. The highest differences were determined in spring when Europe 1 region accounted for 35 % of the total estimated cases and 22 % –Europe 2 region, whereas the highest pollen counts were recorded when the air masses arrived namely from Europe region 1 (69 % of the total cases). In March –September months, small differences (up to 14 %) were observed between atmospheric circulation and backward air mass trajectory direction which stipulated higher pollen counts in the aerobiological stations.

The comparison of pollen data from Vilnius aerobiological station with the data of air mass backward trajectories revealed that taking into account pollen types, different pollen counts are recorded during the season when air masses reach the station after travelling over various regions of Europe. Higher pollen counts are recorded on the days when backward trajectories illustrate air mass movement over Europe regions 2, 3 and 4.

Analysis of the obtained results suggests that *Ambrosia* and *Brassicaceae* Burnett pollen seasons are noted for higher pollen counts when air masses reach the aerobiological station by moving over Central Europe (region 2). Pollen seasons of *Ulmus* L. and *Solidago* genera stand out by the fact that the highest pollen concentrations were recorded when air masses reached Vilnius aerobiological station by travelling over Europe region 3. The pollen seasons of *Betula*, *Salix* and *Acer* genera in Vilnius aerobiological station exhibit high concentrations when air masses reach the station by moving over Europe region 4.

Similar trends were established in Klaipėda aerobiological station, however, in some cases we can distinguish different specific features that depend on Klaipėda's geographical position and distance from the Baltic Sea. In Klaipėda, like in Vilnius, higher concentrations of *Ulmus* and *Solidago* pollen are recorded when air masses arrive from Southeast Europe, whereas higher pollen counts of *Fagus* L., *Betula* and *Salix* genera are recorded when air masses reach the aerobiological station from Europe region 3.

Similar pollen dispersion regularities were established in Šiauliai. *Betula* and *Salix* pollen seasons were noted for higher pollen concentrations that were recorded when backward trajectories illustrated air mass transport from Europe regions 3 and 4. For *Fagus* genus plants, the results of pollen count variation and direction illustrated by backward air mass trajectory concur with those obtained in Klaipėda. *Solidago* genus pollen count relationships with backward trajectories evidenced that in Šiauliai the regularities were the same as in the earlier-mentioned stations. *Ulmus* pollen season was distinguished by higher pollen concentrations when air masses that reached the aerobiological station had been travelling over Europe region 4.

Having established pollen dispersion regularities and considering the results of backward air mass trajectories it is seen that the variation of atmospheric pollen counts depends on air mass transport from certain regions of Europe. The generally established prevailing air mass transport (e.g. Europe region 1) partially determines the size of pollen concentrations that are recorded in the aerobiological stations. This is influenced by the air mass transport over certain territories with abundant communities of the plants under observation.

There were selected two pollen types – *Ambrosia* and *Betula*, which are suitable for the illustration of long-distance transport mechanism in Lithuania. The plants of *Ambrosia* genus do not naturally occur in Lithuania, they partially can be treated as invasive plants. Since 2004, when collection of systematic aerobiological information was started, it has been noticed that increasingly higher counts of *Ambrosia* pollen are annually recorded in Lithuania. The year 2008 stands out by the highest *Ambrosia* concentration in Vilnius. Having estimated the period when ragweed pollen was recorded it was established that on separate days pollen catches were especially high. A maximal concentration of 61 grains/m^3 was recorded on September 7 and it accounted for 27 % of the pollen count of the whole period. It is likely that pollination of *Ambrosia* plants growing in Lithuania could not produce the recorded counts of pollen, therefore for all ragweed pollen record cases we analysed the chances of long-range pollen transport.

Analysis of backward trajectories showed that there was no precipitation in the path of air masses, therefore the pollen carried from Central Europe might be recorded in Vilnius aerobiological station. Plant pollen long-range transport to Lithuania is possible with the air masses that move from Europe region 3, covering Romania, Bulgaria, Macedonia and Serbia. The results of backward air mass trajectories illustrate that air masses from this region reach Lithuania rarely – hardly 7 % over the study period. Yet, there is a chance that atmospheric pollen counts of *Ambrosia* can increase if during plant flowering period air mass transport from this region persists for a longer time.

Records of *Betula* genus pollen before the start of flowering of local plants provide another example of long-range transport. The earliest recorded pollen concentrations are determined before the earliest phenological start of flowering date; however, the greatest differences were established in 2004. Long-range transport period that year lasted for 2 weeks. Twenty four cases were selected when it was possible to state that during 2004-2007 *Betula* genus pollen in Lithuania was recorded due to the long-range transport. To evaluate the mechanism of the long-range transport in Lithuania were chosen the most representative days of those years. In 2004, on April 12–13 both SILAM versions (Euler and Lagrange) showed northwest transport direction when air masses moved through Sweden and Norway and south Denmark. HYSPLIT results revealed that *Betula* pollen concentrations recorded on both days might have arrived with the air masses from western Latvia, Central Sweden and Norway. On April 12, southern Sweden might have been the source of pollen. Yet, beginning of April is an early period for the flowering start of *Betula* in the mentioned territories, except for south Sweden or Denmark.

Other long-range pollen transport episodes were distinguished on April 18–21. Pollen counts in Klaipėda aerobiological station increased on April 18 (Fig. 2), when high pollen concentrations originated from central and east Europe. Another episode of *Betula* pollen increase was recorded on April 21, when pollen might have arrived from Denmark, Germany, Poland, Belarus, Ukraine and Moldova.

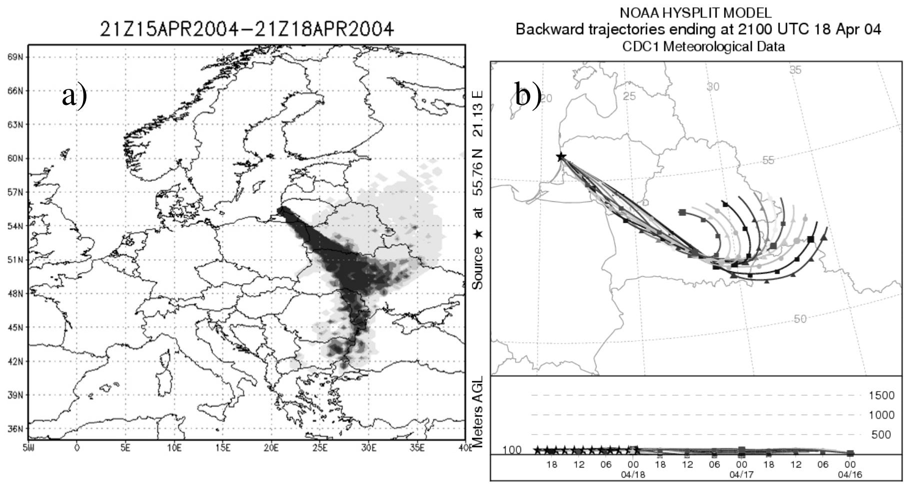

Fig. 2. The predicted footprint for *Betula* pollen and air masses that arrived at Klaipėda aerobiological station on April 18 of 2004: a) Lagrangian SILAM, c) HYSPLIT backward air mass trajectories

On April 24, high pollen concentrations (> 800 grains/m^3) were recorded. The results of modelling evidenced that the *Betula* pollen recorded in Klaipėda might have arrived from west Latvia, and in Šiauliai the *Betula* pollen might have arrived from southeast Latvia, north Belarus and Russia. Yet, such high pollen counts are more likely to have been produced by indigenous plants.

In 2005, high *Betula* pollen counts were recorded on April 26 and April 28–30 in Vilnius aerobiological station. Based on the results of all models it is most likely that pollen reached Vilnius aerobiological station from south Finland and west Latvia. The results indicated the pollen to be of local origin. In 2006, a peak of pollen concentration in all aerobiological stations was recorded on April 25. SILAM model data suggest that the most probable source of pollen recorded in Šiauliai aerobiological station is related with south, southeast direction (from the aerobiological station) parts of Poland, Belarus and north Ukraine. In 2007, on April 15, the results of both models (SILAM and HYSPLIT) indicated that pollen source should be in north Europe, however, this is not plausible since flowering is much later in those regions compared with Lithuania.

The effect of meteorological conditions on pollen dispersion in the atmosphere

When analysing the possible effects of air temperature, relative air humidity, rainfall amount and wind velocity on the dispersion of pollen of the plants of different genera and families, first of all were established the relationships between the meteorological parameters and pollen concentration during the pollen season (2004-2009). From the obtained results it is evident that pollen concentrations of various plant genera and families relate differently with air temperature (Fig. 3 a). However exists a correlation between airborne pollen concentration and air temperature (67% of all cases, p<0.05) according to the data of all aeropalynological stations. Most of the calculated correlation coefficients were positive (58%, p<0.05), which suggests that atmospheric pollen concentrations increase in line with increasing air temperatures.

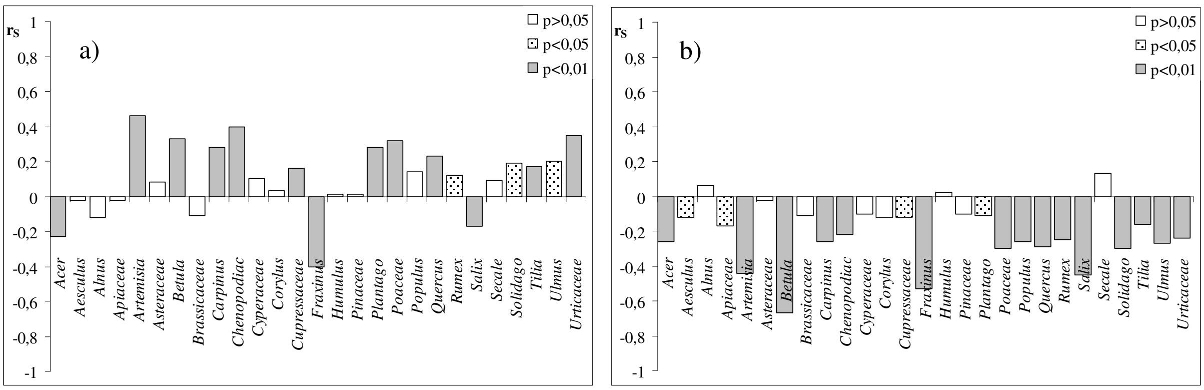

Fig. 3. Correlation coefficients (r_s) of pollen concentrations of plants of various genera and families during the pollen season and air temperature (a) and relative air humidity (b) in Vilnius (2005–2009)

The presented results (Fig. 3 b) revealed that there were obtained statistically significant negative correlation coefficients between the pollen of nearly all plant genera and families recorded in Vilnius and relative air humidity during the pollen season. Most of the calculated correlation coefficients were significant (79% of all cases, p<0.05) according to the data of all aeropalynological stations. Only a very small part exhibited statistically insignificant relationship or statistically insignificant positive correlation coefficients between the mentioned parameters. The obtained results enable us to maintain that pollen counts in the air decline with increasing air humidity.

The results of the correlation coefficients of the amount of rainfall and pollen concentration showed that in about 50% of the studied cases were established significant ($p<0.05$) very weak, weak or moderately strong relationship (from -0.12 to -0.49) between the latter parameters.

Correlation method was used to determine that wind velocity effect on pollen concentration is inappreciable, i.e. over 31% of the tested cases demonstrated significant ($p<0.05$) very weak or weak relationship between pollen concentration and wind velocity.

Multiple regression analysis was used to measure the effects of meteorological parameters. General (2004–2009) derived regression equations ($p<0.01$) describe on average 1-46% of pollen data variation. The obtained low determination coefficients do not reduce interpretation of results. Yet, considering the fact that the equations were made observing the principle that the significance level not only of the equation itself but also of the variables would meet the condition that $p<0.05$, the obtained results may be a proof of meteorological parameters' effect on pollen dispersion. It is difficult to derive a linear relationship between pollen and meteorological parameters (which is also suggested by the low correlation coefficients established), however the obtained results indicate that meteorological conditions determine the variation of pollen count.

The findings evidenced that pollen concentration variation is mostly related to relative air humidity (24 cases of 57, $p<0.01$); however, we can discern the effects of other meteorological parameters, i.e. air temperature (6 cases, $p<0.05$) or the complex of meteorological parameters (27 cases, $p<0.05$). For example, air temperature, wind velocity, and relative air humidity (7 cases), air temperature and relative air humidity (7 cases), wind velocity and relative air humidity (5 cases) or air temperature and wind velocity (3 cases). Considering the results of correlation coefficients of wind velocity and pollen concentration, the multiple regression analysis done revealed that wind velocity is not the most important factor determining pollen dispersion, however, in combination with other meteorological factors, it does affect the pollen catch in the trap.

The results of multiple regression analysis displayed pollen concentration regularities related to the major meteorological conditions. Made equations are not designed for making future predictions, but they are the way allowing presentation of analysis of meteorological parameters' effect on pollen distribution in the air.

The statistical methods employed revealed the importance of meteorological parameters for pollen dispersion, however, they did not indicate which specific meteorological conditions determined pollen catch in traps. The highest *Alnus* pollen concentrations are recorded when the air temperature varies within the 10–15°C range and relative air humidity is low (30–40%). High concentrations of *Betula* pollen are recorded when the air temperature ranges within 15–20°C and the relative air humidity is low (30–40%), whereas for *Pinaceae* at 20–25°C, and relative air humidity 40 60% and 80–100%. The highest pollen counts of *Quercus*, *Salix*, *Acer* genera and *Cupressaceae* family are recorded at low relative air humidity (30–40%). Higher pollen concentrations of *Humulus*, *Secale* and *Solidago* genera plants were established at a relative air humidity of 80–100%. Since during the pollen season the pollen concentrations of these plants are very high we cannot maintain that pollen dispersion is the best at high air humidity.

Analysis of precipitation amount and recorded pollen concentrations indicated that pollen is being recorded even when it is raining. Long-lasting rain cleans the air and precipitates pollen, while short rain does not exert any marked effect on the daily pollen counts recorded.

The highest pollen counts are recorded at a wind velocity range of 0–5 m/s, however some cases occur when high pollen concentrations are recorded even at relatively high wind.

The analysis of variation of plant flowering start dates and thermal regime

In order to estimate the changes in pollen season length in the context of climate change, it is necessary to establish the variations in flowering time in Lithuania and temperature effects on the fluctuation of plant flowering start dates.

C. avellana is a phenoindicator of spring, its flowering start moves in a regular pattern from Lithuania's southwest towards north. Having compared *C. avellana* flowering variations during 1970–1999, it was found that plant flowering start average varies inappreciably – about 10 days from the earliest to the latest date. Analysis of the regularities of *B. pendula* flowering start (according to the averages of flowering dates), revealed a more even flowering start distribution compared with *C. avellana* flowering, however spatial differences between observation dates remained similar – about 8 days. According long term data *B. pendula* started flowering the earliest in the southern part of the territory. *T. cordata* flowering start is linked with midsummer, as a result, it is obvious that the development of this plant is less dependent on temperature variations. This is especially evident having estimated long-term *T. cordata* flowering start data. During the 1970–1999 period, flowering start of the *T. cordata* was rather even, i.e. only 5 days from the earliest to latest average date. Spatial data of *T. cordata* flowering start showed that regional differences do exist. Its flowering start occurs the earliest in the central part of Lithuania, while the latest in the north of the country and the littoral territory.

Based on regression equations, were calculated *C. avellana* flowering advancement in days. In all agrometeorological stations and divisions where flowering start of *C. avellana* was observed, negative trends were established. The results of trends obtained suggest that the flowering advancement of *C. avellana* in Lithuania is 20–25 days ($p<0.05$), while the data from some stations indicate that the linear trend of *C. avellana* flowering start dates shows the advancement of flowering to be ranging within the 25–30 days' range ($p<0.05$). Only the data of two agrometeorological stations exhibited the smallest flowering start advancement of *C. avellana*, which amounts to 16–18 days. Such statistically significant trends reveal that long-term data unanimously show flowering advancement, which can be related to climate change effects.

The flowering start of *C. avellana* in the 9th decade was recorded as early as February (6–15%). The cases of *C. avellana* advanced flowering have doubled over the last decade of the 20th century. Having assessed flowering start of *C. avellana* in Biržai and having calculated the correspondence of January –February to the climate norm, it was found that over a 30-year period (1990–1999) the greatest number of warm and anomalously warm January and February were occurred. Thus, the flowering start of temperature-sensitive *C. avellana* plants depends on the air temperatures of January and February.

For the analysis of whole Lithuania, linear trends were established according to the data of those sites where consistent phenological observations of *B. pendula* were carried out. The negative trends were obtained which showed advancement of *B. pendula* flowering start. In the case of *B. pendula*, advancement of flowering is not as marked as that of early flowering plants and totals 10–15 days ($p<0.05$). Statistically insignificant results suggest that for several stations the drop of flowering start linear trend is related to the 0–10 days' flowering advancement. Comparison of ten-day periods clearly shows the flowering start regularities. The obtained results indicate that during the period 1990–1999 in Biržai *B. pendula* started flowering in the second and third ten-day period of April (70–80%). Such differences might have been determined by the air temperature variation. To identify the probable air temperature effect, were calculated the mean temperature of March and April for Biržai (1970–1999) and discriminated warm and anomalously warm months. The obtained results evidenced that compared with January and February, the mean air temperature in March and April differed little from the long-term climate norm. However, during the 30 year period, January–March months were the warmest namely during the 1989–1998 period, which suggests that advancement of flowering start revealed by the phenological data is determined by the variation of these months' air temperature.

The obtained evidence indicates that the advancement of flowering established for *T. cordata* is not as considerable as that established for *C. avellana* or *B. pendula*. A small part of the changes indicated by the trends are statistically insignificant ($p>0.05$), however part of the changes are significant and cover 5–15 days ($p<0.05$). Considering the air temperature variations it is noteworthy that did not establish high temperature variations in May – June. However the influence of averaged monthly temperature for earlier start of *T. cordata* flowering was evident.

Climate change effects on flowering start in Lithuania in the 21st century

Firstly, considering the different methodologies employed, were identified the most optimal methodology for the evaluation of plant thermal regime effects, allowing the best disclosure of plant response to temperature variations.

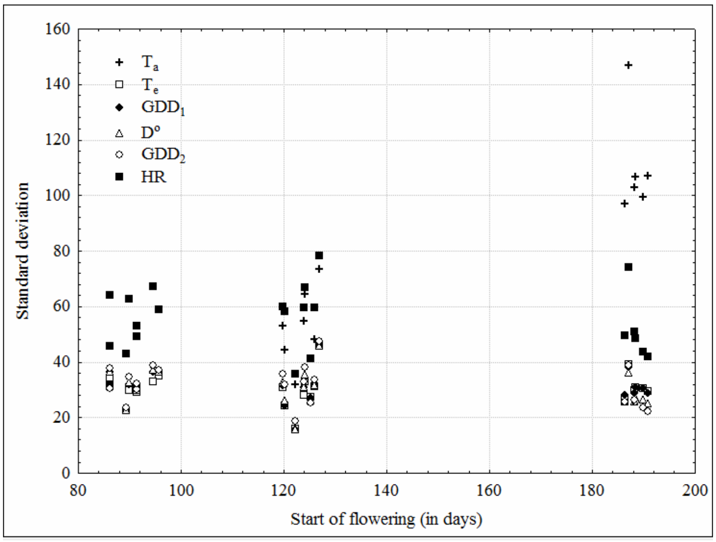

Fig. 4. Different methods, defining thermal regime requirements for the beginning of plant flowering in Lithuania (1970–1999), distribution of the standard deviation of results according to flowering start dates. T_a – the sum of active temperatures, T_e – the sum of effective temperatures, GDD_1 – growth degree days – the sum of active temperatures, D^o – the sum of active temperatures; GDD_2 – growth degree days –the sum of active temperatures, HR – heat requirement

Figure 4 presents the standard deviations distributed over the 80–100- day range (days from the start of the year), which show the dependence of the average flowering dates of *C. avellana* on the of different temperature sums. The 120–140- day average flowering dates illustrate *B. pendula* flowering regularities depending on temperature sums, while 180–200 days – show the regularities for *T. cordata*. Consequently, the higher the standard deviation, the higher the summed air temperature variation is. Since climate change study for plant vegetation start is based on prognostic temperature estimation in terms of a specific species, the least standard deviation indicates the least probable temperature change until flowering. Taking into account the variation of the standard deviation, the obtained results suggest that effective temperature sum (T_e) in the case of *C. avellana*, *B. pendula* and *T. cordata* is the most suitable method using which we can reveal climate change effects on the variations in plant vegetation over another 90 years.

According to the air temperature results of the two climate models (ECHAM5 and HadCM3) and three greenhouse gas emissions scenarios (A1B, B1 and A2), flowering start was modelled for *C. avellana*, *B. pendula* and *T. cordata*. The calculated flowering start differences from the long-term observations data (1970–1999) illustrate the shifts of flowering start dates for a period of 90 years (2001–2090, to take into consideration of

30 years partition). The obtained results indicate that the modelled flowering start of *C. avellana* in Lithuania according to the greenhouse gas emission scenario B1 is advancing the least. Having compared the results exhibiting the least (B1) and the biggest (A2) flowering start change were seen that the averaged difference is from 8 to 50 days depending on the period. Having estimated the fact that the greatest changes will occur in winter temperature, the predicted changes are probable. The data of phenological observations for the 1970–2009 period show a 20–30-day advancement in *C. avellana* flowering start, therefore the projected changes are likely. Thus, depending on which greenhouse gas emissions scenario the development of the world economy will follow, the advancement of flowering start of *C. avellana* at the end of the 21st century may reach from 20 to 80 days (averaged for Lithuania).

The temperature of late spring will not change so dramatically, therefore *B. pendula* flowering start which is determined by the spring positive temperatures will change not as markedly as that of *C. avellana* (Fig. 5).

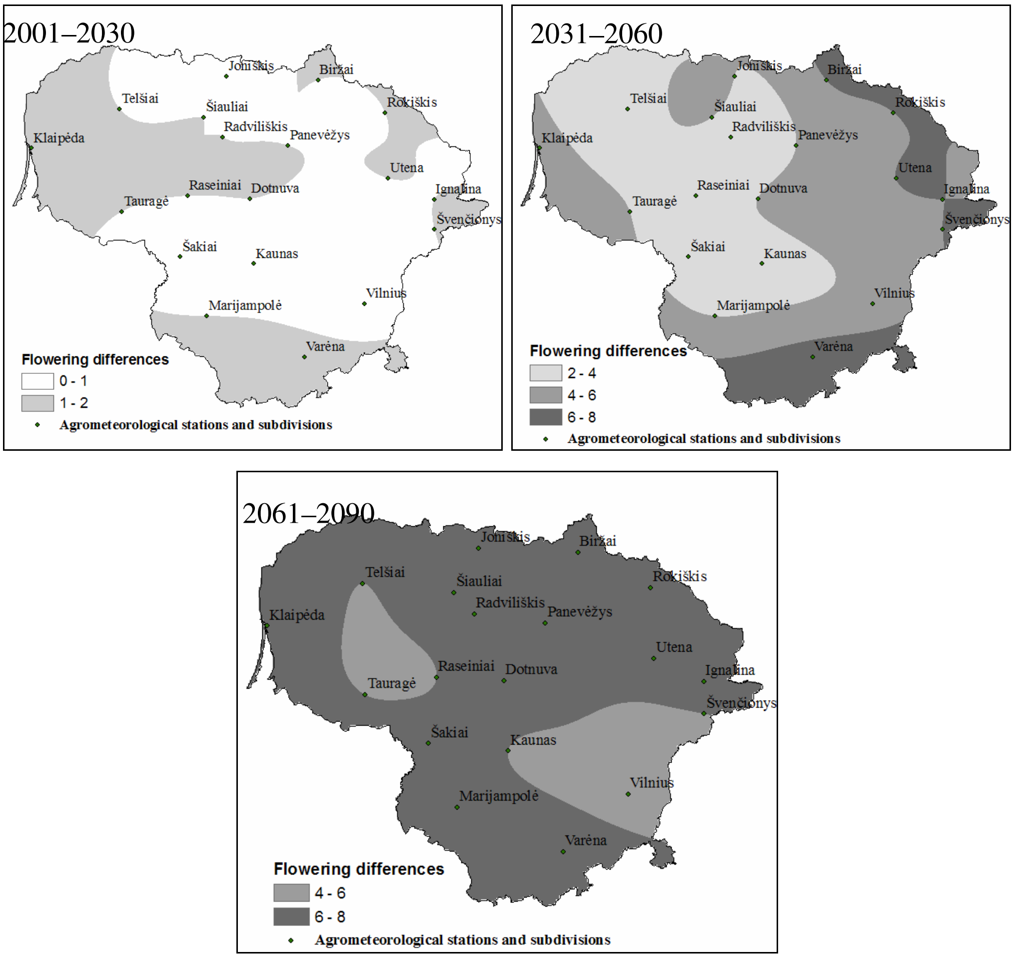

Fig. 5. *B. pendula* flowering differences (in days) between phenological observations (1970–1999) and modelled flowering data according HadCM3 B1 (2001–2090)

The optimistic greenhouse gas emissions scenario (B1) indicates flowering start advancement of not greater than 8 days for *B. pendula*, irrespective of HadCM3 or ECHAM5 model's air temperature output data. In the first half of this century big changes are predicted which, according to the pessimistic greenhouse gas emissions scenario (A2) will increase at the end of the 21st century, and the flowering start of *B. pendula* will advance by up to 25 days. The greatest differences remain between flowering start modelled by B1 and A2 scenarios and depending on the period amounts to 8-20 days for whole Lithuania for the 2001–2090 period.

For the periods 2001–2030 and 2031–2060, did not establish very dramatic differences between *T. cordata* flowering start in Lithuania which was determined based on the temperature changes indicated by the different scenarios of climate models and greenhouse gas emissions. HadCM3 B1 output data suggest that for the period 2001-2030, the difference in *T. cordata* flowering start will be 1–11 days and for the 2031-2060 period – 15–21 days, 2061-2090 period – 17–24 days. Similar data (a little smaller difference) were produced by ECHAM5 B1. According A2 scenario the differences are more drastically (35–43 days). Modelling data show a trend towards advancement of *T. cordata* flowering start.

With the pollinating season becoming earlier in Lithuania, advancement of pollen season of the plants of *Corylus*, *Betula*, and *Tilia* genera is also unavoidable. Such big changes are related to prognostic air temperature situation in Lithuania. Since pollinating period (flowering) and pollen season are closely interrelated and plant pollinating period in Lithuania determines the start of pollen season (not considering the long-range pollen transport), the predicted changes will affect pollen dispersion in the atmosphere. Not only the magnitude of the predicted changes, but also the possible variation trends are important. Since the changes predicted for the 90 years' period will not be sharp, but will follow a slow course, it becomes obvious that after the plants have adapted to the changes in the territory's thermal regime the variation of phenological phases will increase. Pollen dispersion aspects revealed the main trend that with the changes in the vegetation season in Lithuania, alterations of different magnitude will occur in the pollen seasons of specific pollen types. As a result, pollen dispersion regularities will have to be adequately estimated according to the variation conditions that have formed.

Conclusions

1. In Lithuania, during the pollen season, the highest daily pollen concentrations were noted for the plants of *Betula* genus (4 680 grains/m^3) and *Pinaceae* family (3 515 grains/m^3).

2. In Lithuania, the highest atmospheric pollen counts during the pollinating season were recorded for the plants of *Betula* genus (26-32 %), *Pinaceae* family (14-28 %), *Urticaceae* family (12-22 %), *Alnus* genus (6-8 %), *Poaceae* family (5-8 %) and *Artemisia* genus (4-8 %). The average pollen season lasts from 28 days (for *Betula*) to 83 days (for *Poaceae* plants).

3. The dominant pollen in Lithuania's bioaerosol in April is that of the plants of *Betula* and *Alnus* genus (it accounts for 77.4 % of the total monthly pollen count), in May – of *Pinaceae* and *Betula* (88.2 %), in June – of *Pinaceae*, *Poaceae* and *Urticaceae* (88.2 %), in July – of *Urticaceae* and *Poaceae* (82.9 %) and in August – of *Urticaceae* and *Artemisia* (90 %).

4. Compared with Klaipėda and Šiauliai, Vilnius was characterised by higher pollen concentrations of *Betula* genus (33–49 % of the total pollen count in the aerobiological stations) and *Pinaceae* (41–73 %), *Urticaceae* (35–50 %) families. Klaipėda was distinguished for the lowest *Artemisia* pollen concentrations recorded (on average 23 % from the total annual count).

5. Comparative analysis of pollen dispersion in the air and plant flowering start showed that flowering of indigenous plants does not always coincide with the pollen season, consequently, phenological observations alone do not sufficiently accurately describe the country's allergenic situation. Aaeropalinological studies provide a more accurate description.

6. Analysis of backward air trajectories revealed that part of the pollen is of advective origin. In Lithuania, during the plant pollinating period (2004–2009) air mass transport of north and northwest direction dominated (35–45 % of the total cases). Under these conditions there was recorded on average 32 % of the annual pollen count.

7. The air masses arriving from central and southern Europe at the end of summer are potential sources of *Ambrosia* genus pollen. The highest counts of ragweed pollen (10–61 grains/m^3) were recorded at the end of August and beginning of September in Vilnius aerobiological station.

8. It has been established that when high pressure area forms over Russia and deeply low pressure area forms over Iceland and Scotland and southern direction winds become stronger *Betula* genus pollen can be transported to Lithuania from southern Sweden, Denmark, Germany, Poland, Belarus, Ukraine, and Moldova.

9. Having estimated the effects of meteorological parameters, a statistically significant ($p < 0.05$) relationship was established between pollen counts in the air and relative air humidity, air temperature, amount of rainfall and wind velocity. Thus regularity is specific to 79 %, 67 %, 50 % and 31 % of pollen types, respectively.

10. The multiple regression analysis revealed ($p < 0.05$) that in 40 % of the cases analysed pollen concentration in the air is determined by relative air humidity, 12 % by air temperature and humidity, 12 % by air temperature and wind velocity and 9 % by air temperature. Various complexes of air temperature, humidity, rainfall amount, and wind velocity account for the rest 27 % of the cases.

11. Chronological analysis of phenological observations data (1970–1999 and 2003–2009) indicates ($p < 0.05$) that during this period the flowering of *C. avellana* advanced by on average 20–30 days, *B. pendula* on average 10–15 days, and that of *T. cordata* by 5–15 days.

12. Analysis of climate warming effects on the start of flowering of *C. avellana*, *B. pendula* and *T. cordata* revealed that compared with the 20th century, the greatest changes are likely to occur in the start of flowering of the plants that begin flowering early in spring.

13. If the climate change follows the B1 scenario, the most marked changes of flowering start of *C. avellana* (advancement) in the 21st century is expected to occur in the littoral territory (more than 29 days) and the least in Northeast, Southeast Lithuania (8–13 days). According to A2 scenario – more than 53 and 46 days, respectively.

14. According to B1 scenario, flowering start of *B. pendula* in the 21st century is expected to advance by 5 to 8 days in Lithuania. According to A2 scenario is expected the most marked changes in the littoral territory and South Lithuania (more than 33 days) and the least in West Lithuania (approximately 23 days).

15. According to B1 scenario, *T. cordata* will flower earlier in the littoral territory (24 days difference) and later in central part of Lithuania (17 days). According to A2

scenario is expected the most marked changes in West Lithuania (43 days) and least in the littoral territory and South Lithuania (35–36 days).

Publications on the dissertation subject

Articles in the publications included in the database of Institute of Scientific Information (ISI; Thomson Reuters Master Journal List):

1. Šaulienė I., **Veriankaitė L.**, Lankauskas A. 2007. The analysis of the impact of long distance air mass to airborne pollen concentration. *Acta Biologica Universitatis Daugavpiliensis. Cross-Border Cooperation in Researches of Biological Diversity*, Suppl.1: 61–74.
2. Šaulienė I., **Veriankaitė L.** 2009. The distribution of airborne *Ambrosia* pollen in Lithuania. *Acta Biologica Universitatis Daugavpiliensis*, 9(2): 255–262.
3. **Veriankaitė L.**, Siljamo P., Sofiev M., Šaulienė I., Kukkonen J. 2010. Modelling analysis of source regions of long-range transported birch pollen that influences allergenic seasons in Lithuania. *Aerobiologia*, 26 (1): 47–62. (ISI Web of Science)
4. **Veriankaitė L.**, Šaulienė I., Bukantis A. 2010. The modelling of climate change influence on plant flowering shift in Lithuania. *Žemdirbystė-Agriculture*, 97(1): 41–48. (ISI Web of Science)
5. **Veriankaitė L.**, Šaulienė I., Bukantis A. 2010. Analysis of changes in flowering phases and airborne pollen dispersion of the genus *Betula* (birch). *Journal of Environmental Engineering and Landscape Management*, 18(2): 137–144. (ISI Web of Science)

Curriculum Vitae

Laura Veriankaitė was born on March 27, 1982 in Šiauliai. In 2000, she finished Šiauliai Salduvė secondary school. In the same year she entered Šiauliai University, the then Faculty of Physics and Mathematics. In 2004, she graduated from the university with a bachelor’s degree in ecology and environmental science. From 2004 to 2006 she did her master’s degree at Vilnius University’s Faculty of Natural Sciences, Department of Hydrology and Climatology. In 2006, she defended a thesis “The relationship between pollen concentration and meteorological conditions in Šiauliai town during 2003–2005” and was awarded a master's degree in geography sciences. In the same year Laura Veriankaitė was admitted to Vilnius University's PhD studies in geography. During the doctoral study period, she published 5 articles on the subject of her dissertation.

While doing her doctoral studies Laura Veriankaitė was employed at Šiauliai University's Faculty of Natural Sciences Department of Environmental Research and was actively involved in teaching and project activities.

ŽIEDADULKIŲ KONCENTRACIJA ORE: CIRKULIACINIAI IR FENOLOGINIAI ASPEKTAI

Įvadas

Greitas techninis progresas, nuolat kintančios aplinkos sąlygos ir sparti mokslo pažanga neatsiejama šiandieninės visuomenės vystymosi dalis. Sukaupta nemažai mokslo žinių leidžia tinkamai įvertinti gamtoje vykstančių procesų poveikį ne tik gamtinės aplinkos kokybei, bet ir žmogaus veiklai. Aerobiologinių duomenų pagrindu vyksta nuolatinė žiedadulkių sklaidos atmosferoje stebėsena. Dėl mokslinio pritaikymo ir vykdomų tyrimų aktualumo žiedadulkių sklaidos atmosferoje dėsningumų nustatymai sulaukia vis didesnio mokslininkų susidomėjimo. Sujungus biomedicinos ir fizinių mokslų srityse dirbančių mokslininkų iniciatyvą, vystomas naujas tarpdisciplininis mokslas.

Darbo objektas

Lietuvos bioaerozolį sudarančių žiedadulkių sklaida ir ją lemiantys veiksniai bei dėl klimato kaitos vykstantys augalų žydėjimo pokyčiai.

Darbo tikslas

Nustatyti žiedadulkių koncentracijos pokyčius atmosferoje ir įvertinti juos lemiančių cirkuliacinių ir meteorologinių veiksnių poveikį žiedadulkių sklaidai ore kintančio klimato sąlygomis.

Darbo uždaviniai:

1. Nustatyti oru pernešamų žiedadulkių kiekio atmosferoje pokyčius.
2. Palyginti žiedadulkių koncentracijos ore sezonus su augalų pražydimo periodais.
3. Įvertinti atmosferos cirkuliacijos ir tolimosios oro masių pernašos įtaką žiedadulkių koncentracijai.

4. Ištirti meteorologinių veiksnių įtaką žiedadulkių koncentracijos kitimui.

5. Įvertinti terminio režimo poveikį augalų pražydimui ir, remiantis daugiamečiais augalų fenologiniais duomenimis, nustatyti klimato pokyčių įtaką augalų pražydimui XXI a.

Ginamieji teiginiai:

1. Vegetacijos metu Lietuvos oro erdvėje bioaerozolio žiedadulkės yra vietinės ir advekcinės kilmės.

2. Oro masių pernaša yra vienas veiksnių, lemiančių oru sklindančių žiedadulkių koncentraciją Lietuvoje.

3. Oro temperatūra ir santykinis drėgnumas yra svarbiausi meteorologiniai veiksniai, sąlygojantys žiedadulkių koncentracijos kitimą ore.

4. XXI a. Lietuvoje augalų žydėjimo pradžia dėl klimato šiltėjimo paankstės.

Mokslinis darbo naujumas ir jo reikšmė

Šiame darbe pirmą kartą Lietuvoje: 1) remiantis aeropalinologinių stotelių duomenimis, išskirti dideliais žiedadulkių kiekiais atmosferoje pasižymintys žiedadulkių morfotipai Lietuvoje; 2) atliktos sąsajos tarp aeropalinologinių ir fitofenologinių stebėjimo duomenų; 3) remiantis SILAM ir HYSPLIT modeliais, įvertinta žiedadulkių sklaida atmosferoje ir tolimoji žiedadulkių pernaša Lietuvoje; 4) nustatytas oro temperatūros, santykinio oro drėgnumo, kritulių kiekio, vėjo greičio poveikis žiedadulkių sklaidai atmosferoje; 5) remiantis klimato kaitos prognozių duomenimis, sudarytos prognozės, nusakančios augalų žydėjimo pradžią XXI a. trijų dešimčių laikotarpiais (2001–2030 m.; 2031–2060 m. ir 2061–2090 m.).

Darbo aktualumas ir pritaikomumas

Žiedadulkių sklaidos tyrimai yra svarbūs įvairiais aspektais ir suteikia vertingos informacijos, pavyzdžiui: medicinoje – apie natūralių alergenų sklaidos atmosferoje ypatumus, biologijoje – genetinės informacijos mainų lygmenyje, ekologijoje – preliminariai nustatant tam tikrų rūšių paplitimo arealus. Gaunami vertingi duomenys žiedadulkių sklaidos modeliams kurti ir tobulinti, kurie svarbūs žmonėms, turintiems alerginių problemų, susijusių su žiedadulkėmis. Šiame darbe nustatyti dėsningumai yra svarbūs prognozuoti žiedadulkių koncentracijas ore, kurie yra būtini norint užtikrinti visuomenės gyvenimo kokybę. Atlikti žiedadulkių sklaidos tyrimai suformuos aeropalinologinių tyrimų pagrindą Lietuvoje, kuris naudingas žmonėms, turintiems problemų dėl žiedadulkių, taip pat leis įvertinti ateities pokyčius, susijusius su klimato kaita.

Augalų žydėjimo tarpsniai svarbūs ne tik žemės ūkio mokslams, bet ir naujai sparčiai pasaulyje besivystančiai aerobiologijai. Ilgą laiką fenologinė informacija buvo naudojama nustatant fitoindikatorių vystymosi dėsningumus ir aprašant žemės ūkio kultūrų fenofazes. Besivystant naujoms tarpsritinėms mokslo kryptims, fitofenologija įgavo naują pritaikymo galimybę. Ilgalaikiai ir nenutrūkstami augalų žydėjimo duomenys leidžia įvertinti dėsningumus, susijusius su klimato kaitos aspektais bei suteikia pagrindą žiedadulkių sklaidos modeliavimui kintančio klimato sąlygomis.

Darbo rezultatai

Remiantis aerobiologinėse stotelėse fiksuotų žiedadulkių kiekiu, buvo išskirti dominuojantys (2004–2009 m.) žiedadulkių morfotipai Lietuvoje. Nustatyta, kad ore identifikuojamos didelės beržo, pušinių, dilgėlinių, alksnio, miglinių, kiečio žiedadulkių koncentracijos. Didžiausia žiedadulkių morfotipų įvairove pasižymi Vilniaus apylinkės (13 žiedadulkių morfotipų iš 37 stebimų). Klaipėdoje skirtingų žiedadulkių užfiksuojama mažiausiai – tik 9 žiedadulkių morfotipai.

Lietuvoje daugiausiai žiedadulkių ore būna nuo balandžio iki rugpjūčio. Kiekvieną mėnesį aerobiologinėse stotelėse fiksuojamas skirtingas žiedadulkių kiekis. Atsižvelgiant į aerobiologinių stotelių duomenis, išsiskiria ne tik tarpmetiniai žiedadulkių koncentracijų, bet ir tarp pačių stotelių, skirtumai. Daugiausia beržo genties augalų žiedadulkių (žiedadulkių indeksas 35 804), lyginant su kitomis stotelėmis, užfiksuota Klaipėdoje 2006 m. Vilniaus aerobiolginės stotelės duomenimis, didelės beržo žiedadulkių koncentracijos fiksuojamos kasmet. Vilnius išsiskiria ir didelėmis pušinių šeimos žiedadulkių koncentracijomis (5 684–11 431). Žiedadulkių kiekio ore skirtingose Lietuvos vietovėse netolygumą gali lemti ir augalų paplitimas, ir meteorologinės sąlygos, esančios dulkėjimo metu.

Didžiausios paros žiedadulkių koncentracijos, atsižvelgiant į įvairius žiedadulkių morfotipus, labai skirtingos. 2004–2009 m. maksimalios paros žiedadulkių koncentracijos Lietuvoje nustatytos nuo 2 žiedad./m^3 (apynio genties augalų) iki 4 680 žiedad./m^3 (beržo genties augalų).

Palyginus paprastojo lazdyno žydėjimą ir lazdyno genties augalų žiedadulkių sezono trukmę, paaiškėjo, kad fenologinių stebėjimų duomenys negali reprezentuoti lazdyno žiedadulkių sezono. Paprastojo lazdyno pražydimas nustatomas anksčiau nei aerobiologinėse stotelėse nustatomos didelės žiedadulkių koncentracijos.

Lyginamoji analizė tarp beržo genties žiedadulkių koncentracijos ore ir fenologinės informacijos atskleidė, kad beržo genties augalų vidutinis žiedadulkių sezonas iš dalies sutampa su karpotojo beržo pražydimu Lietuvoje. Tačiau nustatyta atvejų, kada žiedadulkių sezonas prasidėjo anksčiau nei augalų pražydimas Lietuvoje. Tai vienas iš tolimosios pernašos pavyzdžių.

Lietuvoje nustatomos nedidelės liepos genties žiedadulkių koncentracijos, kadangi šios genties augalų žiedadulkės nėra prisitaikiusios būti pernešamos vėjo. Nepaisant to, žiedadulkių koncentracijos ir fenologinių duomenų lyginamoji analizė rodo, kad liepos genties žiedadulkių sezonai nesutampa su pražydimu Lietuvoje.

Atgalinių oro masių trajektorijų modeliavimo rezultatai (sausio–rugsėjo) parodė, kad daugiausia Lietuvą pasiekia oro masės (1 Europos regionas), kurios dažniausia susiformuoja ties Islandija ir slenka virš Atlanto vandenyno per Didžiąją Britaniją, Norvegijos jūrą, Daniją, Norvegiją, Švediją bei Baltijos jūrą (35–45 %). Mažesnis procentas (26-28 %) tenka oro masėms, slenkančioms per Centrinę Europą (2 Europos regionas). Susisteminti 6 m. duomenys parodė, kad nustatoma nemažai atvejų, kai atgalinės trajektorijos iliustruoja oro masių slinktį virš kontinento, t. y. virš Europos teritorijų, kuriose paplitę skirtingų augalų sąžalynai, potencialūs žiedadulkių šaltiniai. Bendra nustatyta vyraujanti oro masių pernaša (pvz., 1 Europos regionas), iš dalies susiejama su žiedadulkių koncentracijos kaita aerobiologinėse stotelėse žiedadulkių sezono metu.

Atrinkti du žiedadulkių morfotipai, ambrozijos ir beržo, tinkantys iliustruoti tolimosios pernašos mechanizmą Lietuvoje. Ambrozijos genties augalai Lietuvoje natūraliai nėra paplitę, jie gali būti traktuojami kaip invaziniai. Įvertinus laikotarpį, kada buvo fiksuotos ambrozijos žiedadulkės, nustatyta, kad atskiromis dienomis buvo sugauta ypač dideli žiedadulkių kiekiai(iki 61 žiedad./m^3). Atlikta atgalinių trajektorijų analizė parodė, kad oro masių kelyje nebuvo kritulių, todėl atneštos žiedadulkės iš Centrinės Europos galėjo būti užfiksuotos Vilniaus aerobiologinėje stotelėje. Augalų žiedadulkių tolimoji pernaša į Lietuvą galima ir su oro masėmis, kurios slenka iš 3 Europos regiono, apimančio Rumuniją, Bulgariją, Makedoniją, Serbiją. Atgalinių oro masių trajektorijų rezultatai iliustruoja, kad į Lietuvą oro masės iš šio regiono pasiekia retai – vos 7 % per tiriamąjį laikotarpį. Vis dėlto yra tikimybė, kad atmosferoje gali pagausėti ambrozijos žiedadulkių, jei per augalų žydėjimo laikotarpį ilgesnį laiką išsilaiko oro masių pernaša iš šio regiono.

Beržo genties augalų žiedadulkių fiksavimas prieš vietinių augalų žydėjimą – kitas tolimosios pernašos pavyzdys. 2004 m. tolimosios pernašos laikotarpis truko 2 savaites. SILAM Eulerio ir Lagranžo versijos bei HYSPLIT modelio rezultatai parodė, kad beržo žiedadulkių tolimoji pernaša galima iš Švedijos, Norvegijos, Danijos, Latvijos, Vokietijos, Lenkijos, Baltarusijos, Ukrainos, Rusijos ir Moldavijos. Atsižvelgiant į augalų dulkėjimo laikotarpius ne visi modelių nurodomi žiedadulkių šaltiniai yra tikėtini.

Analizuojant oro temperatūros, kritulių kiekio, santykinio oro drėgnumo bei vėjo greičio galimą poveikį skirtingų genčių ir šeimų augalų žiedadulkių sklaidai, pirmiausiai buvo nustatyti ryšiai tarp meteorologinių parametrų ir žiedadulkių koncentracijos žiedadulkių sezono metu (2004–2009 m.). Nustatyta, kad egzistuoja priklausomybė tarp žiedadulkių kiekio ore ir oro temperatūros (67 % atvejų kai $p<0,05$). Didžioji dalis apskaičiuotų koreliacijos koeficientų gauti teigiami (58% atvejų kai $p < 0,05$). Vadinasi, žiedadulkių kiekis atmosferoje didėja kylant oro temperatūrai.

Buvo gauti statistiškai patikimi neigiami koreliacijos koeficientai (nuo -0,16 iki -0,72, 79% atvejų, kai $p<0,05$) tarp beveik visų aerobiologinėse stotelėse nustatytų genčių ir šeimų augalų žiedadulkių ir santykinio oro drėgnumo žiedadulkių sezono metu. Gauti rezultatai leidžia teigti, kad žiedadulkių kiekis ore mažėja didėjant oro drėgnumui.

Kritulių kiekio ir žiedadulkių koncentracijos koreliacijos koeficientų rezultatai parodė, kad apie 50% tirtų atvejų ($p<0,05$) nustatytas patikimas labai silpnas, silpnas arba vidutinio stiprumo ryšys (nuo -0,12 iki -0,49) tarp pastarųjų parametrų. Koreliacijos metodu nustatyta, kad vėjo greičio įtaka žiedadulkių koncentracijai nežymi, t. y virš 31% iš visų tirtų atvejų ($p<0,05$) parodė patikimą labai silpną arba silpną ryšį tarp žiedadulkių koncentracijos ir vėjo greičio.

Meteorologinių parametrų poveikiui įvertinti buvo atlikta daugialypė regresinė analizė. Rezultatai parodė, kad žiedadulkių koncentracijos kaita daugiausia susijusi su santykiniu oro drėgnumu (24 atvejai iš 57, kai $p<0,01$), tačiau išryškėja ir kitų meteorologinių parametrų įtaka, t. y. oro temperatūros (6 atvejai, kai $p<0,05$) arba meteorologinių parametrų komplekso poveikis žiedadulkių koncentracijos kaitai (27 atvejai, $p<0,05$). Pavyzdžiui, oro temperatūros, vėjo greičio ir santykinio drėgnumo

(7 atvejai), oro temperatūros ir santykinio drėgnumo (7), vėjo greičio ir santykinio drėgnumo (5) arba oro temperatūros ir vėjo greičio (3).

Norint įvertinti žiedadulkių sezono trukmės pokyčius klimato kaitos kontekste, būtina nustatyti žydėjimo laikotarpių kaitą Lietuvoje ir temperatūros poveikį augalų žydėjimo pradžios fluktuacijai. Remiantis regresijos lygtimi buvo apskaičiuotas paprastojo lazdyno augalų žydėjimo anstyvėjimas dienomis. Visose agrometeorologinėse stotyse ir postuose, kur buvo stebimas paprastojo lazdyno pražydimas, nustatyti neigiami trendai. Paprastojo lazdyno ankstyvėjimas Lietuvoje siekia 20–25 dienas ($p < 0,05$). Dalis gautų rezultatų atskleidė 25–30 dienų intervale ($p < 0,05$) esantį žydėjimo ankstyvėjimą. Tik dviejų agrometeorologinių stočių duomenimis, nustatytas mažiausias paprastojo lazdyno pražydimo ankstyvėjimas, kuris siekia 16–18 dienų. Tokie statistiškai patikimi trendai atskleidžia, kad ilgalaikiai duomenys vienareikšmiškai rodo augalų žydėjimo ankstyvėjimą, kurį galima susieti su klimato kaitos poveikiu.

Visos Lietuvos analizei atlikti buvo nustatyti tiesiniai trendai pagal tų vietovių duomenis, kur vykdyti nuoseklūs karpotojo beržo fenologiniai stebėjimai. Gauti neigiami trendai, kurie parodė karpotojo beržo pražydimo ankstyvėjimą. Karpotojo beržo atveju nustatomas žydėjimo ankstyvėjimas ne toks didelis kaip anksti pražystančių augalų ir siekia 10–15 dienų ($p<0,05$).

Mažalapės liepos nustatytas žydėjimo ankstyvėjimas ne toks didelis, kaip paprastojo lazdyno ar karpotojo beržo. Dalis nurodomų pokyčių yra statistiškai nepatikimi ($p > 0,05$), tačiau dalis yra patikimi ir apima nuo 5 iki 15 dienų ($p < 0,05$).

Pagal dviejų klimato modelių (ECHAM5 ir HadCM3) ir trijų šiltnamio dujų emisijų scenarijų (A1B, B1 ir A2) oro temperatūros rezultatus sumodeliuotas paprastojo lazdyno pražydimas. Rezultatų analizėje pateiktas skirtumas dienomis, tarp daugiamečių stebėjimo duomenų (1970–1999 m.) ir paprastojo lazdyno pražydimo 2001–2030 m., 2031–2060 m., 2061–2090 m. Gauti rezultatai atskleidė, kad sumodeliuotas paprastojo lazdyno pražydimas Lietuvoje pagal šiltnamio dujų emisijų scenarijaus B1 išvesties duomenis, mažiausiai ankstyvėjantis. Palyginus gautus rezultatus tarp mažiausią (B1) ir didžiausią (A2) pražydimo pokytį rodančių rezultatų pastebėta, kad skirtumas siekia nuo 8 d. iki 50 d. priklausomai nuo laikotarpio. Didžiausi paprastojo lazdyno pokyčiai, lyginant su daugiamečiais duomenimis, yra numatomi 2061-2090 m. ir siekia vidutiniškai nuo 20 iki 80 dienų.

Pirmoje šio šimtmečio pusėje numatomi nedideli pokyčiai, kurie pagal pesimistinį šiltnamio dujų emisijų scenarijų (A2) padidės XXI a. pabaigoje, o karpotojo beržo pražydimas Lietuvoje vidutiniškai paankstės iki 25 dienų. Optimistinis šiltnamio dujų emisijų scenarijus (B1) rodo ne didesnį nei 8 dienų karpotojo beržo žydėjimo ankstyvėjimą, nepriklausomai nuo HadCM3 ar ECHAM5 modelių oro temperatūros išvesties duomenų. Didžiausi skirtumai išlieka tarp B1 ir A2 scenarijų sumodeliuotų pražydimo skirtumų ir bendrai Lietuvoje 2001–2090 m., priklausomai nuo laikotarpio, siekia 8–20 d.

HadCM3 išvesties duomenimis, 2001–2030 m. mažalapės liepos pražydimo skirtumas Lietuvoje sieks 1–11 dienų, 2031–2060 m. – 15–21 dieną, 2061-2090 m. – 17-24 dienas. Panašiai kaip ir ECHAM5 duomenimis (mažesni pokyčiai). Modeliavimo duomenys rodo tendencingą mažalapės liepos pražydimo ankstyvėjimą.

Paankstyvėjus augalų dulkėjimo laikotarpiui Lietuvoje, lazdyno, beržo liepos genties augalų žiedadulkių sezono ankstyvėjimas, taip pat neišvengiamas. Tokie dideli pokyčiai susiję su prognostine oro temperatūros situacija Lietuvoje. Kadangi dulkėjimo laikotarpis ir žiedadulkių sezonas yra labai susiję tarpusavyje, o augalų dulkėjimo periodas Lietuvoje lemia žiedadulkių sezono pradžią, todėl numatomi pokyčiai yra galimi.

Išvados

1. Lietuvoje žiedadulkių sezono metu didžiausiomis paros žiedadulkių koncentracijomis pasižymi beržo genties (4 680 žiedad./m^3) ir pušinių šeimos (3 515 žiedad./m^3) augalai.

2. Lietuvos atmosferoje augalų dulkėjimo metu daugiausia aptinkama beržo genties (26–32%), pušinių šeimos (14–28%), dilgėlinių šeimos (12–22%), alksnio genties (6–8%), miglinių šeimos (5–8%) ir kiečio genties (4–8%) augalų žiedadulkių. Vidutinis žiedadulkių sezonas tęsiasi nuo 28 (beržų) iki 83 dienų (miglinių augalų).

3. Lietuvos bioaerozolyje balandžio mėnesį vyrauja beržo ir alksnio genties augalų žiedadulkės (77,4% nuo bendro žiedadulkių kiekio per mėnesį), gegužės – pušinių ir beržo (88,2%), birželio – pušinių, miglinių ir dilgėlinių (88,2%), liepos – dilgėlinių ir miglinių (82,9%) ir rugpjūčio –dilgėlinių ir kiečio (90%).

4. Vilniuje, lyginant su Klaipėda ir Šiauliais, fiksuojamos didesnės beržo genties (33–49% bendro žiedadulkių kiekio aerobiologinėse stotelėse) ir pušinių (41–73%), dilgėlinių (35–50%) šeimų augalų žiedadulkių koncentracijos. Klaipėdoje kiečio genties augalų žiedadulkių fiksuojama mažiausiai (vidutiniškai 23% nuo bendro per metus).

5. Žiedadulkių sklaidos ore ir augalų pražydimo lyginamoji analizė parodė, kad vietinių augalų žydėjimas ne visada sutampa su žiedadulkių sezonu, todėl vien tik fenologiniai stebėjimai nepakankamai tiksliai charakterizuoja šalies alergeninę situaciją. Tiksliau ją apibūdina aeropalinologiniai tyrimai.

6. Atgalinių oro masių trajektorijų analizė atskleidė, kad dalis žiedadulkių yra advekcinės kilmės. 2004–2009 m., augalų dulkėjimo laikotarpiu, Lietuvoje vyravo vakarų ir šiaurės vakarų krypties oro masių slinktis (35–45% visų atvejų). Šiomis sąlygomis buvo užfiksuota vidutiniškai 32% metinio žiedadulkių kiekio.

7. Iš Centrinės ir Pietinės Europos atslenkančios oro masės vasaros pabaigoje yra potencialūs ambrozijos žiedadulkių šaltiniai. Daugiausiai ambrozijos žiedadulkių užfiksuota rugpjūčio pabaigoje ir rugsėjo pradžioje Vilniaus aerobiologinėje stotelėje (10–61 žiedad./m^3).

8. Nustatyta, kad, virš Rusijos susidarius aukšto slėgio sričiai, o ties Islandija ir Škotija – giliai žemo slėgio sričiai ir sustiprėjus pietų krypties vėjams, beržų žiedadulkės į Lietuvą gali būti atnešamos iš Pietinės Švedijos, Danijos, Vokietijos, Lenkijos, Baltarusijos, Ukrainos, Moldavijos.

9. Įvertinus meteorologinių parametrų poveikį, nustatytas statistiškai patikimas ($p<0,05$) ryšys tarp žiedadulkių kiekio ore ir santykinės oro drėgmės, oro temperatūros, kritulių kiekio ir vėjo greičio. Toks dėsningumas būdingas atitinkamai 79%, 67%, 50% ir 31% žiedadulkių morfotipų.

10. Daugialypės regresijos analizė atskleidė ($p<0,05$), kad 40% analizuotų atvejų žiedadulkių koncentraciją ore lemia santykinė oro drėgmė, 12% – oro temperatūra ir drėgmė, 12% – oro temperatūra ir vėjo greitis ir 9% – oro temperatūra. Likusius 27% atvejų sudaro įvairūs oro temperatūros, drėgnumo, kritulių kiekio ir vėjo greičio kompleksai.

11. Fenologinių stebėjimų (1970–1999 m. ir 2003–2009 m.) duomenų chronologinė analizė rodo ($p<0,05$), kad paprastojo lazdyno žydėjimas per laikotarpį vidutiniškai

paankstėjo 20–30 dienų, karpotojo beržo – 10–15 dienų, o mažalapės liepos – 5–15 dienų.

12. Analizuojant klimato šiltėjimo įtaką paprastojo lazdyno, karpotojo beržo ir mažalapės liepos pražydimui nustatyta, kad, lyginant su XX a., labiausiai turėtų keisis anksti pavasarį žydinčių augalų pražydimas.

13. Jei klimato kaita vyks pagal B1 scenarijų, didžiausi paprastojo lazdyno pražydimo pokyčiai (ankstyvėjimas) XXI a. numatomi pajūryje (daugiau kaip 29 dienos), mažiausi – Šiaurės rytų, Pietryčių Lietuvoje (8–13 dienų). Jei pagal A2 – daugiau kaip 53 dienos ir 46 dienos atitinkamai.

14. XXI a. pagal B1 scenarijų numatomas 5–8 dienų karpotojo beržo pražydimo ankstyvėjimas visoje Lietuvoje. Pagal A2 scenarijų numatomi didžiausi pokyčiai pajūryje ir Pietų Lietuvoje (daugiau kaip 33 dienos), mažiausi – Vakarų Lietuvoje (apie 23 dienas).

15. Pagal B1 scenarijų mažalapė liepa anksčiausiai pražys pajūryje (24 dienų skirtumas), vėliausiai centrinėje Lietuvos dalyje (17 dienų). Pagal A2 scenarijų numatomi didžiausi pokyčiai Vakarų Lietuvoje (43 dienos) ir mažiausi pajūryje ir Pietų Lietuvoje (35–36 dienos).

Curriculum Vitae

Laura Veriankaitė gimė 1982 metų kovo 27 dieną Šiauliuose. 2000 metais baigė Šiaulių Salduvės vidurinę mokyklą. Tais pačiais metais įstojo į Šiaulių universitetą, tuometinį Fizikos ir matematikos fakultetą. Bakalauro studijas baigė 2004 metais ir jai buvo suteiktas ekologijos ir aplinkotyros bakalauro laipsnis. Nuo 2004 iki 2006 metų studijavo Vilniaus universiteto Gamtos mokslų fakulteto Hidrologijos ir klimatologijos katedroje. 2006 m. apgynė magistro darbą „Žiedadulkių koncentracijos priklausomybė nuo meteorologinių sąlygų 2003–2005 m. Šiaulių mieste“ ir jai buvo suteiktas geografijos mokslų magistro laipsnis. Tais pačiais metais Laura Veriankaitė įstojo į Vilniaus universiteto geografijos krypties doktorantūros studijas. Per studijų laiką disertacinio darbo tema paskelbtos 5 publikacijos.

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