Aerobiologia (2014) 30:423–433
DOI 10.1007/s10453-014-9341-7

ORIGINAL PAPER

Comparison of *Alnus, Corylus, Betula* pollen seasons in Riga, Moscow and Vilnius

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Received: 4 December 2013 / Accepted: 12 April 2014 / Published online: 24 April 2014

Abstract Research characterizes differences and similarities of the seasonal behaviour of *Alnus*, *Betula*, *Corylus* pollen in Riga, Moscow and Vilnius. An important uniting factor dealing with the research is that on the selected territories in spring there are abundance of *Alnus*, *Corylus* and *Betula* airborne pollen. The study is based on the 2004–2011 atmospheric pollen records. Differences and similarities of the analysed territories include the following: (1) the beginning of the *Alnus* and *Corylus* pollen season usually coincided in Riga and Vilnius, whereas significantly differed between Riga and Moscow; (2) no significant differences among separate stations have been estimated concerning the beginning of the *Betula* pollen season; (3) Moscow differed by the shortest period of pollen season, independently of the pollen type; (4) the biennial cycle of *Betula* pollen is characteristic to Riga only; (5) in the spectrum of spring plants' pollen, *Corylus* pollen was found in the least amount (10–23 pgm^{-3} per day on the average); (6) average concentration of *Betula* pollen per day significantly differed in all locations of the survey, in Moscow, the concentration (853 pgm^{-3}) was twice higher that in Riga and Vilnius; (7) *Alnus*, *Corylus* and *Betula* pollen seasons overlap each other in all locations surveyed, thus creating additional load of pollen; (8) in each of the stations, there were 13–15 days when concentration of *Betula* pollen exceeded 100 pgm^{-3}.

Keywords Aerobiology · Betulaceae · Pollen load · Spring allergy

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1 Introduction

Spread of anemophilic pollen in Europe has been assessed in various aspects: from airborne pollen concentration on a chosen territory (Jäger et al. 1996; Emberlin et al. 1997; Rodríguez-Rajo et al. 2004; Myszkowska et al. 2010; Ščevková et al. 2010) and transport features (Siljamo et al. 2008; Skjøth et al. 2009; Veriankaite et al. 2010b) to allergenic characteristics (Viander and Koivikko 1978; Corsico 1993; Rodríguez-Rajo et al. 2010) and research of impact on health (Staikūnienė et al. 2005; Mösges et al. 2010; Bastl et al. 2014). Nevertheless, scientific literature lacks some knowledge on the aerobiological situation on some territories of Eastern Europe (the Baltic States, Belarus, Russia). The data recorded by stations of aerobiological monitoring located in these countries are used for modelling transport (Siljamo et al. 2008; Veriankaite et al. 2010b); however, knowledge on the pollen load is insufficient.

Betulaceae is a group of anemophilous trees and shrubs and includes two traditional subfamilies: Betuloideae (*Alnus*, *Betula*) and Coryloideae (*Carpinus*, *Corylus*, *Ostrya, Ostryopsis*) (Chen et al. 1999). The study concentrates on analysis of pollen load of three genera of plants blooming in early spring, i.e. *Alnus*, *Corylus* and *Betula* because these are genera representing the birch family in northern boreal and temperate zones. *Ostrya and Ostryopsis* are grown here for decorative purposes only. *Carpinus* is not inherent in the northern side of Latvia and Russia forests. In Lithuania, hornbeam occurs in the north-east boundary of its prevalence habitat and divides the territory of the country into milder maritime and colder continental climate zones (Navasaitis et al. 2003).

Alnus, *Corylus* and *Betula* are characterized by intensive flowering and high pollen productivity (Siljamo et al. 2008; Pidek et al. 2009). Pollen grains of these plants are in the group of important agents of seasonal allergy (Mothes and Valenta 2004; Peternel et al. 2007; Schenk et al. 2011). According to the medical reports, about 10–15 % of Europeans are sensitized to *Betulaceae* pollen and the increase in sensitization is prognosticated (Staikūnienė et al. 2005; Mösges et al. 2010). *Betulaceae* pollen season in Northern Europe is long-lasting. The first appearance of alder and hazel pollen can take place in early March or even in February. Birch pollen (Spieksma et al. 2003; Peternel et al. 2007; Stach et al. 2008; Skjøth et al. 2009) is the most frequent reason for spring (April–May) allergy; the amount of the pollen mentioned in the air is determined not only by the blooming of plants but also is related to long-range transport (Siljamo et al. 2008; Veriankaite et al. 2010b). When the blooming of different plants of *Betulaceae* genera coincides, the pollen season extends until summer and causes different symptoms to people who are sensitized to pollen (Mothes and Valenta 2004; Skjøth et al. 2009).

The aim of our research study is to characterize differences and similarities of the seasonal behaviour of *Alnus*, *Corylus* and *Betula* pollen in Riga, Moscow and Vilnius. Knowledge of the pollen concentration in the atmosphere can be tool in the treatment and diagnosis of hay fever, useful for organizing the activities of business and tourism sectors, and the presented results could create added value for general botanical knowledge. The results can be helpful for pollen forecasting both at national and international levels.

2 Materials and methods

2.1 Area of study

The study is based on the atmospheric pollen records obtained from capital cities of three countries: Latvia (Riga), Russia (Moscow) and Lithuania (Vilnius). When characterizing the selected territories, their differences and similarities are found. The countries are of different sizes, and their wood density is different. In Latvia, forest and other wooded land constitute 56 % of the country area, in Lithuania—36 % and in Russia—54 % (Forest Europe et al. 2011).

An important uniting factor dealing with the research is that on the selected territories in spring there are abundance of *Alnus*, *Corylus* and *Betula* airborne pollen (Siljamo et al. 2008; Pidek et al. 2009; Veriankaite et al. 2010a). In all three countries, the same species of anemophilic plants, i.e. *Alnus incana* (L.) Moench, *Alnus glutinosa* (L.) Gaertner, *Corylus avellana* L., *Betula pendula* Roth, *Betula pubescens* L., dominate. According to FRA 2010 Country Reports (Food and Agriculture Organization of the United Nations 2010a, b, c) in all countries, *Betula* ranked as one of the most common species (28.73 % of the total growing stock in Latvia, 16.83 % in Lithuania and 14.4 % in Russia). Meanwhile in the document mentioned, the representatives of *Alnus* genus species are declared among common species in Latvia (19.88 % of the total growing stock) and Lithuania (12.55 %) only. It is worth noting that in all countries, plants of *Corylus* genus are not widely spread and constitute less than 1 % of the total growing stock.

The second factor that unites the territories is a clear season-determined character expressed by differences of positive–negative air temperatures in different seasons of the year (Table 1).

Despite the present article does not analyse the influence of separate meteorological elements on

Table 1 Climatic parameters on the surveyed territories (Galvonaitė et al. 2007, 2013; Kazakov 2014)

	Air temperature (°C)		Rainfall (mm)		
	January Min/average	July Max/average	Annual average	Min/month	Max/month
Riga	−33.7/−2.7	34.1/18.2	633	0.0/January, August	242/August
Moscow	−42.1/−6.5	38.2/19.2	708	0.5/October	187/September
Vilnius	−37.2/−6.1	35.4/17.9	664	6/April	210/July

Table 2 Characteristics of the pollen trap area (Mayor and the Government of Moscow, 2012; Riga municipality, 2012; Vilnius City Municipality, 2012)

City (country)	Pollen monitoring stations				City territory (km^2)	Green spaces (%)	Population (million)
	Latitude	Longitude	Height, m				
			Sea level	Ground level			
Riga (Latvia)	56 57 00 N	24 06 45 E	6	10	304	28	0.706
Moscow (Russia)	55 45 00 N	37 42 00 E	156	23	1,091	30	11.612
Vilnius (Lithuania)	54 40 40 N	25 16 05 E	171	18	400	44	0.556

aerobiological results, the data are interpreted with regard to features of continental conditions making impact on the spread of pollen. According to Köppen–Geiger climate classification (Peel et al. 2007), all three territories are between the Maritime Temperate and Continental Subarctic climates, but they are in different distances from the Baltic Sea: Riga is approximately 13 km away from the sea, Vilnius—281 km and Moscow—1,044 km. The distance, relief characteristics and other geographical factors determine climatic differences of these territories. Riga is located in moderate climate zone influenced by its close proximity to the Baltic Sea. The proximity of the sea causes frequent autumn rains and fogs. Moscow is situated in the zone of moderately continental climate. Vilnius has a humid continental climate with warm summers and no dry season.

The cities where the traps are located differ in the aspects of urbanization, population and green areas (Table 2). All samplers were placed on the roof of the building in highly urbanized area. Parks with ornamental and no-ornamental trees, shrubs and herbaceous species are in distance of 1–2 km (except Moscow).

In the centre of Riga, where the aerobiological monitoring station has been installed, there are city parks with decorative woody plants. Forests that surround the city include the dominating tree genus *Pinus*—88.1 %. The sources of emission of pollen being analysed in the article are sparse: *Betula* plants constitute 6.6 %, *Alnus* reaches 2.8 %, *Corylus* is in small numbers. The pollen trap in Moscow is located within University campus near nature reserve "Vorob'evy Gory" and close to the university botanical garden. Birch and hazel are common both in the botanical garden and on the territory of natural reserve. Birch is also very popular in urban greening on the territory of the campus. Alder is not so common and occupies wet locations on the bank of the Moscow River on the territory of natural reserve (within 1–2 km from the trap). Almost half of Vilnius territory is covered by green space. The pollen trap is located in the central part of the city, surrounded by parks. In the city, from forests plants, such as pine (53 %), birch (20 %), fir (18 %), dominate, whereas *Alnus* and *Corylus* plants constitute a small part of woody plants.

2.2 Aerobiological data analysis

The study is based on the 2004–2011 atmospheric pollen records, when the daily pollen concentration was monitored by using Burkard 7-day volumetric pollen trap (Hirst 1952). Unfortunately, Vilnius site does not have completed data for 2004 (site did not exist at that time) and 2010 (due to technical problems). The Burkard traps were calibrated to continuously sampling at 10 l/min, and the atmospheric particulate matter was deposited onto Melinex tapes coated with mixture of wax and Vaseline. The daily average pollen counts were calculated from data obtained under the light microscope by counting 12 equidistant transverse strips every second hour and expressed as the number of pollen grains per m^3 of air (pgm^{-3}). Pollen was identified up to the genus level of *Alnus*, *Corylus* and *Betula*.

The seasonal pollen index (SPI) is defined as the annual sum of the mean daily concentrations during the main pollen season. The pollen season was defined according to 95 % method (Emberlin et al. 1997): The start day was determined when 2.5 % of the seasonal cumulative pollen count was trapped, the end day on which 97.5 % of the annual pollen index had been registered. The dates of season start and end were expressed as the numbers of days from the 1st of January (DOY). To compare pollen season, the principal pollen season was calculated (Riga and Moscow cover the period of 2004–2011, and Vilnius covers the period of 2005–2009, 2011) which represents the aerobiological situation of each of the territories.

In this study, the pollen season of each taxon was analysed according to three levels of pollen abundance: <30, 30–100 and >100 pgm^{-3}. Such values have been chosen following the thresholds of sensitization to the pollen under analysis (Viander and Koivikko 1978; Myszkowska and Piotrowicz 2009) as well as assessing the abundance of the spread of local plants on the surveyed territories.

2.3 Statistical analysis

The data collected during 8 years of pollen monitoring were graphically presented and statistically evaluated. In cases, when data of several years are compared, statistical analysis employed the results encompassing a continuous sequence of data.

The annual pollen sums, and the principal pollination periods were counted using the statistical facilities of the European Aeroallergen Network. The classical statistics data analysis was performed by using standard statistical tools. Pollen concentration average (Mean), minimum (Min) and maximum (Max) values, standard deviation (SD) were used to characterize the features of the atmospheric pollen dynamic. The comparison among the stations for each type of pollen was carried out by using Student's t test. To assess significance of the differences, the reliability coefficient has been calculated according to estimated $p < 0.01$ and $p < 0.05$ levels. Box–Whiskers method was used to analyse the pollen abundance and pollen seasons timing. Variable width box plots illustrate the average of pollen concentration, the variation in start and end of pollen season with 25–75 % confidence interval. The whiskers extend from the ends of the box to the minimum and maximum values.

3 Results

On the analysed territory, the beginning of blooming of *Alnus* or *Corylus* is the indicator of early spring; however, it is hard to predict plants of which genus will bloom first. The systematized data of the pollen (*Alnus* and *Corylus*) research carried out by us (Fig. 3) demonstrate that the differences of the beginning of the recording of pollen are in regard to the territories only, but not between the pollen types. In Riga and Vilnius, the beginning of the season of the pollen is usually around March 20, and in Moscow, it is around April 3. When assessing separate years, a number of differences have been estimated. One of the differences deals with atypically early pollen seasons. During the period under analysis, the pollen of *Alnus* and *Corylus* was recorded as early as on 23 February 2008 in Vilnius. It should be noted that early beginning of the pollen season in that year was observed in Riga, too (1 March), whereas in Moscow, the season began in compliance to the average of a number of years. On the latter territory, during the period under analysis, the earliest date of the beginning of the season was recorded as 19 March 2007, even though in Riga and Vilnius the pollen season that year started as usual. Significant differences of the *Alnus* and *Corylus* pollen season start were estimated between Riga and Moscow data ($t = -3.05$, $t = -3.02$, respectively, Table 3) only. No significant differences among separate stations have been estimated concerning the beginning of the *Betula* pollen season (Fig. 3; Table 3). Throughout the period being compared, it begins quote synchronously, on 21–25 April on the average, and the earliest case was recorded on 11 April 2007 in Moscow.

Having carried out comparison of the end of the *Alnus* pollen season, it was found out that it ended the earliest in Vilnius (on 18 April), and in Moscow, it lasted longer for 1 week on average (until 26 April)

Table 3 Mean differences (number of days), standard deviation (SD) between pollen seasons and Student's *t* value (*t*), *$p < 0.05$, **$p < 0.01$

Pollen type	Riga/Moscow	Moscow/Vilnius	Riga/Vilnius
Alnus			
Start	−13.36**	13.08	−0.29
SD	10.94	12.86	11.22
t	−3.05	−1.97	−0.04
End	−4.75	8.13	3.38
SD	9.01	10.41	7.73
t	−1.06	1.56	0.77
Corylus			
Start	−13.13**	13.38	0.25
SD	10.79	13.13	11.73
t	−3.02	1.95	0.04
End	−2.5	−2.46	−4.96
SD	8.51	8.47	8.11
t	−0.57	−0.54	−1.15
Betula			
Start	−3.88	4.67	0.79
SD	6.50	6.67	4.89
t	−1.21	1.42	0.29
End	5.88	0.71	6.58
SD	7.43	3.82	7.89
t	1.67	0.33	1.83

and finished the latest on 10 May 2008. In the analysed locations, the end of the *Corylus* pollen season is on 17–21 April on the average. The latest ended season was recorded on 3 May 2006 in Vilnius. *Betula* pollen is found in the air as late as until 21 May on the average (in Moscow and Vilnius, this date is the latest ended seasons). In Riga, in separate cases (e.g. in 2007), the season of these pollen extends until the end of the first decade in June. Differences in days recorded at aerobiological stations (Table 3) estimated when analysing the end of the seasons are insignificant according to Student's criterion.

During the period under analysis, duration of the pollen season changes in the regard of both stations and years. Pollen seasons of early blooming *Alnus* and *Corylus* partly cover each other. The shortest season of *Alnus* was estimated in Moscow (in 2011, for 11 days), and the longest was recorded in Vilnius (in 2008, for 40 days). The average duration of the principal pollen season of such type pollen was from 23 days in Moscow to 31 days in Riga. The *Corylus* season was the longest in Vilnius, too, which in 2008 lasted for 50 days, whereas in Moscow, in the same year, it was recorded as the shortest (8 days) period during the period under analysis. Not a lesser variation in duration of pollen season in the *Betula* case was recorded: 9 days in Moscow (in 2004) and 56 days in Riga (in 2007). Having compared duration *Alnus*, *Corylus* and *Betula* pollen seasons, significant differences between Riga and Moscow have been found in cases of both *Alnus* ($t = 2.40$, $p < 0.05$) and *Corylus* ($t = 4.11$, $p < 0.01$). Also, significant differences between Moscow and Vilnius concerning duration of the *Corylus* pollen season were found ($t = -3.79$, $p < 0.01$).

Having assessed seasonal pollen indices, no significant differences were found. The obtained results show (Fig. 2) that abundance of pollen is not a tendency. Comparing the cases, the biggest *Alnus* and *Corylus* SPI have been obtained in Riga (SPI (*Alnus*) = 8886, SPI (*Corylus*) = 1,416) and the least in Moscow (SPI (*Alnus*) = 555, SPI (*Corylus*) = 52). Later, in the run of years, the indices of recorded abundance of *Betula* pollen (Fig. 1) are different, i.e. the highest SPI was estimated in Moscow (61280) and the lowest in Riga (1,143). The average number of *Betula* pollen grains recorded annually in Moscow (20,972 pgm^{-3}) is more than two times higher than in Riga (10,109 pgm^{-3}) or Vilnius (8,833 pgm^{-3}).

Despite the least *Alnus* SPI was estimated in Moscow, this aerobiological station nevertheless has recorded the highest average concentration of pollen grain (408 pgm^{-3}) during the period under analysis (Fig. 3), whereas in Vilnius, this index reached 109 pgm^{-3} only. *Corylus* pollen is recorded not much, i.e. the average concentration per day seldom (less than one-third of the pollen season days) exceeds 30 pgm^{-3} in Riga and Moscow. In Vilnius, the average concentration of pollen grain per day is almost 2 times lower. When analysing similarities and differences of the average concentration of *Betula* pollen per day, it has been found that in Riga and Vilnius approximately 400 pgm^{-3} and in Moscow approximately 800 pgm^{-3} were recorded. The following can be treated as the exceptional cases: in 2006 in Vilnius when the pollen concentration per day reached 1,525 pgm^{-3} and in 2,010 in Moscow when this index was 3,040 pgm^{-3}.

Having assessed significance of differences and similarities of pollen concentration per day during the season between separate stations, it has been found out

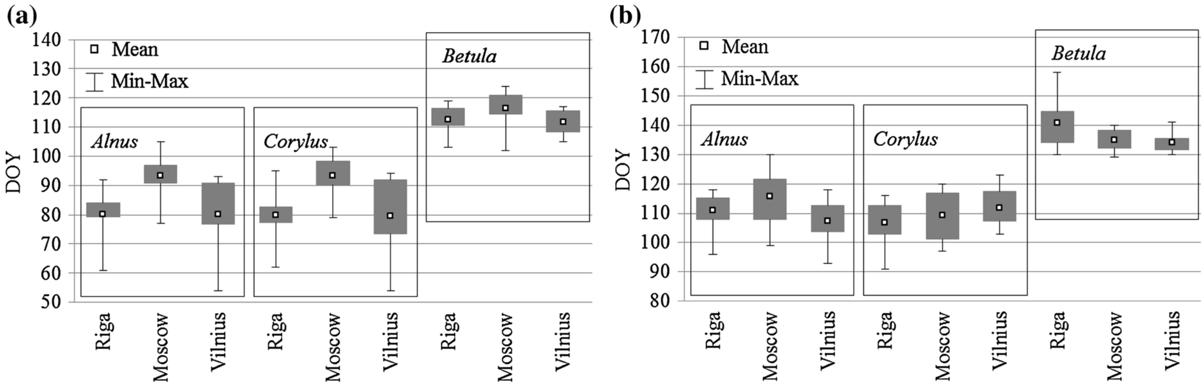

Fig. 1 Variation in the start (a) and the end (b) of pollen seasons

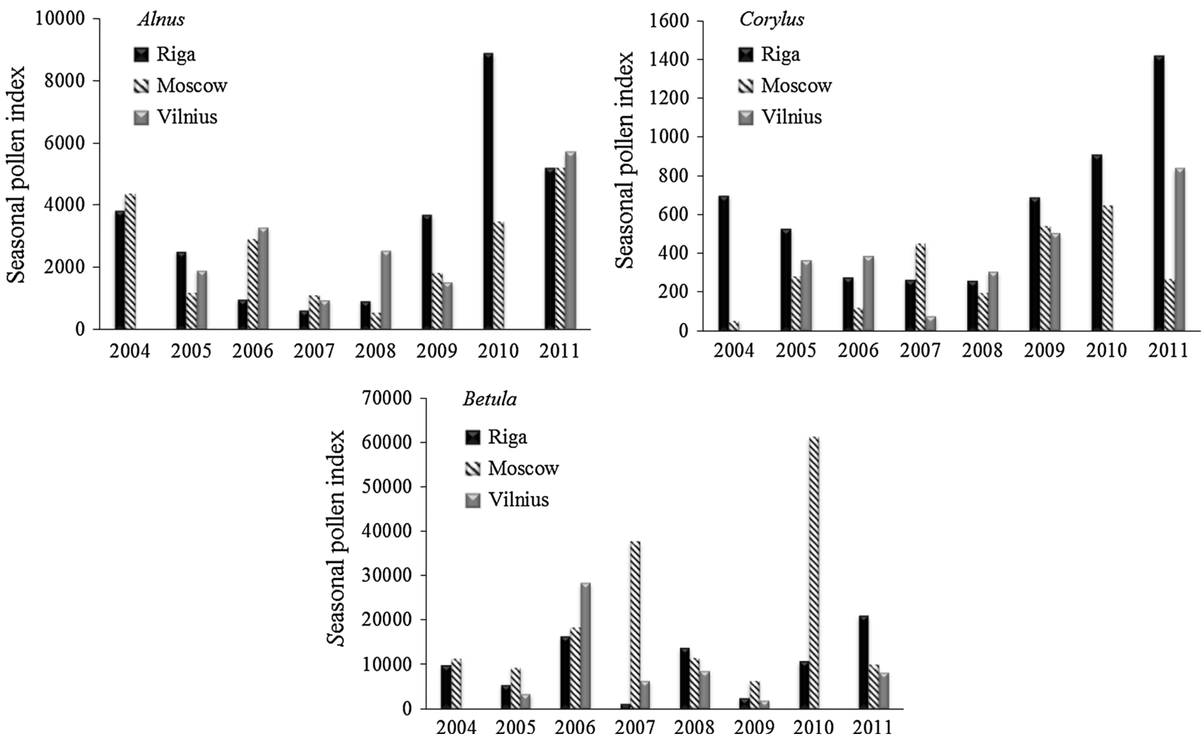

Fig. 2 The comparison of seasonal pollen index of *Alnus*, *Corylus* and *Betula* in selected places

that differences between *Alnus* and *Corylus* were little significant (Table 4). Throughout the period under analysis, one statistically significant case in each was obtained. The same situation when statistically significant cases have been estimated in different years is observed when comparing *Corylus* pollen grain concentrations, too. This characterizes that in all three stations of aerobiological research similar amounts of *Alnus* and *Corylus* pollen are recorded.

Concentration of *Betula* pollen grain per day significantly differs between Riga and Moscow as well as Moscow and Vilnius. The research results revealed that statistically significant differences cover 50 % of the surveyed period. The least significant differences between concentrations of pollen grain have been estimated having compared the data of Riga and Vilnius.

From the allergenic point of view, the pollen abundance in the air is the indicator for sensitization.

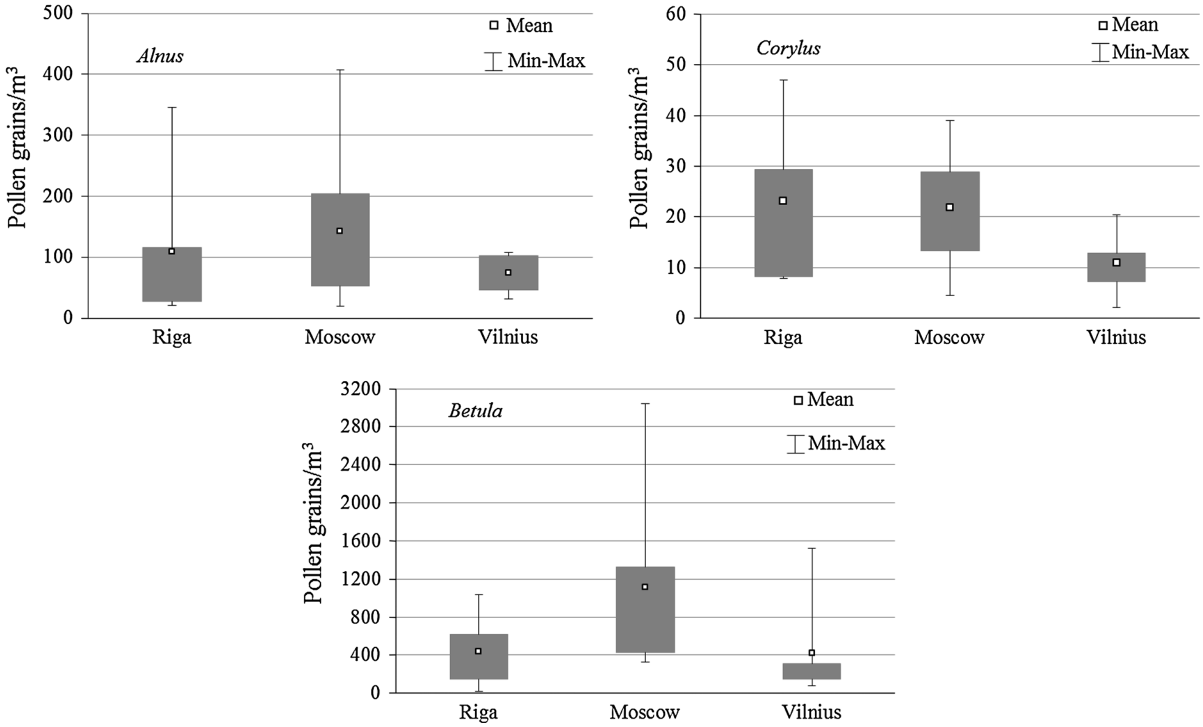

Fig. 3 Average of *Alnus*, *Corylus* and *Betula* pollen concentration per day in each monitoring site during 2004–2011

To both individuals who are sensitized to pollen and allergists, it is important to know for how long concentrations of allergic pollen hover in the air. Systematized information of such kind over the period under analysis is presented in Fig. 4.

During the *Alnus* pollen season, concentration exceeding 30 pgm^{-3} is usually recorded over the half of period; however, the amount is not identical in each of the research station. For instance, from 47 % pollen season days in Vilnius to 60 % in Moscow. Duration of the *Corylus* season differs from one aerobiological station to another; nevertheless, the amount of days when concentration of pollen exceeds 30 pgm^{-3} is only 3 days in Moscow and Vilnius, and 5 days in Riga. During the season of *Betula* pollen, the days characterized as dominated by days when concentration of pollen exceeds 100 pgm^{-3}. Longer periods of pollen in Riga (29 days on the average) and Vilnius (23 days on the average) consist of 51–55 % of such cases. During relatively shorted seasons in Moscow (19 days on the average), the exceeding of 100 pgm^{-3} is recorded in 75 % of the seasons days. Assessing by absolute numbers, it has been found out that in each station, there were 13–15 days when concentration of pollen exceeded 100 pgm^{-3}.

4 Discussion and conclusions

Variations in timing and severity of *Alnus*, *Corylus* and *Betula* pollen seasons were studied in many regions of Europe (Laaidi 2001; Spieksma et al. 2003; Peternel et al. 2007; Ranta and Satri 2007; Smith et al. 2007; Stach et al. 2008; Pidek et al. 2009). *Alnus* and *Corylus* pollen are the first in the spectrum of spring pollen in the European countries (Peternel et al. 2005; Smith et al. 2007; Myszkowska et al. 2010). Results of our research prove this tendency and also highlight differences among the locations being surveyed. In Riga and Vilnius cities which are closer to the Baltic Sea, usually the *Alnus* and *Corylus* pollen seasons start in the end of the second decade—the beginning of the third decade of March, whereas in Moscow city which is located further into the continent it starts only as late as on the first week of April. The difference between pollen season start dates can be explained as the effect of meteorological conditions, especially air temperature (Frenguelli et al. 1991; Rodríguez-Rajo et al. 2004; Myszkowska et al. 2010). The differences of such character in Riga, Vilnius and Moscow are impacted by air temperature which in the winter time

Table 4 Student's test statistics between means of pollen concentrations

Years	Riga/Moscow			Riga/Vilnius			Moscow/Vilnius		
	d	*t*	*df*	*d*	*t*	*df*	*d*	*t*	*df*
Alnus									
2004	−144.31	−1.46	54	–	–	–	–	–	–
2005	43.06	1.88	40	−6.56	−0.16	40	−49.63	−1.21	36
2006	−74.40	−1.82	49	−68.56	−1.56	49	5.83	0.11	44
2007	−25.71	−1.62	46	−12.74	−1.12	46	12.96	0.73	40
2008	5.19	0.49	49	−35.26	−1.90	53	−40.45*	−2.11	44
2009	32.59	0.96	52	59.17*	2.05	52	26.59	0.96	42
2010	153.96	1.60	40	–	–	–	–	–	–
2011	−252.72*	−2.03	42	46.67	0.65	49	299.39	2.68	29
Corylus									
2004	18.32*	3.17	38	–	–	–	–	–	–
2005	8.79	1.63	35	0.57	0.06	34	−8.22	−0.87	31
2006	−4.03	−0.40	41	−4.06	−0.87	51	−0.03*	−0.03	27
2007	−15.85	−1.92	47	5.34*	2.43	43	21.19	2.61	30
2008	−18.62	−1.74	35	0.58	0.16	47	19.20	1.75	24
2009	−10.19	−0.68	40	2.20	0.23	42	12.40	0.79	30
2010	12.33	0.67	32	–	–	–	–	–	–
2011	23.83	1.08	42	28.99	1.29	42	5.16	0.67	24
Betula									
2004	−811.23	−1.98	33	–	–	–	–	–	–
2005	−241.98*	−2.08	46	50.55	0.98	46	292.5**	2.76	38
2006	−357.28	−0.64	32	−713.71*	−2.48	35	−356.43	−0.61	31
2007	−1705**	−4.89	72	−180.7**	−2.66	72	1524**	4.50	38
2008	101.85	0.88	48	93.56	0.81	48	−8.28	−0.08	49
2009	−360.28*	−2.18	44	−8.13	−0.33	51	352.14*	2.29	31
2010	−2491**	−3.11	36	–	–	–	–	–	–
2011	443.07	1.04	33	798.54	1.92	35	355.47	2.88	32

d difference of mean, *t* Student's *t* value, *df* degree of freedom, $*p < 0.05$, $**p < 0.01$

is usually higher in the zone of maritime climate rather than continental. Smith et al. (2007) have stated that the *Alnus* pollen season usually starts earlier in Worcester than Poznań and this phenomenon is probably related to the higher winter temperatures caused by the maritime climate. Having assessed the distance of Vilnius and Riga to the Baltic Sea, the appearing of *Alnus* and *Corylus* pollen should be asynchronous; however, in this case, the differences are small because Riga is located near the Baltic Sea bay. The differences of the beginning of the *Betula* pollen season among the surveyed locations are less but, nevertheless, retaining the same tendency: for Riga/Vilnius, there is 1 day difference, and for Riga–Vilnius/Moscow, there is 4 days difference.

Throughout the period under observation, duration of the pollen season widely varies: from 11 to 40 days in *Alnus*, from 8 to 50 days in *Corylus* and from 9 to 56 days in *Betula* cases. The research results obtained in different countries demonstrate that differences between duration of *Alnus* and *Corylus* seasons are characteristic in many cases (Kasprzyk et al. 2004; Rodríguez-Rajo et al. 2004; Emberlin et al. 2007; Peternel et al. 2007; Myszkowska et al. 2010). Moreover, duration of the same season varies from 10 (Rodríguez-Rajo et al. 2004) to 52 days (Peternel

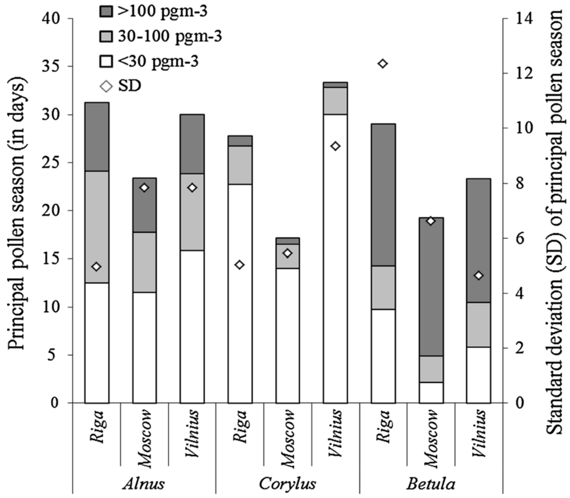

Fig. 4 Distribution of the pollen levels during the principal season

et al. 2007). Results of the research carried out by us show low (3–6 days) variation in duration of *Alnus* and *Corylus* pollen season. In all the cases, the shortest seasons of *Alnus*, *Corylus* and *Betula* were estimated in Moscow. Corden et al. (2000) who carried out similar research suggest that the shortest seasons were usually to be found in more inland locations or very large cities. Ours research supports these both conditions, i.e. Moscow is not only the biggest city (Table 2), but it is also located the deepest into the continent (if to compare the locations under analysis). On the other hand, pollen seasons were longer in the urban area than in rural area for all pollen types (Rodríguez-Rajo et al. 2010). All the research studies illustrate that urbanization makes a direct impact on pollen season timing. Moreover, we have found out that differences of *Alnus* and *Corylus* pollen seasons between Riga and Moscow are statistically significant. In Lublin (Poland) and Skien (Norway) which are twice further, duration of the pollen season is similar (Piotrowska 2004). The research works prove that at the south–north transect, differences in the duration are very small or completely absent (Kasprzyk et al. 2004), whereas our results show that differences in the *Alnus* and *Corylus* pollen season are significant at the east–west transect.

Regional variations in season intensity depend on plant biology and locality (Peternel et al. 2007; Ranta and Satri 2007). When assessing the pollen load during the season, no statistically significant differences were found. The data obtained are contradicting when comparing it to the coverage of the local flora. As in Latvia and Lithuania, the coverage of *Alnus* plants is 19.88 and 12.55 % of the total growing stock, respectively, and in Russia, it is much smaller (Food and Agriculture Organization of the United Nations 2010a, b, c); thus, the pollen load should be proportional. Analysis of the research presented in the article shows that during the half of the season under analysis, the highest *Alnus* pollen SPI was estimated in Riga, what is in compliance with the plants coverage on the territory. Meanwhile, the cases of singled out seasons with maximum SPI in Moscow remain interesting to future scientific research. When we compare *Betula* SPI over the surveyed period, it becomes clear that the biennial rhythm of *Betula* pollen (Jäger et al. 1991, 1996; Corden et al. 2000; Spieksma et al. 2003; Ščevková et al. 2010) is characteristic to Riga but not to Moscow.

To patients who are ill with allergy, the amount of pollen per day is important, especially the amount of days with high concentration of pollen because allergens present in pollen correlate with the amount of pollen in the air (Peternel et al. 2007). On the other hand, the birch pollen season is one of the most difficult for interpretation, because many other allergenic pollen types overlap with the flowering of birch (for example, *Alnus*, *Corylus*) (Bastl et al. 2014). Concerning locations of our research, the *Alnus* and *Corylus* pollen seasons usually cover each other (Fig. 1). In such a way, a bigger amount of days when the pollen load is higher than 30 pgm^{-3} is formed, and the amount of 20–50 pgm^{-3} per 24 h causes symptoms of allergy in sensitized people (Spieksma and Frengueli 1991). Moreover, it is known that *Alnus* and *Corylus* pollen can act as primer for *Betula* pollen allergy resulting as a primer for *Betula* pollen allergy resulting in an extended season (Emberlin et al. 1997). However, it has been pointed out that birch pollen concentrations greater than 30 pgm^{-3} over 24 h trigger severe symptoms and values greater than 80 grains pgm^{-3} over 24 h produce allergic symptomatology in 90 % of patients (Corsico 1993). The beginning of the *Betula* pollen season often covers the seasons of *Alnus* and *Corylus* pollen. Having estimated that during the first days of the season in all locations of our research, the concentration of *Betula* pollen is high, additional load of pollen even worsens quality of sensitized people's life. The increase in the duration of the birch pollen season, in addition to daily pollen concentrations greater than 10 pgm^{-3} of air, is a risk factor for the exacerbation of respiratory morbidity in individuals sensitized to *Betula* (Viander and Koivikko 1978).

Research carried out by us enable characterizing such differences and similarities of the territories under analysis: (1) the beginning of the *Alnu*s and *Corylus* pollen season usually coincided in Riga and Vilnius, whereas significantly differed between Riga and Moscow; (2) Moscow differed by the shortest period of pollen season, independently of the type of pollen; (3) the biennial cycle of *Betula* pollen is characteristic to Riga only; (4) in the spectrum of spring plants' pollen, *Corylus* pollen (10–23 pgm^{-3} per day on the average) was found in the least amount; (5) average concentration of *Betula* pollen per day significantly differed in all locations of the survey, in Moscow the concentration (853 pgm^{-3}) was twice higher that in Riga and Vilnius; (6) *Alnus*, *Corylus* and *Betula* pollen seasons covered each other in all locations surveyed, thus creating additional load of pollen; (7) in each of the stations, there were 13–15 days when concentration of *Betula* pollen exceeded 100 pgm^{-3}.

The article presents information about airborne pollen behaviour in Riga, Moscow and Vilnius might contribute to preventing allergenic diseases and the population (especially allergists and their patients) will have general knowledge about pollen phenology and the levels reached in the atmosphere of the investigated location.

References

Bastl, K., Kmenta, M., Jäger, S., Bergmann, K. C., & Berger, U. (2014). Development of a symptom load index: enabling temporal and regional pollen season comparisons and pointing out the need for personalized pollen information. *Aerobiologia,*. doi:10.1007/s10453-014-9326-6.

Chen, Z. D., Manchester, S. R., & Sun, H. Y. (1999). Phylogeny and evolution of the Betulaceae as inferred from DNA sequences, morphology, and paleobotany. *American Journal of Botany, 86*, 1168–1181.

Corden, J., Millington, W., Bailey, J., Brookes, M., Caulton, E., Emberlin, J., et al. (2000). UK regional variations in Betula pollen (1993–1997). *Aerobiologia, 16*(2), 227–232.

Corsico, R. (1993). L'asthme allergique en Europe. In F. T. M. Spieksma, N. Nolard, G. Frenguelli, & D. Van Moerbeke (Eds.), *Pollens de l'air en Europe* (pp. 19–29). Braine-l'Alleud: UCB.

Emberlin, J., Mullins, J., Corden, J., Millington, W., Brooke, M., Savage, M., et al. (1997). The trend to earlier Birch pollen seasons in the UK: A biotic response to changes in weather conditions? *Grana, 36*, 29–33.

Emberlin, J., Smith, M., Close, R., & Adams-Groom, B. (2007). Changes in the pollen seasons of the early flowering trees *Alnus* spp. and *Corylus* spp. in Worcester, United Kingdom, 1996–2005. *International Journal of Biometeorology, 51*(3), 181–191.

Food and Agriculture Organization of the United Nations. (2010a). *Global Forest Resources Assessment 2010 (FRA 2010) Country Report*. Rome: Latvia. 61 pp.

Food and Agriculture Organization of the United Nations. (2010b). *Global Forest Resources Assessment 2010 (FRA 2010). Country Report*. Rome: Lithuania. 57 pp.

Food and Agriculture Organization of the United Nations. (2010c). *Global Forest Resources Assessment 2010 (FRA 2010). Country Report*. Rome: Russian Federation. 50 p.

Forest Europe, Unece & Fao. (2011). *State of Europe's Forests 2011*. Forest Europe Liaison Unit Oslo: Status and Trends in Sustainable Forest Management in Europe. 344 pp.

Frenguelli, G., Spieksma, F. T. M., Bricchi, E., Romano, B., Mincigrucci, G., Nikkels, A. H., et al. (1991). The influence of air temperature on the starting dates of the pollen season of Alnus and Populus. *Grana, 30*(1), 196–200.

Galvonaitė, A., Misiūnienė, M., Valiukas, D., & Buitkuvienė, M. S. (2007). Lithuanian climate. *Lithuanian service of hidrometeorology: Vilnius*, 180.

Galvonaitė, A., Valiukas, D., Kilpys, J., Kitrienė, Z., & Misiūnienė, M. (2013). *Lietuvos klimato atlasas* (Atlas of Lithuanian climate). Vilnius. 175.

Hirst, J. M. (1952). An automatic volumetric spore trap. *Annals of Applied Biology, 39*, 29–33.

Jäger, S., Nilsson, S., Berggren, B., Pessi, A. M., Helander, M., & Ramfjord, H. (1996). Trends of some airborne tree pollen in the Nordic countries and Austria, 1980—1993: A comparison between Stockholm, Trondheim, Turku and Vienna. *Grana, 35*(3), 171–178.

Jäger, S., Spieksma, E. T. M., & Nolard, N. (1991). Fluctuations and trends in airborne concentrations of some abundant pollen types, monitored at Vienna, Leiden, and Brussels. *Grana, 30*(2), 309–312.

Kasprzyk, I., Uruska, A., Szczepanek, K., Latałowa, M., Gaweł, J., Harmata, K., et al. (2004). Regional differentiation in the dynamics of the pollen seasons of Alnus, Corylus and Fraxinus in Poland (preliminary results). *Aerobiologia, 20*(2), 141–151.

Kazakov, K. (2014). Погода и климат (Weather and Climate). http://www.pogodaiklimat.ru/.

Laaidi, K. (2001). Predicting days of high allergenic risk during Betula pollination using weather types. *International Journal of Biometeorology, 45*(3), 124–132.

Mayor and the Government of Moscow (2012). Territorial authority: Administrative areas. http://www.mos.ru/en/authority/structure/.

Mösges, R., Graute, V., Christ, H., Sieber, H. J., Wahn, U., & Niggemann, B. (2010). Safety of ultra-rush titration of sublingual immunotherapy in asthmatic children with tree-pollen allergy. *Pediatric Allergy and Immunology, 21*(8), 1135–1138.

Mothes, N., & Valenta, R. (2004). Biology of tree pollen allergens. *Current Allergy and Asthma Reports, 4*(5), 384–390.

Myszkowska, D., Jenner, B., Puc, M., Stach, A., Nowak, M., Malkiewicz, M., et al. (2010). Spatial variations in the dynamics of the Alnus and Corylus pollen seasons in Poland. *Aerobiologia, 26*(3), 209–221.

Myszkowska, D., & Piotrowicz, K. (2009). Birch (Betula L.) pollen seasons in Cracow in 1991–2008 in relation to meteorological conditions. *Acta Agrobotanica, 62*(2), 67–75.

Navasaitis, M., Ozolinčius, R., Smaliukas, D., & Balevičienė, J. (2003). *Lietuvos dendroflora (Dendroflora of Lithuania).* Kaunas: Lututė.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences Discussions, 4*(2), 439–473.

Peternel, R., Milanovic, S. M., Hrga, I., Mileta, T., & Culig, J. (2007). Incidence of Betulaceae pollen and pollinosis in Zagreb, Croatia, 2002–2005. *Annals of Agricultural and Environmental Medicine, 14*(1), 87–91.

Peternel, R., Srnec, L., Hrga, I., Hercog, P., & Čulig, J. (2005). Airborne pollen of Betula, Corylus and Alnus in Zagreb, Croatia. A three-year record. *Grana, 44*(3), 187–191.

Pidek, I. A., Piotrowska, K., Kaszewski, B. M., Kalnina, L., & Weryszko-Chmielewska, E. (2009). Airborne birch pollen in Poland and Latvia in the light of data obtained from aerobiological monitoring and Tauber traps in relation to mean air temperature. *Acta Agrobotanica, 62*(2), 77–90.

Piotrowska, K. (2004). Comparison of Alnus, Corylus and Betula pollen counts in Lublin (Poland) and Skien (Norway). *Annals of Agricultural and Environmental Medicine, 11*(2), 205–208.

Ranta, H., & Satri, P. (2007). Synchronized inter-annual fluctuation of flowering intensity affects the exposure to allergenic tree pollen in North Europe. *Grana, 46*(4), 274–284.

Riga municipality. (2012). *Municipal portal of Riga*, https://www.riga.lv/EN/Channels/About_Riga/default.htm.

Rodríguez-Rajo, F. J., Dopazo, A., & Jato, V. (2004). Environmental factors affecting the start of pollen season and concentrations of airborne Alnus pollen in two localities of Galicia (NW Spain). *Annals of Agricultural and Environmental Medicine, 11*(1), 35–44.

Rodríguez-Rajo, F. J., Fdez-Sevilla, D., Stach, A., & Jato, V. (2010). Assessment between pollen seasons in areas with different urbanization level related to local vegetation sources and differences in allergen exposure. *Aerobiologia, 26*(1), 1–14.

Ščevková, J., Dušička, J., Chrenová, J., & Mičieta, K. (2010). Annual pollen spectrum variations in the air of Bratislava (Slovakia): years 2002–2009. *Aerobiologia, 26*(4), 277–287.

Schenk, M. F., Cordewener, J. H., America, A. H., Peters, J., Smulders, M. J., & Gilissen, L. J. (2011). Proteomic analysis of the major birch allergen Bet v 1 predicts allergenicity for 15 birch species. *Journal of Proteomics, 74*(8), 1290–1300.

Siljamo, P., Sofiev, M., Severova, E., Ranta, H., Kukkonen, J., Polevova, S., et al. (2008). Sources, impact and exchange of early-spring birch pollen in the Moscow region and Finland. *Aerobiologia, 24*(4), 211–230.

Skjøth, C. A., Smith, M., Brandt, J., & Emberlin, J. (2009). Are the birch trees in Southern England a source of Betula pollen for North London? *International Journal of Biometeorology, 53*(1), 75–86.

Smith, M., Emberlin, J., Stach, A., Czarnecka-Operacz, M., Jenerowicz, D., & Silny, W. (2007). Regional importance of Alnus pollen as an aeroallergen: A comparative study of Alnus pollen counts from Worcester (UK) and Poznan (Poland). *Annals of Agricultural and Environmental Medicine, 14*(1), 123.

Spieksma, F. T. M., Corden, J. M., Detandt, M., Millington, W. M., Nikkels, H., Nolard, N., et al. (2003). Quantitative trends in annual totals of five common airborne pollen types (Betula, Quercus, Poaceae, Urtica, and Artemisia), at five pollen-monitoring stations in western Europe. *Aerobiologia, 19*(3–4), 171–184.

Spieksma, F. T. M., & Frengueli, G. (1991). Allergenic significance of Alnus (Adler) pollen. In G. D'Amato, F. T. M. Spieksma, & S. Bonini (Eds.), *Allergenic Pollen and Pollinosis in Europe* (pp. 85–87). Oxford: Blackwell.

Stach, A., Emberlin, J., Smith, M., Adams-Groom, B., & Myszkowska, D. (2008). Factors that determine the severity of *Betula* spp. pollen seasons in Poland (Poznań and Krakow) and the United Kingdom (Worcester and London). *International Journal of Biometeorology, 52*(4), 311–321.

Staikūnienė, J., Japertienė, L. M., & Sakalauskas, R. (2005). Žiedadulkių ir maisto alergenais įsijautrinimo įtaka polinozės klinikiniams požymiams (The impact of sensitization to pollen and food allergen on clinical symptoms of pollinosis). *Medicina, 41*(3), 208–216.

Veriankaitė, L., Šaulienė, I., & Bukantis, A. (2010a). The modelling of climate change influence on plant flowering shift in Lithuania. *Žemdirbystė (Agriculture), 97*(1), 41–48.

Veriankaitė, L., Siljamo, P., Sofiev, M., Šaulienė, I., & Kukkonen, J. (2010b). Modelling analysis of source regions of long-range transported birch pollen that influences allergenic seasons in Lithuania. *Aerobiologia, 26*(1), 47–62.

Viander, M., & Koivikko, A. (1978). The seasonal symptoms of hyposensitized and untreated hay fever patients in relation to birch pollen counts: correlations with nasal sensitivity, prick tests and RAST. *Clinical and Experimental Allergy, 8*(4), 387–396.

Vilnius City Municipality (2012). The city. http://www.vilnius.lt/newvilniusweb/index.php/252/?env=110.