

Variations and trends of *Betula* pollen seasons in Moscow (Russia) in relation to meteorological parameters

Elena Severova · Olga Volkova

Received: 6 June 2016 / Accepted: 19 October 2016
© Springer Science+Business Media Dordrecht 2016

Abstract This study investigates possible links of meteorological data and the start date, end date, duration, date of peak, peak value and Seasonal Pollen Index (SPI) of birch pollen seasons recorded in Moscow, Russia, during 1993–2015. Pollen data were collected by a volumetric spore trap. Correlation analysis was used to study relationships between various parameters of pollen seasons. Simple linear regression analysis was conducted to investigate trends over time; multiple stepwise regression analysis was used to describe SPI fluctuations as a function of seasonal or monthly climatic parameters. Air temperatures increased significantly during the study period, but no effect on the timing of the birch pollen season was found. Only the severity of the season showed significant changes that can be considered as a consequence of global warming. Rainfall in May and June of the year preceding flowering, total rainfall in the 40-day pre-season period and average temperature during the pollination were shown to be the most important parameters affecting birch pollen concentrations.

Keywords *Betula* pollen · Meteorological parameters · Regression analysis · Central Russia

1 Introduction

Betula (birch) pollen in Northern and Central Europe is one of the main causes of pollen allergy in spring. In Central Russia, *Betula* is one of the dominant components of native and secondary vegetation. Its pollen is registered in the air from the end of March until mid-May and appears among the most abundant aero-allergenic pollen types. The timing and intensity of birch pollen seasons vary significantly among years. Meteorological factors are among the most important ones affecting this variability (Galán et al. 1991; Jato et al. 1999; Myszkowska et al. 2010; Spieksma et al. 1995). Long-term observations from sampling sites over Europe have shown both similarities and differences in the *Betula* pollen season within a year. Interannual variations in starting dates and Seasonal Pollen Index (SPI) have been reported for each region (Latalowa et al. 2002; Spieksma et al. 1995).

The history of aerobiological studies in Russia is not very long. Short-term series of pollen data were reported by Gubankova (1981), Nikolskaya and Fedoseev (1987), Golovko (2001, 2004), Gandalipova (2003), Posevina (2011) and Morozova and Meshkova (2006), but the majority of them were obtained by Durham gravimetric traps. Permanent volumetric observations were initiated in 1992 in Moscow. This study is the first one examining temporal variation in *Betula* pollen based on accumulated long-term data series recorded over 23 years (1993–2015) in Moscow, Central Russia.

E. Severova · O. Volkova (✉)
Department of Higher Plants, Faculty of Biology, M.V.
Lomonosov Moscow State University, 1, 12, Leninskie
Gory, Moscow, Russia 119234
e-mail: olgavolkova-msu@yandex.ru

2 Materials and methods

2.1 Aerobiological data

The study was performed in the city of Moscow (Russia) located in the middle of the East European Plain, 156 m above sea level. The city covers the area of 2562 km² and has about 12 million inhabitants (Territorial Unit of the Federal Statistical Service of the City of Moscow 2016).

Daily observations of airborne pollen were performed in 1993–2015 from March to October. Pollen was collected with a Hirst-type 7-day recording volumetric spore trap (Hirst 1952) installed on an open rooftop of a meteorological station (55°42'N, 37°32'E) 10 m above ground level. The meteorological station is located within Moscow State University campus near “Vorob’evy Gory” Nature reserve and close to the university botanical garden. Surrounding vegetation is dominated by species *Fraxinus*, *Acer*, *Quercus*, *Betula*, *Malus*, *Populus*, *Ulmus* and *Picea* commonly used in urban greening.

The technique of volumetric trapping followed the standard procedure (Galán et al. 2014). Slides were analyzed under the light microscope by 12 equidistant transverse strips every 2 h. Daily average pollen concentrations were expressed as the number of pollen grains/m³ and summed for cumulative annual totals. The following characteristics of the season were examined, according to Jäger et al. (1996): start date, end date, duration, date of peak, peak value and Seasonal Pollen Index (SPI). SPI was expressed as pollen grains (Comtois 1998). The pollen season was defined as the period in which 95% of the annual total occurred. The start date of the pollen season was defined as the first day when the cumulative pollen count exceeding 2.5% of the annual total; the end date of the season was defined as the day when 97.5% of the annual cumulative total was reached (Goldberg et al. 1988). The dates (start date, end date and date of peak) were displayed as the number of days from January 1 (DOY).

2.2 Meteorological data

The climate in Moscow is continental-temperate with −6.1 °C mean January temperature and +19.5 °C mean July temperature (1981–2010 average). Mean total annual rainfall is 684 mm, and average annual

humidity is 65% (Gorbarenko 2016; Konstantinov 2015).

Meteorological data were obtained from the Meteorological Station of Moscow State University located at the same geographical point where pollen data were recorded. Daily average air temperature (°C), average relative humidity (%) and total rainfall (mm) transformed into annual or seasonal averages were used in analysis.

2.3 Statistical analysis

Correlation analysis was used to study relationships between various characteristics of the pollen seasons. Simple regression analysis was used to investigate the trends in pollen seasons and meteorological data over time (cf. Smith et al. 2014; Ugolotti et al. 2015). Mean, standard deviation (SD), R^2 value, slope of the regression over time, standard error of the regression slope (SE) and coefficient of skewness were calculated. Differences were considered to be statistically significant when $p < 0.05$. Multiple stepwise regression analysis was applied to describe the SPI fluctuation as the function of seasonal or monthly climatic parameters (Galán et al. 1995; Goldberg et al. 1988; Masaka 2001; Ritenberga et al. 2016). As multiple regression analysis makes a number of assumptions about the data (such as normality, linearity and homoscedasticity), SPI data were lognormal-transformed (Mendez et al. 2005; Stach et al. 2008b). Statistical significance of all coefficients in the linear regressions was tested by means of analysis of variance and the Student t test. Calculations were performed using STATISTICA (StartSoft 2013), Microsoft Excel and R package version 3.2.2 (R Core Team 2015). K -fold cross-validation method (R ver.3.2.2 DAAG package; Maindonald and Braun 2015) was used for verification of the regression models. In k -fold cross-validation, the original sample is randomly partitioned into k equal-sized subsamples. Of the k subsamples, a single subsample is retained as the validation data for testing the model, and the remaining $k - 1$ subsamples are used as training data. The cross-validation process is then repeated k times (the folds), with each of the k subsamples used exactly once as the validation data (Maindonald and Braun 2015). In our study, the number of subsamples was three.

3 Results

3.1 General parameters of the pollen season

The 1993–2015 data show that on average the start of the pollen season is at the end of April (DOY 115). The earliest start was observed in 2008 (DOY 101), the latest one—in 2004 (DOY 124). The average duration of the pollen season is 21 days, the shortest pollen season was in 2004 (9 days), the longest one—in 2008 (35 days) (Table 1).

All timing parameters (start date, peak date, end date) have significant positive correlations with each other (Table 2). Seasonal pollen curves are right-skewed: Rapid increase in pollen concentration and subsequent gradual decrease were observed in all studied years. The coefficient of skewness was always positive. The highest skewness values were in 1996 (3.5) and 2003 (3.13), the lowest ones—in 2012 (0.71), 2014 (0.78) and 2004 (0.92). On average, the peak day is 3–4 days after the start of the season.

The highest SPI was observed in 2012 (118057 pg) with peak value of 21171 pg/m³ (DOY 117). The lowest SPI was registered in 2001 (551 pg, peak value 145 pg/m³). Statistically significant negative correlation was found between the SPI and the duration of the pollen season. SPI and peak values are strongly positively correlated (Table 2).

Betula SPI varied significantly between years. Fluctuations appear to be cyclic, generally lower values were recorded after high ones, but no clear period of fluctuation was revealed (Fig. 1). During the period of 1993–2009, the rhythm was triennial, and after 2009 it became biennial.

The analysis of annual pollen curves showed that over 1993–2015 some episodes can be attributed to long-distance transport (see arrows in Fig. 2). One of

them took place in 2004 two weeks prior to the main season when concentration of *Betula* pollen increased from zero to 139 pg/m³ in 3 days. Another episode was 2 weeks before the local anthesis in 2014, with pollen concentration of 137 pg/m³ during 1 day. In 1994, 1997 and 2004, more than 50 pg/m³ was observed 10–14 days before the local flowering.

3.2 Trend in meteorological and pollen season parameters

Temporal variations in the characteristics of *Betula* pollen seasons were investigated by regression analysis (Table 1). Selected meteorological parameters (annual average temperature, average temperature of winter, spring, summer, autumn, annual total rainfall, annual average humidity) recorded over the same time were also examined in order to put the analysis into context. No significant trends of annual total rainfall and average related humidity were found. Significant trend was observed for average annual temperature (Fig. 3), which was associated with a significant trend toward warmer summer ($p = 0.008$) and autumn ($p = 0.006$) temperatures.

No significant trends in the season characteristics related to the timing of pollen season (start date, peak date and end date) were uncovered. A significant increase was observed for the SPI ($p = 0.025$), but the correlation between the SPI and average annual temperature was absent.

3.3 Seasonal Pollen Index in relation to meteorological parameters

The relationships between the SPI and the various meteorological variables were tested by correlation analysis and stepwise multiple regression analysis.

Table 1 Seasonal characteristics and trends of airborne *Betula* pollen in Moscow, Russia, in 1993–2015

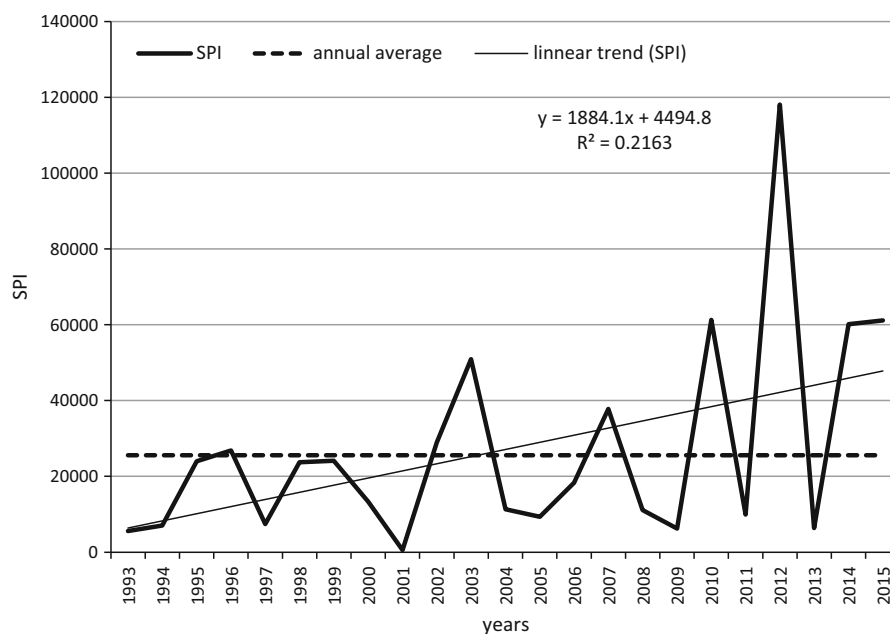
	Mean	Minimum (year)	Maximum (year)	SD	R^2	Slope	SE	P	N
Start day (DOY)	115	101 (2008)	124 (2004)	6.28	0.004	0.063	0.218	0.78	23
Peak day (DOY)	119	107 (2008)	129 (1997)	5.67	0.0007	−0.027	0.218	0.90	23
End day (DOY)	136	123 (1999)	149 (1993)	6.98	0.102	−0.319	0.207	0.138	23
Duration	21	9 (2004)	35 (2008)	7.08	0.137	−0.370	0.203	0.082	23
SPI	27,104	551 (2001)	118,057 (2012)	27,477.3	0.216	0.465	0.193	0.025	23
Peak value	5820	145 (2001)	21,171 (2012)	5377.91	0.099	0.315	0.207	0.14	23

Statistically significant trends ($p < 0.05$) are in bold

Table 2 Correlations among various pollen season parameters

	Start day (DOY)	Peak day (DOY)	End day (DOY)	Duration	SPI	Peak value
Start day (DOY)	1					
Peak day (DOY)	0.88 <i>p</i> = 0.000	1				
End day (DOY)	0.48 <i>p</i> = 0.019	0.58 <i>p</i> = 0.004	1			
Duration	−0.38 <i>p</i> = 0.076	−0.16 <i>p</i> = 0.464	0.59 <i>p</i> = 0.003	1		
SPI	−0.17 <i>p</i> = 0.425	−0.23 <i>p</i> = 0.292	−0.55 <i>p</i> = 0.006	−0.46 <i>p</i> = 0.033	1	
Peak value	0.029 <i>p</i> = 0.893	−0.004 <i>p</i> = 0.986	−0.36 <i>p</i> = 0.090	−0.48 <i>p</i> = 0.020	0.92 <i>p</i> = 0.000	1

Spearman rank correlation

Statistically significant correlations ($p < 0.05$) are in bold**Fig. 1** Variations of *Betula* SPI in Moscow, Russia, from 1993 to 2015

In Central Russia, birch inflorescences start to develop at the end of May–early June of the preceding year (Kostina et al. 2015), so the meteorological data during May–August of the preceding year were used for regression analysis. The following monthly variables were analyzed: mean temperature, total precipitation and mean humidity. Correlations between SPI_N in a given season (N) and individual meteorological variables of the previous year ($N - 1$) are not significant. All meteorological variables were used

in the stepwise multiple regression model. The model (all observation years, all meteorological variables) is not significant ($p = 0.13$). When the seasons with lowest (2001) and highest (2012) SPIs were excluded from further analysis, the resulting model (all meteorological variables, 2001 and 2012 datasets excluded) was significant ($p = 0.009$) and R^2 value was 0.80, adjusted $R^2 = 0.65$. The summary of the linear regression model fitted to the data is presented in Table 3 and Fig. 4. Rainfall and average humidity in

Fig. 2 Episodes of long-distance transport of *Betula* pollen in Moscow. Arrows indicate episodes of long-distance transport

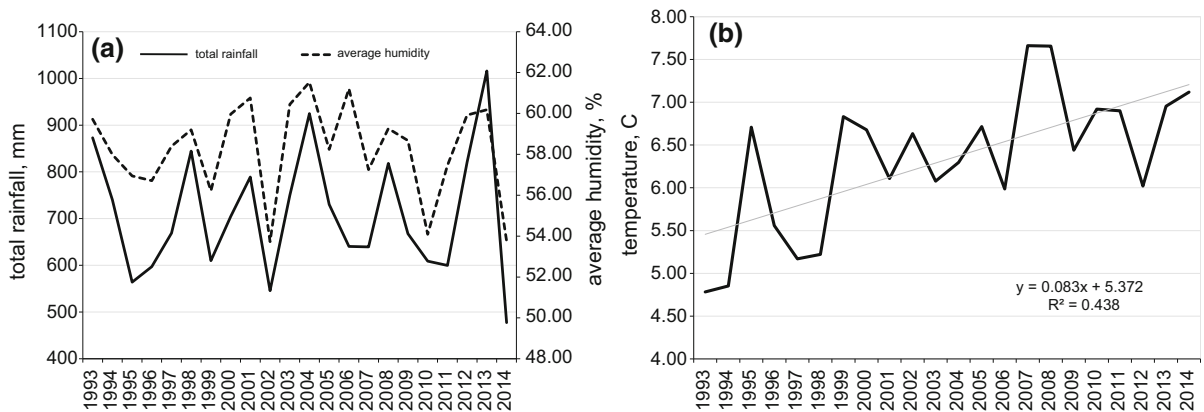
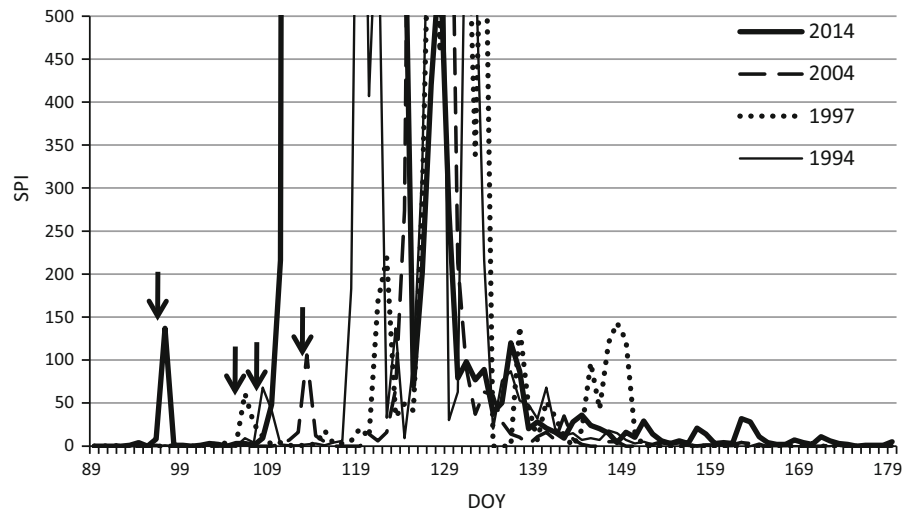


Fig. 3 Variations and trends in meteorological data recorded in Moscow during the study period, **a** annual total rainfall (mm) and average relative humidity (%), **b** annual average temperatures

May and June of the year preceding the release of pollen were found to have the most significant effect on birch pollen concentration. The results of cross-validation are presented in Fig. 5.

To study the most important variable of the current season linked with SPI, correlation analysis between SPI and average temperature, total rainfall and average humidity before and during the season of *Betula* pollen in the air was conducted. The start of *Betula* pollen season has been reported to be dependent upon the meteorological conditions in approximately four decades preceding flowering (Jato et al. 1999; Spieksma et al. 1995), so we determined pre-season as a 40-day period before season's start. Significant negative correlation (-0.48 , $p = 0.034$) was found with total rainfall in

pre-season. Stepwise multiple regression model (all variables, all observation years) is not significant ($p = 0.089$). Regression analysis with outlying datasets (2001 and 2012) eliminated shows that average temperature is the most important parameter during the season and total rainfall is the one before the season. Stepwise linear regression model fitted to the data is the following:

$$\text{SPI} = 0.219T - 0.021R_{40} + 8.388$$

SPI—Seasonal Pollen Index, T —average temperature during the season, R_{40} —total rainfall during pre-season

The model is significant ($p = 0.02$), but the adjusted R^2 (0.28) is considerably low (Fig. 6). The results of cross-validation are presented in Fig. 7.

Table 3 Regression model for predicting the intensity of *Betula* pollen seasons

	<i>B</i>	Std Err of <i>B</i>	<i>T</i>
Intercept	19.892961***	2.644500	7.52
R_{jun}	-0.019768**	0.005952	-3.321
T_{aug}	-0.235938*	0.081930	-2.880
R_{may}	0.023671**	0.005678	4.169
H_{may}	-0.114340*	0.043952	-2.601
R_{jul}	-0.008625*	0.003287	-2.624
H_{jun}	0.072544*	0.030042	2.415
H_{aug}	-0.038677	0.023339	-1.657
T_{jul}	-0.089782	0.058483	-1.535

Only predictors selected by stepwise analyses are included

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

4 Discussion

4.1 General parameters of the pollen season

General parameters of birch pollen season in Moscow—the start, peak and end dates and season duration—vary insignificantly. Early season start in 2008 (DOY 101) can be explained by exceptionally warm February (average T -1.08 °C vs. long-term average T -6.6 °C) and warm March (average T 2.13 °C vs. long-term average T -0.9 °C) (Gorbarenko 2016). The shape of the annual curves is right-skewed, i.e., pollen concentration increases rapidly after the start of the season, which is typical for early flowering species (Grewling et al. 2012).

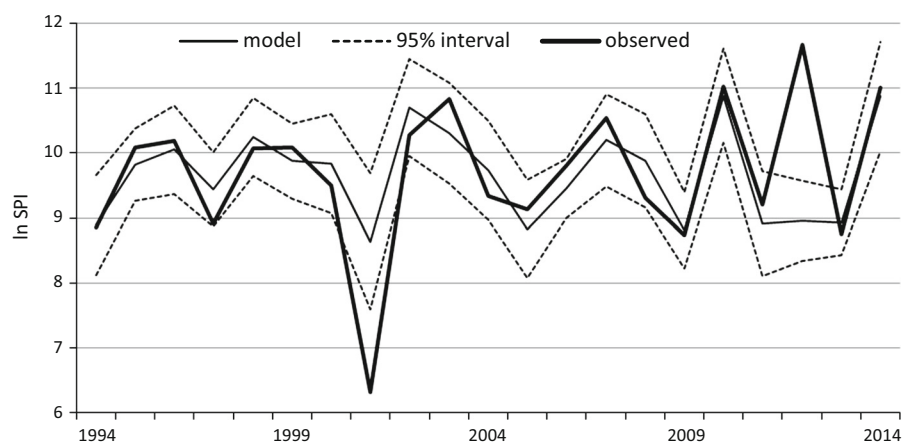
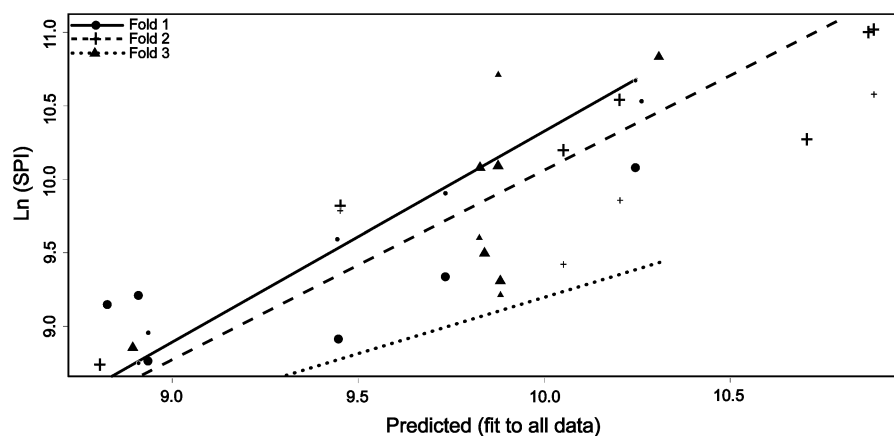
Fig. 4 Observed versus predicted values for *Betula* SPI. Meteorological variables of previous season were used as predictors**Fig. 5** Cross-validation of the regression model (k -folded method, $k = 3$). Small symbols show cross-validation predicted values, and large symbols show observed values

Fig. 6 Observed versus predicted values for *Betula* SPI. Meteorological variables of current season and pre-season were used as predictors

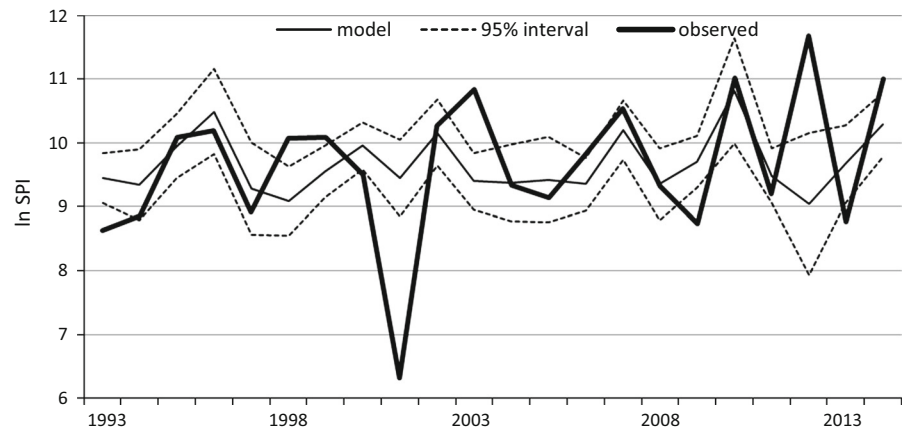
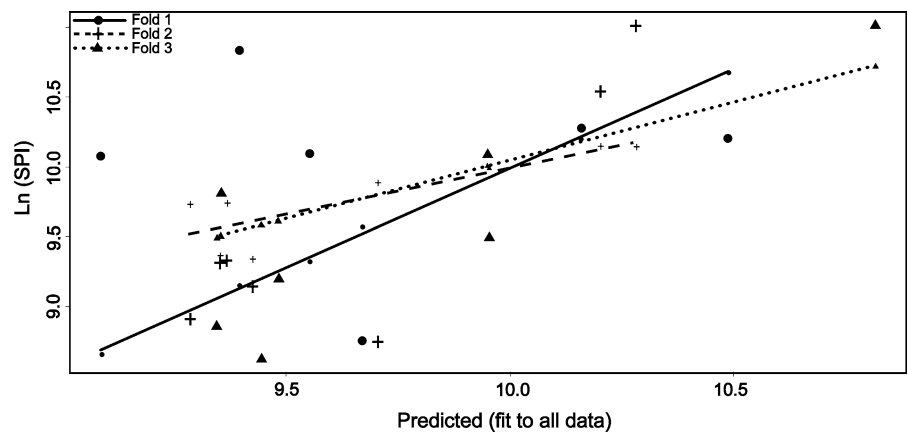


Fig. 7 Cross-validation of the regression model (k -folded method, $k = 3$). Small symbols show cross-validation predicted values, and large symbols show observed values



Reproductive effort in trees usually varies between years. A number of hypothesis, both non-mutually exclusive (Janzen 1971; Ranta et al. 2008) and resource matching (Kelly 1994), have been proposed to explain this phenomenon. In most studies, a biannual rhythm of flowering intensity for *Betula* has been shown (Jäger et al. 1991; Jato et al. 2007; Latałowa et al. 2002; Nilsson and Persson 1981; Spieksma et al. 1995), and triennial cycle was observed in Iceland (Hallsdóttir 1999). According to Dahl and Strandhede (1996), cycle length appears to be affected by the shoot architecture, the rhythms of development of various organs and their possible competition for resources. The authors found evidence for competition between inflorescences and leaves in the same shoot of *Betula pendula* that resulted in a decrease in assimilation capacity and depression of a new inflorescence development. In our study, SPI varied significantly among years but no clear biennial or triennial rhythm was revealed. Varying

environmental conditions, likely limiting factor for reproduction in our region, could be one of the reasons. Emberlin et al. (1993) have also suggested that the sites located far from the main pollen sources may not register the full range of variations.

In Moscow, the highest SPI, five times the average, was observed in 2012. We speculate that extremely high pollen production of 2012 was connected with unusually hot summer in 2010 (average T_{Jul} 26.37 °C vs. long-term average T_{Jul} 19.5 °C, average T_{Aug} 22.24 °C vs. long-term average T_{Aug} 17.3 °C; Gorbarenko 2016). A delayed response of *Betula* is associated with the time of catkins development. Male catkins of *B. pendula* begin to form in late May–early June of the season preceding the pollination (Kostina et al. 2015). In 2010, meteorological conditions in late May/early June did not differ from the average and did not affect the catkins development, so the SPI in 2011 was within the long-term average value. However, a heat wave in July and August 2010 promoted intensive

shoot branching in 2010 (Kostina et al. 2015), which formed a large amount of male catkins in 2011. The catkins formed in 2011 released pollen in 2012. Large amount of catkins together with very favorable weather conditions during late spring of 2012 resulted in a very intensive *Betula* pollination in 2012. The lowest SPI was registered in 2001 and possibly can be explained by the onset of insect phytophagy or early frosts in the previous season (Mayorov, personal communication). SPI and peak values are strongly positively correlated, and similar correlations have been reported in the other studies focusing on *Betula* (Piotrowska and Kubik-Komar 2012; Ugolotti et al. 2015).

A number of studies have demonstrated that local pollen season can be affected by long-distance transport, especially in the north of Europe, e.g., in Fennoscandia (Franzén and Dustfall 1989; Franzen and Hjelmroos 1988; Hjelmroos 1991, 1992; Oikonen et al. 2005; Ranta et al. 2006; Siljamo et al. 2007, 2008; Wallin et al. 1991). In case of *Betula*, long-range pollen can be recognized due to a “wrong” time of appearance, which is significantly outside the local flowering time. In Moscow, episodes of long-distance transport prior to the main season were recognized in 1994, 1997, 2004 and 2014. Back-trajectory analysis showed that these episodes were associated with winds of south or southeast directions (Severova 2007).

4.2 Trend of meteorological and pollen season parameters

Temporal variations in the characteristics of *Betula* pollen seasons were investigated by regression analysis. Various aerobiological studies based on long datasets have shown that during recent years, pollen seasons of early flowering trees tend to start earlier and are more intensive as a result of temperature increase (Ariano et al. 2010; Emberlin et al. 2002; Frei 1998; Laaidi 2001; Oikonen et al. 2005; Rasmussen 2002). An earlier start of pollen season has been seen for *Corylus* (Emberlin et al. 2007; Jäger et al. 1996), *Alnus* (Emberlin et al. 2007; Smith et al. 2007) and *Betula* (Emberlin et al. 1997, 2002). The trends toward earlier birch pollen release in Europe were statistically significant, except for Finnish Lapland, Parma and the UK (Oikonen et al. 2005; Newnham et al. 2013; Ugolotti et al. 2015). The absence of a clear trend

toward earlier birch flowering in Finnish Lapland was attributed to a large amount of non-local pollen recorded even after local anthesis had started (Oikonen et al. 2005). In the UK, birch pollen season has not shifted toward either a later or an earlier beginning (Newnham et al. 2013), contrary to a previously reported shift (Emberlin et al. 2002). Newnham et al. (2013) have suggested that there may be a limit to the advancement of *Betula* pollen season start, which is controlled by a combination of spring temperatures and day length. Thus, a warmer spring would cause the earlier start of pollen season. On the other hand, a potential advancement of pollen season start could be inhibited by a shorter day length and is more risky because of frost damage (Newnham et al. 2013).

Temperature has been emphasized as one of the most important factors in the onset of *Betula* pollination. It has been shown that trees need to accumulate a certain amount of thermal energy (cumulative temperature) before flowering. Therefore, temperature recorded during 40 days before the season's start has a major effect on date of the start of *Betula* season (Jato et al. 1999; Spieksma et al. 1995). Higher cumulative temperatures trigger an earlier season start (Latałowa et al. 2002; Piotrowska and Kubik-Komar 2012; Spieksma et al. 1995; Newnham et al. 2013). However, the links of the climate and the start of birch flowering are more complex. The beginning of *Betula* pollination is also controlled by the chilling period followed by warm temperatures (Emberlin et al. 2007; Frenguelli et al. 1991; Jato et al. 1999; Newnham et al. 2013; Rodríguez-Rajo et al. 2003). A period of exposure to low temperatures is needed for many early flowering trees to break dormancy of the buds (Dahl et al. 2013; Newnham et al. 2013). Some studies have shown that the period of exposure to warmer temperatures decreases with the increased duration of chilling period (Emberlin et al. 2007; Newnham et al. 2013). Thus, in colder winters a shorter thermal period may be needed to initiate flowering (Newnham et al. 2013). In our study, there were no significant trends in the season characteristics related to the timing of pollen season (start date, peak date and end date), possibly because the significant temperature increases in late winter and early spring in Moscow did not occur.

This study demonstrated an increase in pollen concentration over recent years. Temperature has been shown to influence the intensity of airborne *Betula*

pollen season, and the global warming may be one of the causes for an increased season. Increasing pollen concentrations as a result of climate change have been reported in many countries, but the trends are weak (D'Amato et al. 2007; Emberlin et al. 1993, 1997, 2002, 2007; Frei 1998; Piotrowska and Kubik-Komar 2012; Rasmussen 2002; Spieksma et al. 1995; Veriankaitė et al. 2010; Zhang et al. 2014). In our study, there is a significant increase in the SPI ($p = 0.025$) during the study period but the correlation between SPI and average annual temperature is absent.

4.3 Seasonal Pollen Index in relation to meteorological parameters

The amount of *Betula* pollen in a given season is influenced by the temperatures, both in the year of pollen release and in the preceding year, during the initiation of flower buds (Dahl and Strandhede 1996; Rasmussen 2002; Spieksma et al. 1995). A strong positive correlation between the amount of pollen and temperature recorded during the year before pollination has been reported by Emberlin et al. (1993), Rasmussen (2002) and Stach et al. (2008a). The analysis of datasets from Poland showed that the intensity of *Betula* pollen season in a given year was strongly correlated with the June temperature of the previous year (Latałowa et al. 2002). Significant correlations between the intensity of birch pollen seasons and precipitation and relative humidity in April and July of the previous year have been also registered (Latałowa et al. 2002; Stach et al. 2008a).

Various types of regression analysis were used to determine the effect of weather on pollen seasons (Emberlin et al. 1993; Dahl and Strandhede 1996; Galán et al. 1995; Goldberg et al. 1988; Latałowa et al. 2002; Myszkowska 2014, etc.). Meteorological parameters are reportedly the main factors that influence the pollen seasons, but not the only ones. This explains why it is so difficult to find a good fit of a predictive model. In our study, the relationships between the SPI and the various meteorological parameters were tested by correlation and regression analyses. The best results were obtained by the stepwise multiple regression with excluded extreme years (2001, 2012). Preliminary correlation analysis did not allow us to select predictors as all correlations were nonsignificant, so we had to include all predictors into the model. The model is significant ($p = 0.009$),

and an adjusted R^2 is 0.65. Thus, the model explains about more than a half of the variation in birch SPI. R^2 value is higher and equals 0.8. The difference between R^2 and adjusted R^2 can be explained by the short observation period and a large number of predictors included into the model. Cross-validation with three subsamples showed that all models (folds) are similar. The difference between curves (Fig. 5) can be connected with the limited number of observations and the large number of predictors.

Rainfall in May and June of the year preceding the release of pollen was found to be the best predictor of birch pollen concentration. Similar results were obtained for Lublin (Piotrowska and Kubik-Komar 2012) where June rainfall was shown to be the most important factor.

The link of thermal conditions in the year of pollen emission and total concentration of *Betula* pollen was shown in a number of studies (Emberlin et al. 1990; Jato et al. 1999; Latałowa et al. 2002; Pidek et al. 2009; Piotrowska and Kubik-Komar 2012; Spieksma et al. 1995). Weather parameters prior to pollination and during the pollination season are important factors determining SPI. Thermal conditions in February were found to have the greatest effect on the severity of birch pollen (Pidek et al. 2009). The more abundant pollen release was associated with lower temperatures in February. However, the correlation is weak, i.e., *Betula* pollen concentration is only slightly influenced by the weather during the atmospheric pollen seasons (Piotrowska and Kubik-Komar 2012). In our study, average temperature during the season was found to be the most important parameter, and before the start of the season, total rainfall plays the main role. The obtained model is significant ($p = 0.02$) but the adjusted R^2 (0.28) is low, which indicates that birch SPI in a given year is only slightly linked with climate conditions of the current season. Inclusion of the extreme values for 2001 and 2012 decreases the quality of the model. Cross-validation with three subsamples showed that all models (folds) are similar. The difference between curves (Fig. 7) can be connected with the limited number of observations.

5 Conclusions

The objective of this study was to analyze the variations of *Betula* pollen season observed in

Moscow over 23 years in relation to meteorological data. Air temperature increased significantly during the study period, but this did not appear to have a corresponding impact on the timing of the birch pollen season. Only severity of the season showed significant changes that can be attributed to global warming. Regression models for prediction of the intensity of *Betula* pollen season have shown that rainfall in May and June of the year preceding the flowering, total rainfall in 40 days of pre-season period and average temperature during the pollination are the most important parameters effected on the birch concentrations. The data on the relationship between pollen season parameters and meteorological variables presented in this paper will facilitate forecasting of *Betula* pollen season in Central Russia.

Acknowledgements This research was conducted with the financial support of Russian Science Foundation (RNF), Grant No. 14-50-00029 “Scientific basis of the national biobank—depository of the living systems.” The authors are very thankful to Bulat Khasanov for help in model development and to Olga Shilovtseva, the head of the Meteorological Station of Moscow State University, for providing meteorological data.

References

- Ariano, R., Canonica, G. W., & Passalacqua, G. (2010). Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Annals of Allergy, Asthma & Immunology*, 104, 215–222.
- Comtois, P. (1998). Statistical analysis of aerobiological data. In P. Mandrioli, P. Comtois, & V. Levizzani (Eds.), *Methods in aerobiology*. Bologna: Pitagora Editrice.
- D’Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., et al. (2007). Allergenic pollen and pollen allergy in Europe. *Allergy*, 62, 976–990.
- Dahl, A., Galán, C., Hajkova, L., Pauling, A., Sikoparija, B., Smith, M., et al. (2013). The onset, course and intensity of the pollen season. In M. Sofiev & K.-C. Bergmann (Eds.), *Allergenic pollen. A review of the production, release, distribution and health impacts* (pp. 29–70). Dordrecht: Springer.
- Dahl, A., & Strandhede, S.-O. (1996). Predicting the intensity of the birch pollen season. *Aerobiologia*, 12, 97–106. doi:10.1007/BF02248133.
- Emberlin, J., Detandt, M., Gehrig, R., Jaeger, S., Nolard, N., & Rantio-Lehtimäki, A. (2002). Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe. *International Journal of Biometeorology*, 46, 159–170. doi:10.1007/s00484-002-0139-x.
- 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., Savage, M., & Woodman, R. (1993). Annual variations in the concentrations of *Betula* pollen in the London area, 1961–1990. *Grana*, 32, 359–363.
- 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, 181–191.
- Emberlin, J. C., Norris-Hill, J., & Bryant, R. H. (1990). A calendar for tree pollen in London. *Grana*, 29, 301–310.
- Franzén, L., & Dustfall, A. (1989). Episode on the Swedish West Coast, October 1987. *Geografiska Annaler, Series A, Physical Geography*, 71, 263–267.
- Franzen, L., & Hjelmroos, M. (1988). A coloured snow episode on the Swedish west coast, January 1987. A quantitative study of air borne particles. *Geografiska Annaler, Series A, Physical Geography*, 70, 235–243. doi:10.2307/521075.
- Frei, T. (1998). The effects of climate change in Switzerland 1969–1996 on airborne pollen quantities from hazel, birch and grass. *Grana*, 37, 172–179.
- 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, 196–200.
- Galán, C., Emberlin, J., Dominguez-Vilches, E., Bryant, R. H., & Villamandos, F. (1995). Comparative analysis of daily variations in the *Gramineae* pollen counts at Córdoba, Spain and London, UK. *Grana*, 34, 189–198.
- Galán, C., Smith, M., Thibaudon, M., Frenguelli, G., Oteros, J., Gehrig, R., et al. (2014). Pollen monitoring: minimum requirements and reproducibility of analysis. *Aerobiologia*, 30, 385–395. doi:10.1007/s10453-014-9335-5.
- Galán, C., Tormo, R., Cuevas, J., Infante, F., & Domínguez, E. (1991). Theoretical daily variation patterns of airborne pollen in southwest of Spain. *Grana*, 30, 201–209.
- Gandalipova, E. (2003). *Qualitative and quantitative composition of pollen in the atmosphere of Ufa*, Ph.D. Thesis, Ufa (in Russian).
- Goldberg, C., Buch, H., Moseholm, L., & Weeke, E. V. (1988). Airborne pollen records in Denmark, 1977–1986. *Grana*, 27, 209–217.
- Golovko, V. (2001). *The study of the atmospheric aerosol pollen component in south of Western Siberia*, Ph.D. Thesis, University of Novosibirsk (in Russian).
- Golovko, V. (2004). *Ecological aspects of aeropalynology: An analytical review* (Vol. 73). Novosibirsk: SPSTL SB RAS. (in Russian).
- Gorbarenko, E. V. (2016). Air temperature. In O. A. Shilovtseva & Y. I. Nezval’ (Eds.), *Environmental and climate characteristics of the atmosphere in 2015 according to the measurements of the meteorological observatory of Moscow State University*. Moscow: MAKSS Press. [in press] (in Russian).
- Grewling, L., Jackowiak, B., Nowak, M., Uruska, A., & Smith, M. (2012). Variations and trends of birch pollen seasons during 15 years (1996–2010) in relation to weather conditions in Poznań (western Poland). *Grana*, 51, 280–292. doi:10.1080/00173134.2012.700727.

- Gubankova, S. G. (1981). *Aeropalynology in Moscow*, Ph.D. Thesis, University of Moscow (in Russian).
- Hallsdóttir, M. (1999). Birch pollen abundance in Reykjavik, Iceland. *Grana*, 38, 368–373.
- Hirst, J. M. (1952). An automatic volumetric spore trap. *The Annals of Applied Biology*, 39, 257–265.
- Hjelmroos, M. (1991). Evidence of long-distance transport of *Betula* pollen. *Grana*, 30, 215–228.
- Hjelmroos, M. (1992). Long-distance transport of *Betula* pollen grains and allergic symptoms. *Aerobiologia*, 8, 231–236.
- Jäger, S., Nilsson, S., Berggren, B., Pessi, A.-M., Helander, M., & Ramford, H. (1996). Trends in some airborne tree pollen in the Nordic countries and Austria, 1980–1993: A comparison between Stockholm, Trondheim, Turku and Vienna. *Grana*, 35, 171–178.
- Jäger, S., Spieksma, F. T. M., & Nolard, N. (1991). Fluctuations and trends in airborne concentrations of some abundant pollen types, monitored at Vienna, Leiden, and Brussels. *Grana*, 30, 309–312.
- Janzen, D. H. (1971). Seed predation by animals. *Annual Review of Ecology and Systematics*, 2, 465–492.
- Jato, V., Aira, M. J., Iglésia, M. I., Alcázar, P., Cervigón, P., Fernández, D., et al. (1999). Aeropalynology of birch (*Betula* sp.) in Spain. *Polen*, 10, 37–47.
- Jato, V., Rodríguez-Rajo, F. J., & Aira, M. J. (2007). Use of phenological and pollen-production data for interpreting atmospheric birch pollen curves. *Annals of Agricultural and Environmental Medicine*, 14, 271–280.
- Kelly, D. (1994). The evolutionary ecology of mast seeding. *Trends in Ecology & Evolution*, 9, 465–470.
- Konstantinov, P. I. (2015). Atmospheric precipitation. In O. A. Shilovtseva & Y. I. Nezval' (Eds.), *Environmental and climate characteristics of the atmosphere in 2014 according to the measurements of the meteorological observatory of Moscow State University* (pp. 47–50). Moscow: MAKSPress. (in Russian).
- Kostina, M. V., Yasinskaya, O. I., & Bityugova, G. V. (2015). Intensity of pollen dispersion depends on the structure of shoots bearing male catkins in drooping birch (*Betula pendula* Roth.). *Bulletin of Moscow Society of Naturalists, Biological series*, 120, 79–85.
- Laaidi, K. (2001). Predicting days of high allergenic risk during *Betula* pollination using weather types. *International Journal of Biometeorology*, 45, 124–132.
- Latalowa, M., Miętus, M., & Uruska, A. (2002). Seasonal variations in the atmospheric *Betula* pollen count in Gdańsk (southern Baltic coast) in relation to meteorological parameters. *Aerobiologia*, 18, 33–43.
- Maindonald, J. H. & Braun W. J. (2015). *DAAG: Data analysis and graphics data and functions*. R package version 1.22. <http://CRAN.R-project.org/package=DAAG>.
- Masaka, K. (2001). Modelling the masting behaviour of *Betula platyphylla* var. *japonica* using the resource budget model. *Annals of Botany*, 88, 1049–1055.
- Mendez, J., Comtois, P., & Iglesias, I. (2005). *Betula* pollen: One of the most important aeroallergens in Ourense, Spain. Aerobiological studies from 1993 to 2000. *Aerobiologia*, 21, 115–124.
- Morozova, O. V., & Meshkova, R. Y. (2006). Analysis of results of aeropalynology monitoring and uptake of pollinosis patients in Smolensk region. *Russian Allergology Journal*, 4, 11–16. (in Russian).
- Myszkowska, D. (2014). Predicting tree pollen season start dates using thermal conditions. *Aerobiologia*, 30, 307–321.
- 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, 209–221.
- Newnham, R. M., Sparks, T. H., Skjøth, C. A., Head, K., Adams-Groom, B., & Smith, M. (2013). Pollen season and climate: Is the timing of birch pollen release in the UK approaching its limit? *International Journal of Biometeorology*, 57, 391–400.
- Nikolskaya, L., & Fedoseev, G. (1987). Palynological air characteristics and peculiarities of pollinosis in Leningrad. *Immunologia*, 3, 76–77. (in Russian).
- Nilsson, S., & Persson, S. (1981). Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana*, 20, 179–182.
- Oikonen, M. K., Hicks, S., Heino, S., & Rantio-Lehtimäki, A. (2005). The start of the birch pollen season in Finnish Lapland: separating non-local from local birch pollen and the implication for allergy sufferers. *Grana*, 44, 181–186. doi:10.1080/00173130510010602.
- 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, 77–90.
- Piotrowska, K., & Kubik-Komar, A. (2012). The effect of meteorological factors on airborne *Betula* pollen concentrations in Lublin (Poland). *Aerobiologia*, 28, 467–479. doi:10.1007/s10453-012-9249-z.
- Posevina, Y. M. (2011). *Palynoecological monitoring of Ryazan city air*, Ph.D. Thesis, Moscow (in Russian).
- R Core Team (2015). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Ranta, H., Hokkanen, T., Linkosalo, T., Laukkanen, L., Bondestam, K., & Oksanen, A. (2008). Male flowering of birch: Spatial synchronization, year-to-year variation and relation of catkin numbers and airborne pollen counts. *Forest Ecology and Management*, 255, 643–650.
- Ranta, H., Kubin, E., Siljamo, P., Sofiev, M., Linkosalo, T., Oksanen, A., et al. (2006). Long distance pollen transport cause problems for determining the timing of birch pollen season in Fennoscandia by using phenological observations. *Grana*, 45, 297–304. doi:10.1080/00173130600984740.
- Rasmussen, A. (2002). The effects of climate change on the birch pollen season in Denmark. *Aerobiologia*, 18, 253–265.
- Ritenberga, O., Sofiev, M., Kirillova, V., Kalnina, L., & Genikhovich, E. (2016). Statistical modelling of non-stationary processes of atmospheric pollution from natural sources: example of birch pollen. *Agricultural and Forest Meteorology*, 226–227, 96–107.
- Rodríguez-Rajo, F. J., Frenguelli, G., & Jato, M. V. (2003). Effect of air temperature on forecasting the start of the *Betula* pollen season at two contrasting sites in the south of

- Europe (1995–2001). *International Journal of Biometeorology*, 47, 117–125.
- Severova, E. (2007). Long-transported pollen in aeropalynological spectrum of Moscow. In L. Kalnina & E. Luksevics (Eds.), *Volume of abstracts, pollen monitoring programme, 6th international meeting, 3–9 June 2007* (pp. 74–77). Riga: University of Latvia.
- 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, 211–230. doi:[10.1007/s10453-008-9100-8](https://doi.org/10.1007/s10453-008-9100-8).
- Siljamo, P., Sofiev, M., Severova, E., Ranta, H., & Polevova, S. (2007). On influence of long-range transport of pollen grains onto pollinating seasons. Developments in environmental science. In C. Borrego & E. Renner (Eds.), *Air pollution modelling and its applications XVIII* (pp. 708–716). Amsterdam: Elsevier. doi:[10.1016/S1474-8177\(07\)06074-3](https://doi.org/10.1016/S1474-8177(07)06074-3).
- 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 Poznań (Poland). *Annals of Agricultural and Environmental Medicine*, 14, 123–128.
- Smith, M., Jäger, S., Berger, U., Škoparija, B., Hallsdóttir, M., Sauliene, I., et al. (2014). Geographic and temporal variations in pollen exposure across Europe. *Allergy*, 69, 913–923.
- Spieksma, F. T. M., Emberlin, J. C., Hjelmroos, M., Jäger, S., & Leuschner, M. (1995). Atmospheric birch (*Betula*) pollen in Europe: Trends and fluctuations in annual quantities and starting dates of the seasons. *Grana*, 34, 51–57.
- Stach, A., Emberlin, J., Adams-Groom, B., Smith, M., & Myszkowska, D. (2008a). Factors that determine the severity of *Betula* spp. pollen seasons in Poland (Poznań and Cracow) and the United Kingdom (Worcester and London). *International Journal of Biometeorology*, 52, 311–321.
- Stach, A., Smith, M., Baena, J. C. P., & Emberlin, J. (2008b). Long-term and short-term forecast models for Poaceae (grass) pollen in Poznań Poland, constructed using regression analysis. *Environmental and Experimental Botany*, 62, 323–332.
- StatSoft, Inc. (2013). *Electronic statistics textbook*. Tulsa, OK: StatSoft. <http://www.statsoft.com/textbook/>.
- Territorial Unit of the Federal Statistical Service of the City of Moscow (2016). http://moscow.gks.ru/wps/wcm/connect/rosstat_ts/moscow/ru/statistics/population/.
- Ugolotti, M., Pasquarella, C., Vitali, P., Smith, M., & Albertini, R. (2015). Characteristics and trends of selected pollen seasons recorded in Parma (Northern Italy) from 1994 to 2011. *Aerobiologia*, 31, 341–352. doi:[10.1007/s10453-015-9368-4](https://doi.org/10.1007/s10453-015-9368-4).
- Veriankaitė, L., Siljamo, P., Sofiev, M., Sauliene, I., & Kukkonen, J. (2010). Modelling analysis of source regions of long-range transported birch pollen that influences allergenic seasons in Lithuania. *Aerobiologia*, 26, 47–62. doi:[10.1007/s10453-009-9142-6](https://doi.org/10.1007/s10453-009-9142-6).
- Wallin, J.-E., Segerström, U., Rosenhall, L., Bergmann, E., & Hjelmroos, M. (1991). Allergic symptoms caused by long-distance transported birch pollen. *Grana*, 30, 265–268. doi:[10.1080/00173139109427809](https://doi.org/10.1080/00173139109427809).
- Zhang, Y., Bielory, L., & Georgopoulos, P. G. (2014). Climate change effect on *Betula* (birch) and *Quercus* (oak) pollen season in the United States. *International Journal of Biometeorology*, 58, 909–919. doi:[10.1007/s00484-013-0674-7](https://doi.org/10.1007/s00484-013-0674-7).