

## Variations and trends of birch pollen seasons during 15 years (1996–2010) in relation to weather conditions in Poznań (western Poland)

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### Abstract

Birch (*Betula*) pollen seasons were examined in relation to meteorological conditions in Poznań (1996–2010). Birch pollen grains were collected using a volumetric spore trap. An alternate biennial cycle of birch pollen season intensity was noticed in Poznań. The main factors influencing birch pollen season intensity were average daily minimum temperatures during the second fortnight of May and the month of June one year before pollination as well as the intensity of the pollen season of the previous year. Most of the pollen grains are recorded during the first week of the season; the number of pollen grains recorded at this time is positively correlated with mean maximum temperature and negatively correlated with daily rainfall. The significant effect of rainfall in reducing the season pollen index was noticed only during weak pollen seasons (season pollen index < mean). In addition, mean daily maximum temperature during the first two weeks of the birch pollen season markedly influences its duration. No significant trends in duration and intensity of the pollen season were recorded, however, a slight tendency towards early pollination was observed ( $-0.4$  days/year,  $p = 0.310$ ).

**Keywords:** *Betula*, biennial cycle, meteorological parameters, climate change

In Poland, the genus *Betula* (birch trees, family Betulaceae) is represented by seven species, two of which are considered to be the most common, namely *B. pendula* Roth and *B. pubescens* Ehrh. These two species are mainly lowland plants, but can also occur in mountains (Browicz, 1979). Moreover, due to the relatively high resistance to pollution of atmosphere and soil (Eränen, 2006), birch is a popular taxon planted in cities like Poznań (Jackowiak, 1993). *Betula* trees produce large amounts of pollen, which is rated one of the most important aeroallergens in Central Europe (d'Amato et al., 1998). It has been estimated that in Poznań 28% of allergy patients are sensitised to birch pollen (Hofman et al., 1996).

In Poznań, the birch pollen season usually starts in the middle of April and lasts until end of May (Corden et al., 2002). However, strong differences between both start dates and the sum of birch pollen

recorded in the season (season intensity) have been reported, which has been linked with changes in weather conditions in the months preceding flowering (Stach, 2000; Stach et al., 2008b). Similar inter-year variations in these characteristics of birch pollen seasons were noticed in other cities in Poland and Europe (Kasprzyk, 2003; Peternel et al., 2005; Stach et al., 2008b; Myszkowska & Piotrowicz, 2009; Melgar et al., 2012; Piotrowska & Kubik-Komar, 2012). Differences in the intensity of birch pollen seasons can also be caused by cyclic rhythms of high and low years of pollen production that have been observed in a number of European locations (Spieksma et al., 1995; Corden et al., 2000; Latałowa et al., 2002; Stach et al., 2008b). This phenomenon can be explained by competition between vegetative and reproductive organs, when leaves act as a sink of growth substances and inhibit the development

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of male inflorescences (Dahl & Strandhede, 1996). The abundance of seeds after intense pollen seasons can also reduce the amount of pollen produced the following year (Latałowa et al., 2002; Ranta et al., 2005). However, in some regions, the biennial cyclic rhythm of pollen production is not as distinct and can be interrupted by asynchronous years or the intensity of pollen seasons can be similar during consecutive years (Emberlin et al., 1993; Hicks et al., 1994; Spieksma et al., 1995; Myszkowska & Piotrowicz, 2009; Piotrowska & Kubik-Komar, 2012).

Birch pollen seasons in Poznań have been examined in several studies, although previous analyses were based on much shorter aerobiological time series (Stach & Silny, 1996; Stach, 2000; Corden et al., 2002) or took into consideration only one selected aspect of the pollen season (Stach & Silny, 1999; Stach et al., 2008b). This current work comprehensively summarises all available birch pollen data in Poznań from the last 15 years and describes several characteristics of the birch pollen season in Poznań (i.e. start date, end date, duration, intensity, timing and magnitude of peak date) in relation to weather conditions. Trends in the characteristics of the birch pollen season mentioned earlier are also presented.

## Material and methods

### *Pollen monitoring*

Daily average *Betula* pollen counts (1996–2010) were collected in Poznań by a volumetric spore trap of the Hirst design (Hirst, 1952) situated 33 m above ground level, approximately 1 km southwest of the city centre. In previous studies conducted in Poznań (Stach et al., 2008a, 2008b; Rodríguez-Rajo et al., 2009), two pollen-monitoring sites were used in order to extend the length of the dataset. In these studies, pollen data from 1995 and 1996 were taken from a trap situated in an old district of Poznań. However, the trap at Esculap was also operational in 1996 and the dataset is now of sufficient length for just one site to be needed in the analysis. The neighbourhood around the pollen-monitoring site has been described in detail by Rodríguez-Rajo et al. (2009). Two different pollen counting methods have been employed. From 1996 to 1999, pollen data were collected following the methods outlined by Stach (2000), and from 2000 to 2010, by the method described by the Spanish Aerobiological Network (REA) (Galán et al., 2007). These two counting methods have been shown to produce comparable results (Cariñanos et al., 2000) and so the two datasets have been spliced together to produce one

complete time series running from 1996 to 2010. Birch pollen counts are presented as concentrations in 1 m<sup>3</sup> air.

### *Analysis of pollen seasons*

According to Viander and Koivikko (1978), 90% of patients in Finland with birch pollinosis reported mild symptoms when the daily average birch pollen counts exceeded 80 grains/m<sup>3</sup> in the early season. Similar threshold values (75 grains/m<sup>3</sup>) were announced in Poland by Rapiejko et al. (2007). It was therefore decided to use the Threshold 80 (T80) method for defining the limits of the birch pollen season, where the start and end of the birch pollen season is defined as the first and last days when the pollen count is greater than or equal to 80 grains/m<sup>3</sup>. However, two exceptions had to be applied to this method. Stach and Silny (1999) reported an episode of long distance transport of birch pollen that was observed in 1997 at the beginning of June (one month after the main pollen season). Pollen levels at this time exceeded 100 grains/m<sup>3</sup>, which artificially extended the length of the pollen season and influenced the analysis (data not shown). A similar situation occurred in 2000 when the sudden increase in pollen concentrations was observed two weeks after the main pollen season. It was decided to exclude these short peaks from the analysis. Retrospective methods for defining the limits of pollen season, such as the 90% (Nilsson & Persson, 1981), 95% (Goldberg et al., 1988) or 98% (Emberlin et al., 1993) methods, were also taken into consideration, but did not solve the problem of short peaks occurring outside the main pollen season.

The following characteristics of the birch pollen season were examined: start date, end date, duration (days), the duration of the pre-peak period (number of days from the start of the birch pollen season to the peak date), the intensity of the birch pollen season (season pollen index, SPI), the timing and magnitude of the peak day, the number of days during the season with daily average birch pollen levels above certain thresholds (>80, 150 and 500 grains/m<sup>3</sup>), the percentage of the total SPI recorded on the peak day (%), and the percentage of the total SPI recorded during 4 × 1 weekly periods recorded during the birch pollen season (%). Data related to the start, end and peak day of the pollen season were converted to the day of the year from 1 January (DOY). Variations of all the characteristics of the pollen season mentioned above were presented by following statistical parameters: mean (*M*), standard deviation (*SD*), coefficient of variation (*CV*), maximum (*MAX*) and minimum (*MIN*) values.

*Climate and weather data*

Poznań is located in an area of western circulation (Bartkowski, 1970), but has continental climatic influences. Prevailing winds are from a westerly direction (mainly southwest). Mean January and July temperatures in Poznań are  $-1.0^{\circ}\text{C}$  and  $18.0^{\circ}\text{C}$ , respectively, and mean annual precipitation is approximately 550 mm (1971–2000 average) (Woś, 1994; Stach, 2000; Lorenc, 2005).

Meteorological data used in the study were recorded from 1995 to 2010 by the station located at Ławica Airport ( $52^{\circ} 25' \text{N}$ ,  $16^{\circ} 49' \text{E}$ ), situated 4.25 km west of the pollen-monitoring site at Esculap. The monthly mean temperature and the monthly sum of rain recorded during the studied period are presented in Table I. The following meteorological parameters were examined in order to analyse the influence of weather conditions on variations and trends (expressed by linear function) of the birch pollen season:

- Fortnightly, 1-monthly, 1.5-monthly and 2-monthly averages of daily mean, maximum and minimum temperatures and daily rainfall from the year preceding pollination (May–December, 1995–2009) as well as from the same year as pollination (January–March, 1996–2010);
- Averages of daily mean, maximum and minimum temperatures, daily rainfall and the number of rainy days with the following amounts of rain recorded during the first and second week of the birch pollen season and during the whole birch pollen season:  $> 0 \text{ mm}$ ,  $> 3 \text{ mm}$ ,  $> 5 \text{ mm}$ ,  $> 10 \text{ mm}$ .

*Statistical analysis*

All calculations were carried out with the Microsoft Excel, XLSTAT 2010 and Statistica 8.0 software packages. Correlations between chosen meteorological parameters (see earlier) recorded both before and during the pollination period and particular characteristics of the birch pollen season were examined using the parametric Pearson correlation test. This test was used because almost all ( $> 90\%$  of variables) of the examined data had a normal distribution (Shapiro–Wilk test with  $p = 0.05$ ; data not shown). Simple linear regression analysis was used to describe trends in the chosen characteristics of the birch pollen season. The following statistics are shown: the slope of the regression, coefficient of determination ( $R^2$ ) and probability level ( $p$ ).

More detailed analyses were performed to emphasise the characteristic features of the SPI.

First, in order to examine the existence of the alternate cycle of birch pollen production, the autocorrelation function was applied for the available time series (1996–2010). Second, the pollen seasons were divided into two groups: (1) intensive pollen seasons ( $\text{SPI} > \text{MEAN}$ ,  $n = 8$ ) and (2) weak or low intensity pollen seasons ( $\text{SPI} < \text{MEAN}$ ,  $n = 7$ ). The dataset was divided in this way in order to examine whether meteorological conditions during the birch pollen season have a different influence on the SPI during years with high and low intensity. The duration and start date of intensive and weak pollen seasons were compared with each other by using the Student's  $t$ -test (the normality of data was checked by the Shapiro–Wilk test and the homogeneity of variance by Levene's test).

**Results***Variations and trends in birch pollen seasons*

Start dates of birch pollen seasons recorded during the years studied varied by about three weeks from year-to-year (Table II). Early start dates were observed in 1998 and 1999 when the first pollen grains were recorded in the first week of April. The latest start dates of the birch pollen season were recorded in 1997 and 2001 (24 April, DOY 114). Similar variations were observed with the end of the birch pollen season and the date of the maximum daily average birch pollen concentration. On average, the duration of birch pollen season in Poznań lasts three weeks and ranges from 10 to 40 days.

The highest daily average birch pollen level (peak day) was usually recorded within a few days of the pollen season start date, although in 1998, the peak day occurred during the third week of the pollen season. Most of the birch pollen grains ( $> 85\%$  of SPI) were recorded during the first two weeks of the pollen season. In general, the amount of birch pollen recorded during the first week of the pollinating period was about 45% higher than during the second week and 300% higher than during the third week of the season. In the fourth week of the birch pollen season, the number of birch pollen grains did not reach 10% of the SPI (mean 2.5% of SPI). During two years (2000 and 2004), daily average birch pollen concentrations that could potentially induce allergy symptoms ( $> 80 \text{ grains/m}^3$ ) were recorded every day of the pollinating period. In other years, this threshold was exceeded (on average) through 75% of the pollen season (from eight to 24 days depending on the year). Daily average birch pollen levels did not reach the threshold value of  $500 \text{ grains/m}^3$  during one season (2002). This year

Table I. Variations and trends of mean monthly temperature and sum of rain in Poznań, Poland, 1995–2010.

|                                      | 1995–2009                     |              |              |              |              |             |                   |              |             |             | 1996–2010                      |             |  |  |
|--------------------------------------|-------------------------------|--------------|--------------|--------------|--------------|-------------|-------------------|--------------|-------------|-------------|--------------------------------|-------------|--|--|
|                                      | (one year before pollination) |              |              |              |              |             |                   |              |             |             | (the same year as pollination) |             |  |  |
|                                      | May                           | June         | July         | August       | September    | October     | November          | December     | January     | February    | March                          | April       |  |  |
| <i>Mean monthly temperature (°C)</i> |                               |              |              |              |              |             |                   |              |             |             |                                |             |  |  |
| <i>M</i>                             | 14.3                          | 17.2         | 19.2         | 18.8         | 14.1         | 9.2         | 4.0               | 0.1          | –1.2        | 0.6         | 3.5                            | 9.3         |  |  |
| MIN                                  | 12.7 (2004)                   | 15.1 (2001)  | 15.8 (1996)  | 16.4 (1998)  | 10.7 (1996)  | 5.5 (2003)  | –0.2 (1998)       | –4.3 (1995)  | –6.4 (2010) | –4.2 (1996) | –0.3 (1996)                    | 5.6 (1997)  |  |  |
| MAX                                  | 16.9 (2002)                   | 19.3 (2007)  | 24.1 (2006)  | 21.3 (2002)  | 17.1 (2006)  | 12.0 (2001) | 6.8 (2006)        | 4.7 (2006)   | 4.5 (2007)  | 4.4 (2008)  | 6.6 (2007)                     | 12.2 (2000) |  |  |
| Slope                                | 0.066                         | 0.109        | 0.178        | 0.037        | 0.174        | –0.040      | 0.229             | 0.265        | –0.020      | –0.038      | 0.101                          | 0.116       |  |  |
| <i>R</i> <sup>2</sup>                | 0.053                         | 0.141        | 0.151        | 0.018        | 0.197        | 0.009       | 0.254             | 0.213        | 0.001       | 0.004       | 0.061                          | 0.106       |  |  |
| <i>Monthly sum of rainfall (mm)</i>  |                               |              |              |              |              |             |                   |              |             |             |                                |             |  |  |
| <i>M</i>                             | 53.4                          | 55.6         | 85.1         | 57.4         | 48.9         | 41.2        | 31.4              | 37.2         | 34.8        | 33.0        | 38.5                           | 34.8        |  |  |
| MIN                                  | 10.9 (2008)                   | 10.4 (2008)  | 13.5 (2006)  | 9.14 (2003)  | 18.3 (2003)  | 8.1 (2005)  | 13.7 (1997, 2005) | 5.6 (1996)   | 2.0 (1997)  | 8.4 (2003)  | 7.6 (1996)                     | 11.7 (2007) |  |  |
| MAX                                  | 81.8 (2009)                   | 118.1 (1995) | 217.4 (1997) | 117.6 (2006) | 116.1 (2001) | 94.5 (2002) | 48.5 (2000)       | 104.1 (2005) | 71.1 (2007) | 67.6 (2002) | 94.5 (2000)                    | 83.6 (2008) |  |  |
| Slope                                | –0.116                        | –0.982       | –4.334       | 0.918        | –4.057       | –0.129      | 0.485             | 0.825        | 1.655       | –1.142      | 0.132                          | 0.591       |  |  |
| <i>R</i> <sup>2</sup>                | 0.001                         | 0.020        | 0.104        | 0.021        | 0.324*       | 0.001       | 0.035             | 0.027        | 0.118       | 0.109       | 0.001                          | 0.019       |  |  |

 Years with extreme MIN and MAX values are indicated in parenthesis, significant trends \*  $p < 0.05$  in italic typeface.

Table II. Characteristics of birch pollen season in Poznań, Poland, 1996–2010.

| Year                 | Characteristics of pollen season |           |               |              |                      |                 | Number of days with pollen concentrations over |                             |                              |                              | Percentage of total amount of pollen during (%) |             |            |             |
|----------------------|----------------------------------|-----------|---------------|--------------|----------------------|-----------------|------------------------------------------------|-----------------------------|------------------------------|------------------------------|-------------------------------------------------|-------------|------------|-------------|
|                      | Start (DOY)                      | End (DOY) | Length (days) | SPI (grains) | Maximum pollen level | Peak date (DOY) | N days start-peak (days)                       | 80 (grains/m <sup>3</sup> ) | 150 (grains/m <sup>3</sup> ) | 500 (grains/m <sup>3</sup> ) | First week                                      | Second week | Third week | Fourth week |
|                      |                                  |           |               |              |                      |                 |                                                |                             |                              |                              |                                                 |             |            |             |
| 1996                 | 112                              | 135       | 24            | 14641        | 4542                 | 113             | 1                                              | 14                          | 12                           | 5                            | 90.2                                            | 6.6         | 3.1        | 1.0         |
| 1997                 | 114                              | 126       | 13            | 4237         | 1365                 | 122             | 8                                              | 12                          | 10                           | 3                            | 31.6                                            | 61.6        | 2.1        | 0.7         |
| 1998                 | 97                               | 136       | 40            | 10046        | 1025                 | 114             | 17                                             | 24                          | 18                           | 7                            | 11.6                                            | 34.7        | 42.6       | 6.5         |
| 1999                 | 92                               | 119       | 28            | 11376        | 1938                 | 100             | 8                                              | 21                          | 16                           | 8                            | 39.3                                            | 47.7        | 8.5        | 4.5         |
| 2000                 | 108                              | 117       | 10            | 5216         | 1306                 | 109             | 1                                              | 11                          | 9                            | 4                            | 71.0                                            | 21.7        | 4.4        | 3.1         |
| 2001                 | 114                              | 134       | 21            | 10197        | 2308                 | 120             | 6                                              | 16                          | 13                           | 7                            | 56.3                                            | 38.2        | 5.5        | 1.1         |
| 2002                 | 102                              | 117       | 16            | 1549         | 241                  | 111             | 9                                              | 8                           | 5                            | 0                            | 37.2                                            | 53.5        | 14.2       | 3.8         |
| 2003                 | 107                              | 121       | 15            | 16972        | 3920                 | 116             | 9                                              | 12                          | 12                           | 8                            | 44.7                                            | 54.1        | 2.7        | 0.6         |
| 2004                 | 104                              | 122       | 19            | 6224         | 931                  | 113             | 9                                              | 19                          | 13                           | 4                            | 42.4                                            | 42.7        | 15.8       | 2.3         |
| 2005                 | 104                              | 122       | 19            | 2972         | 506                  | 107             | 3                                              | 14                          | 7                            | 1                            | 60.3                                            | 21.2        | 20.2       | 1.9         |
| 2006                 | 110                              | 134       | 25            | 16137        | 2167                 | 112             | 2                                              | 18                          | 16                           | 11                           | 59.8                                            | 12.9        | 24.7       | 3.2         |
| 2007                 | 101                              | 120       | 20            | 5474         | 1045                 | 107             | 6                                              | 10                          | 8                            | 4                            | 84.8                                            | 9.1         | 6.4        | 3.3         |
| 2008                 | 103                              | 129       | 27            | 18849        | 3112                 | 113             | 10                                             | 22                          | 18                           | 12                           | 20.0                                            | 60.9        | 16.2       | 2.9         |
| 2009                 | 98                               | 114       | 17            | 6144         | 1500                 | 99              | 1                                              | 14                          | 9                            | 4                            | 74.3                                            | 21.2        | 6.9        | 3.1         |
| 2010                 | 102                              | 120       | 19            | 11011        | 2193                 | 109             | 7                                              | 18                          | 16                           | 7                            | 46.4                                            | 41.3        | 12.9       | 0.7         |
| <i>M</i>             | 104.5                            | 124.4     | 20.9          | 9403.0       | 1873.3               | 111.0           | 6.47                                           | 15.5                        | 12.1                         | 5.7                          | 51.3                                            | 35.2        | 12.4       | 2.6         |
| <i>SD</i>            | 6.4                              | 7.4       | 7.3           | 5413.3       | 1218.1               | 6.3             | 4.4                                            | 4.7                         | 4.1                          | 3.4                          | 22.6                                            | 18.7        | 10.8       | 1.7         |
| <i>CV (%)</i>        | 6.1                              | 5.9       | 35.0          | 57.6         | 65.0                 | 5.7             | 67.9                                           | 30.2                        | 33.7                         | 59.2                         | 44.1                                            | 53.1        | 87.0       | 64.7        |
| <i>MIN</i>           | 92                               | 114       | 10            | 1549         | 241                  | 99              | 1.0                                            | 8                           | 5                            | 0                            | 11.6                                            | 6.6         | 2.1        | 0.6         |
| <i>MAX</i>           | 114                              | 136       | 40            | 18849        | 4542                 | 122             | 17.0                                           | 24                          | 18                           | 12                           | 90.2                                            | 61.6        | 42.6       | 6.5         |
| <i>R<sup>2</sup></i> | 0.079                            | 0.145     | 0.020         | 0.008        | 0.014                | 0.161           | 0.028                                          | 0.002                       | 0.001                        | 0.040                        | 0.012                                           | 0.007       | 0.005      | 0.009       |
| <i>Slope</i>         | −0.400                           | −0.629    | −0.229        | 105.096      | −32.504              | −0.564          | −0.164                                         | 0.050                       | 0.025                        | 0.150                        | 0.545                                           | −0.338      | 0.174      | −0.035      |
| <i>p</i>             | 0.310                            | 0.162     | 0.619         | 0.758        | 0.672                | 0.138           | 0.551                                          | 0.866                       | 0.923                        | 0.475                        | 0.702                                           | 0.775       | 0.798      | 0.738       |

DOY, day of the year.

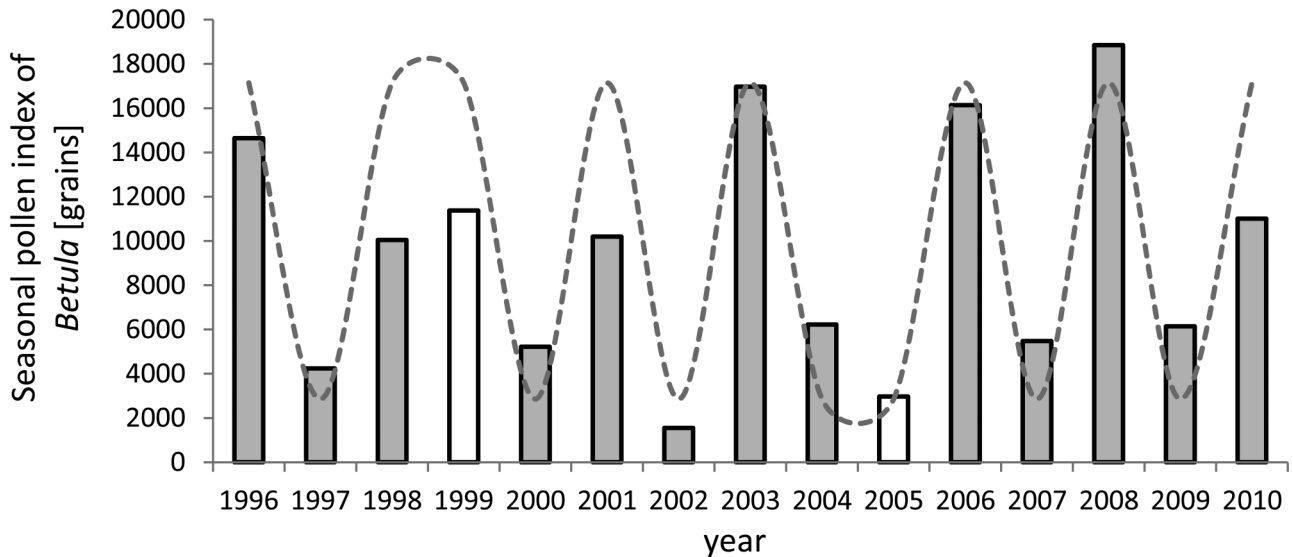


Figure 1. Variations in birch seasonal pollen index (SPI) recorded in Poznań, Poland, 1996–2010. Dotted line: cycle of low and high SPI, white bars: disturbances to alternate cycle of SPI.

was the least intense of the whole study period with an SPI of < 2000 pollen grains.

The sum of birch pollen recorded during the season for the years studied varied markedly from year to year ( $CV = 57.6\%$ ) (Table II). During the most intensive pollen seasons, the sums of pollen grains were more than ten times higher than during the least intense. Usually, very intensive seasons were followed by a year with a low SPI (Figure 1). The sum of birch pollen recorded during the season was on average three times higher or lower (depending on cycle phase) than the SPI in the previous year. In Poznań, the difference in SPI values between two consecutive years was around 8500 grains. This characteristic sequence of low and high SPI values was observed 13 times during the studied period (86.7% of cases). Only during two seasons (1999 and 2005), this cycle was disturbed when the sum of pollen was respectively higher or lower than expected (Figure 1). The results of autocorrelation function revealed that during the analysed time series (1996–2010), the birch SPI depends significantly on the amount of pollen recorded in the birch pollen season the previous year ( $r = -0.644$ ,  $p = 0.013$ ) (Figure 2A). The  $t$ -test revealed that the duration of intensive pollen season was significantly longer (on average nine days) compared to weak pollen seasons (Figure 3A). No differences were noticed when considering the start dates of these two types of pollen seasons (Figure 3B).

No statistically significant trends in the characteristics of the birch pollen season were noticed for Poznań during the studied period. However, slight tendencies towards earlier start ( $-0.4$  days/

year,  $p = 0.310$ ) and end ( $-0.6$  days/year,  $p = 0.162$ ) dates of the birch pollen season were observed (Table II).

#### *Relationship between birch pollen season characteristics and weather conditions*

Pearson correlation analysis showed that average daily maximum temperature during the second fortnight of March had the highest correlation with the beginning of the birch pollen season in Poznań (Figure 2B, Table III). Average daily mean temperature during March and the first fortnight of April significantly influenced the end of the birch pollen season ( $r = -0.676$ ,  $p = 0.006$ ) (Table III). In addition, it was observed that the average daily maximum temperature during the first week of the pollen season strongly influences ( $r = -0.803$ ,  $p = 0.0003$ ) the timing of the peak birch pollen account during the season (Figure 2C). It was noticed that when the average daily maximum temperature during the first week of the birch pollen season exceeds  $18.0^\circ\text{C}$ , the peak day occurs within the first few days of the season. The weather conditions, especially average daily mean temperature during the first two weeks of the season, also influences the magnitude of the peak day (percentage of pollen released during peak day to the SPI).

Statistical analysis shows that weather conditions during the initiation of catkins and resources allocation in birch (one year before pollination) can significantly influence the SPI. The strongest relationships were obtained between average daily minimum temperature from the middle of May until the end

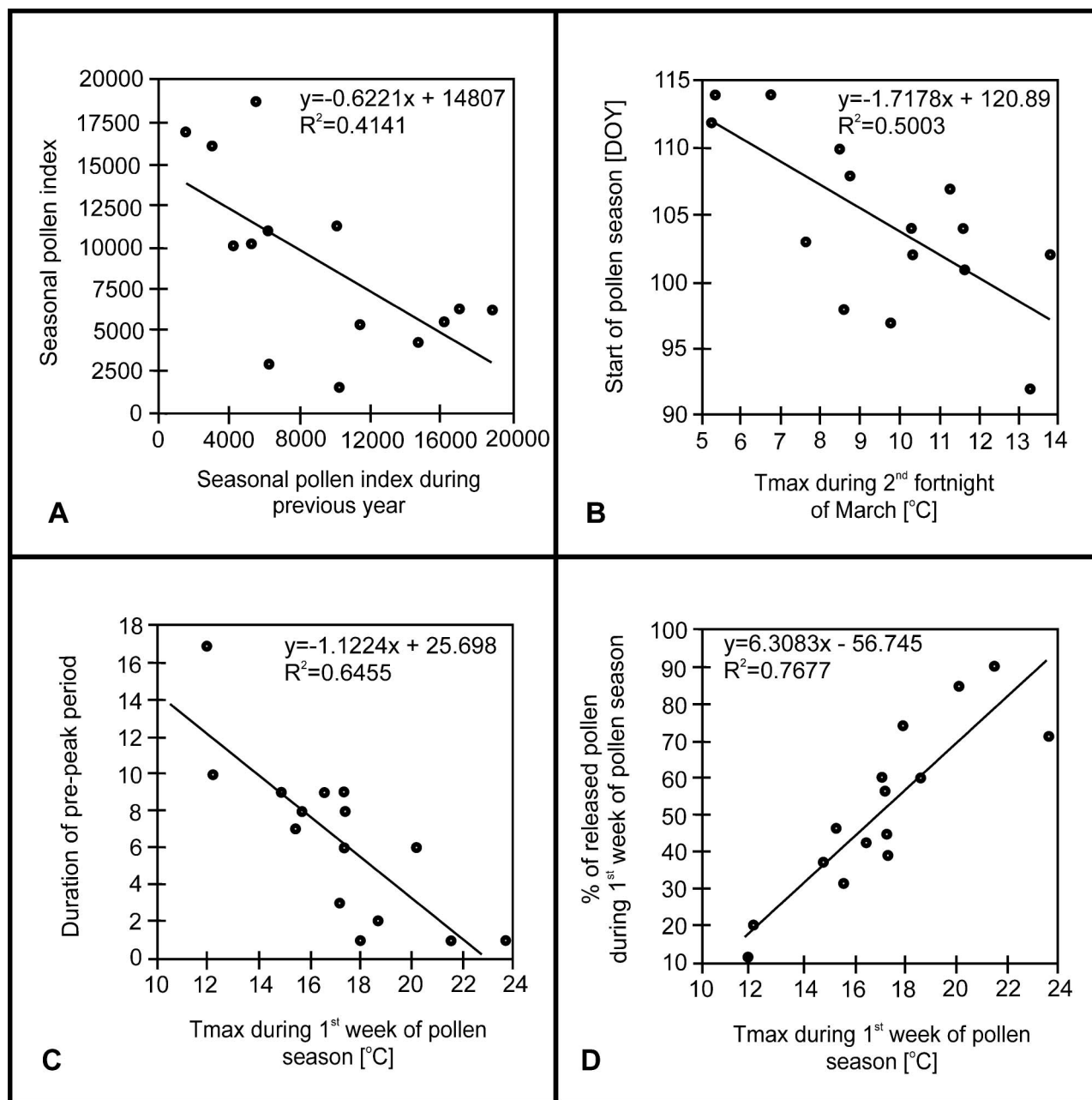


Figure 2. Selected significant relationships between birch SPI and birch SPI recorded in previous years (A) and between characteristics of the birch pollen season and chosen meteorological parameters (B–D).

of June in the year before pollination ( $r = -0.670$ ,  $p = 0.006$ ) (Table III). Moreover, results showed that rainfall during February in the same year as pollination can also influence the intensity of birch pollen seasons ( $r = -0.811$ ,  $p = 0.0002$ ). No statistically significant correlations were found between weather parameters during pollen season and SPI (results not shown). However, there was a significant negative correlation between rainfall (the number of rainy days) and the total number of birch pollen grains recorded during weak pollen seasons (SPI < mean)

(Table IV). This relation was not noticed during intensive pollen seasons.

The amount of birch pollen recorded during the first week (percentage of SPI) was positively correlated with the mean daily maximum temperature during that period (Figure 2D, Table V). It was noticed that when the maximum temperature during the first week of the birch pollen season is < 14.0 °C, only 20–30% of the total number of birch pollen grains will be recorded during that period. However, when maximum temperatures during the first week

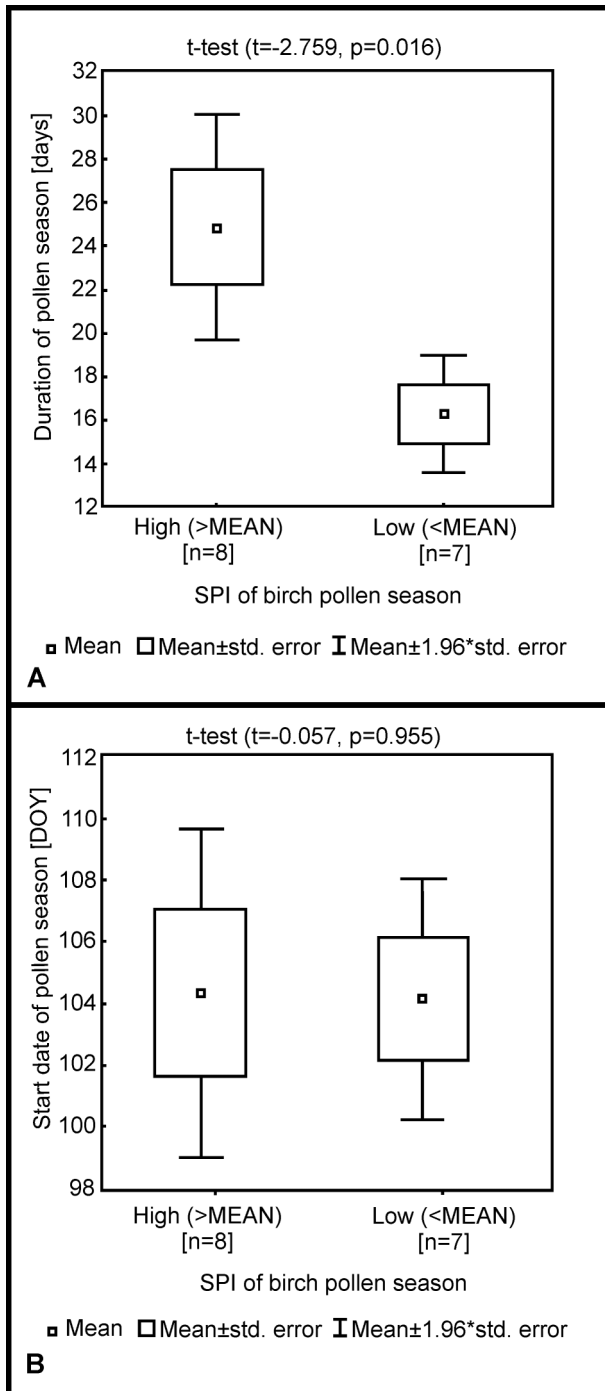


Figure 3. Comparison of duration (A) and start date (B) of birch pollen seasons with low and high SPI.

reached 20.0 °C, about 90% of birch pollen could be recorded in the trap during the first few days of the season. The amount of birch pollen recorded during the first week is also negatively correlated with the sum of rain during that period ( $r = -0.662$ ,  $p = 0.007$ ).

The length of the birch pollen season was negatively correlated with the average daily maximum

temperature during the first two weeks of the season ( $r = -0.670$ ,  $p = 0.006$ ). No significant correlations between rainfall during the birch pollen season and the length of pollination period were observed. However, some weak relationships ( $p = 0.086$ ) between the number of rainy days in the first week of the season and the duration of pollen season could be identified (Table V).

## Discussion

In Poznań, variations in atmospheric concentrations of birch pollen (the pollen curve) are strongly dependent on the weather conditions during the first week of the birch pollen season. High average daily mean temperatures at this time significantly ( $p < 0.05$ ) reduce the duration of the pre-peak period as well as the birch pollen season as a whole. The role of cooling episodes and adverse weather conditions in modifying the duration of pollen seasons has been previously discussed (Huynen et al., 2003; Mendez et al., 2005; Myszkowska & Piotrowicz, 2009), but a clear causal mechanism of these changes has not been proposed so far. The results of this study suggest that warm dry conditions at the beginning of the birch pollen season aid the release and dispersal of pollen and, thereby, shorten the pollination period, whereas inclement weather at this time can have an opposite affect and extend the length of time that birch trees flower. Such information will be useful for modelling birch pollen seasons and for making projections about possible impacts of climate change.

It has been hypothesised that, as an effect of earlier pollination caused by global warming, the seasons will be interrupted more often by unfavourable weather conditions in late winter/early spring and this will prolong the pollination period (Huynen et al., 2003). However, many studies show that the duration of pollen seasons of early-flowering tree species, including birch, has remained fairly stable (Clot, 2001; Rasmussen, 2002; Gamble et al., 2008; Yli-Panula et al., 2009). The slight trend towards a longer pollen seasons was generally noticeable only in Nordic countries (Jäger et al., 1996). In southern Europe, e.g. in Perugia, Italy (Frenguelli, 2002), a shortening of the pollination period of allergenic species was observed. Also in Poznań, the birch pollen season is getting shorter ( $-0.2$  days/year), but the observed changes are not statistically significant ( $p = 0.619$ ). This lack of consistency suggests that the effect of global warming on this pollen season characteristic is complex and assumptions of a general lengthening of tree pollen seasons should be reconsidered in the light of our results. When examining the pollen season duration, models projecting

Table III. Chosen significant Pearson's correlations between particular characteristics of pollen season (start, peak day, end and SPI) and meteorological parameters recorded before pollen season.

| Characteristic of pollen season/meteorological parameters (MP)               | Correlation coefficient |
|------------------------------------------------------------------------------|-------------------------|
| Start date of pollen season (MP taken from the same year as pollination)     |                         |
| daily average maximum temperature during second fortnight of March           | −0.707**                |
| daily average mean temperature during second fortnight of March              | −0.676**                |
| daily average mean temperature of March                                      | −0.567*                 |
| daily rainfall of January                                                    | −0.536*                 |
| Peak day during pollen season (MP taken from the same year as pollination)   |                         |
| daily average mean temperature during second fortnight of March              | −0.544*                 |
| End date of pollen season (MP taken from the same year as pollination)       |                         |
| daily average maximum temperature during March and second fortnight of April | −0.676**                |
| daily average mean temperature during March and second fortnight of April    | −0.609*                 |
| daily average mean temperature of March                                      | −0.607*                 |
| daily average maximum temperature of March                                   | −0.596*                 |
| Seasonal pollen index (SPI)                                                  |                         |
| • MP taken from the year before pollination                                  |                         |
| daily average minimum temperature during second fortnight of May and June    | 0.670**                 |
| daily average minimum temperature during second fortnight of May             | 0.659**                 |
| daily average mean temperature during second fortnight of May                | 0.606*                  |
| daily rainfall during May and first fortnight of June                        | 0.526*                  |
| • MP taken from the same year as pollination                                 |                         |
| daily rainfall of February                                                   | −0.811***               |
| daily rainfall during first fortnight of February                            | −0.674**                |
| daily average maximum temperature during first fortnight of February         | −0.557*                 |

\* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

the impacts of climate change should also include factors that affect pollen production as we have shown that intensive pollen seasons last significantly longer ( $p = 0.016$ ) than pollen seasons with low SPI.

Conversely, the effect of climatic warming on the start dates of the birch pollen season has, in the past, been much more consistent. Studies using long-term data from many sites in Europe have shown that the beginning of the birch pollen season has become markedly earlier during recent decades (Emberlin et al., 1997; Frei, 1998; Emberlin et al., 2002; Rasmussen, 2002; Van Vliet et al., 2002; Frei & Gassner, 2008; Linkosalo et al., 2009; Yli-Panula et al., 2009). This shift was especially pronounced in the late 1970s (Cecchi et al., 2010). However, in Poznań, there is only a slight trend towards earlier flowering and results are not statistically significant ( $p = 0.310$ ). A possible explanation for this observation is the variation in the climatic conditions during the studied period and the length of the birch pollen dataset. A recent report by the Intergovernmental Panel on Climate Change (IPCC) showed that 11 out of the 12 years between 1995 and 2006 ranked amongst the 12 warmest years since the year 1850 (Solomon et al., 2007). The aerobiological time series in Poznań commenced in 1996 and so only covers the period when the highest increase in temperature was recorded. In addition, temperatures in Poznań during spring months (especially in March) were stable without any strong increases between 1996 and 2010 (Table I), which was reflected in the

lack of significant trends in birch pollen season start dates. Similar results, based on a pollen database comparable to Poznań, were recently reported from other cities in Poland (Myszkowska et al., 2011; Piotrowska & Kubik-Komar, 2012).

The intensity of birch pollen seasons in Poznań, unlike start dates and duration, do not reveal a clear dependence on temperature. Spieksma et al. (1995) showed that the seasonal sum of pollen is affected by many different factors (e.g. air temperature, rainfall, radiation) on different stages of plant development (e.g. bud formation, pollen maturation, pollen release). In Poznań, the SPI was predominantly influenced by average daily minimum temperatures (second fortnight of May and June) and the sum of rain (May and the first fortnight of June)

Table IV. Pearson's correlations between pollen seasons with low (&lt; MEAN) and high (&gt; MEAN) SPI and meteorological parameters recorded during whole pollen season.

| Meteorological parameters during pollen season | Pollen season with SPI |        |
|------------------------------------------------|------------------------|--------|
|                                                | < MEAN                 | > MEAN |
| Average mean temperature (°C)                  | n.s.                   | n.s.   |
| Average maximum temperature (°C)               | n.s.                   | n.s.   |
| Average minimum temperature (°C)               | n.s.                   | n.s.   |
| Mean rainfall during pollen season (mm)        | n.s.                   | n.s.   |
| Number of days with rain > 0 mm                | n.s.                   | n.s.   |
| Number of days with rain > 3 mm                | −0.781*                | n.s.   |
| Number of days with rain > 5 mm                | −0.758*                | n.s.   |

Note: n.s., not significant. \* $p < 0.05$ .

during the growing season in the year before pollination. The importance of warm summer weather during catkin initiation in increasing birch SPI was announced previously (Latałowa et al., 2002; Ranta et al., 2008; Stach et al., 2008b; Piotrowska & Kubik-Komar, 2012). Also Dahl and Strandhede (1996) indicated that temperatures during the period May–July one year before pollination were a significant factor influencing pollen production. The SPI in Poznań was negatively correlated with the sum of rain in February, which supports previous results from Poznań (Stach et al., 2008b). In addition, the mean maximum temperature in the first week of February influences the intensity of the pollen season. Similar findings were recorded before from the south-eastern part of Poland (Pidek et al., 2009; Piotrowska & Kubik-Komar, 2012) showing that low temperatures in February promote the occurrence of high birch pollen concentrations.

The competition in resource allocation between vegetative and generative organs can result in fluctuations of the reproductive output, e. g. catkins, fruits and pollen grains (Dahl & Strandhede, 1996). Such alternate cycles in pollen production were also observed in Poznań, which supports previous findings (Spiessma et al., 1995; Latałowa et al., 2002; Ranta et al., 2005; Ščevkova et al., 2010). However, the sequence of low followed by high SPI values was not observed during the whole studied period, and can explain why Stach et al. (2008b) showed that the alternate cycle was less evident in Poznań com-

pared to sites in the UK. The disturbances in cyclic rhythm occurred twice (1999 and 2005). First, after the intensive pollen season in 1998, the SPI in the next year was again high. The second disturbance to this rhythm occurred when weak seasons were recorded during two consecutive years (2004 and 2005). We could not identify any causal explanations for the observed disturbances to the biennial rhythm. During 1999 and 2005, the weather conditions did not differ much from the 15-year-mean. The rain episodes during the pollen season, which were suggested by Ranta et al. (2008) and Yasaka et al. (2009) as being potentially responsible for reducing SPI, were not common in Poznań during the examined period (e.g. only three rainy days during 2005 pollen season). Even during the wettest pollination period in 1999 (17 rainy days), the sum of birch pollen was still very high ( $> 11\,000$  grains). As our results show, the significant effect of rainfall in reducing SPI ( $p=0.038$ ) was observed only during seasons with low SPI ( $< \text{MEAN}$ ). During intensive pollen seasons ( $> \text{MEAN}$ ) the influence of rainfall was negligible. Therefore, we suspect that even though the rainfall caused a strong decrease in the daily average concentration of airborne particles as previously reported (Emberlin, 2003; Perez et al., 2009), the rain episodes do not markedly influence the total sum of pollen recorded during intensive pollen seasons. In turn, they cannot be responsible for the observed disturbances in alternate cycle of birch SPI in Poznań.

Table V. Selected Pearson's correlations between particular characteristics of pollen season and meteorological parameters recorded during pollen season.

| Characteristic of pollen season/meteorological parameters                            | Correlation coefficient |
|--------------------------------------------------------------------------------------|-------------------------|
| Duration of pollen season                                                            |                         |
| daily average mean temperature during first week of pollen season                    | −0.550*                 |
| daily average mean temperature during second week of pollen season                   | −0.604*                 |
| daily average maximum temperature during second week of pollen season                | −0.666**                |
| daily average mean temperature during the first two weeks of pollen season           | −0.649**                |
| daily average maximum temperature during the first two weeks of pollen season        | −0.670**                |
| number of rainy days during first week of pollen season                              | 0.458n.s.               |
| Percentage of total amount of pollen released during the first week of pollen season |                         |
| daily average mean temperature during first week of pollen season                    | 0.835***                |
| daily average maximum temperature during first week of pollen season                 | 0.876***                |
| daily sum of rain during first week of pollen season                                 | −0.661**                |
| number of rainy days during first week of pollen season                              | −0.634*                 |
| Percentage of total amount of pollen released during the peak day                    |                         |
| daily average mean temperature during first week of pollen season                    | 0.554*                  |
| daily average mean temperature during second week of pollen season                   | 0.545*                  |
| daily average mean temperature during the first two weeks of pollen season           | 0.613*                  |
| daily average maximum temperature during the first two weeks of pollen season        | 0.598*                  |
| Number of days from start of pollen season to peak day                               |                         |
| daily average mean temperature during first week of pollen season                    | −0.812***               |
| daily average maximum temperature during first week of pollen season                 | −0.803***               |
| daily average minimum temperature during first week of pollen season                 | −0.673**                |
| daily average maximum temperature during the first two weeks of pollen season        | −0.630*                 |

Note: n.s., not significant. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

## Conclusions

Characteristics of birch pollen seasons in Poznań vary greatly from year to year. The duration of the birch pollen season varies from ten to 40 days and is highly dependent on the average maximum temperature recorded in the first two weeks of the pollen season. The pollen season start date can vary by as much as three weeks and its intensity can be ten times higher between two consecutive years. Biennial rhythms in SPI were observed, although this can change in some years. Disturbances in the alternate cycle cannot be explained by the effect of adverse weather conditions, e.g. by rainfall during the pollen season, and thus, the causal mechanism for these changes is still to be found. Most pollen (up to 90% of the SPI) was recorded in the first week of the season and its amount was significantly dependent on the maximum temperature recorded at this time. No significant trends were noticed during the studied period. Neither duration, nor intensity of the birch pollen season changed markedly. This lack of significant trends in the characteristics of birch pollen season could be linked to stable climatic conditions between 1996 and 2010 in Poznań. The mean temperatures and the amount of rain during the growing season, which could affect SPI, generally remained constant. The average mean temperature of March, which influences pollen season start dates ( $r = -0.567$ ,  $p < 0.05$ ) increased, but not significantly ( $0.1^\circ\text{C}/\text{year}$ ,  $p = 0.375$ ), and resulted in only a slight trend towards earlier flowering ( $-0.4$  days/year,  $p = 0.310$ ). The observed variations in characteristics of the birch pollen season make accurate forecasting essential. This study supplies quantitative data that can be used in modelling annual variations and future changes in birch pollen season start dates and SPI in Poznań. The resulting forecasts can be used to aid the general public and health care professionals in timing prophylactic treatment and help in planning avoidance strategies for this important aeroallergen.

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