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A study on the spatial and temporal variability in airborne *Betula* pollen concentration in five cities in Poland using multivariate analyses

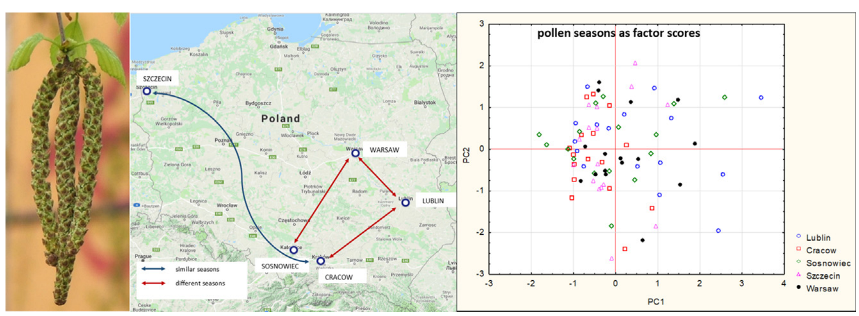
Agnieszka Kubik-Komar [a], Krystyna Piotrowska-Weryszko [b,*], Elżbieta Weryszko-Chmielewska [b], Izabela Kuna-Broniowska [a], Kazimiera Chłopek [c], Dorota Myszkowska [d], Małgorzata Puc [e], Piotr Rapiejko [f,g], Monika Ziemianin [d], Katarzyna Dąbrowska-Zapart [c], Agnieszka Lipiec [h]

[a] *Department of Applied Mathematics and Computer Science, University of Life Sciences in Lublin, Głęboka 28, 20-950 Lublin, Poland*
[b] *Department of Botany, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland*
[c] *Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland*
[d] *Department of Clinical and Environmental Allergology, Jagiellonian University Medical College, Śniadeckich 10, 31-531 Cracow, Poland*
[e] *Department of Botany and Nature Conservation, Faculty of Biology, University of Szczecin, Felczaka 3c, 71-412 Szczecin, Poland*
[f] *Department of Otolaryngology with Division of Cranio-Maxillo-Facial Surgery in Military Institute of Medicine, Szaserow 128, 04-141 Warsaw, Poland*
[g] *Allergen Research Center, Kalinowej Łąki 8, 01-934 Warszawa, Poland*
[h] *Department of the Prevention of Environmental Hazards and Allergology, Medical University of Warsaw, Banacha 1a, 02-097 Warsaw, Poland*

HIGHLIGHTS

- The birch pollen seasons in selected regions of Poland were studied.
- Multivariable statistical analyses of season characteristics were performed.
- The whole dataset and data grouped according to the severity of a season were analyzed.
- Season end, annual total pollen count, and peak value are the most varied features.
- Seasons in Warsaw and Sosnowiec differ the most, in Cracow and Szczecin - the least.

GRAPHICAL ABSTRACT



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ABSTRACT

During the spring period, *Betula* pollen is the main cause of inhalant allergies in Poland and therefore it is important to monitor and forecast airborne pollen concentrations of this taxon. This study conducted a comparative analysis of the basic characteristics of *Betula* pollen seasons at the regional scale. The study was carried out from 2001 to 2016 in five cities in Poland: Lublin, Warsaw, Cracow, Sosnowiec, and Szczecin. To find the attributes of birch pollen seasons that mostly differentiated the individual cities, a general discriminant analysis (GDA) was performed, while a principal component analysis (PCA) allowed us to reduce the data space and present a scatterplot of PCA scores in order to compare pollen seasons in the individual cities. The contingency table was also analyzed to check whether there was a significant relationship between pollen counts in the studied years and cities. At most of the sites, biennial cycles of low and high pollen concentrations can be observed. Due to the high variation in seasons in each of these cities, two data groups were distinguished: Group 1 was composed of seasons with high pollen deposition (2001, 2003, 2006, 2008, 2010, 2012, 2014, 2016), and Group 2 comprising the other seasons. Multivariate analyses were performed on both these groups as well as in the entire dataset. End98, Peak Value, and Annual Total had the highest discriminant power. In Group 1, Warsaw and Sosnowiec differed the most in the investigated parameters, while Cracow and Szczecin differed

* Corresponding author.
E-mail address: krystyna.piotrowska@up.lublin.pl (K. Piotrowska-Weryszko).

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the least. In both groups, most seasons with the highest pollen birch concentration were observed in Lublin, followed by Warsaw, while in Cracow, the number of such seasons was the smallest.

1. Introduction

During the spring period, the main cause of inhalant allergies in Poland is birch pollen. Therefore, it is important to monitor and forecast airborne pollen concentrations of this taxon. In Central/Western Europe sensitization to *Betula* allergens was observed in 37.6% of patients with a suspected inhalant allergy, while in Poland in 27.7% (Heinzerling et al., 2009). In the most extensive Polish epidemiological study (the ECAP study), the prevalence of positive skin prick tests with birch pollen allergens in the representative population examined reached 14.9% (Samoliński et al., 2014). This is due to the fact that the trees of many species of this genus are widespread and the flowers of this taxon produce large amounts of pollen. Piotrowska (2008) found that one *B. pendula* inflorescence produces 10,044,000 pollen grains. Allergy symptoms appear suddenly in people allergic to birch pollen, without initial symptoms developing gradually, as in the case of allergies to other allergens (Rapiejko, 2005), which is associated with very high birch pollen concentrations at the beginning of the pollen season. Worth noting is the fact that in Poland, birch belongs to arboreal taxa that reach the highest values of daily concentrations and annual total pollen counts (Weryszko-Chmielewska, 2006). Due to an increase in the number of people allergic to plant pollen (including birch), special attention is paid to the start and end dates of pollen shed and the intensity of the pollen seasons of allergenic plants in individual areas of the country (Puc et al., 2015).

Betula pollen recorded in European countries primarily originates from the following four native species: *B. pubescens*, *B. pendula*, *B. humilis*, and *B. nana* (Walters, 1993). In Poland, airborne *Betula* pollen grains originate from trees and shrubs of 5 species and their hybrids, among which *B. pendula* occurs most frequently (Rutkowski, 2004; Seneta and Dolatowski, 2007). In Europe, *Betula* is found from Scandinavia (Yli-Panula et al., 2009) to central Spain (Skjøth et al., 2013), northern Greece (Charalampopoulos et al., 2013), southern Italy (Rizzi-Longo et al., 2007; Skjøth et al., 2013), Croatia (Peternel et al., 2007; Stefanic et al., 2007), and in western and central Russia (Skjøth et al., 2013; Novoselova and Minaeva, 2015). The highest *Betula* pollen concentrations are recorded in the boreal region: in Finland, Lithuania, Latvia, Estonia, Poland, Russia, and Belarus, whereas medium concentrations are recorded in Germany and also in some regions of Poland (Skjøth et al., 2008, 2013; Puc et al., 2015).

Fig. 1. Location of aerobiological monitoring stations.

Birch flowering starts on different dates in particular regions of Europe: in northern Spain in February and March, in western Europe at the end of March, in central Europe in the first half of April, while in the northern part of Europe flowering lasts from the end of April to May (Emberlin et al., 2002; Piotrowska, 2008; Ščevková et al., 2010; Grewling et al., 2012; Melgar et al., 2012; de Weger et al., 2013; Piotrowska-Weryszko and Weryszko-Chmielewska, 2014; Borycka and Kasprzyk, 2018). In Scandinavia and other boreal zone countries, among others Poland, *Betula* pollen occurs in dominant amounts and its concentration often exceeds 3000 grains/m^3 of air per 24 h (Weryszko-Chmielewska, 2006; Yli-Panula et al., 2009; Puc et al., 2015). In phenological research in Poland, the beginning of *B. pendula* pollen shedding is a sign of early spring (Niedźwiedź and Jatczak, 2008).

To date, it has been shown that there is high spatial and temporal variability in birch pollen seasons in Poland (Weryszko-Chmielewska, 2006; Puc et al., 2015). The effects of different factors (climate, meteorology, topography, vegetation and so on) on the large-scale occurrence and abundance of pollen have been documented in the literature (Dybova-Jachowicz and Sadowska, 2003; Grewling et al., 2012; Skjøth et al., 2015a), whereas in our study we check whether the present variation in pollen seasons exists not only in a large area, but also at a microscale. Airborne pollen concentration fluctuations significantly affect symptoms in allergic people. Therefore, pollen monitoring results are very useful for proper pollen allergy diagnosis and prevention as well as for pollen allergy treatment control and treatment effectiveness (Bousquet et al., 2015). Pollen forecasts provide equally important information for allergy sufferers. A substantial part of aerobiological literature is devoted to this issue. Pollen forecasting models are constructed for small areas (Kubik-Komar et al., 2018) or at a national scale (Nowosad et al., 2016), but forecasts for areas covering a large part of the European continent are also found more and more frequently (Prank et al., 2013). The reliability of forecasts based on these models largely depends on the density of monitoring sites from which data are derived to construct them.

This study conducted a comparative analysis of the structure of the basic characteristics of birch pollen seasons in order to answer the question whether particular regions of Poland differ significantly in the investigated features of the pollen season and which of these features most differentiate the cities analyzed.

Moreover, this study checks whether the differences found in the pollen season pattern are adequate to the distances between the stations. It seems to be an important issue in the context of the currently

Table 1
Characteristics of pollen monitoring sites.

Study site	Longitude (E)	Latitude (N)	Altitude a.s.l. (m)	Altitude a.s.l. (m)
Lublin	22° 32′	51° 14′	197	18
Warsaw	21° 05′	51° 15′	106	19
Cracow	19° 59′	50° 04′	220	20
Sosnowiec	19° 08′	50° 17′	263	20
Szczecin	14° 33′	53° 26′	52	21

Table 2
Matrix of correctly classified instances.

	Correct classification	Lublin	Cracow	Sosnowiec	Szczecin	Warsaw
Lublin	37.50%	6	2	3	2	3
Cracow	43.75%	1	7	2	3	3
Sosnowiec	25.00%	4	5	4	1	2
Szczecin	18.75%	3	5	3	3	2
Warsaw	56.25%	1	4	0	2	9
Total	36.25%	15	23	12	11	19

Table 4
Standardized coefficients of the first discriminant function (F1).

Parameter	F1
Annual total	0.84
Peak date	0.19
Peak value	−1.28
End	−0.91
Start	0.27

existing network of monitoring stations in Poland as well as in other countries.

To this end, the pollen data were subjected to multivariate statistical analyses, discriminant analysis, principal component analysis, and contingency table analysis. Statistical techniques of this type are rarely applied in aerobiological studies and, according to our current knowledge, have not been used for spatial comparison of the pollen season pattern. Moreover, the data analysis was amplified by studying more and less abundant seasons separately.

2. Materials and methods

2.1. Aerobiological data

Pollen data came from monitoring carried out during the years 2001–2016 in five Poland's cities: Lublin, Warsaw, Cracow, Sosnowiec, and Szczecin (Fig. 1). Hirst-type pollen traps (Lanzoni VPPS 2000 and Burkard), which are standard equipment in aerobiological research, were used to measure pollen concentrations. In all of the regions in question, a pollen trap was installed on a flat roof of a building located in the city center (Table 1).

The following atmospheric pollen season (APS) parameters were analyzed: start, end, maximum pollen concentration (peak value), date of maximum concentration (peak date), and annual total. The 98% method was used to determine the atmospheric pollen season, in which the start is defined as the day when 1% of the annual total is recorded, and the end occurs when 99% of the total catch is reached (Emberlin et al., 1993).

2.2. Climate

Poland's climate is often described as a hybrid oceanic/continental temperate climate, where oceanic air masses flow from the west and continental air masses from the east. Most winds blow from the western sector (west, southwest, and northwest), and the average wind speed ranges between 2 and 4 m/s (Woś, 2010).

The West Pomeranian Region, where Szczecin is located, is characterized by moderately cold weather, generally without precipitation and with a more frequent occurrence of ground frost than in the other regions. The climate of the area where Cracow and Sosnowiec are situated is distinguished by the relatively highest number of warm days with precipitation. Lublin lies in a region where days with moderately warm weather occur rarely, whereas days with moderately cold weather with ground frost and precipitation are more numerous. The Warsaw Basin belongs to the Central Mazovian Region characterized by the relatively highest number of very warm and cloudy days, generally without precipitation (Woś, 2010).

2.3. Statistical analyses

To find the attributes of birch pollen seasons that most differentiated the individual cities, general discriminant analysis (GDA) was performed, while principal component analysis (PCA) allowed us to reduce the data space and present a scatter plot of factor scores in order to compare pollen seasons in the individual cities. Contingency table analysis was also performed to check whether there was a significant relationship between pollen counts in the studied years and cities. Due to the high variation in seasons in each of these cities, two data groups were distinguished. Group 1 was composed of seasons with high pollen deposition: 2001, 2003, 2006, 2008, 2010, 2012, 2014, 2016, and Group 2 comprised the other seasons. This division is also biologically justified by the biennial rhythm of *Betula* flowering (Malkiewicz et al., 2016). GDA and PCA were performed on both these groups, similarly as for the entire data set. Calculations and graphs were made using the general discriminant analysis (GDA) and Factor Analysis packages in Statistica software (Statsoft, 2011).

3. Results

3.1. Pollen analysis. Entire data set

Out of the 4 discriminant functions established, only 1 was statistically significant, which was not sufficient to separate well the classes determined based on the cities. It is best illustrated by the results in the correct classification matrix table (Table 2) which shows that the percentage of correctly classified observations is slightly >36%. In the rows of the table, there are cases that actually belong to the individual regions and the columns show how they are classified by the functions established. The classification gives the best results in the case of Warsaw and this is justified if we compare the results in the squared Mahalanobis distance table (Table 3), which shows that in terms of the season features investigated, Warsaw was the city that differed most from the other ones, while in two cases, for Lublin and Sosnowiec, it was a statistically significant difference. A significant difference also occurred between Lublin and Cracow. The studied features varied least between Cracow and Szczecin.

The discriminant power of the individual features of the pollen season, which takes into account their intercorrelation, is represented by the absolute values of the standardized coefficients of the first discriminant function (Table 4). The values contained in this table demonstrate

Table 3
Mahalanobis square distances between regions.

	Cracow	Sosnowiec	Szczecin	Warsaw
Lublin	1.77*	0.76	0.99	2.06*
Cracow		1.14	0.24	1.40
Sosnowiec			1.03	2.82*
Szczecin				1.33

* p-Value < 0.05.

Table 5
Factor loadings after VARIMAX rotation.

Parameter	PC1	PC2
Start	0.23	0.83[a]
End	−0.31	0.44
Peak date	−0.03	0.91[a]
Annual total	0.96[a]	−0.07
Peak value	0.96[a]	0.11
Proportion of variance	0.40	0.35

[a] Factor loadings > 0.75.

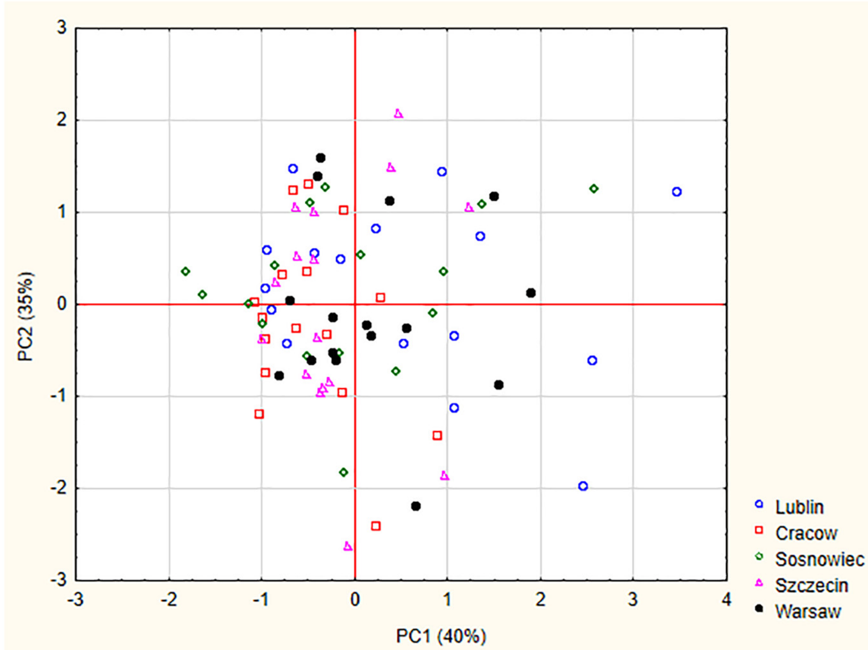

Fig. 2. Factor scores in the PC1-PC2 coordinate system.

that the parameters that differed the most between the cities were the following, in decreasing order: peak value, season end date, and annual total.

The PCA results allow us to look at the entire data structure, but this time not from the point of view of separation as in discriminant analysis, but in order to compare the individual cities to one another in terms of the season characteristics studied in the data space reduced to two dimensions. The number of principal components was chosen on the basis of Kaiser's criterion (Irwing et al., 2018). Together, these two determined components explained 74% of the total variance of the system. Due to the high variation in the factor loading values, it is possible to easily interpret the individual components, among which PC1 determines the abundance of pollen seasons, whereas PC2 is most strongly related to season start and peak date (Table 5).

The graph in Fig. 2 presents the determined factor scores, from which we can read that the most abundant birch pollen seasons were

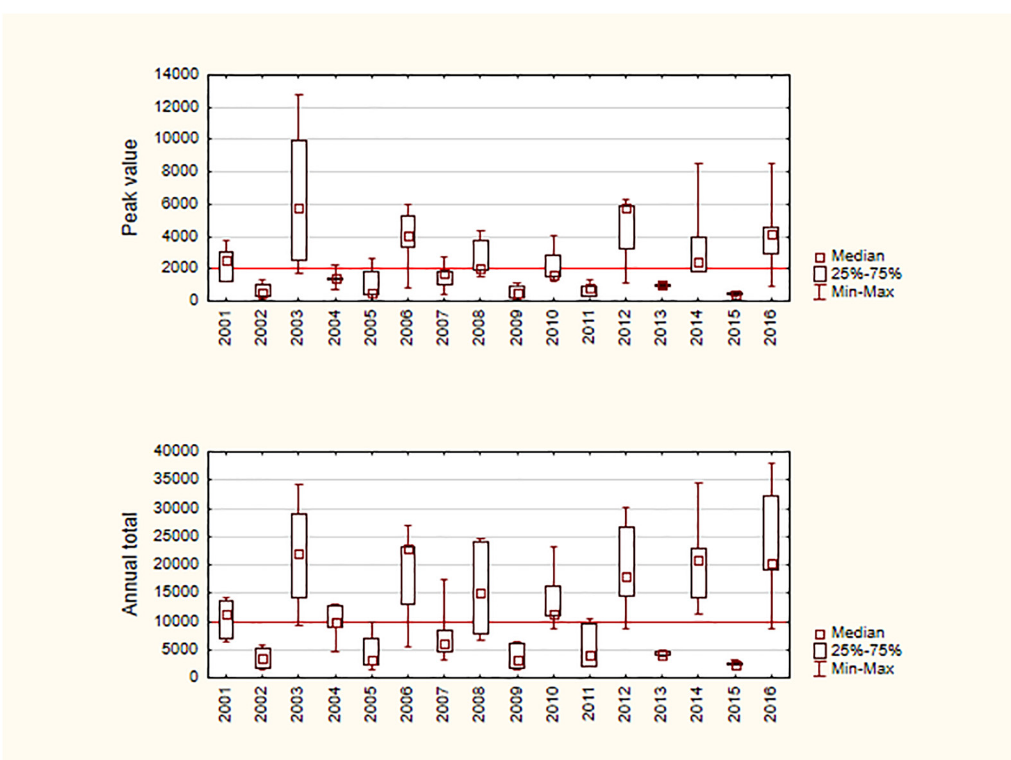

Fig. 3. Basic statistics of Peak Value and Annual Total for pollen seasons.

observed in Lublin (the blue points are most noticeable to the right from the PC2 axis). The lowest airborne pollen concentration occurred in Cracow (the red points predominate on the left side of the PC2 axis). In terms of the annual total pollen count, Sosnowiec was characterized by the largest differences between seasons, whereas in terms of season start and peak date, it was Szczecin.

At the end of the analyses, a contingency table analysis was performed for the entire data set using the χ^2 test to check whether there was a relationship between the annual total pollen count in the years under study and the cities. This test showed a significant relationship between seasons and regions ($p < 0.01$), but its strength, checked using the Cramer's V contingency coefficient, showed that this relationship was weak ($V = 17\%$).

Due to the fact that both Annual Total and Peak Value were the characteristics that most strongly varied among regions, as shown by the analysis results, the seasonal variation of these two features was observed and these characteristics were found to vary greatly (Fig. 3). Intra-group variation is an undesired feature and hence, in order to reduce the variance for the individual regions, the data set was divided into two groups on which the multivariate analysis was performed once again. Group 1 was generally related to more abundant pollen shed; based on both graphs included in Fig. 3, the pollen seasons in 2001, 2003, 2006, 2008, 2010, 2012, 2014, and 2016 were assigned to this group. The other seasons in 2002, 2004, 2005, 2007, 2009, 2011, 2013, and 2015, characterized by less abundant pollen shed and lower variation, made up the second group (Group 2).

3.2. Results for Group 1

The results of the analysis narrowed down to Group 1's data showed greater variation in the season characteristics between the studied cities, and this allowed us to discriminate two classes that were interesting to us. Two discriminatory variables proved to be statistically significant. The percentage of correctly classified observations increased and the class determined by Warsaw was still characterized by the highest value (Table 6). The season characteristics analyzed differed to a greater extent between the regions considered. Significant differences, as measured by the squared Mahalanobis distance, were found between Warsaw and the other cities as well as for Lublin in relation to Cracow and Szczecin (Table 7). As far as the characteristics studied are concerned, Cracow and Szczecin were most similar to each other, similar to the case of the entire data set.

The features with the highest discriminant power were peak value, annual total, and season end. The values of the standardized coefficients of the first discriminant function were, respectively: −1.746, 1.748, and −1.012.

The variables PC1 and PC2 determined after VARIMAX rotation are related to the following parameters, respectively: PC1 to start, end and season peak dates, whereas PC2 to pollen abundance (Table 8). Both variables explain >81% of the variance of the system. In Fig. 4, the points relating to the observations from Lublin can be seen in the highest parts of the graph, which is evidence that the most abundant birch pollen seasons were observed in this region of Poland. Abundant seasons also occurred in Warsaw and Sosnowiec, but to a smaller extent. The points relating to the observations from Cracow located below the PC1 axis are evidence that, as far as Group 1's data are concerned, the lowest airborne pollen concentrations occurred in this city. The large scatter of the points originating from the different cities along the PC1 axis means that in all the cities, there was high variation in the features associated with season start, end, and peak dates.

3.3. Results for Group 2

The discriminant analysis for the Group 2 data was not successful. Discriminant functions separating the cities studied could not be established, which means that the vectors of the average values of the parameters for the less abundant seasons did not differ significantly between the cities. This fact is not surprising if we look again at the graphs in Fig. 3. It can be seen there that the variation in the most discriminating characteristics for Group 2's seasons (below the horizontal line) is distinctly smaller than among abundant pollen seasons.

Table 6
Percentage of correctly classified instances for Group 1.

	Correct classification	Lublin	Cracow	Sosnowiec	Szczecin	Warsaw
Lublin	62.5%	5	1	0	0	2
Cracow	50.0%	0	4	1	3	0
Sosnowiec	37.5%	3	2	3	0	0
Szczecin	50.0%	1	1	2	4	0
Warsaw	75.0%	0	1	0	1	6
Total	55.0%	9	9	6	8	8

The principal component analysis allowed two variables to be determined: PC1 positively correlated to peak value and annual total, and PC2 negatively correlated to start and peak dates (Table 9). Similarly as in the case of the entire data set, the determined variables explain >74% of the variance of the system. The predominance of the points related to Cracow and Sosnowiec on the left side of the graph allows us to conclude that these regions were characterized by the lowest total pollen counts and peak values (Fig. 5). On the other hand, the large number of points located in the upper part of the graph, in relation to its entire area, is evidence that most of Group 2's seasons started earlier and that their peak date also occurred earlier (regardless of the city).

4. Discussion

Our study used, for the first time, an in-depth statistical analysis to compare spatial and temporal variability in airborne *Betula* pollen concentration between monitoring sites. *Betula* pollen seasons in the cities located a significant distance from one another were shown to exhibit high similarity, in spite of the climatic differences due to their geographic location. Among the five compared sampling sites located in cities situated in different parts of Poland, at a distant of 65 to 597 km from one another, the greatest similarity in *Betula* pollen seasons was shown between Szczecin and Cracow, in spite of the large distance between these cities (527 km). Pollen seasons in these cities were characterized by the lowest annual totals and the lowest average peak values as well as by a small difference in the average season end dates and season duration, which was only one day. The values of the above-mentioned parameters for the period of 2001–2011 are presented in the paper by Puc et al. (2015). On the other hand, Lublin and Warsaw, located close to each other (153 km), were characterized by the most different *Betula* pollen season among the cities studied. Despite this, the highest values of Annual Total were recorded in Lublin and Warsaw, with the same average start date of the pollen seasons, significant differences related to the end date of the season and its duration (on average 8 days). These two latter features proved to be the ones that resulted in the largest differences in the characteristics of pollen seasons for Lublin and Warsaw. Variation in season end dates, and thus in season duration, largely depends on topography and land use. Urban climate and increasing turbulence caused by buildings have a large impact on pollen dispersal. In large cities, pollen seasons can be extended due to the impaction of

Table 7
Mahalanobis square distances between regions for Group 1.

	Cracow	Sosnowiec	Szczecin	Warsaw
Lublin	5.84*	1.90	4.20*	5.54*
Cracow		2.17	0.83	4.88*
Sosnowiec			1.40	6.60*
Szczecin				6.44*

* p-Value < 0.05.

Table 8
Factor loadings after VARIMAX rotation for Group 1.

Parameter	PC1	PC2
Start	0.87[a]	0.10
End	0.79[a]	−0.16
Peak value	0.11	0.96[a]
Peak date	0.89[a]	0.03
Annual total	−0.14	0.96[a]
Proportion of variance	0.44	0.38

[a] Factor loadings > 0.75.

pollen between buildings (Emberlin and Norris-Hill, 1991). The presented differences in the pattern of *Betula* pollen seasons in the cities located relatively close to each other (Lublin, Warsaw) can be due to their different urban morphology (building density and the area of impervious surfaces) and the distance of the monitoring stations from the city center.

Data from the official websites of the Regional Directorates of State Forests ([1–5]) show that birch trees have a high percentage in forest stands around Lublin (8%), Warsaw (8%), and Sosnowiec (7%), while this percentage is much smaller in the case of forest stands around Szczecin (4.3%) and Cracow (1.2%).

The proportion of birch in forests of the regions analyzed has a clear impact on airborne pollen concentrations. The data for Lublin and Warsaw, which have the highest percentage of birch in forest stands around them, clearly correspond to high pollen concentrations in the atmospheric air of these cities. The much lower percentage of birch in forest stands around Szczecin and Cracow is reflected in pollen concentration in these cities.

Smith et al. (2014) studied geographic and temporal variations in airborne pollen concentration at 13 European sites. Their results presented in Table 1, as regards the percentage dominance of birch pollen among the taxa studied, confirm our supposition that differences in pollen concentration are not determined by the distances between monitoring sites. While this is understandable in the case of large distances, the differences between monitoring stations located close to one another are not quite obvious at all. A study by Werchan et al. (2018), which found a significant variation in the concentration of birch pollen within one city, can be such an example.

Thus, we believe that applying analyses similar to those used in our research to any area of Europe would lead to interesting and even similar conclusions. For example, similar start dates as well as very high and comparable *Betula* pollen concentrations were found for Lublin and a city located at a great distance from it, Mûnster in Germany (Melgar et al., 2012; Piotrowska-Weryszko and Weryszko-Chmielewska, 2014).

This study revealed that among the studied cities, the largest differences in the pollen season pattern over the study period occurred in the city with the highest degree of industrialization (Sosnowiec). Almost all the pollen season parameters in Sosnowiec were characterized by the greatest variation. Only peak date was least varied in Sosnowiec as compared to the other cities. The high variation in the annual total pollen count in Sosnowiec can be attributed to the impact of industrial pollution on plants, a periodic increase in temperature due to industrial processes, or long-distance pollen transport from the south, which is possible due to the depressions in the Beskidy Mountains.

Pollen grains of some anemophilous plants are transported over very large distances. In a study carried out in London, it was found that in the case of birch, the proportion of pollen from distant areas seemed to exceed its proportion originating from the immediate surroundings (Emberlin and Norris-Hill, 1991). In turn, it was found using the HYSPLIT model that in Wrocław (Poland) and Worcester (UK), local trees are primarily the source of birch pollen, but long-distance transport also plays some role (Skjøth et al., 2015a). Based on back trajectory calculations, Skjøth et al. (2015b) demonstrated in Worcester the long-distance transport of *Betula* pollen grains. The results of this study reveal that small woodlands play a major role in the overall pollen load in urban areas. A study by Oteros et al. (2015) also reveals that the origin of airborne grains is not only associated with the nearest area.

Some birch species are considered to be pioneer plants. They stand atmospheric industrial pollution well. *B. pendula* is very resistant to drought and grows well on poor soils, e.g. dunes or industrial wasteland, and it is also resistant to air pollution. It is used in open and urbanized landscapes, and is planted singly, in groups and in park avenues (Seneta and Dolatowski, 2007). *B. pubescens* requires humic fresh soils. It also tolerates wet and waterlogged soils, and is mainly used in open landscapes (Seneta and Dolatowski, 2007).

The data included in the maps in the paper by Zając and Zając (2001) show that in Poland, *B. pendula* is much more frequent than

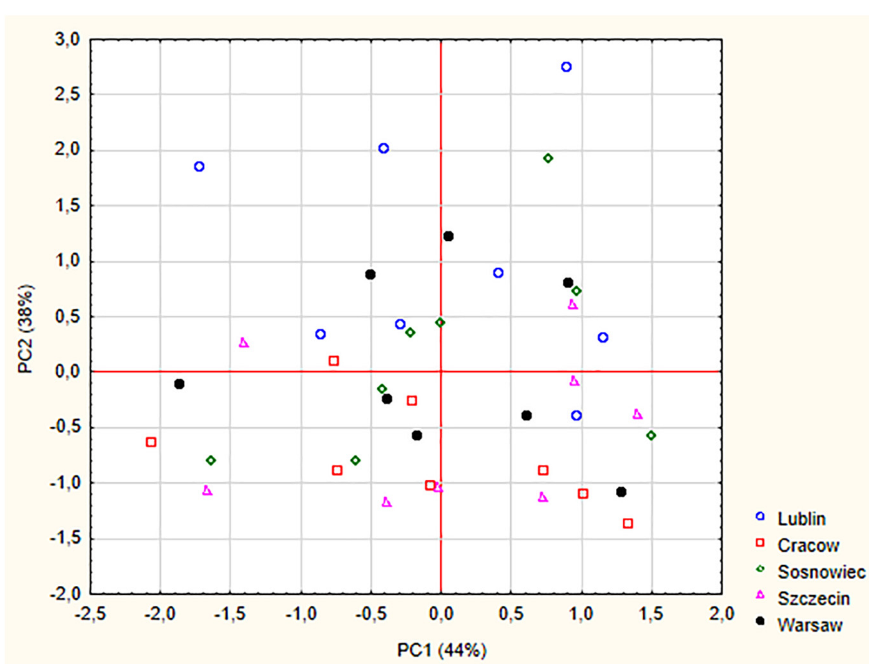

Fig. 4. Factor scores in the PC1-PC2 coordinate system for Group 1.

Table 9
Factor loadings after VARIMAX rotation for Group 2.

	PC1	PC2
Start	−0.25	0.88[a]
End	0.49	−0.28
Peak value	−0.94[a]	0.07
Peak date	0.18	0.89[a]
Annual total	−0.94[a]	−0.04
Proportion of variance	0.42	0.33

[a] Factor loadings > 0.75.

B. pubescens. Meanwhile, *B. pendula* is found throughout Poland with a similar density, whereas *B. pubescens* is recorded only in some areas, predominantly in central and central-eastern Poland (Lublin, Warsaw). Cracow, Szczecin, and Sosnowiec are located in the regions where *B. pubescens* has a lower frequency or does not occur at all. The above fact can also be an explanation of the reason for the occurrence of the largest amounts of *Betula* pollen in Lublin and Warsaw.

The forest inventories conducted for many European regions also indicate that in Poland, there is a greater density of birch trees in broadleaved forests in the northern and central parts of the country than in the southern part (Skjøth et al., 2008). The data of these authors are largely in agreement with the results of our aerobiological research. In all our study sites, located in large cities, the sources for birch pollen are not only birch trees in the natural vegetation but also ornamentally planted trees in settled areas.

Many authors draw attention to the alternate biennial cycle of high and low annual totals (Latałowa et al., 2002; Spieksma et al., 2003; Skjøth et al., 2015b; Malkiewicz et al., 2016). Such a cycle was also observed in Lublin during the period of 2001–2010 (Piotrowska and Kubik-Komar, 2012a) as well as in other cities of Poland (Weryszko-Chmielewska, 2006). Given the above-mentioned pollen emission cycle, the intensity of the birch pollen season changes significantly from year to year and the differences between successive years can be very high. For example, in Lublin the annual total pollen count recorded in 2016 was >16 times higher than in 2015. Our study found that significant differences in pollen seasons between the cities analyzed occurred in years of abundant pollen. Nevertheless, throughout the study period (2001–2016), the highest annual totals were recorded in Lublin, while the lowest were in Cracow and Szczecin.

Based on birch pollen dispersion, a birch vegetation distribution map has been created for many European countries (Pauling et al., 2012). In Poland, the highest values of birch pollen concentration are located in the central part of the country, which is similar to the results of our research.

In this study, multivariate statistical analyses were applied to compare the birch pollen season patterns in different regions of Poland. Discriminant analysis is not a common technique of aerobiological research. In the available literature, we did not find this analysis to be applied for spatial comparison of pollen seasons and therefore our study can be regarded as innovative in this respect. However, some examples of its use in aerobiology can be found. For instance, linear and quadratic discriminant analysis was applied to the image analysis measurements obtained in the comparison of genera and species of fungal spores (Benyon et al., 1999). It was also used to build a forecasting model of Poaceae pollen season severity on the basis of pre-season weather variables with a series of season characteristics (Sánchez Mesa et al., 2005).

PCA is often used to compare pollen seasons in terms of weather (Piotrowska and Kubik-Komar, 2012a,b) or in terms of season characteristics (Kubik-Komar et al., 2018). In the paper by González Parrado et al. (2009), weather-related parameters and pollen counts in one dataset were used, which changes the way the results of this study could be interpreted. PCA can also be applied as a simple technique of data space reduction for further analysis (Chao et al., 2002).

5. Conclusions

The above analyses have allowed us to formulate the following conclusions:

- Among the pollen season characteristics analyzed, the most varied features in the studied cities were the following: season end, annual total pollen count, and peak value.
- Seasons with a higher airborne pollen count and a higher peak value occurred in Lublin and Warsaw, whereas in Cracow, seasons with low values of these parameters were predominant.

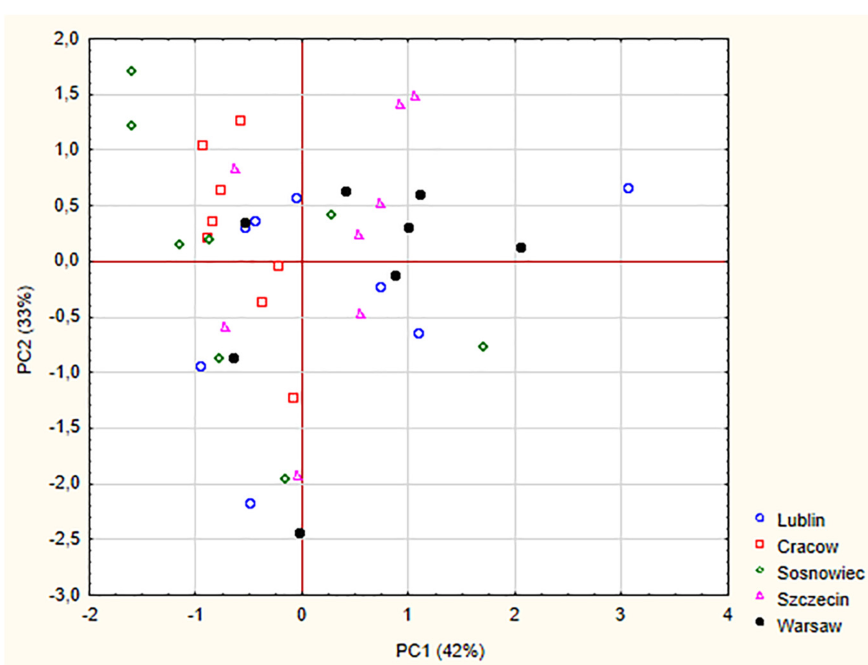

Fig. 5. Factor scores in the PC1-PC2 coordinate system for Group 2.

- The greatest similarity of *Betula* pollen seasons was found in the cities that are ones of the most distant from each other. The proximity of the location of monitoring stations does not guarantee the similarity of the pollen season. This fact confirms that pollen monitoring should be carried out locally.
- The density of pollen monitoring sites can be of essential importance for allergic people as a higher density results in increasing the reliability of information from a specific area.
- The values of the pollen season parameters differed significantly between the cities in years of abundant pollen, as opposed to years with less intense pollen emission.
- Due to the very high variability of birch pollen seasons, as determined in this study, it is suggested that allergologists should check current pollen reports since the specificity of the season may affect the diagnosis and treatment of the patient.

Competing interests

No competing interests declared.

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