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Allergenic pollen concentrations in the air of urban parks in relation to their vegetation

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ABSTRACT

In the face of the intensifying process of urbanization and the increased incidence of pollen allergies among urban residents, there is still a need to continuously monitor the airborne concentration of allergenic plant pollen. Urban green spaces (UGS) are a desirable element of the urban fabric and necessary for the proper functioning of cities, but they are a rich source of allergenic pollen that may pose a certain risk to people visiting them. The main aim of this study was to analyse the airborne allergenic pollen content in parks of different types relative to a reference point located on the roof of a building. Moreover, this study investigated the relationship between tree canopy volume and the number of recorded airborne pollen grains (SPIn- Seasonal Pollen Integral), and these parameters were compared with the potential impact of vegetation in the parks studied through the Index of Urban Green Zones Allergenicity (I_{UGZA}). Aerobiological monitoring was carried out in Rzeszów, SE Poland in 2016. A volumetric Hirst-type device was used. The pollen seasons of many taxa largely overlapped at each site where the monitoring was carried out, but the concentration values clearly differed. Tree pollen concentration values were not dependent on total canopy volume, and the greatest disproportions were found for *Acer, Betula, Quercus*, and *Tilia* pollen. This may be due to the fact that a solitary tree produces more pollen than a tree growing near others of the same species. The downtown park, surrounded by densely built-up areas, exhibited the highest allergenic potential, and the concentration of pollen, in particular tree pollen, was highest there. It is undesirable to plant hedges of allergenic plants, as they are a rich local source of pollen. Aerobiological monitoring carried out in urban parks provides information about the real threat of allergenic pollen to park visitors.

1. Introduction

In terms of spatial transformations, urbanization is the most irreversible human-induced transformation of land use. It causes changes in hydrological, geochemical, and climatic regimes, contributes to reduced biological diversity, and results in habitat loss and species extinction (Morris et al., 2017). Based on a meta-analysis of scientific publications, Seto et al. (2011) demonstrated that the rate of urbanization in all regions of the world has been greater than or equal to the increase in the population over a period of three decades starting in the 1970s. Their forecasts concerning the increase in urban areas on the Earth until 2030 indicate values reaching from 430,000–12,668,000 km^2, depending on the assumptions regarding population increases and economic growth. Moreover, it is understood today that urban green spaces (UGS) are extremely important for the proper functioning of cities and the high quality of life of city residents. Green spaces offer all types of ecosystem services (ES). They improve climate, regulate mineral cycles, support soil formation, and offer cultural and habitat services such as recreation and education. UGS are places of contact with nature and are also of essential importance for the health and living comfort of city dwellers (Ignatieva et al., 2017; Song et al., 2018; Speak et al., 2018). The literature data show mainly health benefits resulting from visits to green spaces, particularly for people who have easy access to UGS (Ekkel and Vries, 2017). Nonetheless, UGS also cause nuisances (urban ecosystem disservices (UEDS); von Döhren and Haase, 2015), which is why special attention is paid to factors that have a direct adverse impact on human health (Mrđan et al. 2017). In the case of vegetation, these are, among others, decomposing fallen leaves

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or broken branches that hinder walking (Song et al., 2018) as well as poisonous plants. The allergenic plant pollen is the most common and strongest UEDS (Kihlström et al., 2003). In Spain, allergenic trees accounted for 17%–67% of all the species present in a number of parks (Cariñanos et al., 2017). It should therefore be assumed that in cities, urban parks may create the most important elements of UEDS due to the possibility of parks producing huge amounts of pollen (von Döhren and Haase, 2015). Plant pollen causes a number of disease symptoms such as sneezing, conjunctivitis, nasal congestion, itchy and sore throat, cough, wheezing, dyspnoea, and those can lead to asthma. This problem is very alarming because it is estimated that 10–40% of the global population suffers from inhalant allergies, and by 2018, more than 55 % of the global population lived in built-up urban areas (http,//www.demographia.com/db-worldua.pdf) where the number of people allergic to plant pollen is clearly on the rise (Timm et al., 2016). This increase is caused by, among other factors, introducing allergenic, non-native species to urban greenery (Kasprzyk et al., 2019), the impact of air pollutants on molecular changes in proteins, which enhance their allergenic potential (Kanter et al., 2013; Ribeiro et al., 2017). It is also increasingly emphasized that elevated CO_2 concentrations result in increased pollen production in some plants, an extension in pollen seasons, and an expansion in the ranges of plants, including non-native species known to be strongly allergenic in other regions. According to these predictions, as a result of increased temperatures, the content of the allergens Bet v1 in birch pollen and Amb a1 in *Ambrosia* pollen grains will clearly increase (Ahlholm et al., 1998; Singer et al., 2005), whereas in 20–40 years' time, the number of people allergic to *Ambrosia* pollen will rise in countries where this problem has not been observed to date, from approximately 230 % in Germany to 290 % in Poland (Lake et al., 2018). Social group particularly vulnerable to the allergic diseases are children. In Poland, in the years 1993–2014 the percentage of school children suffering from any allergy or allergic disease increased from 13.1%–32.7 %, including allergic rhinitis from 4.3%–13.9 % (Brozek et al., 2015).

In light of these reports, the need for continuous monitoring of pollen content in city air is justified. The diverse urban fabric, the configuration of streets, and city architecture all induce air movement as well as affecting pollen transport and deposition (Peel et al., 2014), and this determines spatial variations in pollen seasons and pollen concentration values (Fernández-Rodríguez et al., 2014a). These parameters clearly differ in the horizontal profile (Fernández-Rodríguez et al.;, 2014b). Borycka and Kasprzyk (2018) report that birch pollen concentrations recorded by a pollen trap installed on a roof are higher by 50 % than nose-level concentrations and indicate the need to also monitor concentrations at low heights because such information is useful for allergic people. This is not a commonly occurring phenomenon. Rojo et al (2019) showed that in many aerobiological monitoring stations, the concentration of pollen in the air decreases with altitude, and above 10 m above ground level concentrations are much more homogenous.

Considering the above considerations, an attempt was made to evaluate the risk of airborne allergenic pollen in urban parks of different typologies. It became an important issue to answer the question whether information obtained from the reference station, located on a roof in the city centre, provides sufficient knowledge on the aerobiological situation in urban parks where visitors stay a longer time. The thesis regarding a relationship between park vegetation and the quantitative and qualitative composition of the airborne pollen detected in parks was also verified. Aerobiological monitoring offered the possibility of answering the question of whether the Index of Allergenicity of Urban Green Spaces that describes the allergenic potential of parks' vegetation is sufficient to recommend a specific park as safe or unsafe for allergic people.

2. Materials and methods

2.1. Study area

This study was carried out in Rzeszów (south-eastern Poland, 50°02′28″N, 021°59′56″E), which is a medium-sized city (127 km^2) with a population reaching almost 200,000 (http://www.rzeszow.pl/miasto-rzeszow/dane-statystyczne) at the boundary of two large geographical regions, the Carpathian Mountains and their foothills. Due to its location, it is characterized by intensive climatic variation, which manifests itself in significant climate gradients in the southern part of the city situated at the foothills of the mountains (Romer, 1949). These dynamics result not only from substantial variation in the topography but also from changes associated with climate warming. Over the last decade, for the first time, the mean annual temperature in Rzeszów has exceeded 10 °C, with a simultaneous very high interannual variation in precipitation from below 500 mm to almost 1000 mm (Tutiempo, 2019). In turn, the observations of temperature changes over a more than 150-year period (1851–2010) conducted in the Carpathian Mountains, within whose area the southern part of Rzeszów is located, indicate an increase in mean annual air temperature reaching 1.5 °C (Wypych et al., 2018). The mean annual temperature in this part of the city is now 8 °C (Tutiempo, 2019).

The urban structure of Rzeszów is characterized by large variation (Borycka et al., 2017). Apart from typically urbanized areas, green spaces, occupying a total area of more than 1000 ha, are present here. Among them, there are 14 urban parks with an area of 81.5 ha. The Wisłok River, along which green areas of high nature value are located, is an important element of the city's landscape. Natural and semi-natural patches of vegetation have been preserved here. They include dry-ground forests of the *Carpinion betuli* association and riparian forests of the *Alno-Ulmion* association in the Lisia Góra nature reserve (Wójcik et al., 2018), as well as aquatic vegetation of the *Potametea* class and rush vegetation of the *Phragmitetea* class growing on the Rzeszów reservoir (Ziaja and Wójcik, 2015).

The specific study sites were located in three significantly different urban parks (Figs. 1 and 2): Park Zdrowia (P1), Park Jedności Polonii z Macierzą (P2), and Park Kultury i Wypoczynku (P3). They were created in the 60 s and 70 s years. All the sites analysed distinctly differ in terms of land management. P1 is a peripheral park since it is located to the west to the city centre. This park is surrounded by densely built-up areas and is characterized by the lowest number of visitors. P2 is the smallest of the studied parks (no more than 5 ha). It is a typical downtown park, located within a densely built-up area in the city centre. However, given the area of parks and the number of visitors, it is the most-loaded park. In turn, P3, an open space park, is located in the river valley, which determines its attractiveness and contributes to the fact that many people readily rest and practice sport there. The area of the park exceeds 12 ha. All parks are located near important spatial barriers such as busy roads, the river (Ćwik et al., 2018). The studied parks show high floristic variation. In all the parks, native tree species are predominant (among others, *Acer pseudoplatanus*, *A. platanoides*, *Betula pendula, Fraxinus excelsior*, *Tilia cordata*, and *T. platyphyllos*), whereas shrub vegetation is predominantly represented by taxa of foreign origin. Among herbaceous plants, *Lolium perenne*, *Poa annua*, and *Trifolium repens* have the highest cover in the park grassland. P1 is a park that is marked by the lowest diversity of the Index of Allergenicity of Urban Green Spaces. Its shrub cover is low, whereas the canopy-covered area accounts for almost 60 % of its total area. P2 is distinguished by the highest biodiversity. Among all the parks studied, P2 is characterized by the highest allergenic potential, as described by the I_{UGZA}, which is the effect of numerous *B. pendula* and *Corylus avellana* individuals. P3 is also characterized by high biodiversity, but its

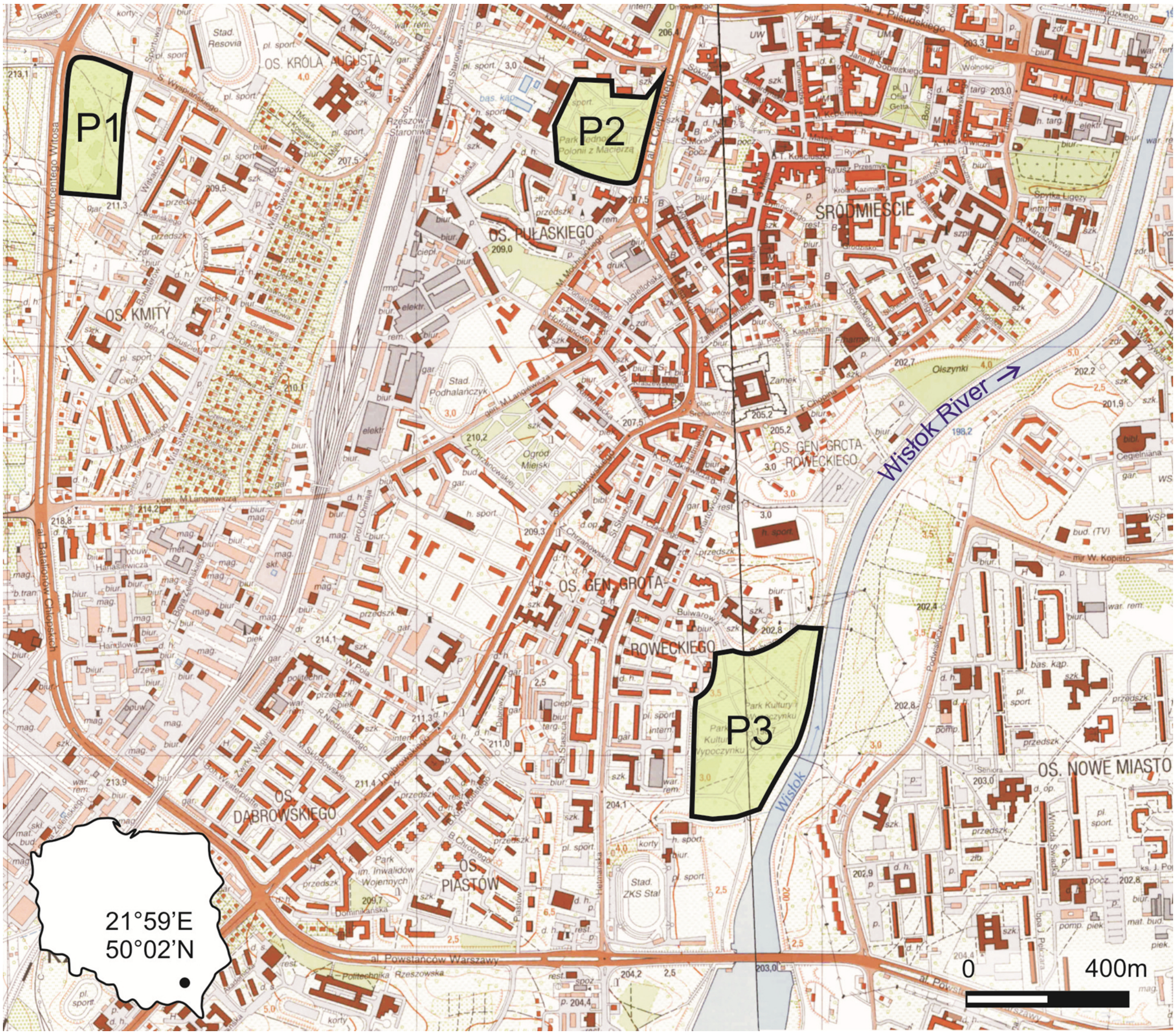

Fig. 1. Location of parks (P1, P2, P3) on a background of urban fabric.

allergenic potential is distinctly lower. This park is the least shaded and has large open spaces (Kasprzyk et al., 2019).

2.2. Aerobiological and vegetation studies

Aerobiological monitoring was conducted from the beginning of April to the end of September 2016, which means that it was carried out during the season when climatic conditions are favourable for visiting parks. Pollen sampling in parks was performed using a portable Burkard Personal Sampler (Burkard Manufacturing Co. Ltd) during sunny days, every 3 or 4 days (in total 50 days). The air was sucked directly onto a microscopic slide covered with silicone medium. The sampling was carried out within the parks between 11:00 am and 2:00 pm (the period with maximum pollen concentrations of many plants; Ščevková et al., 2015). The sampler takes in 10 l of air per minute and was operated for 30 min in each park. The results were expressed as pollen grain concentration per 1 m^3 of air at the time of sampling. In the parks, the pollen sampler operated in places without trees and architectural barriers. Dominant species growing within four buffer zones from the monitoring sites, up to 1 m, 1 m–5 m, 5 m–10 m, and 10 m–20 m, were identified (Fig. 2).

Additionally, continuous aerobiological monitoring was carried out. A Lanzoni volumetric pollen trap (VPPS 2000, Lanzoni s.r.l., Bologna Italy) was installed at a height of 12 m agl on the roof of a building located near park P3, and this sampling station was considered a reference to compare with those located in the parks. To arrive at results comparable to those obtained using the portable sampler, the average number of pollen grains per 3 h was calculated; this time interval corresponded to the sampling time in the parks, i.e., between 11:00 am and 2:00 pm. The calculation was performed only on days when sampling in parks was conducted.

The turf volume and tree canopy volume, which are proxies for pollen production, were compared with the actual concentration of grass and tree pollen grains expressed as the SPIn index. The crown volume was calculated on the base of three dimensions: crown height and its two perpendicular diameters. Each tree has been assigned a similar mathematical shape and using the standard mathematical crown volume was calculated. Knowing the surface of the lawn and assuming the height of 25 cm, its volume was estimated (Kasprzyk et al.;, 2019). For each park, the allergy index (I_{UGZA}) developed by Cariñanos et al. (2014) was calculated. It determines the degree of risk of allergenic vegetation of the park. The value of this parameter is determined by the features of individual plant species growing in parks: the length of the pollination period, pollination strategy, and their pollen allergenicity. These features were expressed on a scale of 1–3. Important parameters are also the area of the park and the total volume of vegetation producing pollen.

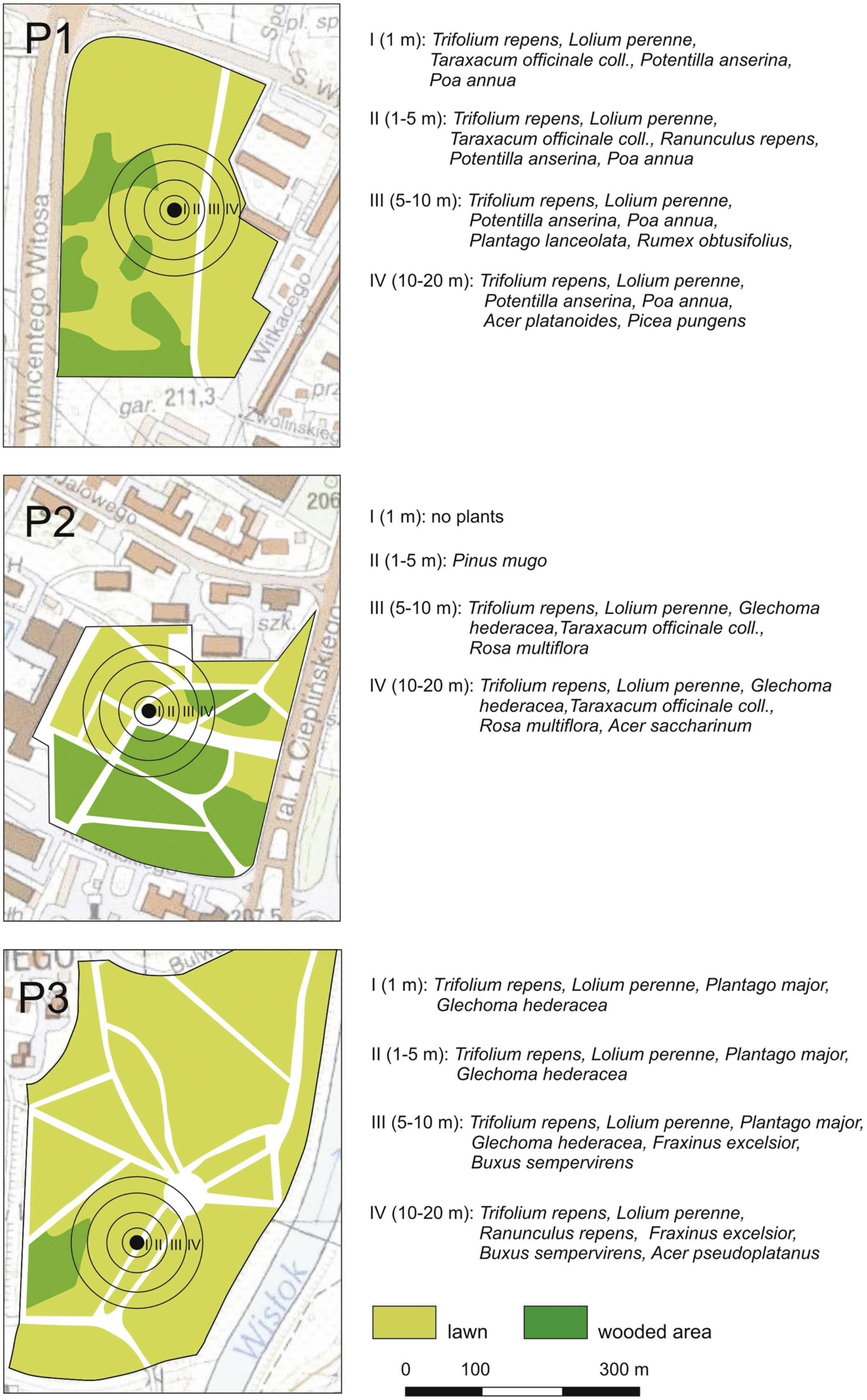

Fig. 2. Location of aerobiological monitoring stations in the parks.
Rays denote buffer zones in which dominant plant species were identified; dark colour – area occupied by trees, grey colour – area occupied by grass.

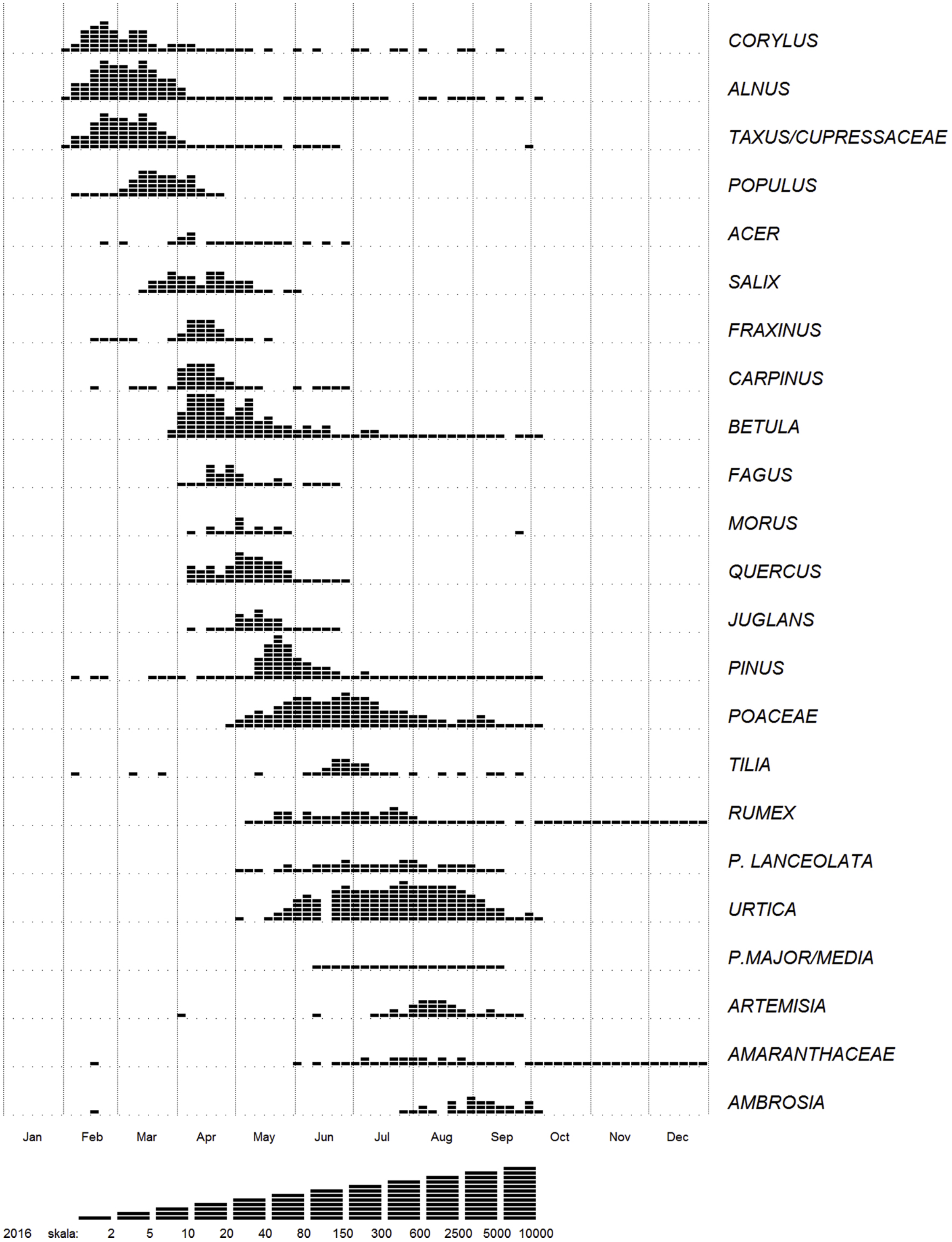

Fig. 3. Pollen calendar for 2016 (based on roof-level data).

2.3. Data analysis

The synchronization of pollen incidence at all study sites was tested using Spearman's rank correlations due to the absence of a normal distribution, which was confirmed by the Shapiro-Wilk test. These methods were also used to analyse the relationship between pollen concentration and meteorological factors. The following parameters were taken into account: minimum, maximum and mean temperature, relative air humidity, precipitation, irradiation and wind speed. The level of significance was selected at $\alpha \leq 0.05$. These tests were analysed using Statistica 12 software. A pollen calendar was prepared based on the data collected at the roof level with the help of AEROPOLPAL software (https://adamwalanus.pl/Polpal.html). In this calendar, daily concentrations were presented as the 5-day mean. Multivariate analysis between pollen taxa and parks were determined using Principal Component Analysis. The results were presented in a two-dimensional scatterplot showing the relationships among location of the vectors (pollen taxa) and points (parks) representing the first two principal components. The smaller the distance between the vectors and points, the stronger the relationship among pollen taxa and parks. Such an

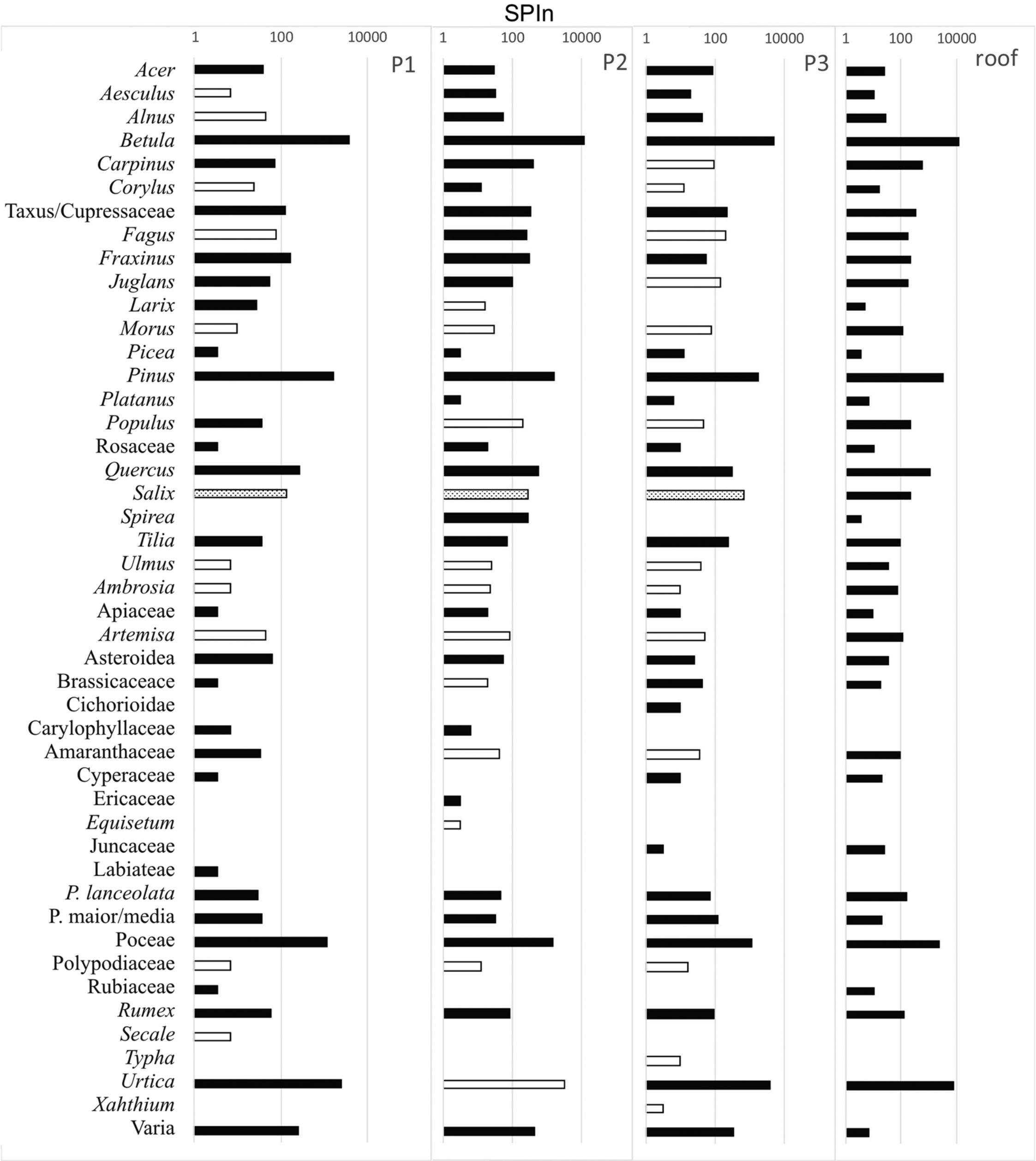

Fig. 4. Total sum of pollen grains (SPIn) recorded in the parks (P1-P3) and at the roof level.
(black bar - pollen of a taxon found in the park, white bar - pollen of a taxon not found in the park, dotted bar - pollen of a taxon of which only female individuals were found in the park; see logarithmic scale).

analysis was conducted by excluding taxa with single pollen grains. This method was applied using Canoco5 software.

3. Results

The continuous aerobiological monitoring of the air was carried out on the building's roof throughout the entire year, and a pollen calendar showed the aerobiological situation across the whole city. The trap on the roof recorded pollen grains outside the period of their continuous occurrence. The group of plants whose pollen was present year-round includes both tree pollen and the pollen of herbaceous plants, e.g., *Betula, Pinus, Alnus, Rumex,* and Amaranthaceae. *Populus, Quercus*, and *Fagus* belonged to the group of taxa whose pollen season, as recorded in the parks and on the roof, was relatively short and condensed (Fig. 3).

The diversity of pollen taxa found in all three parks was very similar. In total, 45 taxa were found, and those that were not identified were included in the Varia group. In P2 and P3, the pollen of 38 taxa was recorded, whereas in P1, the pollen of 37 taxa was recorded. The lists of taxa largely overlapped among parks. Taxa whose pollen was found only in one park were an exception; these were, among others, *Spirea* and Ericaceae in P2, Rubiaceae and *Secale* in P1, and *Typha, Juncus* and *Xanthium* in P3 (Fig. 4). The pollen of entomophilous plants was rarely recorded in the air at the sites, and if recorded, it was in low concentrations despite the fact that the presence of these plants was significant on lawns at a close distance from the sampling sites (e.g., *T. repens*, *Glechoma hederacea*, and *Taraxacum officinale*) (Fig. 2). An unusual situation was observed in the downtown park, P2, where on 16 June, the *Spirea* pollen grain concentration was 284 (Fig. 4).

The pollen seasons of many taxa, in particular *Urtica*, *Quercus*, *Betula*, and *Carpinus*, largely overlapped at each site where the monitoring was carried out. A detailed analysis of the occurrence of pollen of some taxa revealed that the maximum concentrations occurred

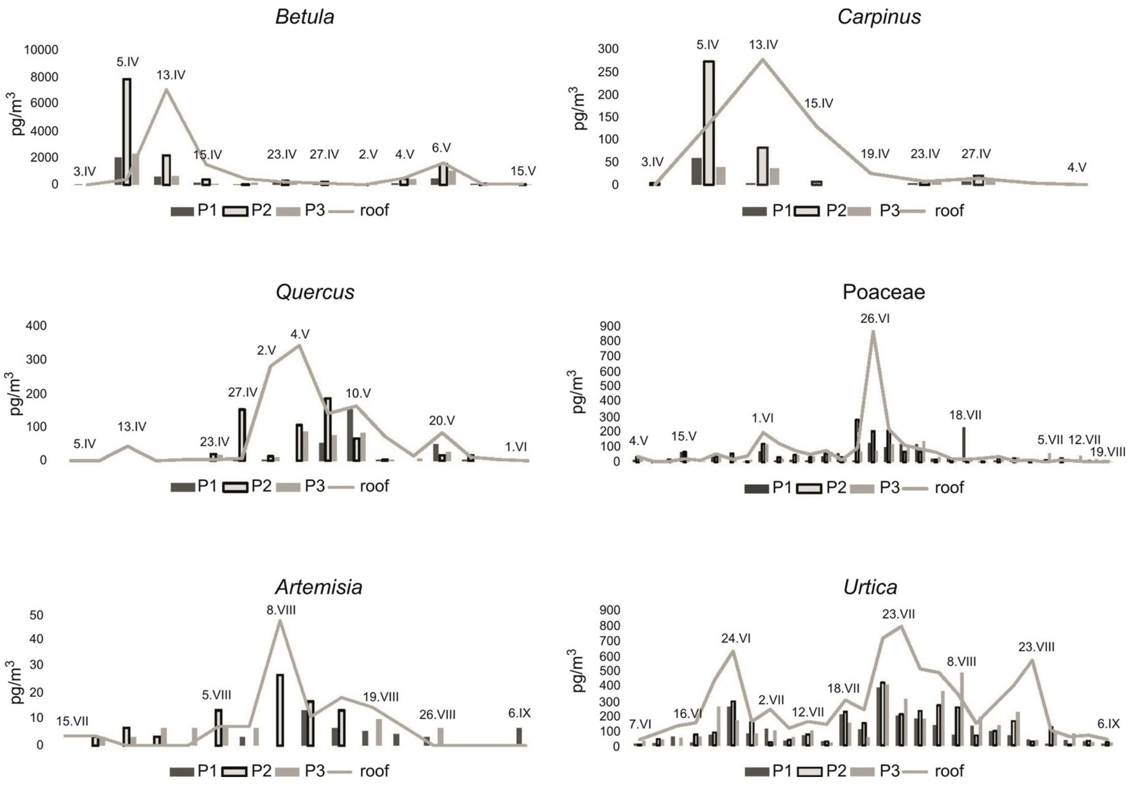

Fig. 5. Seasonal occurrence of airborne pollen of *Betula*, Poaceae, *Artemisia*, *Quercus*, *Carpinus*, *Fraxinus*, *Urtica* in the parks P1, P2, P3, and at roof level.

during a similar period both in the parks and on the roof (Fig. 5). *Betula* is an interesting example. Very high peak concentrations were found on the same day in each of the parks during the main pollen season and also two weeks later when a second peak concentration was recorded. The pollen seasons in the different parks were found to be unsynchronized only in the case of *Artemisia, P. lanceolata* and P. major/media (Table 1). Although lower airborne pollen concentrations were generally observed in the parks than at the reference station, it is worth noting that in the case of some taxa, people visiting the parks were frequently exposed for longer periods to concentrations posing a risk to allergy sufferers than might have resulted from the standard monitoring conducted on the roof. Such a situation was found for Poaceae, whose pollen remained longest in the air in the open space park P3, and for *Artemisia* in P1 (Fig. 5).

The concentrations of airborne pollen grains recorded in parks at near-ground level were poorly or not at all correlated with meteorological parameters. Temperature was the most important factor influencing this phenomenon, and among the all studied taxa, the weather had the strongest influence on pollen concentrations of *Carpinus* and *Fraxinus* (See Table A1 in Appendix A).

What differentiates the parks is the total sum of pollen grains of all taxa and strongly allergenic taxa (Table 1). The largest number of pollen grains was found in the downtown park, P2 (SPIn = 23,387). In the case of this park, it is worth noting that there are distinctly higher values of this index for many taxa than in the other parks: almost three times higher for *Betula*, four times for *Carpinus*, and two times for *Artemisia*. The opposite was true for P1, in which the SPIn value was approximately 50 % lower than the value for P2. In all the parks, the highest concentrations were recorded for *Betula*, followed by *Urtica*, *Pinus*, and Poaceae. The total pollen count was highest in the material sampled from the trap installed on the roof (SPIn = 29,780). There was clearly more pollen of *Quercus*, *Carpinus*, *Morus*, *Pinus*, *Populus*, Cyperaceae, Amaranthaceae, *P. lanceolata*, and Poaceae on the roof than in the parks (Figs. 3 and 4). In many cases in the parks, pollen of plants that did not grow in the respective park was observed. This was found not only with regard to single pollen grains, such as *Juncus* or *Typha* pollen, but some concentrations were observed to be substantial, such as those of *Morus*, *Fagus*, and *Ulmus*, as well as *Salix* and *Populus,* though only female individuals grew in the parks (Fig. 4).

Based on the PCA analysis, taxa that are characteristic of each park, or not, can be indicated (Fig. 6). According to the first ordination axis, P2 most distinguishes itself and is characterized by the highest number of taxa, in particular those whose pollen is allergenic, notably *Alnus*, *Populus*, *Betula*, *Quercus*, *Carpinus*, Poaceae, and *Artemisia*. This park is also characterized by the presence of *Spirea* pollen. The pollen of *Acer*, P. major/media, and *Pinus* was characteristic of P3. In P1, the only characteristic taxon was *Corylus*, though no hazel trees were found there and its pollen grains occurred at an unusual time for this taxon – in September. PCA analysis also allows us to determine which taxa certainly do not characterize the parks. These are taxa whose concentrations were low or for which no pollen grains were recorded at all, such as *Larix* in P3 and *Fagus* in P1. A large group of taxa that did not characterize any park can also be indicated, and these were taxa whose SPIn values, except for those of *Urtica*, were low, i.e., *P. lanceolata*, *Ulmus*, *Juglans*, *Salix*, and *Rumex* (Fig. 4).

No relationship was found between the seasonal pollen counts in the parks and the tree canopy volume and the turf volume (Fig. 7). The greatest disproportions were found for the genera *Acer* and *Tilia* in each of the parks, for *Betula* in P2 and P3, *Quercus* in P1, and *Fraxinus* in P3. In these parks, with a very high total canopy volume of the studied species of maple (*A. pseudoplatanus*, *A. platanoides*, *A. tataricum sbsp. ginnala*, *A. negundo*), linden (*T. cordata*, *T. platyphyllos*, *T. americana*, *T. x euchlora*), oak (*Q. rubra*, *Q. robur*), and ash (F. *pennsylvanica*, *F. excelsior)*, the SPIn index was very low. The latter species is a flagrant example of such disproportion. With more than 100 specimens, including one individual growing at a distance of 20 m from the sampling site (Fig. 2), and the highest total canopy volume of all trees growing at the site, its SPIn index was the lowest. It is also interesting that in P2, with 38 *B. pendula* specimens, the birch pollen concentration was highest, whereas in P1, there were the same number of birch trees of

Table 1

Spearman's rank correlation coefficients as a measure of synchronization of pollen seasons in the parks (P1-P3) and at roof level.

	P1	P2	P3	Roof		P1	P2	P3	Roof
Betula					***Artemisia***				
P1		0.597	0.716	0.694	**P1**		0.2161	0.290	0.591
P2	0.597		0.698	0.652	**P2**	0.2161		0.386	0.603
P3	0.716	0.698		0.713	**P3**	0.290	0.386		0.352
Roof	0.694	0.652	0.713		**Roof**	0.591	0.603	0.352	
Poaceae					***Rumex***				
P1		0.673	0.713	0.688	**P1**		0.717	0.493	0.597
P2	0.673		0.812	0.807	**P2**	0.717		0.422	0.596
P3	0.713	0.812		0.780	**P3**	0.493	0.422		0.399
Zmn9	0.688	0.807	0.780		**Roof**	0.597	0.596	0.399	
Pinus					***P. lanceolata***				
P1		0.459	0.637	0.662	**P1**		0.1715	0.2682	0.354
P2	0.459		0.496	0.501	**P2**	0.1715		0.367	0.339
P3	0.637	0.496		0.636	**P3**	0.2682	0.367		0.633
Roof	0.662	0.501	0.636		**Roof**	0.354	0.339	0.633	
Quercus					**P. major/media**				
P1		0.845	0.625	0.724	**P1**		−0.0742	0.357	0.344
P2	0.845		0.794	0.825	**P2**	−0.0742		0.2263	0.1657
P3	0.625	0.794		0.801	**P3**	0.357	0.2263		0.294
Roof	0.724	0.825	0.801		**Roof**	0.344	0.1657	0.294	
Urtica					***Carpinus***				
P1		0.880	0.919	0.909	**P1**		0.829	0.999	0.745
P2	0.880		0.923	0.882	**P2**	0.829		0.829	0.775
P3	0.919	0.923		0.889	**P3**	0.999	0.829		0.747
Roof	0.909	0.882	0.889		**Roof**	0.745	0.775	0.747	
Salix					**Cupressaceae**				
P1		0.871	0.759	0.756	**P1**		0.566	0.641	0.573
P2	0.871		0.847	0.851	**P2**	0.566		0.862	0.878
P3	0.759	0.847		0.956	**P3**	0.641	0.862		0.888
Roof	0.756	0.851	0.956		**Roof**	0.573	0.878	0.888	
Fraxinus					***Tilia***				
P1		0.557	0.546	0.755	**P1**		0.602	0.503	0.569
P2	0.557		0.738	0.681	**P2**	0.602		0.613	0.575
P3	0.546	0.738		0.662	**P3**	0.503	0.613		0.529
Roof	0.755	0.681	0.662		**Roof**	0.569	0.575	0.529	
Fagus									
P1		0.572	0.572	0.440					
P2	0.572		0.745	0.816					
P3	0.572	0.745		0.608					
Roof	0.440	0.816	0.608						

Small letters: not statistically significant.

this species, but the birch pollen concentration was even lower than that in P3, where only 5 birch trees were found. *Carpinus* is another example of disproportion. No hornbeams were found in park P3, but the hornbeam pollen concentration was similar to that in P1, where 5 hornbeam trees grew (Kasprzyk et al., 2019, Fig. 7).

When linking the I_{UGZA} results and SPIn values (Table 2) for the specific park types, a clear compatibility between these indices can be found for the downtown park (P2), surrounded by densely built-up areas. In the riverside open-space park (P3), this relationship is only partial. However, no clear relationship can be established between potential allergenic risk from park vegetation as estimated by the I_{UGZA} index and the risk arising from the actual presence of airborne plant pollen in peripheral park P1, where the value of I_{UGZA} was high but that of SPIn was the lowest.

4. Discussion

In the literature, there are an increasing number of papers dealing with urban park disservices resulting from the allergenicity of urban vegetation and with methods showing the strength of the deleterious effects of vegetation (Kuchcik et al., 2016; Speak et al., 2018). Cariñanos et al. (2014, 2017) proposed the Allergenicity Index (I_{UGZA}), which illustrates the potential impact of a park on humans based on the allergenic species growing on it. This index provides important information for the organizations involved in planning urban green spaces (Ćwik et al., 2018; Jochner-Oette et al., 2018) as well as for allergic people and their doctors in developing treatment strategies. It is also essential for allergy prevention because, according to good medical practice, avoiding contact with an allergen is a much better solution than costly and long-lasting treatment (Panwankar et al., 2013). Nevertheless, for people visiting parks, the most important information is what the pollen concentration is during their visit to the park, and such information can only be obtained by carrying out *in situ* monitoring. The potential negative impact of the Rzeszów parks' vegetation was not high (Kasprzyk et al., 2019) because, according to the interpretation of Cariñanos et al. (2017), a park's vegetation poses a potential hazard if the I_{UGZA} index exceeds a value of 0.3. On the basis of the values of the indices, it can be assumed that P3 is the place that should be most recommended to the city's residents, whereas P2 poses the greatest risk. The aerobiological study reveals that P2, the most frequently visited downtown park, is a place where allergic people should not stay for long periods because the pollen concentration of most of the taxa was highest in P2. The open space park P3, in turn, is a place worth recommending, especially to people seeking contact with nature, due to its low allergenic potential as expressed by the I_{UGZA} (Kasprzyk et al., 2019). The peripheral park P1, with its allergenic potential being slightly lower than that of P2 (but higher than the critical value of 0.3), is actually the safest place for people visiting this park since its SPIn value is more than two times lower than that of P2. This shows that the potential allergenic risk does not need to correspond to the actual impact of park vegetation. SPIn determines the pollen concentration inside a park at a specific time, but weather

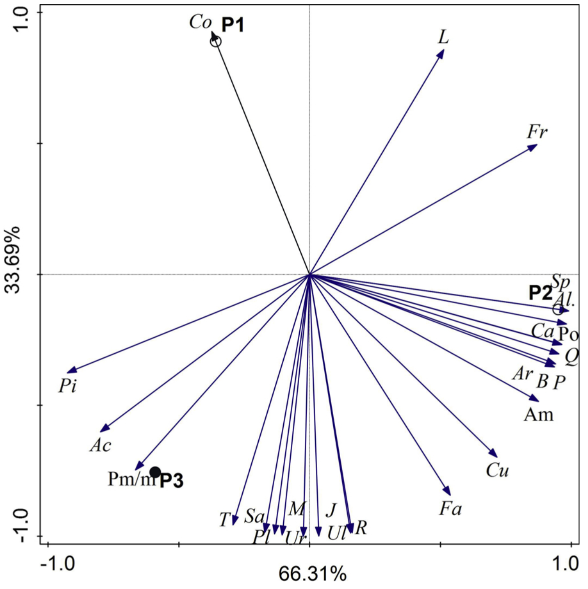

Fig. 6. A PCA scatterplot visualizing the relationship between parks and pollen taxa (*Ac- Acer*, *Al- Alnus*, *Am-* Amaranthaceae, *Ar- Artemisia*, *B- Betula*, *Ca- Carpinus*, *Co- Corylus*, *Cu- Cupressaceae*, *Fa- Fagus*, *Fr- Fraxinus*, *J- Juglans*, L- *Larix*, *M- Morus*, *Pi- Pinus*, *P- Populus*, *Q- Quercus*, *Sa- Salix*, *Sp- Spirea*, *T- Tilia*, *Pl- P. lanceolata*, *Pm/m-* P. major/media, *Po-* Poaceae, *R- Rumex*, *Ur- Urtica, Ul- Ulmus*).

conditions as well as the structure of a park and its location within the urban fabric are important parameters affecting the actual pollen concentration; however, the I_{UGZA} does not take these parameters into account. For these reasons, these parameters cannot be directly compared to each other, but in evaluating the impact of plants on humans, they perfectly complement each other.

It should be emphasized that concentrations can be very high even in parks with low allergenic potential, which proves the need to conduct monitoring of concentrations at sites that are frequently visited by urban residents, in particular children and older people, who are more vulnerable to environmental stress. This was observed in the case of *Betula* and *Quercus*, among others. The greatest hazard from the allergenic pollen of these taxa occurred in the downtown park, whereas in the other parks, the pollen of these taxa occurred at the same time, but their concentrations were much lower. For the patient, it is most important to know what allergen he or she has come into contact with. As we showed, the spectrum of taxa and pollen concentrations recorded in the parks differ both between parks and in relation to the reference station installed on the roof. Rojo et al. (2019) pointed, that the pollen concentrations recorded near ground level are characterized by high variability. Their values strongly depend on microscale environmental factors. In the described studies, this was most likely the local pollen emission, the location of sampling stations in relation to park avenues, wide roads, the Wisłok River, and buildings. Along with the altitude, the impact of local flora on pollen concentrations decreases (Rojo et al., 2019). This is a challenge to an aerobiologist making pollen forecasts and a serious problem in medical treatment because it is difficult to establish which aeroallergen the patient has had direct contact with.

A question also arises as to why the pollen concentrations of some tree taxa in the studied parks are at a moderate or low level, even though the number of individuals and their total canopy volume are very high. This phenomenon relates to, among others, anemophilous *Fraxinus* and *Quercus*, and entomophilous *Tilia* and *Acer* species (Tomanek and Witkowska-Żuk, 2008). It seems that, apart from the level of pollen production by a given species, not only the number of trees itself or the total canopy volume are important, but whether a tree grows singly or in clusters, in what habitat (shaded/sunny), and what its crown shape is, e.g., an open or wide canopy (Adams-Groom et al. 2017). These parameters can influence the number of flowers/inflorescences as well as their distribution on branches and across the crown and, in effect, determine pollen production. If the crown is well lit by sun, the number of flowers in maples and lindens increases (Faliński and Pawlaczyk, 1991), whereas in oak trees, inflorescences cover the entire crown (Suszka, 2006). In the case of *Tilia* spp. and *Quercus rubra* in P1 as well as *Fraxinus excelsior* in P3, the trees grew very close to one another, and their crowns overlapped, forming a dense canopy; this may have been the reason why there was no relationship between their number or canopy volume and the SPIn values. A solitary tree produces much more pollen than a tree growing in a dense stand (Aaby, 1994). Anderson (1990), in turn, stressed that in the case of grains with good dispersion properties, pollen can be transported much further, particularly if pollen is released at the top of the crown in trees growing in dense stands (Kuparinen et al., 2007). Another reason for the lack of a relationship between SPIn and canopy volume or number of trees can be the location of the pollen sources in relation to the urban structure. Urban development and street arrangement strongly affect air circulation, which undoubtedly has an impact on the evident spatial variation in the intensity and pattern of pollen seasons (Peel et al., 2014) confirmed by this study. Green areas and buildings adjacent to them are thermally contrasting spaces, which dynamizes the exchange of air together with plant pollen that can be blown into or out of a city (Rawski, 2017) as a result of pollen transport from its outskirts. In the case of Rzeszów, the Wisłok River valley can also play a role in plant pollen dispersal. Park P3 is located next to the riverbank, and it can be presumed that the pollen of plants that were not found in P3, for example, arrives in the park through this air channel. The Lisia Góra nature reserve, which is located approximately 1 km to the southwest of this park and where *Q. robur*, *Carpinus betulus*, and *Ulmus campestre* are predominant, can be a source of *Carpinus, Ulmus* and *Fagus* pollen (Wójcik et al., 2018). Pollen grains of *Juncus*, *Typha*, *Populus*, and *Salix* were also recorded in P3 air, and many species of these genera are characteristic of rush habitats, flooded areas, and fens; such areas were found along the riverbank close to the Lisia Góra nature reserve (Ziaja and Wójcik, 2015).

The study by Kasprzyk et al. (2019) showed that the allergenic potential of lawns in the parks studied is low because grasses, which are regularly cut, account for only half of the park surface area. Not all grass species affect allergic people with the same strength. Romero-Morte et al. (2018) found that a small number of species were the important source of airborne grass pollen in central Iberian Peninsula. To this group belong *Dactylis glomerata, Lolium rigidum, Arrenatherm album*. They occur frequently in this area and produce small pollen grains in very high quantity. In Perugia, Italy, *D. glomerata* cause inhalant allergy in spring and early summer, whereas *Cynodon dactylon* in late summer (Ghitarrini et al., 2017). Several species considered to be a cause of allergies produce relatively small amounts of pollen (Peel et al., 2014). A good example is *Lolium perenne,* a species with a long growing season that regrows perfectly after being cut and is found most frequently in the parks studied, alongside *Poa annua* (Kasprzyk et al., 2019). Its allergens are considered to be very strong (Armentia et al., 2002), but pollen production per spike is low compared to that of other common grass species, such as *D. glomerata* or *Holcus lanatus* (Peel et al., 2014). In London, after a change in the park grass mixtures from the dominant grass species *D. glomerata* to *L. perenne*, the SPIn values for grass pollen decreased (1964–1981) (Emberlin et al., 1999). *P. annua* pollen production is even lower than that of *L. perenne* (Peel et al., 2014). Therefore, theoretically, the risk from lawns was not very high, but there were many grass pollen grains in the air, with their highest amount in P2. Grasses are cosmopolitan, occupy almost all habitats, and produce huge amounts of pollen that are easily dispersed in the air (Peel et al., 2014). Thus, it is not surprising that although lawns are mowed, the Poaceae pollen concentration in parks can be high, posing a hazard to sensitive people. It is different with herbaceous, entomophilus plants. Our study showed that despite the fact that around the aerobiological

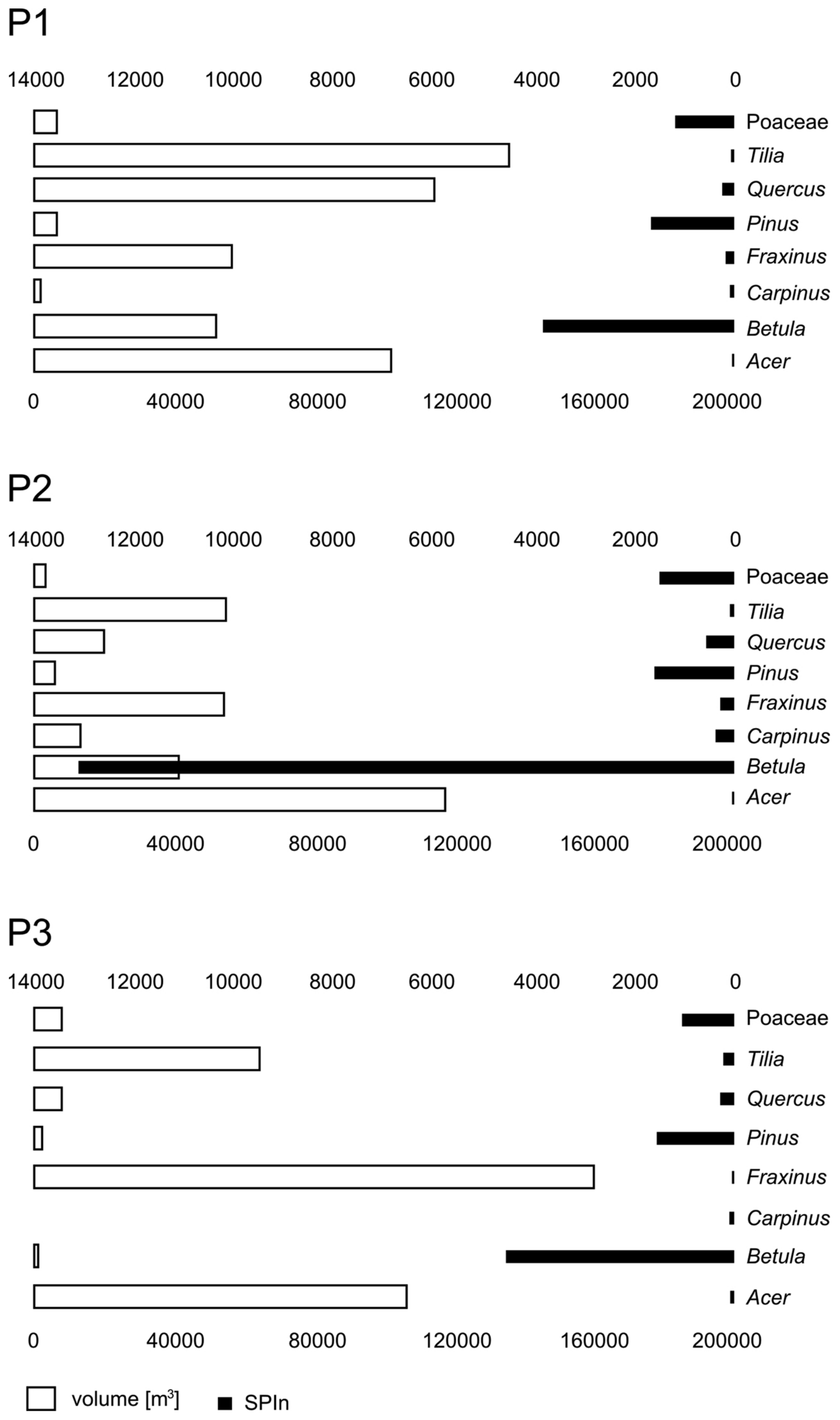

Fig. 7. SPIn versus the total canopy volume (m^3) of selected tree species and the grassland turf volume (n- number of specimens, %- percentage of lawns covered by grass species; based on Kasprzyk et al., 2019).

Table 2

Summary of results describing the parks' allergenic potential (I_{UGZA}), the total volume of pollen-producing vegetation, and the total sum of pollen grains of all taxa and selected strongly allergenic taxa recorded in the air of the urban parks (SPIn- the number of pollen grains detected during the study period; the I_{UGZA} values were taken from the paper by Kasprzyk et al., 2019).

Park	IUGZA	Total volume [m^3]	SPIn	*Betula* SPIn	*Carpinus* SPIn	*Fraxinus* SPIn	*Quercus* SPIn	Poaceae SPIn	*Artemisia* SPIn
P1	0.310	7,293,671	10,857	3835	73	165	267	1185	43
P2	0.331	6,224,389	23,387	13,071	393	320	577	1531	82
P3	0.127	5,842,155	14,963	5082	92	56	307	1202	49
Roof	–	–	29,531	12,008	593	232	1166	2352	119

monitoring sites *T. repens*, *G. hederace*a plants dominated in the pollen spectra their pollen grains were not observed.

Shrub hedges can be a serious risk to allergic people because plants composing them grow at high density, and their pollen is released at the nose level (Alcazar et al., 1999). This problem was raised by Cariñanos et al. (2011), who call this phenomenon '*proximity pollinosis*' and described it with respect to *Ligustrum* (Cariñanos et al., 2002). We also noticed this risk and confirmed it by pollen monitoring. *Spirea japonica* occurs in hedges in each park (Kasprzyk et al., 2019), but it grew close to the site where the monitoring was carried out only in P2. In two samples collected, a very large number of *S. japonica* pollen grains was found. The pollen of this taxon was not found in the other parks or at the reference station. These results show that people resting in parks close to large clusters of plants can be occasionally exposed to very high concentrations of sometimes strongly allergenic pollen without realizing it. This makes it difficult for physicians to determine the cause of disease symptoms because these pollen concentrations are not discovered through standard monitoring conducted at a height of at least a dozen metres (Aboulaïch et al., 2008).

Aerobiological monitoring demonstrates the danger of introducing plants of foreign origin into park vegetation, particularly those whose pollen is allergenic but which do not pose a clinical problem in a specific geographic region (Kozłowska et al., 2007). *Platanus* pollen is a serious risk to residents of Southern Europe (Maya-Manzano et al., 2017). Polish patients have also shown positive skin test responses to *Platanus* pollen, while some of them also show a positive response to allergens of linden, which is planted very frequently in Polish parks (Kozłowska et al., 2007). Plane trees grow in two parks, P2 and P3, and airborne plane pollen was recorded there. In the former park, these are 3 young individuals that already flower, whereas in P3, there are several trees with impressive crowns (Kasprzyk et al., 2019). Therefore, *in situ* monitoring can show the presence of their pollen grains even with a small number of trees.

5. Conclusions

The risk from allergenic plant pollen investigated *in situ* depends on the urban park type. Downtown parks, often surrounded by densely built-up areas, seem to be the riskiest for allergic people, followed by riverside open-space parks and finally peripheral parks located on the outskirts of densely built-up areas with rather low plant species diversity and land cover diversity.

Pollen concentrations differ in the vertical profile, which is why it would be advisable to locate an additional aerobiological monitoring station at a lower height in parks. It seems that the most appropriate type of park in which to locate such a station is a downtown park, which, due to its nature, is frequently visited. Data obtained in this way should be a significant component in making reliable pollen forecasts for allergy sufferers.

When arranging plantings not only in urban parks but also citywide in the warm temperate zone, one should decidedly avoid trees of the genus *Betula* because, regardless of their number in parks, the concentration of *Betula* pollen is high, and its pollen has strong allergenic properties. In the development of urban green spaces, it is also undesirable to plant hedges of allergenic plants, as they are a rich local source of pollen that will not be detected by a monitoring station located outside the relevant park.

Estimation of the potential plant pollen risk in parks based on the I_{UGZA} index, which includes, among other factors, the tree canopy volume and pollen season duration of specific species found in a park, is a effective forecasting tool with respect to downtown parks. In parks of other types with a more open character, the *in situ* investigated risk differs from the estimated potential risk; it appears that the main reasons for this difference are canopy density and the presence of ventilation channels. Therefore, further research should focus on these two aspects.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ufug.2019.126486.

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