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ORIGINAL PAPER

Evaluation of the allergenicity of various types of urban parks in a warm temperate climate zone

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Abstract There is a common belief that contact with nature provides many benefits to humans. Numerous studies on urban vegetation confirm this belief, but the negative effects of excessive exposure to allergenic pollen in urban parks are being more frequently identified. This problem was studied in detail in areas with warm temperate climate conditions. A study of allergenic flora was conducted in 3 types of urban parks: a downtown park, a peripheral park, and a landscape-like park. A total of 90 woody plant species were identified, among which *Picea pungens*, *Tilia cordata*, *Acer pesudoplatanus*, *Acer platanoides*, *Quercus rubra,* and *Betula pendula* were found most frequently. Among the herbaceous plants, *Lolium perenne*, *Poa annua*, *Achillea millefolium*, and *Potentilla anserina* were predominant. The allergenicity level of these parks was described using an allergenicity index. This study showed that under a warm temperate climate the potential harmful impacts of parks are determined by the number of birches and oaks and their crown volumes, as well as by the total tree canopy. The volume of turf covered with grass species as well as the number of maple and ash trees and their crown volumes are of minor importance. Unlike the downtown parks, the landscape-like park poses the lowest risk to sensitive people. Research on parks that is focused on allergenic flora and allergenic

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pollen production should be used in designing new parks and in the revitalization of old parks.

Keywords Pollen · Allergenicity index · Urban park · Allergenic flora · Lawn · Allergy

1 Introduction

Urban ecosystems have become the subject of an extensive number of studies due to the strong pressure of humans on the environment (Nielsen et al. 2014; Palliwoda et al. 2017). Vegetation constitutes a key element of the urban fabric, and its importance in urban planning has grown. Most studies focus on the benefits of urban parks because they are the most prevalent aspects of urban parks (Camacho-Cervantes et al. 2014); hence, there is widespread acceptance for planning new ones. One of the most frequently mentioned benefits of urban parks is the improvement of city climate. Urban green spaces reduce the heat island effect, and some of the important reasons for remaining in a park are nice weather, comfortable wind flow, temperature, and insolation (Wang et al. 2017). Vegetation filters air, removes pollution, attenuates noise, and provides natural sounds and smells. Park visits provide health benefits to people with obesity, diabetes, and cardiovascular problems and promote physical activity and social cohesion as well as improve mental health, well-being and pregnancy outcomes (van den Bosch 2017). Nonetheless, there are some that believe that an urban park may also adversely affect visitors (Dadvand et al. 2014; van den Bosch 2017). Due to the increasing involvement of the population in decision-making related to urban activities, the aspects of a park that can bother people or cause damage or discomfort during park visits have also been highlighted (Camacho-Cervantes et al. 2014). Plants can reduce the comfort of staying in a park by flowers with unpleasant odours, shrubs with thorns or spines, and herbaceous plants with stinging hairs, and in the autumn, a large amount of fallen leaves and soft fruits may reduce visitor comfort levels (Vogt et al. 2017). Other harmful effects on humans that have also been considered include biogenic volatile organic compounds and toxic and poisonous plants as well as plants that produce allergenic pollen (Hruska 2003; Jianan et al. 2007; Camacho-Cervantes et al. 2014; Cariñanos et al. 2014; Mrdan et al. 2017). Studies on the allergenicity of urban green spaces are extremely important because, as reported by the World Allergy Organization in the White Book of Allergy, a growing trend in the number of allergy sufferers has been observed. In Europe, it has been documented that approximately 87 million people have allergies (Pawankar et al. 2013). The influence of urban vegetation on sensitive people has been investigated indirectly by studying the relationship between vegetation and airborne pollen composition (Staffolani et al. 2011; Velasco-Jiménez et al. 2015; Alcázar et al. 2016; Maya-Manzano et al. 2017b). These studies have been performed mostly at a regional scale, where monitoring is conducted at one station in a city, and the studies revealed that a large area occupied by a given type of vegetation, such as forest or arable land, can be a serious source of pollen grains. These findings have drawn attention to studies on urban vegetation, mainly the dendroflora of urban parks, and its major threats to city residents in terms of aeroallergens (Cariñanos and Casares-Porcel 2011; Maya-Manzano et al. 2017a). Studies on allergenic flora have been carried out for over a dozen years (Hruska 2003; Jianan et al. 2007; Jochner-Oette et al. 2018). Hruska (2003) proposed a formula (allergen index—AI) for estimating the impact of an allergenic plant on people based on its life cycle, pollination period, cross-reactivity, and abundance. The AI was also used by Ciferri et al. (2006) to assess the threat from urban greenery to people in select cities in Central Italy. Recently, Mrdan et al. (2017) have applied this indicator to evaluate the risk posed by allergenic flora in school yards in Novi Sad, Serbia. According to Ianovici (2008), the pollen index and cross-reactivity of pollen allergens are the important parameters to evaluate impact of allergenic flora on sensitized people. Cariñanos et al. (2014) proposed another model that considered not only biological features of plants but also biometric parameters of tree crowns and the volume of turf, allowing the assessment of potential pollen production by a park. Using this index, it is possible to compare parks in different climatic regions with different vegetation and designs, as presented by Cariñanos et al. (2017). The index carries substantial information about the current state of a given park and can also be used as the basis for recommendations for the future fate of parks—revitalization or improvements (Maya-Manzano et al. 2017a). Recently

Jochner-Oette et al. (2018) have proposed an index for the individual-specific allergenic potential, which is based on accurate measure of tree crown volume. Currently, when planning the vegetation for new parks, urban environmental conditions, ecosystem services, and biodiversity as well as human needs and expectations are mainly considered (Ståle 2006) However, in the new database *Planning software for tree selection in urban areas*, the description of urban tree species includes information about risks related to potential allergenicity (Vogt et al. 2017).

Urban vegetation can be a significant source of aeroallergens. Therefore, the development of methods to assess the threat posed by the vegetation in urban parks in relation to sensitized people becomes an important issue. The main purpose of our work was to estimate the potential allergenicity of various types of urban parks using the allergenicity index. Additionally, we aimed to (1) assess the factors that influence the value of the index in warm temperate climate conditions, (2) refine the index formula with a detailed analysis of the lawn vegetation, and (3) elaborate the recommendations regarding urban vegetation management.

2 Materials and methods

2.1 Study area

This study was conducted in four urban parks in Rzeszów (50°02′28″N; 21°59′56″E), which is located in south-eastern Poland (Fig. 1). The city is located in the warm temperate climate zone, and polar maritime air masses are the main climate driver. From 2006 to 2015, the mean annual temperature in the city was 9.26 °C, and the mean annual total precipitation was 667 mm (https://en.tutiempo.net/climate). The local climate of Rzeszów is primarily determined by the city's location in a vast river valley that runs meridionally. In the southern part of the city, a storage reservoir was constructed on the Wisłok River, and similarly to the river itself, this reservoir contributes to the rather high number of foggy days—on average 50 per year. The city's only forest nature reserve is located at the edge of the valley and loess uplands. The reservoir and its shores are high nature value areas, while due to valuable fauna and flora habitats, this part of the city is protected as a Natura 2000 site (Ziaja and Wójcik 2015). Rzeszów has a relatively large area of greenery (389 ha). Urban parks are an important part of it. Between 2000 and 2017, area of the parks increased from 69 to 81.6 ha. There are more and more new plantings of trees and shrubs every year (on average 766 and 9556, respectively; data retrieved from City Hall of Rzeszów).

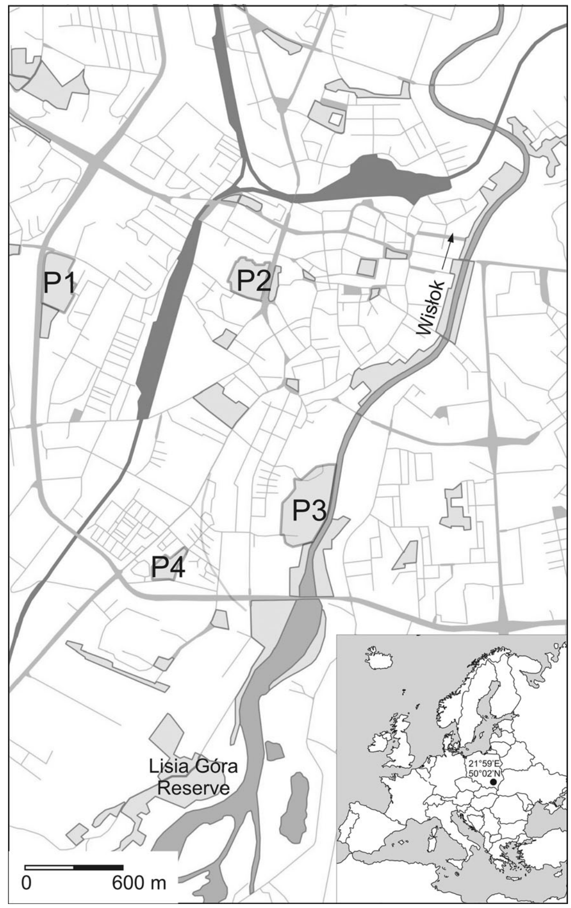

Fig. 1 Location of the study area (P1–P4-parks under the study)

2.2 Description of the parks

Out of the 14 parks that exist in the city, the following four parks were selected for analysis (Table 2): Park Zdrowia (P1), Park Jedności Polonii z Macierzą (P2), Park Kultury i Wypoczynku (P3), and Park Inwalidów Wojennych (P4). These parks date back to the period after World War II, mainly the 1960s and 1970 s, and the character of these parks is diverse. Now, in every park there are well-equipped outdoor fitness areas, sandpits, and in P2 and P3 concert shells (Ćwik et al. 2018). P1 is situated on the outskirts of the city near the city's western bypass. This park has the lowest percentage of shrubby vegetation, whereas paths and lanes account for 7% of its area (Table 1). P2 and P4 are surrounded by densely built-up areas, which contribute to their downtown character. P2 is located in the city centre, close to the several educational institutions, shopping centres, and public administration offices. Among all the parks, it is the most frequently visited park (Ćwik et al. 2018). It is worth noting that asphalt-covered lands and alleys account for as much as 27% of the area. P3, which is located on a floodplain, is exposed to denser mist, stronger winds and flooding. Despite these environmental inconveniences, P3 is the most frequently visited park by people practising sports. Its popularity is based on its significant size, open landscape-like character, the length of walking and bike paths (30% of total area), and by the most balanced land cover proportions (Table 1).

2.3 Floristic study

In 2016–2017 in each park, detailed quantitative and qualitative investigations of the dendroflora were conducted. With a few exceptions, flora identification was made to the species level, and each species was assigned to its respective botanical family (Seneta and Dolatowski 2008). The field investigations also included the flora of vascular plants growing on lawns. The percentage of cover of the most frequently occurring species was determined. In each park, ten 100 m^2 (10 × 10 m) patches were randomly selected, which was from 2.3 to 11.1% of total lawn area. It was sufficient to determine the type of plant community and dominant species. For each patch, a list of species was made, specifying their botanical families, and their per cent cover was determined at 5% intervals. Species whose lawn cover was less than 5% were included in the group 'Others'. Based on the data from the 10 patches, the average percentage of lawn cover of a specific species was determined. Using these data, a list of species with the highest percentage contribution to lawn structure and a list of companion species were developed for each park.

Table 1 Descriptive statistics of parks (P1–P4) and their dendroflora

	Total area (m^2)	Percentage in the total area of urban park (%)	Paths and paved area (m^2)	Lawn area (m^2)	Trees area (m^2)	Shrubs area (m^2)	Canopy (m^2)	N	N with PAV ≥ 18	*n*	*n** with PAV ≥ 18	*n** with PAV ≥ 18 per (ha)	Shannon–Weiner index *H*′	Evenness index *J*	I_{UGZA}
P1	62,242	7.6	4737	21,256.71	35,243	1006	36,248	32	9	779	112	18.0	2.64	0.7922	0.310
P2	49,776	6.1	13,456	9004.17	23,047	4269	27,316	57	14	3998	212	42.6	3.07	0.838	0.331
P3	121,306	14.9	36,500	43,135.76	36,078	5593	41,670	48	16	2118	300	24.7	2.859	0.8041	0.127
P4	25,084	3.1	4265	10,540.8	9456	822	10,278	46	10	594	63	25.1	2.89	0.8416	0.281

N—number of woody species; *n*—number of individuals without individuals growing in dense hedges; ecological indices (*H*′, *J*) were counted for individuals without growing in dense hedges; *n**—excluding female individuals; PAV—potential allergenicity value for particular species excluding female individuals; I_{UGZA}—index of allergenicity of urban green spaces

2.4 Calculation of the volume of pollen-producing vegetation

The volume of the crowns of woody plants growing in the parks and turf volume were calculated according to the following procedure. Three dimensions were given for each tree/shrub: crown height and two perpendicular crown diameters. Measurements were taken using a laser altimeter TruPulse 360B. If trees were situated in a manner such that their crowns overlapped, they were measured as one object. Subsequently, crown shape was determined. Five basic shapes were selected: cylinder, cone, sphere, hemisphere, and cuboid (for hedges). Using the standard mathematical formulas for these figures and considering the flattening of figures, crown volume was calculated for each. Crown volume was calculated in the case of new plantings if a tree had not entered its reproductive phase. During the next stage of the analysis, the turf area of each park was estimated. It was assumed that under shrubs and tree crowns herbaceous vegetation does not occur or it is poor. Based on the already calculated diameters of the tree crowns, the area of the land covered by tree crowns and shrubs (canopy) was calculated. The area occupied by open grassland was calculated by deducting the canopy area and the paths from the total park area. The turf height was assumed to be 0.25 m, and the turf volume was calculated by using the cuboid formula. The total volume of the park's pollen-producing vegetation was calculated by adding the turf volume and the tree and shrub crown volume (V), excluding female individuals of dioecious species (*Salix*, *Taxus*, *Populus*), but the surface area of the crowns of these individuals was included in the calculation of the canopy. All types of land cover areas in the parks were calculated using GIS techniques in QGIS 2.18 programme.

2.5 Allergenicity index

The allergenicity index (I_{UGZA}) is a novel tool established by Cariñanos et al. (2014) to estimate the potential allergenicity of urban green spaces. In this estimate, the intrinsic allergenicity to the plant species that grow in a park/green zone and the allergen emission capacity of these plants are considered. In relation to the intrinsic allergenicity of a species, it is necessary to calculate the potential allergenic value (PAV) of each species, which is related to a series of biological and phenological parameters (Cariñanos et al. 2016). Among the biological parameters related to the PAV, the pollination strategy (sp) considers the pollen quantities emitted during the pollination process, assigning the maximum value on a scale of 1–3 to anemophilous plants. The potential allergenicity (ap) of a species is determined by the adverse reactions that its pollen grains cause. This potential has been assigned to different species based on information recorded in a specialized bibliography in the fields of medicine and public health. The detailed description of these parameters was presented by Cariñanos et al. (2016). The pollen allergenicity was expressed in the scale from 0 to 3, exceptionally *r* for main pollen allergen in a given are. When the maximum value of ap was assigned, the information referring to the study area was used, which recognizes *Betula*, *Alnus*, Poaceae, and *Artemisia* as the main cause of allergies in the local human population (Samoliński et al. 1996). A third parameter considers the duration of the pollination period (dpp) in terms of the longer the period, the greater the risk. This phenological parameter has also been adjusted to the bioclimatic characteristics of the area.

$$\mathrm{PAV} = \mathrm{ap} * \mathrm{sp} * \mathrm{dpp}$$

The value of PAV ranged from 0 to 36.

In evaluating the allergenic potential of turf, a specific change was proposed in relation to the earlier proposal of Cariñanos et al. (2014). The authors distinguished between two groups of species: grasses and flower beds with an ap = 4 and 0, respectively. Our detailed inventory indicated that herbaceous species growing on lawns differ in terms of their biological and phenological features, which affects their different contributions to the I_{UGZA}. To assess their contributions, herbaceous species were classified into 3 groups of different potential allergenicity value: (1) grasses (ap = 4; PAV = 36); (2) species with high allergenic potentials (ap = 3; PAV = 27); and (3) other species (entomophiles) with PAV $\leq$ 12. According to the Cariñanos et al. (2014) proposal, the height of turf was accepted as 0.25 m. For these 3 groups, the turf area and subsequently the volume of pollen-producing vegetation were calculated.

To sum up, the value of the allergenicity index (I_{UGZA}) depends of the total volume of pollen-producing vegetation (tree crowns and lawns), and the potential allergenic value (PAV) of each species (tree) and groups of herbaceous species, in the relation to the total of park area.

$$I_{\mathrm{UGZA}} = \frac{1}{378 S_{\mathrm{T}}} \sum_{i=1}^{k} n_i \times \mathrm{PAV}_i \times V_i$$

where k = number of species, n_i = number of individuals belonging to the i-species, PAV = potential allergenic value to the i-species, V_i = volume of pollen-producing vegetation (the turf volume/the tree and shrub crown volume, and S_{T} = total surface area of the park

2.6 Data analysis

Biological diversity of park dendroflora was described using 3 ecological indicators. The simplest and easiest indicator to interpret is species richness, that is, the number of noted species. The measure of diversity is the Shannon–Wiener index (H'). A high value of this index demonstrates a level of high biodiversity. The description of the parks was supplemented by the evenness index (J). The highest possible diversity (J = 1) is when all species are present in an equal percentage. Relationships and dependencies among the selected features describing the parks were determined by the Principal Component Analysis (PCA). The variables that most strongly correlated with the allergenicity index were selected for this analysis, and this had been verified earlier by calculating the Spearman's rank correlation coefficient. Statistical analyses were performed using PAST3 and Canoco5 software.

3 Results

A floristic survey was the starting point for evaluating the level of risk for people with allergies visiting parks and living near them.

First, an analysis of the dendroflora was conducted. In total, 90 woody plant species from 24 families were identified in all parks. Most of these species belonged to angiosperms, while gymnosperms, accounting for 14 of the species, represented only three families. As many as 24 species belonged to Rosaceae, whereas the family Pinaceae ranked second in terms of the number of species. A total of 7489 tree and shrub individuals were noted, with the largest number in P2 at almost 4000 individuals (Tables 1, 2). The floristic investigations showed that the trees growing in the parks were generally native species, whereas the shrubs were predominantly garden varieties. Tree species typical in all the parks were mostly the following native deciduous trees: *Tilia cordata*, *Acer pseudoplatanus*, *Acer platanoides*, *Fraxinus excelsior*, *Betula pendula*, *Tilia platyphyllos*, *Quercus rubra*, and *Sorbus aucuparia*. In terms of coniferous species, *Picea pungens* (the most common among all tree species) and *Pinus nigra* were found in each park. Among the shrubs, entomophilous deciduous shrubs growing in hedges were predominant. The only shrub species that was found in all the parks was *Spiraea japonica* (Tables 1, 2).

In terms of dendroflora diversity, the floristic composition, and the number of individuals, each park has different values (Tables 1, 2). P1, a peripheral park, has the least number of shrubs. There were many *Crataegus* individuals clustered in one area. This park is characterized by the lowest biodiversity (H') and species richness. P2 is characterized by high shrub species diversity, and their relative cover is highest. Many hedges composed of hundreds of low shrubs of *S. japonica*, *Pinus mugo*, *Berberis thunbergii,* and *Buxus sempervirens* were found here. The species evenness, as expressed by the index J, is very high, exceeding 0.8. P3 has the largest number of *Malus baccata* individuals, and the diversity of willows is also high. *Fraxinus pennsylvanica* and adult specimens of *Platanus* × *hispanica* occur only in this park. Biodiversity is high in P3. The park is characterized as the lowest canopy-covered area. P4 has the highest evenness index (J). In addition, the lowest number of woody plant specimens (n = 594) was found here (Table 1).

Herbaceous plants were the second group that was surveyed. A total of 69 species were identified, including 26 sporadically occurring species. Twenty-eight species in the downtown parks (P2 and P4) and 46 species in the landscape parks (P3) were found. The most frequently occurring species belonged to the Poaceae family (n = 18), including 13 species that occurred at a high frequency. In descending order of frequency, these species are *Lolium perenne*, *Poa annua*, and *Festuca rubra* (Table 3).

The percentage various grass turf species ranges from 38% in P4 to 50% in P1 (Fig. 2). Entomophilous herbaceous plants, such as *Achillea millefolium*,

Table 2 List of tree and shrubs taxa noted in parks under the study; *n*—number of individuals; *x*—individuals growing in dense hedges

Species name	Family name	P1		P2		P3		P4	
		n	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}
Abies concolor (Gordon & Glend.) Lindl. Ex Hildebr.	Pinaceae			3	0.02			1	0.01
Acer negundo L.	Aceraceae	5	1.54	13	4.35			1	0.99
Acer platanoides L.	Aceraceae	49	5.32	17	2.81	62	8.97	2	0.59
Acer pseudoplatanus L.	Aceraceae	64	4.73	27	3.82	44	6.36	30	7.89
Acer saccharinum L.	Aceraceae	2	0.39	41	8.37			11	5.69
Acer tataricum sbsp. *Ginnala* (Maxim.) Wesm.	Aceraceae	14	0.74			10	0.53		
Aesculus hippocastanum L.	Hippocastanaceae			30	6.24	27	4.79	6	2.67
Alnus glutinosa L.	Betulaceae			1	0.38	3	0.85		
Alnus incana (L.) Moench	Betulaceae					1	0.22		
Amorpha fruticosa L.	Fabaceae					30×	0.02		
Berberis thunbergii DC.	Berberidaceae			704×	0	103×	0		
Berberis vulgaris L.	Berberidaceae			1	0			111×	0
Betula pendula Roth	Betulaceae	38	25.89	38	24.04	5	0.93	22	36.57
Buxus sempervirens L.	Buxaceae			83×	< 0.01	11×	< 0.01	23×	< 0.01
Carpinus betulus L.	Betulaceae	5	0.54	6	5.82			2	6.35
Cerasus vulgaris Mill.	Rosaceae	2	< 0.01			1	0.01		
Cornus alba L.	Cornaceae			1	< 0.01	431×	0.80		
Corylus sp.	Betulaceae			41	7.21				
Cotinus coggygria Scop.	Anacardiaceae			8	< 0.01	8	0.01		
Cotoneaster sp.	Rosaceae			900×	< 0.01			1	< 0.01
Crataegus monogyna Jacq.	Rosaceae			1	< 0.01				
Crataegus persimilis Sarg.	Rosaceae			4	< 0.01			1	0.02
Crataegus × *media* Bechst.	Rosaceae					9	0.04		
Crataegus sp.	Rosaceae	60	0.02	1	< 0.01				
Cytisus scoparius (L.) Link	Fabaceae							13×	0
Fagus sylvatica L.	Fagaceae			3	2.15				
Forsythia × *intermedia* Zabel	Oleaceae			3	< 0.01	2	< 0.01		
Fraxinus excelsior L.	Oleaceae	32	14.02	32	15.88	98	53.72	4	3.55
Fraxinus pensylvanica Marshall	Oleaceae					6	0.56		
Hibiscus syriacus L.	Malvaceae							6×	< 0.01
Hydrangea heteromalla D. Don	Hydrangeaceae			3	0			11×	0
Hydrangea macrophylla (Thumb.) Ser.	Hydrangeaceae							9×	0
Juglans ailantifolia Carrière	Juglandaceae							2	1.47
Juglans nigra L.	Juglandaceae			3	1.75			2	2.48
Juglans regia L.	Juglandaceae	1	< 0.01						
Juniperus chinensis L.	Cupressaceae			5	0.04				
Juniperus communis L.	Cupressaceae			1	0.01			2	< 0.01
Juniperus horizontalis Moench	Cupressaceae	1	0.032			32	0.06		
Kerria japonica (L.) DC.	Rosaceae			34×	< 0.01				
Larix decidua Mill.	Pinaceae	42	0.83			3	0.03	11	1.14

Table 2 continued

Species name	Family name	P1		P2		P3		P4	
		n	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}
Ligustrum vulgare L.	Oleaceae	×	0.02	×	< 0.01			×	0.09
Malus baccata (L.) Borkh.	Rosaceae	3	0.02	14	0.02	106	0.06	3	0.06
Parthenociscus quinquefolia (L.) Planch. In A. et C. DC.	Vitaceae					4	< 0.01		
Philadelphus coronarius L.	Hydrangeaceae			10	< 0.01	117	< 0.01		
Physocarpus opulifolius (L.) Maxim.	Rosaceae					30	< 0.01		
Picea abies (L.) H. Karst.	Pinaceae			5	< 0.01	34	0.43		
Picea omorika (Pančić) Purk.	Pinaceae			9	0.05				
Picea pungens Engelm.	Pinaceae	132	2.38	55	0.88	119	2.78	14	0.58
Pinus mugo Turra	Pinaceae	23	1.12	×	0.02				
Pinus nigra J. F. Arnold	Pinaceae	1	0.02	25	1.15	23	0.63	1	0.02
Pinus sylvestris L.	Pinaceae			1	< 0.01				
Populus alba L.	Salicaceae	1	0.52						
Platanus × hispanica Mill ex Münchh. *'Acerifolia'*	Platanaceae			3	0.11	7	1.90		
Populus × berolinensis (K. Koch) Dippel	Salicaceae			3	0.24				
Prunus cerasifera Ehrh.	Rosaceae	6	< 0.01					1	0.022
Prunus laurocerasus L.	Rosaceae			40	< 0.01				
Pseudotsuga menziesii (Mirb.) Franco	Pinaceae			5	0.20				
Pyracantha coccinea M.Roem	Rosaceae			18	< 0.01				
Quercus robur L.	Fagaceae	1	< 0.01	5	0.37	1	0.12	13	3.07
Quercus rubra L.	Fagaceae	30	28.09	5	5.45	2	2.34	13	22.38
Robinia pseudoacacia L.	Fabaceae							1	0.02
Rosa multiflora Thunb.	Rosaceae							1	< 0.01
Rosa rugosa Thunb.	Rosaceae							8	< 0.01
Rosa sp.	Rosaceae			1064×	< 0.01			88×	< 0.01
Potentilia fruticosa L.	Rosaceae					101×	< 0.01		
Salix alba L.	Salicaceae					39	0		
Salix × sepulcralis Simonk. *'Chrysocoma'*	Salicaceae	5				27	0	2	0.34
Salix fragilis L.	Salicaceae			10	0	8	0		
Salix integra Thunb.	Salicaceae					36	0.04		
Salix purpurea L.	Salicaceae					69	0.07		
Sambucus nigra L.	Viburnaceae	2	< 0.01					3	0.01
Sorbus aucuparia L. emend. Hedl.	Rosaceae	36	0.55	1	< 0.01	8	0.08	2	0.18
Sorbus torminalis (L.) Crantz	Rosaceae	3	0.01			2	0.01		
Spiraea cinerea Zabel	Rosaceae			15×	< 0.01	20×	< 0.01	16	0.01
Spiraea japonica L. f.	Rosaceae	39	< 0.01	511×	< 0.01	145×	< 0.01	20×	< 0.01
Spiraea nipponica Maxim.	Rosaceae					51×	< 0.01		
Stephanandra incisa (Thumb.) Zabel	Rosaceae							80×	< 0.01
Symphoricarpos albus (L.) S.B.Blake	Caprifoliaceae					×	0.01	1	< 0.01
Syringa microphylla Diels	Oleaceae			6	< 0.01			8×	< 0.01
Syringa vulgaris L.	Oleaceae			27	0.023	35×	0.09		

Table 2 continued

Species name	Family name	P1		P2		P3		P4	
		n	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}	*n*	% in I_{UGZA}
Taxus baccata L.	Taxaceae	19	0	44	0.73	148	0.88		
Thuja occidentalis L.	Cupressaceae			15	0.34	16	0.68		
Tilia americana L.	Tiliaceae	13	0.55						
Tilia cordata Mill.	Tiliaceae	123	5.71	60	3.32	54	3.47	13	2.44
Tilia × *euchlora* K. Koch	Tiliaceae	2	0.13			4	0.31		
Tilia platyphyllos Scop.	Tiliaceae	25	1.05	9	0.42	21	1.16	2	0.29
Tsuga canadensis (L.) Carrière	Pinaceae			4	0.02				
Viburnum lantana L.	Viburnaceae			2	< 0.01				
Viburnum opulus L.	Viburnaceae							10×	< 0.01
Weigela florida DC.	Diervillaceae			5	< 0.01			23×	0.011

Potentilla anserina, *Trifolium repens*, *T. pratense,* and *Taraxacum officinale coll*, occur at an equal rate. On average, this plant group covers from 42 to 45% of the turf (Fig. 2). The parks differed in their species composition. P4, where there are only 3 dominant herbaceous species, stands out most in terms of turf coverage. *L. perenne*, *T. repens,* and *Plantago major* are dominant. The first two species were found in large numbers at all the parks, but *P. major* occurs sporadically in the other parks (P1–P3) (Table 2).

The parks differ in their allergenic potential. Among all the woody plant species identified, only 22 posed a significant risk to allergy sufferers since they had a VPA $\geq$ 18. *B. pendula*, *C. avellana*, and *Alnus* sp. are characterized by the highest VPA at 36. In addition, the groups with a VPA $\geq$ 18 include *Carpinus betulus*, *Juniperus* sp. *Quercus* sp., *Fraxinus* sp., *A. negundo*, *Thuja* sp., *Salix* sp., *Taxus baccata*, and *Platanus* × *hispanica.* P2 had the highest density of trees with strong allergenic properties; however, out of the 57 tree and shrub species found, approximately one-fourth of the species had a VPA $\geq$ 18. This park has the highest I_{UGZA} (0.331), which is attributable to specimens of *B. pendula* ($n = 38$) and *C. avellana* ($n = 41$) that occur in large numbers as well as *F. excelsior*, *C. betulus*, *Quercus* sp., and *Acer* sp. The importance of the abundant ornamental shrubs, mainly entomophilous species such as *Rosa* sp. or *Spirea* sp., is low. For P4, the I_{UGZA} is slightly lower than the critical value of 0.3. It is the smallest park with a very small number of woody plants with a VPA $\geq$ 18, but 22 *B. pendula* trees and 26 oaks grow in this park; their contribution to the value of I_{UGZA} is very high—more than 36% and 25%, respectively. In the largest park (P3), 47 tree and shrub species were found, and one-third of the species have a high VPA (Table 1). *B. pendula* is represented by only 5 individuals; thus, *F. excelsior* (988 trees) poses the greatest risk. The contribution percentage of this species to the I_{UGZA} is 53%. In P1, the density of allergenic trees and shrubs is lowest, but 38 *B. pendula*, 32 ash and 30 northern red oak trees occur (Table 2). Due to these species, the I_{UGZA} is above 0.3. The role of lawns in all the parks was small (Fig. 2).

A multidimensional data analysis (PCA) reveals that the number of oak and birch trees as well as their crown volumes, the value of I_{UGZA} and canopy-covered area are the variables that most strongly differentiate the examined parks. Based on these variables, P1 and P2 are the parks that are most similar to each other, whereas P3 stands out most. P3 can be best described by its percentage of the area occupied by lawns and alleys. On the other hand, P4 is distinguished by its high values of the indices H' and J. The I_{UGZA} is positively correlated with the number of oak and birch trees and their total crown volume as well as with canopy-covered area. The value of I_{UGZA} is negatively correlated with alley, lawn and shrub area. The crown volume and tree number of *F. excelsior* and *Acer* sp. and the volume of grass pollen-

Table 3 List of herbaceous species, mean percentages of cover of lawns by these species and their frequency (number of plots where they were found in parks P1–P4)

Species name	Family name	P1		P2		P3		P4	
		f	%	*f*	%	*f*	%	*f*	%
Achillea millefolium	Asteraceae	4	3.5	×		6	7.5	1	0.5
Aegopodium podagraria	Apiaceae			1	0.5	×		×	
Agrostis capillaris[a]	Poaceae	4	12	×				×	
Arrhenatherum elatius[a]	Poaceae					7	11		
Bellis perennis	Asteraceae			5	2.5	1	0.5	1	0.5
Bromus hordeaceus[a]	Poaceae							×	
Calamagrostis epigejos[a]	Poaceae	1	0.5						
Carex hirta	Cyperaceae					×		1	0.5
Cerastium holosteoides	Caryophyllaceae	2	1	×		×		×	
Crepis biennis	Asteraceae	1	1					×	
Dactylis glomerata[a]	Poaceae	×				2	1		
Deschampsia caespitosa[a]	Poaceae	×		1	0.5				
Elymus repens[a]	Poaceae	1	0.5			×			
Festuca arundinacea[a]	Poaceae					2	1		
Festuca pratensis[a]	Poaceae			3	4				
Festuca rubra[a]	Poaceae			1	1	3	1.5		
Geranium pratense	Geraniaceae					4	2		
Glechoma hederacea	Lamiaceae	4	2	7	10	3	2.5	×	
Holcus lanatus[a]	Poaceae	1	0.5						
Leontodon autumnalis	Asteraceae			2	1.5	1	0.5	1	0.5
Leontodon hispidus	Asteraceae			1	2				
Leucanthemum vulgare	Asteraceae			×					
Lolium perenne[a]	Poaceae	9	34	8	27	10	25	10	29.5
Medicago falcata	Fabaceae					1	0.5		
Medicago lupulina	Fabaceae					2	2.5		
Phleum pratense[a]	Poaceae							×	
Plantago lanceolata[a]	Plantaginaceae	5	3	×		4	3.5	×	
Plantago maior[a]	Plantaginaceae	×		4	4	2	3	10	14.5
Poa annua[a]	Poaceae	3	2	7	11	3	2.5	8	8.5
Polygonum aviculare	Polygonaceae			2	1	×		1	0.5
Potentilla anserina	Rosaceae	1	0.5	2	3.2	2	1	×	
Potentilla reptans	Rosaceae			1	0.5	×		×	
Prunella vulgaris	Lamiaceae			7	8			4	5.5
Ranunculus acris	Ranunculaceae					2	1		
Ranunculus repens	Ranunculaceae	4	3.5	×		2	1.5	2	1.5
Rorippa sylvestris	Brassicaceae	1	1			×			
Stellaria graminea	Caryophyllaceae	1	0.5						
Tara × acum officinale coll.	Asteraceae	9	6.5	1	0.5	6	4	5	3
Trifolium dubium	Fabaceae							×	
Trifolium pratense	Fabaceae	1	0.5	×		5	6	×	
Trifolium repens	Fabaceae	10	22.5	6	13	8	14.5	9	30
Veronica chamaedrys	Scrophulariaceae			1	0.1	1	0.5	×	

Table 3 continued

Species name	Family name	P1		P2		P3		P4	
		f	%	*f*	%	*f*	%	*f*	%
Viola odorata	Violaceae	×		2	1			×	
Alopecurus pratensis[a]	Poaceae	×							
Chamomilla suaveolens	Asteraceae							×	
Chenopodium album[a]	Amaranthaceae	×							
Cichorium intybus	Astraceae					×			
Daucus carota	Apiaceae					×			
Convolvulus arvensis	Convolvulaceae							×	
Erigeron annuus[a]	Poaceae					×			
Geranium pusillum	Geraniaceae					×			
Heracleum sphondylium	Apiaceae					×			
Hopochoeris radicata	Asteraceae					×			
Lotus corniculatus	Fabaceae					×			
Lysimachia nummularia	Primulaceae			×		×			
Myosotis arvensis	Boraginaceae	×							
Phalaris arundinacea[a]	Poaceae					×			
Phleum pratense[a]	Poaceae					×			
Poa trivialis[a]	Poaceae	×		×					
Polygonum amphibium	Polygonaceae					×			
Prunella vulgaris	Rosaceae					×			
Ranunculus acris	Ranunculacea	×							
Rumex acetosa[a]	Polygonaceae					×			
Rumex confertus[a]	Polygonaceae	×							
Sisymbrium officinale	Brassicaceae					×			
Symphytum officinale	Boraginaceae	×				×			
Trisetum flavescens[a]	Poaceae	×							
Urtica dioica[a]	Urticaceae	×				×			

Bold—Poaceae species

[a]Strong allergenic pollen

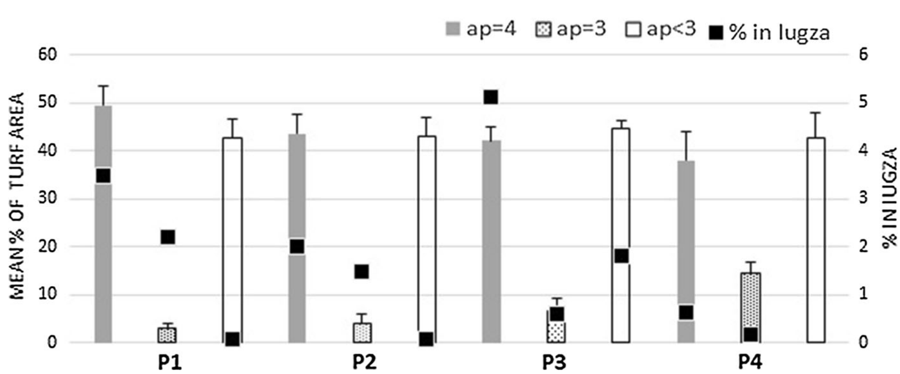

Fig. 2 Mean percentage of turf area occupied by 3 groups of herbaceous plants ($\bar{x}$ ± standard error) and their percentage contribution in the I_{UGZA}; ap-allergenicity potential

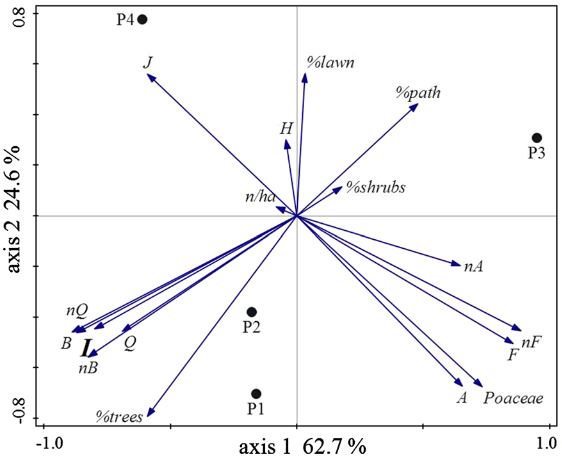

Fig. 3 PCA plot that shows the relationships among the parks (P1–P4) and the selected features that describe them. % of the tree-covered area, lawn-covered area, shrub-covered area, and paved area; A, B, F, Q—the crown volume of *Acer* sp., *Betula pendula*, *Fraxinus excelsior*, *Quercus* sp.; Poaceae—the volume of turf covered by Poaceae species; *n*—number of trees; *n*/ha—tree density; *H*—Shannon index; *J*—evenness index

producing lawns are least correlated with the value of I_{UGZA} (Table 1; Figs. 2, 3). P3, with a high percentage of grasses, has the lowest I_{UGZA} (Table 3; Fig. 2).

4 Discussion

Although urban parks are characterized by high species richness (Nielsen et al. 2014), there are generally only a dozen species that are dominant. In many cases, these species are allergenic like in Spanish and Italian parks *Olea europaea*, *Castanea*, and species of the family Cupressaceae (Cariñanos and Casares-Porcel 2011; Staffolani et al. 2011; Maya-Manzano et al. 2017b), in warm temperate climate zone *Fagus*, *Quercus*, *Fraxinus*, and *Betula* (Conway and Vander Vecht 2015; Pretzsch et al. 2015). In Rzeszów, the woody plants found in its parks mostly overlap with those presented by Pretzsch et al. (2015), Reháčková and Pauditšová (2004), Kuchcik et al. (2016), and Jochner-Oette et al. (2018), and the most of them are allergenic.

A detailed analysis of the risks posed by urban parks was conducted for Spanish parks. This risk can be expressed by the allergenicity index (I_{UGZA}), which was proposed by Cariñanos et al. (2014, 2016) and which was also used in our study with minor modifications. These authors give a list that contains as many as 17 frequently occurring species for which their VPA $\geq$ 18. In the parks of Rzeszów, the number of strongly allergenic species was not much lower, but only several species occurred with a high frequency, and less than one-third of the species was characterized by a high VPA. It is accepted that if the value of I_{UGZA} exceeds 0.3, then we can consider that the park has a harmful effect on humans (Cariñanos et al. 2017); as many as 16 Spanish parks were found to have adverse effects on allergy sufferers, including 5 parks that had I_{UGZA} values above 0.6. The I_{UGZA} values for the parks analysed in our study as well as by Jochner-Oette et al. (2018) in Bavaria, Germany (all in the warm temperate climate zone), were distinctly lower. It is difficult to clearly identify all the reasons for these different results, but it appears that the duration of the pollination period is important. In a Mediterranean climate, pollen grains occur in the atmosphere throughout a year (Pérez-Badia et al. 2010; Martínez-Bracero et al. 2015), while in Poland pollen grains occur from February to September (Kasprzyk 2011). Cariñanos et al. (2017) report that in Spain a park's impact on allergy sufferers primarily depended on tree density and the total number of trees. In many parks in Spain, the values of H' index were distinctly higher than that in the Rzeszów parks, but biodiversity did not have a significant effect on the value of I_{UGZA} (Cariñanos et al. 2017). In Rzeszów, the parks with greater biodiversity were characterized by lower allergenicity index, but Jochner-Oette et al. (2018) pointed that that the increase in biodiversity does not always lead to lower allergenic potential of park's vegetation. In Rzeszów, tree density was irrelevant, whereas the number of trees was significant but only in the case of some species and the park canopy-covered area. P3, which is a landscape-like park with relatively large areas of turf and paved areas, was characterized by the lowest I_{UGZA}. The downtown parks (P2 and P4) and the park located on the outskirts of the city (P1) have a much larger canopy, and the values of their indices were much higher. Tree crown volume is another characteristic that strongly affects the I_{UGZA}. The study showed that *B. pendula* and the oaks *Q. rubra* and *Q. robur* are of key importance for the I_{UGZA}, although according to Pretzsch et al. (2015), the average diameter of their crowns is not largest among typical urban trees. These species are attractive due to their aesthetic qualities as well as their great cultural and symbolic importance, and hence, there are many of these species in parks. However, these species produce large amounts of pollen (Tormo Molina et al. 1996) that contain strong or very strong allergens, and their VPA values are 36 for *B. pendula* and 18 for the oaks (Cariñanos et al. 2016). In Poland, as in many European countries, birch is considered the most frequent cause of tree pollen-related allergies (Pawankar et al. 2013). The co-occurrence of these species, as well as *C. avellana* in P2, in large numbers in one park creates an additional risk to park users because pollen seasons overlap, and the pollen allergens display cross-reactivity (de Weger et al. 2013). Because one birch inflorescence can produce 10 million pollen grains (Piotrowska 2008), people with allergies should not stay in parks with many birches for a long time during their pollination period. Kihlström et al. (2003) reported that pregnant women in contact with high birch pollen concentrations can have children that are more sensitive to birch pollen.

From the group of herbaceous plants occurring in Poland, grass pollen and mugwort pollen cause allergies most frequently (de Weger et al. 2013). In the parks studied, herbaceous species, with pollen that is strongly or very strongly allergenic, accounted for 50% of the turf cover. These species are Poaceae, *P. lanceolata*, and *Chenopodium* sp.; their pollination period is very long, while their VPA values are 36, 27, and 27, respectively. If we assume that lawns are often mowed appropriately, then their contribution to I_{UGZA} is not that significant, although clearly higher than one of the parks of Granada. This result is attributable to the fact that the volume of grasses that produce strongly allergenic pollen is very small relative to the tree crown volume. In evaluating the contribution of individual grass species to the I_{UGZA}, one should consider not only the production per inflorescence or plant but also the production per area occupied by a specific species. *L. perenne* and *P. annua* are found in every park, but *P. annua* produces much less pollen than *L. perenne* (Peel et al. 2014) and occupies 2–11% of the turf area, whereas *L. perenne* occupies 25–34% of the turf area. Although the contribution of grasses to the index is not large, we should remember that other grass parts (blades, leaves) contain allergens, and therefore, sunbathing or playing on lawns can be harmful to allergy sufferers, specifically after mowing when there are elevated concentrations of aeroallergens in the air that originated from pollen and other grass parts (D'Amato et al. 1991).

A park with good infrastructure, diverse land development and diverse flora and fauna is attractive to visitors (Palliwoda et al. 2017). The high floristic diversity of these parks stems from the introduction of many ornamental species and their varieties, both native and non-native. These characteristics were observed in the downtown parks, especially in P2 where there is a high diversity of ornamental shrubs. The introduction of alien species or cultivars should be carried out with special caution (Lonezoni-Chiesura et al. 2000; Velasco-Jiménez et al. 2015), because as pointed (Jochner-Oette et al. 2018) inappropriate management of urban greenery can increase their harmful effect. *P. hispanica* is non-native in Poland. This species was planted in the past in manor parks (Baniukiewicz 1972). Due to its interesting bark and showy leaves, it is currently planted but at a much larger scale (Nowak et al. 2012). A few impressive trees grow in P3, while in P2, young plantings were observed. Considering a park to be a source of aeroallergens is a very unfavourable action. The pollen of this species is a serious cause of allergies in southern Europe. *P. hispanica* produces 13 million pollen grains per inflorescence (Tormo Molina et al. 1996), and its crown size is highest among urban trees (Pretzsch et al. 2015). To date in Poland, this species has not been regarded as an important cause of a pollen-induced allergy; however, Nowak et al. (2012) warn that large clusters of trees of this species are a source of such a large amount of pollen that it may pose a threat to people sensitive to plant allergens.

5 Conclusions

Given the increase in information on the allergenicity of urban parks, this topic is extremely important for those responsible for green urban development as well as residents of cities. We conclude that the adverse effect of vegetation on those suffering from allergies increases with the presence of wind pollinated trees in urban parks. Under warm temperate climate conditions, planting *Betula*, *Corylus*, *Carpinus,* and *Quercus* should be substantially reduced. The pollen of these four taxa is a primary cause of inhalant allergies, and their allergens display cross-reactivity. A high occurrence of *A. pseudoplatanus* and *A. platanoides* does not cause a significant increase in park allergenicity.

The allergenicity index is an excellent tool for assessing the allergenicity of urban parks. So far, research has focused on wood allergenic plants. We emphasize the need for a detailed inventory of herbaceous plants, as we have demonstrated that the load of lawn in I_{UGZA} is not as high as commonly believed. In the region under the study, the park with the greatest lawn area presents a lower risk for allergy sufferers than downtown parks with larger tree canopies. Floristic investigations are particularly important because different lawn seed mixes are used in different regions and thus the impact of lawns on humans may differ.

In Rzeszów, since 2008, there has been a growing interest of the municipal services of green infrastructure, but they do not pay attention to the potential threat from some plant species. Based on the obtained results, we elaborate the recommendations for urban greenery planning. We recommend that in the case of dioecious species, female individuals be planted. A good example is the various *Salix* species, with large-sized crowns that provide the desired shading without a high I_{UGZA}. Biodiversity increases the attractiveness of urban parks, but it is also associated with the higher I_{UGZA}. It is therefore necessary to plant various tree species with low allergenic potentials and at the same time attractive appearance. Introducing non-native plant species such as *Platanus* for temperate climate zone should also be avoided as its pollen has been recognized as allergenic in other regions. Pollen grains of many entomophilous species are not generally considered to be highly allergenic. Nevertheless, if their individuals occur in large hedges such as *Ligustrum*, then they can threaten those that suffer from allergies. Given this result, special attention should be given to the species composition of plants growing close to playgrounds, fountains, and pergolas, that is, in places where park visitors stay for a longer time. Therefore, it is recommended that plants with short flowering periods or with cleistogamous flowers should be planted in these areas. This study indicates that research on allergenic park vegetation should be taken into consideration in designing new parks or revitalizing old parks.

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