

Article

The Influence of Individual-Specific Plant Parameters and Species Composition on the Allergenic Potential of Urban Green Spaces

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Abstract: Green planning focusses on specific site requirements such as temperature tolerance or aesthetics as crucial criteria in the choice of plants. The allergenicity of plants, however, is often neglected. Cariñanos et al. (2014; *Landscape and Urban Planning*, 123: 134–144) developed the Urban Green Zone Allergenicity Index (I_{UGZA}) that considers a variety of plant characteristics to calculate the allergenic potential of urban green spaces. Based on this index, we calculated an index for the individual-specific allergenic potential (I_{ISA}) that accounts for a varying foliage volume by accurate measurements of crown heights and surface areas occupied by each tree and only included mature individuals. The studied park, located in Eichstätt, Germany, has an area of 2.2 ha and consists of 231 trees. We investigated the influence of species composition using six planting scenarios and analysed the relationship between allergenic potential and species diversity using Shannon index. Only a small number of trees was female and therefore characterised as non-allergenic, 9% of the trees were classified as sources of main local allergens. The allergenic potential of the park based on literature values for crown height and surface was $I_{UGZA} = 0.173$. Applying our own measurements resulted in $I_{ISA} = 0.018$. The scenarios indicated that replacing trees considered as sources of main local allergens has the strongest impact on the park's allergenic potential. The I_{UGZA} offers an easy way to assess the allergenic potential of a park by the use of a few calculations. The I_{ISA} reduces the high influence of the foliage volume but there are constraints in practicability and in speed of the analysis. Although our study revealed that a greater biodiversity was not necessarily linked to lower index values, urban green planning should focus on biodiversity for ameliorating the allergenic potential of parks.

Keywords: urban parks; landscape planning; allergenic potential; ecosystem disservices

1. Introduction

Allergic diseases are considered as important human health issues as they substantially restrict many allergic people [1,2]. In Germany, almost 20% of the adult population suffers from at least one type of allergy [1] and 30% of the adult population and 50% of the adolescent generation show sensitisations [2]. Since 15% of the population are affected by hay fever [3], pollen allergy poses a major risk for humans.

In light of these rising numbers of allergic diseases, the consideration of allergy-friendliness in urban green planning seems to be essential [1,4]. Actually, pollination is regarded as an ecosystem service provided by green infrastructure [5]. When related to pollen allergies, however, it can also

be considered as an *ecosystem disservice* [6] representing a conflict to other ecosystem services such as recreation and health benefits as green spaces regulate climate and improve air quality [5].

Urban green planning mainly focusses on specific site requirements (e.g., temperature tolerance, pest resistance, tolerance to pruning) and aesthetics as crucial criteria in the choice of plants [7]. The allergenic potential of plants, however, is often neglected [1,4,8]. Still, more research is required regarding the use of allergenic plants in green spaces and the development of allergy-friendly green areas in urban environments. Some attempts have been made to formulate planning recommendations to reduce negative health impacts caused by plants producing allergenic pollen [9–11]. For example, it was recommended to develop gardens with only female plants or with a great diversity of non-allergenic plants [10]. Microbial diversity was found to positively affect the human immune system by reducing certain allergenic and respiratory diseases (e.g., reviewed by [12]). A study conducted in eastern Finland showed that atopic individuals were associated with lower environmental biodiversity in the surroundings of their homes and significantly lower generic diversity of gammaproteobacteria on their skin [13]. Since there is a link between richness of macroorganisms and the associated microbial biodiversity [12], a greater biodiversity of plants in general may reduce the risk of allergy sensitisations. In addition, an increased biodiversity linked to a reduction of traditional species with a high allergenic capacity leads to lower concentrations of monospecific pollen [14].

The allergenic potential of plants was assessed by [10] who developed the Ogren Plant Allergy Scale (OPALS). This scale considers different plant-specific criteria based on studies about similarities between allergenic and non-allergenic plants. Characteristics include pollen weight and size, pollen moisture, flower fragrance as well as the position of male flowers of monoecious species. The scale categorises species at ten levels with 1 being non-allergenic and 10 being highly allergenic. Another attempt to categorise plants according to their allergological characteristics was made by [15] who developed the allergen index (A.I.). This index is based on information on the plant's life cycle, the length of its phenanthestic period, the presence of phenomena of cross reactivity and species abundance [15,16]. In addition, [17] developed the so-called Urban Green Zone Allergenicity Index (I_{UGZA}) to calculate the allergenic potential of urban green spaces. This index compares an existent green space with a hypothetical space with maximum allergenicity. The index is based on the following assumptions: Plants with a higher crown volume emit higher pollen quantities [18], anemophilous trees produce more pollen than other trees [19] and pollen release is directly proportional to the number of individuals belonging to one species.

In this study, the current allergenic potential of the trees and shrubs in an urban park (Hofgarten, located in Eichstätt, Germany) was examined using I_{UGZA} .

Based on this index, we developed I_{ISA} , an index for the individual-specific allergenic potential of urban green spaces. Therefore, we measured the height and the surface covered by each individual tree or shrub and only included mature individuals already emitting pollen. In addition, we investigated the influence of species composition on the allergenic potential of the park using six different planting scenarios and analysed the relationship between allergenic potential and species diversity using Shannon index. Thus, our main aims were to develop and evaluate management tools (indices and planting scenarios) in order to formulate recommendations for urban planning. Although this study only includes a single park, our methods are also applicable for any park of any size and therefore illustrative for the practicability of the management tools presented in our study.

2. Materials and Methods

2.1. Study Area

The studied park Hofgarten (48°53'20.54" N, 11°11'17.78" E, 385 m a.s.l.) is located in the city of Eichstätt, Bavaria, Germany (Figure 1a,b). The climate is temperate with an average annual temperature of 8.0 °C and an annual precipitation of 776.5 mm (1961–1990, German Meteorological Service, station "Landershofen"). Eichstätt is located at the Altmühl river and has a few open green

areas. The rectangular-shaped urban park lies south-east of the city center, next to the main campus of the Catholic University of Eichstätt-Ingolstadt (Figure 1c). Hofgarten has an area of 22,480 m² (~2.2 ha). In 1735, the park was designed as a baroque garden and partially transformed to an English garden after 1817. In recent times, these concepts were combined leading to a composition of geometrically designed and accurately pruned baroque elements with long and structured avenues and a variety of some very old trees originating from Europe, North America and Asia [20]. Recently, the park counts 231 trees and shrubs of 69 different species (excluding hedges, flowerbeds and grass and herb species) (Table 1).



Figure 1. Location of the study site in Germany (Eurostat, NUTS 2013/EU-28) (a) and in the city of Eichstätt, red border; (b) OpenStreetMap; (c) GoogleEarth.

Table 1. Number (*N*) of individuals planted in Hofgarten belonging to 69 species and 31 plant families (according to the APG system [21]). ap: allergenic potential, pe: type of pollen emission, ppp: duration of principal pollination period (see Table 2 for parameters and values).

Species	N	Family	ap	pe	ppp	Species	N	Family	ap	pe	ppp
<i>Acer griseum</i> (Franch.) Pax 1902	1	Sapindaceae	2	2	1	<i>Liquidambar styraciflua</i> L.	1	Altingiaceae	2	3	1
<i>Acer monspessulanum</i> L.	1	Sapindaceae	2	1	2	<i>Liriodendron tulipifera</i> L.	1	Magnoliaceae	1	1	2
<i>Acer negundo</i> L.	1	Sapindaceae	2	2	1	<i>Magnolia × soulangeana</i> Soul.-Bod.	3	Magnoliaceae	2	1	2
<i>Acer pensylvanicum</i> L. 1753	1	Sapindaceae	2	2	1	<i>Magnolia kobus</i> DC.	1	Magnoliaceae	2	1	2
<i>Acer platanoides</i> L.	19	Sapindaceae	3	2	2	<i>Magnolia stellata</i> (Siebold & Zucc.) Maxim.	3	Magnoliaceae	2	1	2
<i>Acer pseudoplatanus</i> L. 1753	24	Sapindaceae	3	2	1	<i>Morus alba</i> L. 1753	1	Moraceae	2	1	1
<i>Acer rubrum</i> L. 1753	2	Sapindaceae	1	2	2	<i>Nothofagus Antarctica</i> (G. Forster) Oerst.	1	Nothofagaceae	4	3	2
<i>Aesculus × carnea</i> Zeyh.	2	Sapindaceae	2	2	2	<i>Ostrya carpinifolia</i> Scop.	1	Betulaceae	4	3	3
<i>Aesculus hippocastanum</i> L.	18	Sapindaceae	2	2	2	<i>Paeonia × suffruticosa</i> Andrews	1	Paeoniaceae	1	1	2
<i>Ailanthus altissima</i> (Mill.) Swingle	1	Simaroubaceae	3	2	1	<i>Paulownia tomentosa</i> (Thunb.) Steud.	1	Paulowniaceae	2	1	2
<i>Berberis vulgaris</i> L.	1	Berberidaceae	1	1	3	<i>Philadelphus coronarius</i> L.	4	Hydrangeaceae	1	1	3
<i>Betula pendula</i> Roth	2	Betulaceae	4	3	2	<i>Picea omorika</i> (Pančić) Purk.	1	Pinaceae	1	3	1
<i>Buxus sempervirens</i> L.	24	Buxaceae	2	1	2	<i>Picea pungens</i> Engelm.	1	Pinaceae	1	3	3
<i>Carpinus betulus</i> L.	1	Betulaceae	4	3	2	<i>Platanus × hispanica</i> (Aiton) Willd.	1	Platanaceae	3	3	1
<i>Castanea sativa</i> (Mill.)	2	Fagaceae	2	3	1	<i>Potentilla fruticosa</i> (L.) Rydb.	1	Rosaceae	1	1	3
<i>Catalpa bignonioides</i> Walter	1	Bignoniaceae	3	1	2	<i>Prunus padus</i> L.	2	Rosaceae	2	1	2
<i>Celtis australis</i> L.	1	Cannabaceae	3	3	1	<i>Prunus sargentii</i> 'Accolade' Rehder	3	Rosaceae	2	1	2
<i>Cercidiphyllum japonicum</i> Siebold & Zucc.	1	Cercidiphyllaceae	2	1	2	<i>Prunus serrulata</i> 'Kanzan' LINDL.	1	Rosaceae	2	1	2
<i>Cercis siliquastrum</i> L.	1	Fabaceae	2	1	3	<i>Prunus tomentosa</i> Thunb.	1	Rosaceae	1	1	2
<i>Chaenomeles japonica</i> (Thunb.) Lindl. ex Spach	1	Rosaceae	1	1	2	<i>Pterocarya fraxinifolia</i> (Lam.) Spach	1	Juglandaceae	2	3	2
<i>Chamaecyparis lawsoniana</i> (A. Murray) Parl.	1	Cupressaceae	3	3	2	<i>Quercus petraea</i> (Matt.) Liebl.	1	Fagaceae	4	3	1
<i>Chamaecyparis nootkatensis</i> D. Don 1824	1	Cupressaceae	3	3	2	<i>Quercus robur</i> L.	4	Fagaceae	4	3	1
<i>Cornus mas</i> L.	4	Cornaceae	2	1	3	<i>Ribes alpinum</i> L.	2	Grossulariaceae	1	0	2
<i>Corylus avellana</i> L.	1	Betulaceae	4	3	3	<i>Sequoiadendron giganteum</i> (Lindl.) J. Buchh.	2	Cupressaceae	2	3	2
<i>Corylus colurna</i> L.	1	Betulaceae	4	3	2	<i>Sorbus aria</i> (L.) Crantz	1	Rosaceae	1	1	1
<i>Crataegus monogyna</i> Jacq.	1	Rosaceae	1	1	2	<i>Sorbus aucuparia</i> L.	2	Rosaceae	1	1	2
<i>Deutzia scabra</i> Thunb.	1	Hydrangeaceae	1	1	2	<i>Sorbus domestica</i> L.	1	Rosaceae	1	1	1
<i>Fagus sylvatica</i> L.	3	Fagaceae	4	3	2	<i>Sorbus torminalis</i> (L.) Crantz	1	Rosaceae	1	1	2
<i>Fraxinus excelsior</i> L.	6	Oleaceae	4	3	2	<i>Spiraea × arguta</i> Zabel	1	Rosaceae	2	1	2
<i>Ginkgo biloba</i> L.	3	Ginkgoaceae	2	3	1	<i>Styphnolobium japonicum</i> (L.) Schott	1	Fabaceae	2	2	2
<i>Gleditsia triacanthos</i> L.	1	Fabaceae	1	0	2	<i>Taxus baccata</i> L.	12	Taxaceae	3	0	3
<i>Hedera helix</i> 'Arborescens' L.	2	Araliaceae	2	1	3	<i>Tilia cordata</i> Mill.	15	Malvaceae	2	2	2
<i>Ilex aquifolium</i> L.	1	Aquifoliaceae	2	0	2	<i>Tilia platyphyllos</i> Scop.	21	Malvaceae	2	2	1
<i>Kolkwitzia amabilis</i> Graebn. Christenh.	1	Caprifoliaceae	1	1	2	<i>Tilia tomentosa</i> Moench	4	Malvaceae	2	2	2
<i>Larix decidua</i> (Mill.)	1	Pinaceae	1	3	3	Sum	231				

2.2. I_{UGZA} —Urban Green Zone Allergenicity Index

The Urban Green Zone Allergenicity Index (I_{UGZA} , [17], Equation (1)) compares an existent green space with a hypothetical space with maximum allergenicity. The index considers a variety of plant characteristics, partially adjusted for our study (Table 2).

$$I_{UGZA} = \frac{1}{378 \cdot S_T} \cdot \sum_{i=1}^k n_i \cdot ap_i \cdot pe_i \cdot ppp_i \cdot S_i \cdot H_i \quad (1)$$

Table 2. Scale of values for the parameters used for I_{UGZA} (Urban Green Zone Allergenicity Index) and I_{ISA} (Index of individual-specific allergenic potential of green spaces).

Parameters	Values for I_{UGZA} and I_{ISA}	
Allergenic potential (ap)	0 = non-allergenic (OPALS 1)	
	1 = low allergenicity (OPALS 2–4)	
	2 = moderate allergenicity (OPALS 5–7)	
	3 = high allergenicity (OPALS 8–10)	
	4 = main local allergens	
Type of pollen emissions (pe)	0 = only female-sex individuals	
	1 = entomophilous	
	2 = ampiphilous	
	3 = anemophilous	
Principal pollination period (ppp)	1 = 1–4 weeks	
	2 = 5–8 weeks	
	3 \geq 9 weeks	
	I_{UGZA}	I_{ISA}
Crown height (H)	Mean height attained at reproductive maturity: 2, 6, 10, 14 m or exceptionally 18 m	Individual-specific measurements [m]
Plant surface (S)	Small-diameter: <4 m, medium-diameter: 4–6 m, large-diameter: >6 m	Individual-specific measurements using 4 radii [m]

OPALS: Ogren Plant Allergy Scale [10].

Relevant variables for I_{UGZA} are the total area of the examined green space in square meters (S_T), the number of species (k), the number of individuals belonging to one species i (n_i), species-specific and classified values for allergenicity (ap_i), type of pollen emission (pe_i), duration of the main pollination period (ppp_i), crown height in meters (H_i) and surface area of the plant in square meters (S_i) (classification see Table 2). The values for the parameters of the index were—apart from the base area of the green space (S_T) and of the present number of species and individuals (k , n_i)—obtained from databases or reports and in this study adapted to conditions prevailing in the biogeographic region of our investigated park (see Section 2.4). The capacity of species-specific pollen emission ($S_i \times H_i$) was calculated using a volume calculation of geometric plant shapes. A cylindrical shape was used for trees and a hemispherical shape for shrubs. The height of the crown (H_i) and surface area of trees and shrubs (S_i) refer to the maximum values of a mature individual of the respective species. For simplification, these literature-based values of H_i and S_i were also classified or scaled.

The figure 378 is an expression of the maximum values ($ap_i \times pe_i \times ppp_i \times H_i$) a species i can obtain and serves, together with the base area of the green space (S_T), as reference unit of the formula. Although, maximum values for height can reach 18 m and main local allergens are considered as $ap = 4$, [17] used $ap = 3$, $pe = 3$, $ppp = 3$ and $H = 14$ for the calculation of this factor.

An index value of 0 can only be obtained if the tree is female ($pe = 0$) or the emitted pollen is non-allergenic ($ap = 0$).

Values higher than 0.5 already relate to a high allergenic potential [17]. When a densely planted green space is considered, the sum of all surface areas occupied by the plants can be greater than the base area of the green space (S_T). In this case and when all factors and parameters measured are maximal, the index can also exceed the value of 1.

2.3. I_{ISA} —Index of Individual-Specific Allergenic Potential of Green Spaces

The index of the individual-specific allergenic potential of green spaces (I_{ISA}) was calculated using the same formula as for I_{UGZA} (Equation (1)). In contrast to I_{UGZA} , we measured the crown height (H_i) and surface areas (S_i) of each plant. In addition, I_{ISA} uses a different constant (1/1188) since we considered main local allergens ($ap = 4$) and the maximum tree height differs in our study due to plant-specific measurements. The highest crown represented by the species *Tilia tomentosa* was $H = 33$ m. In contrast to the study presented by [17] we only included mature individuals that are already producing flowers and hence emitting pollen. For both variants (I_{UGZA} and I_{ISA}), we excluded flowerbeds and herb and grass species and revised all parameters according to the descriptions below.

2.4. Parameters Used for I_{UGZA} and I_{ISA}

For the classification of the allergenic potential (ap_i) of plants, we used the Ogren Plant Allergy Scale (OPALS, [10], reclassification see Table 2). Different species composition and airborne pollen concentrations imply varying sensitisation rates for specific species between countries/regions [8]. Thus, locally occurring highly allergenic plants were additionally taken into account ($ap = 4$). In our studied park, this relates to species of Betulaceae, Fagaceae and Oleaceae [11]. For missing species not listed in [10], we calculated the median. e.g., the median of all *Acer* species was used to obtain the value for missing information on the allergenic potential of *Acer monspessulanum*.

The factor type of pollen emission (pe_i) consists of information about the type of pollination. E.g., female dioecious plants do not emit any pollen whereas anemophilous plants emit far more pollen than entomophilous plants [22]. The classification of female plants resulted in $ap = 0$. This classification was mainly made by means of optical characteristics (presence of fruits, e.g., berries on *Ilex aquifolium* = female). If optical inspections were not possible due to plant height, we used the mean of the allergenicity values for female and male plants of the respective species. For the classification of missing species not evaluated by [17], we used information of the databases BioFlor [23] and Baumkunde.de [24]. In case of diverging specifications, a plant was attributed to $pe = 2$.

To adopt the length of the pollination period (ppp_i) to the biogeographical region of our study, information on this parameter was obtained from literature and databases [23–26]. Therefore, it was also necessary to adjust the width of classes for this parameter (see Table 2).

The individual-specific volume ($S_i \times H_i$) of each tree is considered to represent the capacity of pollen emission [18]. In contrast to I_{UGZA} , the newly developed I_{ISA} does not incorporate mean values for adult trees but takes the actual information of S_i and H_i for each individual into account. As described by [17], a cylindrical shape was used for trees and a hemispherical shape for shrubs. The unequal symmetry of many trees and shrubs implies that the calculation of the volume of the cylinder remains imprecise when an average radius of the crown is applied. Therefore, the plant's radius was measured at four positions. Tree and crown height was assessed using a height meter (SUUNTO PM-5/1520).

Since I_{ISA} only includes mature individuals, the age of the trees as an indicator for maturity was assessed using a commonly used method proposed by [27] which is based on the measurement of trunk circumferences at a height of 1.5 m. According to [27], the age of the tree is its circumference in centimetres divided by 2.5. In the case of fast-growing trees (e.g., *Sequoiadendron giganteum*, *Pterocarya fraxinifolia*, *Nothofagus antarctica*, *Liriodendron tulipifera*), the circumference is divided by 5. Information regarding species-specific age of maturity was obtained from different publications [28–31]. In case of missing information the mean age of maturity of all available species (=20.1 years) was used as a threshold value of maturity. Note that the growth of solitary trees may differ but could not be assessed in the course of our study.

2.5. Planting Scenarios

Since I_{UGZA} uses the maximum plant height and surface of the crown (values known from literature), but I_{ISA} requires individual-specific values, it was more sensible to use I_{UGZA} in planting scenarios. In all six scenarios, the number of hypothetical planted individuals equals the number of individuals currently growing in the studied park ($N = 231$).

For scenario 1, we selected 14 typical park trees according to [32,33]. We calculated their count (see numbers in brackets) according to their current proportional occurrence in the park: *Acer platanoides* (34.3), *Acer pseudoplatanus* (43.3), *Aesculus hippocastanum* (32.5), *Betula pendula* (3.6), *Carpinus betulus* (1.8), *Fagus sylvatica* (5.4), *Fraxinus excelsior* (10.8), *Larix decidua* (1.8), *Picea omorica* (1.8), *Picea pungens* (1.8), *Taxus baccata* (21.7), *Tilia cordata* (27.1), *Tilia platyphyllos* (37.9), *T. tomentosa* (7.2). Scenario 2 is based on the exclusion of locally high-allergenic species. In total 21 trees/shrubs with $ap = 4$ belonging to the plant families Betulaceae, Fagaceae and Oleaceae were replaced by randomly selected individuals. The median of this new selection was $ap = 2$. For scenario 3, all present species were selected but uniformly distributed. With 231 individuals and 69 different species, a frequency of 3.35 was assigned to these species. In scenario 4, only the ten most prevalent species were considered (*A. pseudoplatanus*, *T. platyphyllos*, *A. platanoides*, *A. hippocastanum*, *T. cordata*, *T. baccata*, *F. excelsior*, *T. tomentosa*, *Quercus robur*). The number of individuals were uniformly distributed among species. Thus, a frequency of 23.1 was assigned to each species. For scenario 5, also only the ten most prevalent species were incorporated in our calculations, however, with an unequal distribution. The frequencies were 1, 2, 3, 5, 10, 20, 30, 40, 50 and 70 with the lowest frequency related to the species that is represented fewest of all. We considered 24 species in scenario 6 recommended by [34] for city trees and shrubs that were classified at least as suitable in the categories of drought tolerance and winter hardiness. Those climate-tolerant species were uniformly distributed and yielded a count of 9.6. Species belonging to this category were *Acer negundo*, *Sorbus aria*, *Buxus sempervirens*, *Cornus mas*, *Acer rubrum*, *Ailanthus altissima*, *Ginkgo biloba*, *Gleditsia triacanthos*, *Styphnolobium japonicum*, *Sorbus domestica*, *Sorbus torminalis*, *T. tomentosa*, *A. monspessulanum*, *A. platanoides*, *Aesculus x carnea*, *B. pendula*, *C. betulus*, *P. omorika*, *T. cordata*, *Crataegus monogyna*, *Castanea sativa*, *Corylus colurna*, *F. excelsior* and *Quercus petraea*.

2.6. Shannon Index (H_S)

The Shannon index H_S is a commonly used index to describe biodiversity [35] and was used for the comparison of different planting scenarios. If $H_S = 0$, only one species is prevailing, accounting for 100% of the individuals. The highest diversity represents many different species with an even distribution of individuals. The Shannon index was calculated using Equation (2):

$$H_S = \sum_{i=1}^S p_i \cdot \ln(p_i) \text{ with } p_i = \frac{n_i}{N} \quad (2)$$

where S = number of species, p_i = relative frequency of the i th species, n_i = number of individuals belonging to one species, and N = number of individuals.

3. Results

3.1. Plant Characteristics and Current Allergenic Potential of the Park

The allergenic potential of the investigated 231 trees is predominantly moderate (53%; Figure 2a). Only a small number of trees (11%) was characterised as low allergenic and a comparable amount (9%) is even considered as a source of main local allergens (e.g., *B. pendula* or *Corylus avellana*). The most common pollination strategy (48%) is the mixture of entomophily and anemophily (Figure 2b). Only 7% of the individuals were female plants producing no pollen (e.g., *T. baccata* or *I. aquifolium*). The majority of trees (59%) have a principal pollination period of 4–6 weeks; merely 12% of the plant species flower for 9 weeks or even longer (Figure 2c).

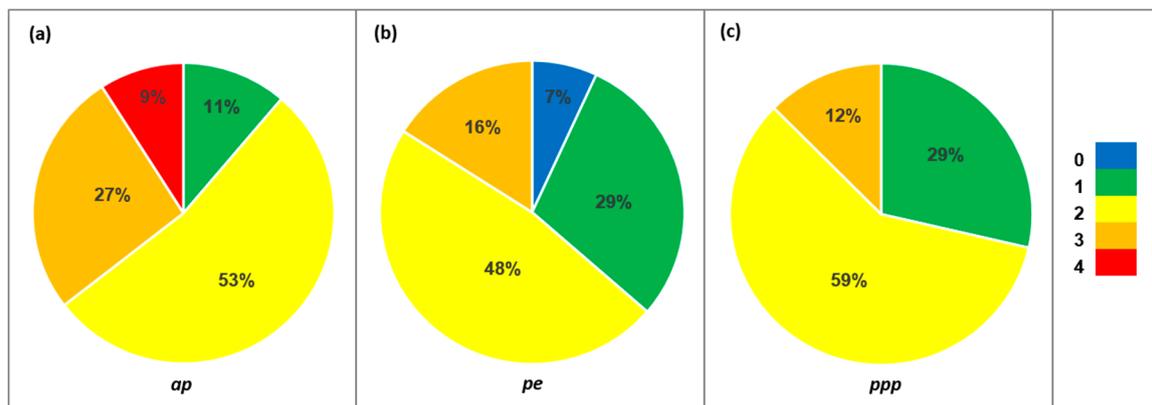


Figure 2. Percentage of plant individuals ($N = 231$) in the urban park Hofgarten classified according to their (a) allergenic potential (ap); (b) type of pollen emission (pe) and (c) duration of principal pollination period (ppp, see Table 2 for parameters and values).

The allergenic potential of the park calculated using literature values for crown height and surface was $I_{UGZA} = 0.173$. Assuming no alterations of planted species, the park's potential is limited to a low allergenic potential. Applying our own measurements to the data reduced the index to $I_{ISA} = 0.018$. Thus, the current allergenic potential is substantially overestimated using I_{UGZA} .

3.2. Planting Scenarios and Associated Biodiversity

Although some species producing pollen known as main local allergens (e.g., pollen of *B. pendula* and *F. excelsior*) were considered in scenario 1, the planting of typical park trees [32,33] according to their current proportional occurrence was associated with the highest allergenic potential ($I_{UGZA} = 0.226$, see Table 3). Replacing trees considered as sources of main local allergens (scenario 2) had the strongest positive impact on the park's allergenic potential ($I_{UGZA} = 0.147$), almost comparable to scenario 5 ($I_{UGZA} = 0.150$) where the ten most predominant species with an unequal distribution were selected. An equal distribution, however, induced a comparable high value ($I_{UGZA} = 0.197$, scenario 4). Applying scenario 3 (uniform distribution of all present species) or scenario 6 (climate-tolerant species [34]), yielded quite similar values for I_{UGZA} compared to the current state (see Table 3).

A greater biodiversity (according to Shannon index H_s) was not necessarily linked to a lower allergenic potential of the park (Table 3 and Figure 3). In fact, the highest biodiversity ($H_s = 4.23$) in scenario 3 (uniform distribution of all present species) only yielded an average allergenic potential ($I_{UGZA} = 0.170$). The lowest biodiversity ($H_s = 1.81$) in scenario 5 (unequal distribution of ten most occurring species) was even associated with a relatively low allergenic potential ($I_{UGZA} = 0.150$).

Table 3. Urban Green Zone Allergenicity Index (I_{UGZA}) for the current state of the urban park (0) and for current state and different planting scenarios and their corresponding Shannon index (H_s).

	I_{UGZA}	H_s
Current state (0)	0.173	3.47
Scenario 1	0.226	2.20
Scenario 2	0.147	3.39
Scenario 3	0.170	4.23
Scenario 4	0.197	2.30
Scenario 5	0.150	1.81
Scenario 6	0.171	3.18

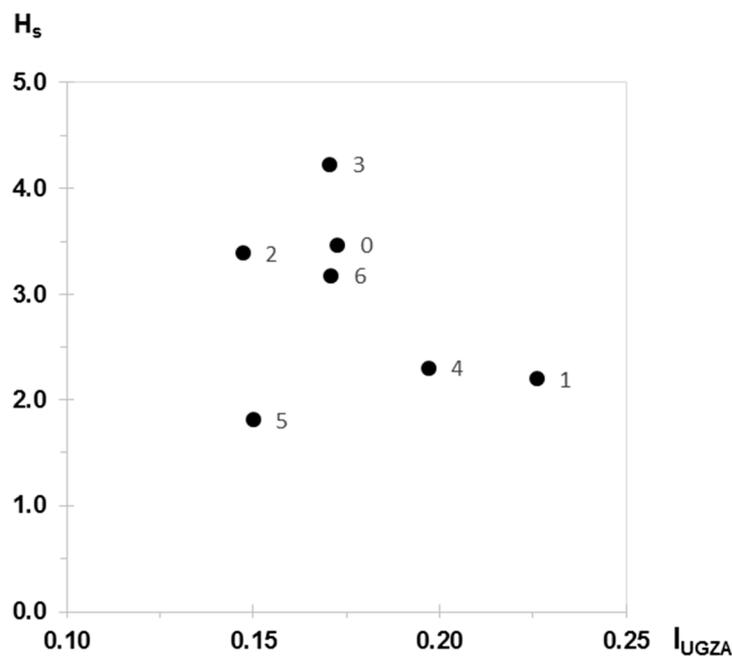


Figure 3. Scatterplot with the variables Shannon index (H_s) and Urban Green Zone Allergenicity Index (I_{UGZA}) for the current state of the urban park (0) and for six planting scenarios (values see Table 3).

4. Discussion

4.1. Comparison of Indices and Conceptual Remarks

The indices I_{UGZA} and I_{ISA} used in our study can be used as a management tool in urban green planning. These indices offer a comparison of the allergenic potential of different parks or planting scenarios, therefore, they can contribute to the development of allergy-friendly parks. Since the presented indices account for the total area of the examined green space (see Equation (1)), the methods presented in our study are applicable for any park of any size. In fact, recommendations for planting trees can be applied with little effort, leading to positive effects for pollen allergy sufferers.

The I_{UGZA} facilitates an easy way to assess and predict the allergenic potential of an urban green space by the use of only a few mathematical calculations. To assess the individual-specific allergenic potential of urban green spaces, we developed an index (I_{ISA}) that includes individual-specific foliage volume by accurate measurements of crown heights and surface areas occupied by each plant. Since there exists an apparent link between foliage volume and number of flowers (and therefore intensity of pollen emission [18]), it is sensible to use individual-specific measurements. Therefore, the I_{ISA} has advantages such as the improvement in accuracy and the reduction of a high influence of the parameters height and surface area. On the other hand, there are constraints in practicability and in speed of the analysis.

In general, the I_{ISA} resulted in a lower value compared to I_{UGZA} (0.018 vs. 0.173). This difference is not surprising because the data obtained for calculating I_{UGZA} are based on mean values of mature individuals (which is different to the individual-specific measurement). The actual growth rate of trees is dependent on different site-specific factors such as climate, competition or nutrient supply [36]. Therefore, the calculation of I_{UGZA} based on literature data may lead to an overestimation of the actual crown volume and in turn to an underestimation of the intrinsic allergenic potential. This fact was also mentioned by [37] who applied this index to three localities in Spain.

The purpose of both indices is to compare an actual green space with a hypothetical green space with maximum allergenicity. Generally, plant crowns might overlap resulting in a higher surface area occupied by plants compared to the geometrical surface area of the park. Thus, a conceptual weakness

of both indices is the fact that values can also be higher than 1 (see Methods section). In reality, however, the indices are rather small for parks (see Results [17,37]), but not for dense forests [38]. Even smaller values would be obtained when the constant of the formula for I_{UGZA} is adjusted to 648 (by applying the prevailing maximum values for the parameters used: $a_p = 4$, $p_e = 3$, $ppp = 3$ and $H = 18$). The value for I_{ISA} (0.018) was considerably smaller since the constant used in the equation (1188) included sources of main local allergens ($a_p = 4$) and was adapted to the maximum measured crown height ($H = 33$ m, *T. tomentosa*). Some species, e.g., *C. avellana*, will never reach a comparable height. Therefore, this index might yield in more meaningful values when the height of trees does not differ very much among planted trees or shrubs.

Another modification was the reduction of the number of considered individuals due to the fact that only mature species were included for the calculation of I_{ISA} . Considering all species (both mature and immature), the index was quite similar (0.019, data not shown). This is probably attributable to the fact that immature individuals are smaller in size and therefore do not contribute much to the magnitude of the index.

Allergenic pollen is not only restricted to trees and shrubs. The high sensitisation rate in German adults of 37.9% linked to grass pollen [39] shows the importance of lawns. In our studied park, grass is cut on a regular basis and only some small areas covering less than 5% of the park's area are not cut to promote spontaneous vegetation for insects. Thus, this study does not include the allergenic potential of non-woody plants but only the allergenic potential based on trees and shrubs. The inclusion of lawn area which accounts for 55.9% of the park area (1.3 ha) would result in an increase of I_{UGZA} by 0.00254 when a medium height of 0.2 m is assumed. Including grass for I_{ISA} is not sensible since this index is based on accurate measurements of plant heights (which varies in the course of the vegetation season in the case of grass) and only includes mature individuals. Most grasses, however, do not flower in our park due to frequent cutting. Nevertheless, in other urban green areas, the inclusion of non-woody plants may have to be considered as well.

The employment of pruning can be an effective management tool. In our park, accurately pruned individuals of *B. sempervirens* expose a lower risk since flowers are kept to a minimum. Ideally, information on pruning practices should be included in assessing the allergenic potential of parks. The studies of [17,37] accounted for the effects of grass and flower species. Here, we excluded hedges and lawns since they are very frequently cut.

An important factor not considered in our study is the pollen emission of areas outside the study area [8]. In case of Hofgarten, an inflow especially from south-eastern (plantings and lawns), south-western (large green areas and riverside vegetation) and north-western directions (plant nursery) is possible, despite walls and buildings enclosing this park. Depending on species and wind conditions, pollen can be spread over large areas and great distances [40,41] substantially influencing the allergenic potential of a given place. Pollen abundance is further affected by numerous surfaces for impaction and filtration [42] such as walls and buildings that surround Hofgarten. In addition, needles of conifers or leaves of deciduous trees may influence the impaction of pollen. Early flowering anemophilous plants such as hazel and birch may be able to disperse their pollen more efficiently since their own leaves and most leaves of other plants are not unfolded yet. Except for some fountains, lakes or ponds are not present in Hofgarten, but they allow the deposition of pollen [38]. Since the length of the pollination period (ppp) may vary due to different weather conditions from one year to another [43], phenological observations and/or airborne pollen measurement might contribute to a more accurate index in further studies. In the study of [37], pollen concentrations were monitored at the roof of high buildings, but not in the investigated parks. An exact assessment of the influence of pollen transport however, is only possible with on-site airborne pollen measurements.

4.2. Planting Scenarios and Recommendations for Plantings in Urban Green Areas

The selection of 14 typical park trees in German cities [32,33] according to their current proportional occurrence resulted in the highest allergenic potential ($I_{UGZA} = 0.226$) among all six

planting scenarios. This finding suggests that the planting of common park trees in general is not very suitable for designing allergy-friendly green spaces. This may be attributed to some species whose pollen are known as main local allergens such as *B. pendula* or *F. excelsior*. Regarding the current state of the park, a comparison between these typical park trees (93 individuals) and the remaining trees and shrubs which are not very common or even exotic (138 individuals) shows that their proportional I_{UGZA} is almost equal (0.087 vs. 0.086; data not shown). This finding also suggests that typical park trees include species with negative effects for allergy sufferers. It was pointed out that a moderate planting of exotic species leads to an increasing floral diversification, but the overuse of these exotics should be avoided [14]. *Olea europaea* is an example of a species producing highly allergenic pollen that is mainly planted because of its exotic appearance [10]. Frequently planted individuals of *O. europaea* lead to an increase of airborne Oleaceae pollen and therefore to an increase of the sensitisation rate of German adults which is currently at 9.7% [39]. This species might pose a risk since a high degree of family relationship with another more common species with allergenic pollen (*Fraxinus* spp.) exists [44]. The role of exotic species is controversially debated: Whereas [45] attribute exotic species a preventive measure to reduce sensitisations, other authors noted that some species attracted negative attention. For southern Spain, [46] mentioned allergy symptoms in autumn related to the genus *Casuarina* that is native to Australia and Asia but extensively used as an ornamental tree, especially in coastal cities [47].

The role of main local allergens for the allergenic potential of green spaces is evident: Regarding the current state of the park, 21 major local allergenic trees and shrubs are contributing with a value of 0.036 to the allergenic potential (data not shown). This means that only 9% of the trees and shrubs are responsible for 21.1% of the allergenic potential calculated with I_{UGZA} . For example, major local allergenic pollen of birch, hazel and grasses are triggering clinically relevant symptoms in over 90% of the German adults and on over 75% of Europeans [39]. Thus, replacing main local allergenic plants (scenario 2) had a considerable impact on the park's allergenic potential ($I_{UGZA} = 0.147$). The substitution was made by randomly selected individuals with a medium allergenic potential of $ap = 2$. Using solely non-allergenic plants would yield in even lower values of I_{UGZA} .

To assess the suitability of the current selection of trees, we incorporated three different scenarios. Although a uniform distribution of all planted species (scenario 3) was linked to a similar I_{UGZA} as the actual selection, an equal distribution of the ten most frequently occurring plants (scenario 4) resulted in a comparably high allergenic potential ($I_{UGZA} = 0.197$). This indicates that the actual preferential selection of trees is not very suitable with respect to their allergenic potential. An unequal distribution (scenario 5, $I_{UGZA} = 0.156$) reduced the high influence on I_{UGZA} of some species such as the main local allergenic trees *Q. robur* and *F. excelsior* as well as the high allergenic potential of *T. tomentosa* because of its great foliage volume. As a result, the mass use of certain plants results in large quantities of monospecific pollen, probably affecting the frequency of new sensitisations and the aggravation of symptoms in people allergic to this pollen [14].

The categorisation of climate-tolerant species by [34] does not include any parameters related to the risk for allergy sufferers. The species that are able to perform well under changed climatic conditions (scenario 6) yielded similar values for I_{UGZA} compared to the current state. However, for these and for all other species, it has to be considered that plant-related factors such as the length of the pollination period or the pollen's allergenicity might change with ongoing climate change [48]. In the future, these changes might result in different assessments and have to be timely regarded in urban planning.

The results of our planting scenarios suggest that a greater diversity of trees, assessed using Shannon index, is not linked to a lower allergenic potential of the park. However, several studies claim that urban green planning should focus on biodiversity for ameliorating the allergenic potential of parks [14,17]. Additional species are increasing species diversity but we suppose that the mass use of common pollen emitters leads to high pollen levels increasing the risk of new sensitisations and aggravating allergic reactions.

Allergy sufferers should have access to green spaces where they are not put at additional health risk. In Germany, pollen allergens can be found nearly year-round in the air [26], which can strongly affect those concerned. The occurrence of highly allergenic and anemophilous plants should be limited or avoided, because of their high pollen emission [8]. Furthermore, plants with a long pollination period and the increased planting of only male individuals of dioecious species pose a risk for allergy sufferers. It was suggested that the concept of a female park is suitable for allergy sufferers, because female individuals of dioecious species do not release any pollen [10]. However, the sterility of such green spaces results in a minimised capability of pollination [8]. In addition, female trees are often not favoured for planting due to higher amounts of litter or undesirable odour as observed in *G. biloba* [14].

5. Conclusions

In order to keep and design cities as liveable as possible, it is important to regard urban green spaces as providers for not only positive ecosystem services but possibly also for *ecosystem disservices* related to allergies. Until now, not many specific recommendations for the implementation of allergy-friendly city greening exist and are therefore needed. Indices are a useful management tool for analysing and assessing allergenic potential in public green spaces. With purposive consideration of single individuals, they allow to make an actual site-specific assessment. Based on literature values and a few mathematical equations the I_{UGZA} is easy to calculate. The individual-specific allergenic potential of urban green spaces assessed by I_{ISA} requires more information obtained by accurate measurements of crown heights and surface areas occupied by each plant. Thus, the calculation of this index is more time consuming but the result is more precise. Planting scenarios and assessing biodiversity are useful for the formulation of recommendations for urban planning. In further studies, influences such as pollen flow from neighbouring or distant green areas should be taken into account.

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