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Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health

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ABSTRACT

Urban parks play a key role in the provision of ecosystem services, actively participating in improving the quality of life and welfare of local residents. This paper reports on the application of an index designed to quantify the allergenicity of urban parks in a number of Spanish cities. The index, which records biological and biometric parameters for the tree species growing there, classifies parks in terms of the risk they pose for allergy sufferers, graded as null, low, moderate or high. In this initial phase, the index was applied to 26 green areas in 24 Spanish cities; green areas varied in type (urban park, historical or modern garden, boulevard, square or urban forest), size 1–100 ha), geographical location, species richness, number of trees and tree density (number of trees / ha.). The data obtained were used to calculate the percentage of allergenic species in each park, which varied between 17–67%; density ranged from 100 to 300 trees/ha. The index values recorded ranged from a minimum of .07 to a maximum of .87; a significant correlation was found between index value and both number of trees and tree density. Taking an index value of .30 as the threshold considered sufficient to trigger allergy symptoms in the sensitive population, 12 of the parks studied may be regarded as unhealthy at any time of the year. Corrective measures to mitigate the impact of pollen emissions include the implementation of nature-based solutions at various levels: planning and design, handling and management, and strengthening of urban green-infrastructure elements. The index proved to be a useful tool for environmental analysis, and complies with the principles of portability and scalability central to current and horizon scientific research.

1. Introduction

Urban parks play a key role in the provision of ecosystem services, actively participating in improving the quality of life and welfare of citizens (Latinopoulus et al., 2016; Livesley et al., 2016). One of the main functions of these green infrastructure elements is to improve air

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quality by reducing the presence of gases and particulate matter (PM) (Beckett et al., 2000; Dzierzanowski et al., 2011). Moreover, parks have a direct effect on the welfare of local residents (Carrus et al., 2015), and the aesthetic value of green areas is undeniable (Shackleton et al., 2015); these considerations account for the accelerated greening process in which many cities have been immersed in recent decades (Jim, 2013; Grant, 2012).

However, offsetting this positive balance of services and functions, certain factors or hazards may have a negative impact on the quality of life and the health of the local population (von Döhren and Haase, 2015). Pollen emissions from urban vegetation during the reproductive process are one of the main ecosystem disservices which transversely generate significant economic, social, environmental and, most important, health costs (Cariñanos and Casares-Porcel, 2011). According to data from the World Health Organization, 30% of the world population suffers from some form of allergic reaction to pollen emissions (Pawankar, 2014), and annual spending on the palliative treatment of allergy symptoms in the United States alone has been estimated at several billion dollars (Weis et al., 2001). Moreover, allergy-related health issues are among the most common reasons for absence from work and school (Blaiss, 2010), especially in urban environments where interaction with other pollutants prompts a severe worsening of symptoms (Bosh-Cano et al., 2011).

Since urban environments are the main scenario for allergic episodes, it is there that the causes must be identified and solutions sought. A recent review of the major causes of increased urban pollinosis highlighted as one of the chief factors the inadequate design and planning of green areas (Cariñanos and Casares-Porcel, 2011). This does not necessarily mean that landscape and environmental criteria are not taken into account in the aesthetic design of these spaces (Gómez et al., 2004; Wolch et al., 2014), or that they do not boast a broad range of species (Vlachokostas et al., 2014); but it does mean that they have failed to address certain factors that exacerbate the allergenicity of ornamental plants (Cariñanos et al., 2016a). To date, the main measures implemented to deal with this issue have been: aerobiological sampling to determine the qualitative and quantitative composition of the pollen spectrum (Belmonte and Roure, 1991; González Parrado et al., 2014; Rodriguez de la Cruz et al., 2010); association of pollen counts with urban and peri-urban flora (Cariñanos et al., 2016b; Velasco-Jiménez et al., 2014; Belmonte et al., 2012); and the establishment of general guidelines for mitigating the impact of pollen emissions on the local population (Cariñanos and Casares-Porcel, 2011).

Given the need to prepare cities for the future effects of climate change (Baker, 2012; Leichenko, 2011) and for the population increases expected over the coming decades (Grimm et al., 2008), broader measures should be envisaged, aimed at improving the quality of life and health of citizens, strengthening their resilience and complying with the precepts governing the renaturing of cities with nature-based solutions (Connop et al., 2016). This paper reports on the application of an index designed to quantify the allergenicity of various elements of urban forests in a number of Spanish cities. The data obtained were used to identify the causes of increasing allergenicity in urban green spaces, and a set of nature-based solutions were put forward.

2. Materials and methods

2.1. Estimating the Index of Allergenicity of Urban Parks

The potential allergenicity of urban parks was calculated using the index of allergenicity of urban green zones (I_{UGZA}) developed by Cariñanos et al. (2014), which takes into account a number of biological and biometric parameters for tree and palm species growing in green spaces. Analysis of biological parameters enables a potential allergenic value (VPA) to be assigned to each species, while the biometric parameters enable estimation of their actual behaviour as a source of allergen emissions. VPA itself results from combining three natural variables: type of pollination, duration of the pollen season and intrinsic allergenicity of pollen grains. A list of biological parameters for the 100 most common tree species in Mediterranean cities is provided in Cariñanos et al. (2016a).

Biometric parameters were based on crown diameter and height; this facilitates calculation of allergen emission volumes by assimilating treetops to a geometric figure of similar shape.

Finally, in order to determine the relative value of allergen emissions in a given area or space, the values obtained were compared with those of a space with the same features and surface area, in which all trees planted had maximum values for all parameters, according to the following formula (Cariñanos et al., 2014):

$$I_{UGZA} = \frac{1}{maxVPAxS_T} \sum_{i=1}^{k} VPA \times S_i \times Hi$$

Where:

VPA= Potential Allergenicity Value for each species.

S_T= Surface area of the urban park.

k= number of species in the park.

S_i= Area occupied by each species in the park.

H_i= maximum height reachable by mature tree.

Application of the index yields a value of between 0 (null allergenicity) and 1 (maximum allergenicity). In principle, and given the findings of earlier studies (Cariñanos et al., 2014, 2016a), the threshold considered sufficient to trigger allergy symptoms in the local population was set to .30.

To supplement the data obtained by applying the index, species richness and Shannon´s diversity index (Shannon and Weaver, 1949) were calculated for each green space, in order to compare parks and explore possible correlations between these indices and allergenicity. Spearman non-parametric tests were performed to check for correlations between I_{UGZA} and other parameters, including: surface area, number of trees and tree density. In addition, the relationship between the variables studied (I_{UGZA}, Shannon's Index, surface area, number of trees, species richness, and tree density) was analysed using Principal Component Analysis (PCA) to rank parks as a function of the variables tested. All statistical analyses were carried out using R Software (R Core Team, 2016).

2.2. Selection of Parks: type and location

Since this study sought to cover a range of types and locations (Rall et al., 2015), green areas were selected with a view to ensuring a representative sample in term of number of tree species, design, types of space and climatic amplitude. In this initial phase, a total of 26 green areas located in 24 Spanish cities were analysed, including: urban parks, modern urban gardens, historic gardens, boulevards, squares and urban forests. The main features of each area, including annual maximum and minimum temperature and total rainfall for the period 1981–2010 (State Agency of Meteorology, AEMET, 2012) are detailed in Table 1.

The inventory of tree and palms was supplied in some cities (Barcelona, Cartagena, Cordoba, Huesca, Madrid, Palma de Mallorca, Salamanca, Santander and Valencia), by the Parks and Gardens Services of the respective Town Councils; while in the other cities, inventories were made by the authors themselves in visits to the different spaces, in the months prior to the completion of this study. Some of the most widely-used keys were used to identify the species: Los árboles y arbustos de la Peninsula Ibérica y Baleares (López González, 2006), Arboles en España, Manual de Identificación (López Lillo and de de Lorenzo Cáceres, 2001) Moreover, data on the following parameters were recorded in order to estimate the allergenicity index, with a view to identifying improvement strategies that should be

Table 1
General characteristics of the green areas considered in this study: Geographic coordinates: NW: North-western; N: North; NE: North-eastern; W: Western; C: Centre; E: Eastern; SW: South-western; S: South; SE: South-eastern, regarding the location of the Iberian Peninsula. Tª Max., Tª min., Annual Rainfall: Average annual values for each city during the series 1981–2010 (AEMET, 2012).

CITY	GREEN AREA (TIPOLOGY)	COORDINATES (GEOGRAPHIC LOCATION)	SURFACE (m^2)	Nº TREES	TªMAX Tªmin.	ANNUAL RAINFALL
ALMERÍA	RAMBLA DE BELÉN (BOULEVARD)	36 º51´N 2 º27´W (SE)	29.796	622	23.4 14.7	200
BADAJOZ	PLAZA DE SAN FRANCISCO (SQUARE)	38 º52´N 6 º58’ W (SW)	10.800	116	23.8 10.3	447
BARCELONA 1	JARDIN DE JOAN BROSSA (MODERNIST)	41 º22´N 2 º10´E (NE)	52.000	956	20.3 11.8	588
BARCELONA 2	JARDIN DEL PALACIO DE PEDRALBES (HISTORICAL)	41 º23´N 2 º07´E (NE)	72.800	1095	20.3 11.8	588
CÁCERES	PARQUE EL RODEO (MODENIRST)	39º 27´ 57´´ N, 6º 22´ 20´´ W (W)	40.036	367	21.9 10.7	551
CARTAGENA	PARQUE DE LA ROSA (MODERNIST)	37 º37´13´´ N −0º59´29´´E (SE)	47.651	420	22.3 12.9	313
CEUTA	PARQUE SAN AMARO (HISTORICAL)	35 º53´N 5 º17´W (S)	12.128	305	19.9 12.3	588
CÓRDOBA	JARDINES LA AGRICULTURA (GARDEN)	37 º53´N 4 º47´W (S)	30.542	356	25.1 11.4	605
GRANADA 1	PARQUE GARCÍA LORCA (URBAN)	37 º10´N 3 º34´W (SE)	71.500	788	22.3 9.0	352
GRANADA 2	BOSQUE DE GOMÉREZ (URBAN FOREST)	37 º10´13´´N 3 º35´W (SE)	73.000	2664	22.3 9.0	352
HUESCA	PARQUE MIGUEL SERVET (URBAN)	42 º08´13´´N 0 º24´45´´W (NE)	65.000	1725	19.6 8.4	480
LEÓN	LA GRANJA (MODERNIST)	42 º35´N 5 º33´W (NW)	60.800	754	16.7 5.5	515
MADRID	PARQUE DEL RETIRO (HISTORICAL)	40 º24′N 3 º41′O (C)	1.180.000	19.022	19.9 10.1	421
ORENSE	CAMPUS NORTE (URBAN)	42 º20´57´´N 7 º51´23´´W (NW)	16.400	353	21.3 8.5	811
OVIEDO	PARQUE DE SAN FRANCISCO (HISTORICAL)	43 º21´41´´N 5 º21´01´´W (N)	90.000	836	17.4 9.1	960
PALMA DE MALLORCA	SA RIERA (MODERNO)	39 º34´39´´N 2 º38´89´´ E (E)	123.812	1.142	22.4 10.6	411
PAMPLONA	PARQUE LA TACONERA (HISTÓRICO)	42 º49´01´´N 1 º39´05´´W (N)	90.000	1333	18.4 7.4	674
PLASENCIA	PARQUE DE LOS PINOS (HISTORICAL)	40 º02´N 6 º05´W (W)	54.000	283		
SALAMANCA	LA ALAMEDILLA (HISTORICAL)	40 º58´N 5 º39´W (NW)	23.512	321	18.7 5.6	372
SANTANDER	PARQUE DE LAS LLAMAS (URBAN)	43 º28´18´´N 3 º48´36´´ W (N)	110.000	1.709	18.5 10.5	1.129
SANTIAGO DE COMPOSTELA	LA ALAMEDA (HISTORICAL)	42 º52´N 8 º32´W	56.087	749	17.6 8.3	1.787
SEVILLA	PARQUE AMATE (URBAN)	37 º22´N 5 º57´W (SW)	316.800	3.697	25.4 13.0	539
TOLEDO	CAMPUS FÁBRICA DE ARMAS (HISTORICAL)	39 º51´N 4 º2´W	122.084	1.091	22.1 9.5	342

(continued on next page)

Table 1 *(continued)*

CITY	GREEN AREA (TIPOLOGY)	COORDINATES (GEOGRAPHIC LOCATION)	SURFACE (m^2)	N° TREES	TªMAX Tªmin.	ANNUAL RAINFALL
		(C)				
ÚBEDA (JAÉN)	PARQUE NORTE (URBAN)	38 °00´N 3 °23´ (SE)	78.088	1.002	20.99 9.31	502.8
VALENCIA	JARDÍN DE AYORA (HISTORICAL)	39 °28´N 0 °20´W (E)	22.000	442	22.8 12.4	461
ZARAGOZA	PARQUE DE LA ALJAFERÍA (MODERNIST)	41 °39´N 0° 53´W (NE)	53.610	1.669	21.0 10.0	322

implemented in order to address risk situations: percentage of allergenic species, tree density (number of trees / ha.), species richness and main contributory species to the index.

3. Results

The major findings are shown in Table 2. The proportion of highly-allergenic species, expressed as a percentage of the total number of trees, ranged from 17% for the North Campus at Orense to 67% for the Miguel Servet Park in Huesca. The number of trees per hectare also varied considerably, from less than 100 trees/ha (Cáceres, Plasencia, Palma de Mallorca and Toledo), to over 200 trees/ha (Almería, Ceuta, Huesca, Orense, Valencia and Zaragoza). No clear correlation was observed between species richness and Biodiversity Index (H'); different green areas displayed low species richness and high H' (Cartagena, Caceres, Sevilla, Valencia), high species richness and high H' (Barcelona 1 and 2, Ceuta, Oviedo, Pamplona, Santiago and Toledo), and very high species richness and high H' (Granada-García Lorca and Orense).

In order to estimate the allergenicity index, the VPA of all tree species was calculated. The final list enabled around 200 species to be classified as a function of their allergenicity; the highest values were found for those taxa with the following natural features: wind pollination, pollen season lasting longer than six weeks, and allergenic pollen grains. Some of the genera and species recording maximum VPA—among them members of the Cupressaceae, Moraceae and Betulaceae families—are listed in Table 3.

The results obtained by applying potential allergenicity index to the study areas are shown in Fig. 1. Values ranged from a minimum of .08 for the Plaza de San Francisco, Badajoz, to a maximum of .87 for La Alamedilla Park in Salamanca. Since an index value of .30 was taken as the threshold considered sufficient to trigger allergy symptoms in the sensitive population, 12 of the spaces analysed here, with substantially higher values, may be regarded as unhealthy for pollen-allergy sufferers. A further three parks recorded values close to this threshold and may therefore be classed as moderately-allergenic. The remainder yielded values well below the threshold, and were thus classed as having low or very low allergenicity levels.

4. Statistical results

Spearman correlation tests revealed a significant positive correlation between I_{UGZA} and both tree density per hectare and number of trees (Table 4). Interestingly, although correlations with other parameters were not significant, a negative correlation was found between the allergenicity index and Shannon´s diversity index (H '). The findings for principal component analysis (PCA) were consistent with those of correlation analysis, a strong association being noted between IUGZA and tree density (Fig. 2). This relationship was included In the second principal component, which also correlated negatively with Shannon´s Index. On the basis of the second PCA component, parks were then ranked by I_{UGZA}, which yielded a classification similar to that recorded for allergenicity index, shown in Fig. 1. Parks with the highest IUGZA value were located in Granada (Granada 2: Alhambra Forests), Zaragoza and Huesca, which also recorded the highest values for tree density (365, 315 and 265 trees/ha respectively). The parks with the lowest tree density were in Plasencia, Cartagena, Toledo and Cáceres (57, 89, 89, 92 trees/ha respectively); these also recorded low IUGZA values (Fig. 1).

Elsewhere, however, the correlation between tree density and IUGZA (Fig. 2) was considerably weaker. Parks in Almeria and Badajoz were among those with the lowest IUGZA (Fig. 1), yet recorded high tree density; they also displayed low values for Shannon´s Index and very low species richness values (Table 2). Similar results were observed for Madrid, except that species richness was much greater than in the other parks studied (Table 2).

5. Design and landscape elements

In the plant-group populations of many of the parks studied, there was a predominance of moderately-allergenic or highly-allergenic species. Noteworthy findings included significant numbers of *Cupressus* in the Miguel Servet Park, Huesca, and the La Aljafería park in Zaragoza (462 and 400 individuals respectively), of *Platanus* both in Huesca and in La Taconera, Pamplona, of *Ligustrum* in the forests of La Alhambra in Granada and of *Quercus robur* in La Alameda, in Santiago de Compostela. Significantly, almost one third of the over 19,000 trees in Madrid's El Retiro park are *Aesculus hippocastanum*, which could minimize the potential impact of the almost 1000 plane trees growing in the park's 120 ha. Other formations of interest included those of *Lagunaria patersonii* in Almeria, *Citrus* in Cordoba, *Tamarix africana* in Cartagena, *Ginkgo biloba* in Granada, *Broussonetia papyrifera* in Madrid, *Taxus baccata* in Oviedo, *Betula* sp. in Santander, *Schinus molle* in Seville and *Trachycarpus fortunei* and *Ailanthus altissima* in Toledo.

6. Discussion

Application of the index in order to assess the potential allergenicity of green infrastructure elements in various Spanish cities enabled identification of the major situations and factors to be borne in mind when evaluating their allergenic risk. Findings were enhanced by the diversity of green area types studied, which included squares, modern urban parks, historic gardens, boulevards and urban forests *sensu stricto* (Lafortezza et al., 2013). The distribution of the study cities across the whole of Spain enabled results to be recorded for a broad climatic spectrum, especially in terms of the origin, hardiness and water requirements of the various species (Magarey et al., 2008). In the parks located in the Euro-Siberian region of the country, the most common species were gymnosperms and gregarious deciduous species with high water requirements, such as *Betula, Fagus, Carpinus, Taxus, Alnus, Aesculus* and the deciduous *Quercus* group, which benefit from

Table 2
Percentage of allergenic species, density of trees, Species richness, Index of Diversity of Shannon (H´) and main contributory species of the 26 urban spaces considered in this study.

CITY	GREEN AREA (TIPOLOGY)	ALLERGENIC SPECIES (%)	DENSITY (TREES/ha.)	SPECIES RICHNESS	SHANNON´S INDEX (H´)	MAIN CONTRIBUTORY SECIES (N° INDIVIDUALS)
ALMERÍA	RAMBLA DE BELÉN (BOULEVARD)	37	214.48	8	2.3	*Ulmus minor* (91) *Lagunaria patersonii* (51)
BADAJOZ	PLAZA DE SAN FRANCISCO (SQUARE)	33	116	4	1.9	*Phoenix* spp. (31) *Platanus hispanica* (26)
BARCELONA 1	JARDIN DE JOAN BROSSA (MODERNIST)	32	183.84	56	4.6	*Pinus pinea* (197) *Cupressus semperivirens* (51) *Ligustrum* spp. (54)
BARCELONA 2	JARDIN DEL PALACIO DE PEDRALBES (HISTORICAL)	60	150.41	51	4.2	Cupressaceae(147) *Pinus* spp. (224) *Tilia* spp.
CÁCERES	PARQUE EL RODEO (MODENIRST)	58	91,75	38	4.25	*Fraxinus* spp. (62) Cupressaceae (34) *Morus alba* (30)
CARTAGENA	PARQUE DE LA ROSA (MODERNIST)	43	89.36	42	4.48	*Tamarix* spp. (34) *Morus* alba(20) *Olea europaea* (12)
CEUTA	PARQUE SAN AMARO (HISTORICAL)	21	254.16	59	5.03	*Olea europaea* (19) *Fraxinus* spp. (17) *Ginkgo biloba* (12)
CÓRDOBA	JARDINES LA AGRICULTURA (GARDEN)	31	118.66	32	3.77	*Platanu hispanica* (54) *Phoenix* sp. (60) *Citrus aurantium* (118)
GRANADA 1	PARQUE GARCÍA LORCA (URBAN)	31	110.98	77	4.38	*Cupressus* spp (88) *Ginkgo biloba* (52) *Morus* sp. (26) *Ligustrum* sp. +*Olea* (21)
GRANADA 2	BOSQUE DE GOMÉREZ (URBAN FOREST)	42	365	30	2.16	*Ligustrum* spp. (516) *Platanus hispanica* (112) *Acer negundo* (69) *Ulmus minor* (51)
HUESCA	PARQUE MIGUEL SERVET (URBAN)	67	265.38	62	3.92	*Platanus hispanica* (400) *Cupressus* spp. (462) *Ligustrum* spp. (73) *Carpinus betulus* (41) *Tamarix gallica* (41)
LEÓN	LA GRANJA (MODERNIST)	39	125.6	38	3.91	*Platanus hispanica* (119) *Aesculus* hippocastanum (111) *Fraxinus* sp.p (57) *Morus* sp(35)
MADRID	PARQUE DEL RETIRO (HISTORICAL)	60	161.20	147	3.85	*Aesculus hippocastanum* (6579) *Broussonetia papyrifera* (179) *Carpinus betulus* (79) *Cupressus sempervirens* (575) *Cupressocyparis leylandii*(153) *Platanus hispanica* (956)
ORENSE	CAMPUS NORTE (URBAN)	17	236.87	70	4.11	*Platanus hispanica* (120) *Ligustrum* spp. (63)
OVIEDO	PARQUE DE SAN FRANCISCO (HISTORICAL)	49	92.88	57	4.08	*Aesculus hippocastanum* (183) *Platanus hybrida* (102) *Taxus baccata* (30) *Fraxinus* spp. (27)
PALMA DE MALLORCA	SA RIERA (MODERNO)	43	92.84	35	3.76	*Cupressus* spp.(159) *Fraxinus* +*Olea* (158) *Pinus* spp. (249)
PAMPLONA	PARQUE LA TACONERA (HISTÓRICO)	56	148.11	53	4.24	*Platanus hispanica*(483) *Aesculus hippocastanum* (82) *Betula* spp. (27) *Fraxinus* spp. (57)
PLASENCIA	PARQUE DE LOS PINOS (HISTORICAL)	37	56.6	22	3.26	*Fraxinus* spp. (82) *Populus alba* (13)
SALAMANCA	LA ALAMEDILLA (HISTORICAL)	39	139.56	28	2.65	*Platanus hispanica* (183) Cupressaceae (20) *Ligustrum* spp. (19)

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Table 2 *(continued)*

CITY	GREEN AREA (TIPOLOGY)	ALLERGENIC SPECIES (%)	DENSITY (TREES/ha.)	SPECIES RICHNESS	SHANNON´S INDEX (H´)	MAIN CONTRIBUTORY SECIES (N° INDIVIDUALS)
SANTANDER	PARQUE DE LAS LLAMAS (URBAN)	29	155.36	57	5.31	*Alnus glutinosa* (120) *Quercus ilex, Q. robur* (185) *Betula pubescens, B. papyrifera, B. alba* (134)
SANTIAGO DE COMPOSTELA	LA ALAMEDA (HISTORICAL)	35	133.75	64	4.03	*Quercus robur* (279) *Ligustrum lucidum* (51) Cupressaceae (18)
SEVILLA	PARQUE AMATE (URBAN)	49	116.99	88	4.12	*Ligustrum* spp. (68) *Schinus molle* (73)
TOLEDO	CAMPUS FÁBRICA DE ARMAS (HISTORICAL)	53	89.42	55	4.62	*Ulmus* spp. (155) *Trachycarpus fortunei* (137) *Ailanthus altissima* (102) *Cupressus* spp. (103) *Tilia* spp. (90)
ÚBEDA (JAÉN)	PARQUE NORTE (URBAN)	30	128,46	69	3.67	*Cupressus* spp (158) *Platanus hispanica* (95) *Ulmus* spp (40)
VALENCIA	JARDÍN DE AYORA (HISTORICAL)	38	200	44	4.61	*Acer negundo* (45) *Ligustrum* spp. (44) *Casuarina equisetifolia* (21) *Cupressuss sp* (29)
ZARAGOZA	PARQUE DE LA ALJAFERÍA (MODERNIST)	53	314.9	45	3.76	Cupressaceae (574) *Platanus hispanica*(122) *Populus* spp. (129)

Table 3
Tree Species with maximum Value of potential Allergenicity (VPA) in Spanish Urban Parks.

SPECIES	VPA*
Acer negundo	18
Aesculus hippocastanum	12
Alnus glutinosa	18
Betula spp.	27
Broussonetia papyrifera	27
Carpinus betulus	27
Casuarina equisetifolia	27
Cupressus arizonica; C. sempervirens	27
Cupressocyparis leylandii	27
Fraxinus spp.	18
Ligustrum japonicum	12
Morus alba; M. nigra	27
Olea europaea	18
Platanus hispanica	18
Populus alba; P. nigra	18
Quercus spp.	18
Ulmus minor	18

VPA: pollination strategy x duration of pollination period x allergenicity of pollen grains. Máximum value VPA=27 (Cariñanos et al., 2014, 2016a).

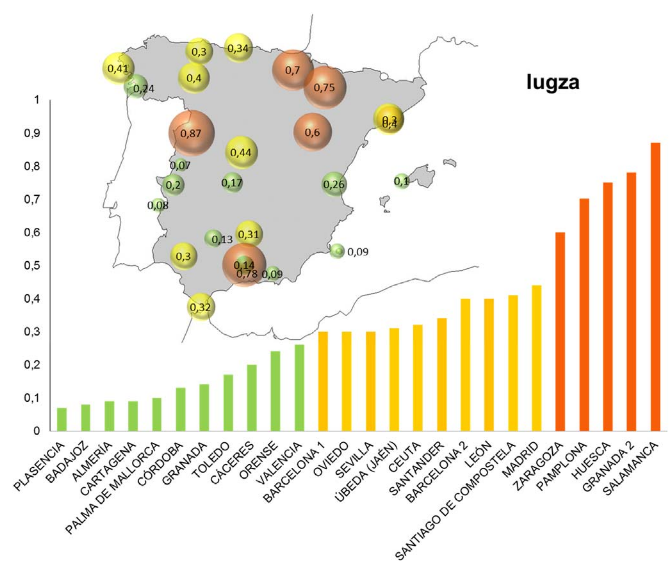


Fig. 1. Index of Allergenicity of the urban parks considered in this study, according to the Index proposed by Cariñanos et al. (2014).

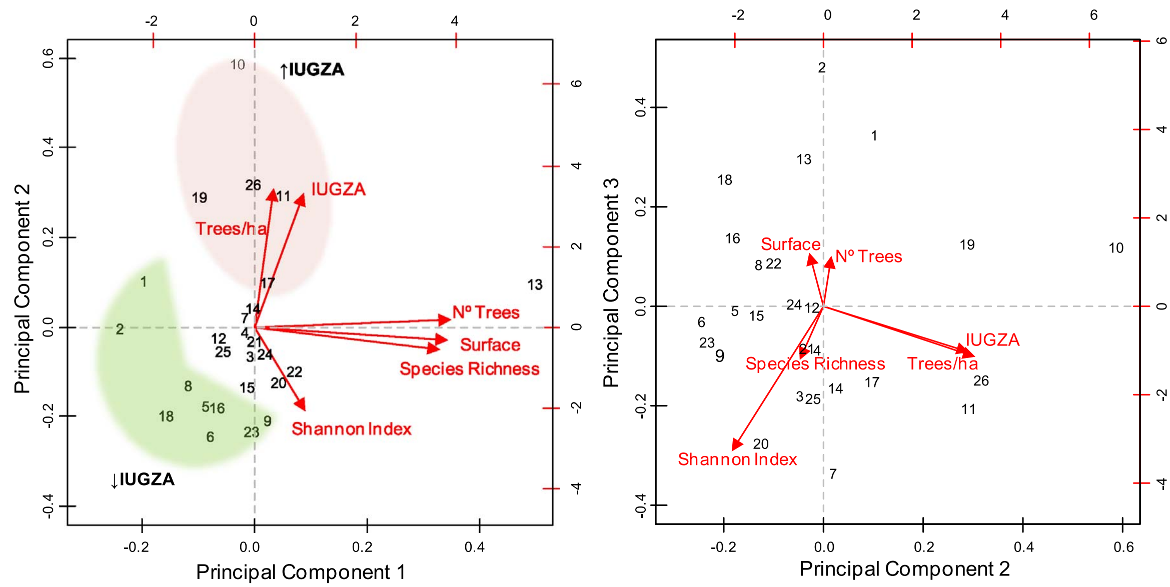
Table 4
Spearman's correlations between IUGZA and several parameters of the parks.

	SHANNON INDEX (H´)	SURFACE (m^2)	No OF TREES	SPECIES RICHNESS	DENSITY OF TREES
I_{UGZA}	−.023 .913	.258 .202	.521** .006	.323 .108	.612*** .001

Significance levels *95, **99, ***99.9%.

annual rainfall rates of over 600 mm (Table 1). All these are predominantly wind-pollinated and highly allergenic, and they are among the leading causes of pollen allergy in central and northwestern Spain (Aira et al., 1998; Blanco Reinosa et al., 2006; Rodriguez-Rajo et al., 2003; González Parrado et al., 2009). In contrast, the milder weather conditions in the rest of the country favour the presence of a wide variety of Mediterranean-type (Roloff et al., 2009) and even tropical taxa, including *Erythrina, Jacaranda, Tipuana, Phytolacca, Lagunaria* and *Citrus*, all of which, though predominantly insect-pollinated and emitting lower amounts of pollen, may still be of some importance as allergens (Alcázar et al., 2016; Cariñanos et al., 2016a). One exception is the Forests of the Alhambra in Granada, south of the Iberian Peninsula, where its anthropogenic origin favours a high presence of water, which resembles the behaviour of an Atlantic forest (Casares-Porcel and Tito-Rojo, 2011).

The analysis of various types of green area yielded a wealth of interesting information. The study areas ranged from small, locally-used squares and gardens with a surface area of less than 25,000 m^2 (Badajoz, Ceuta, Salamanca, Orense and Valencia) to large parks of over 100,000 m^2 (Palma de Mallorca, Santander, Toledo and Madrid). This meant that a broad spectrum of potential allergenicity could be covered: some areas contained formations comprising only small



	PC1	PC2	PC3
Standard deviation	1.65	1.28	1.03
Proportion of Variance	45.53%	27.45%	17.54%
Cumulative Proportion	45.53%	72.98%	90.53%

Fig. 2. Results of Principal Component Analysis taking into account three Principal Components (*PC1 vs. PC2 and PC2 vs. PC3*). Considered Urban Parks: *1* Almería, *2* Badajoz, *3* Barcelona1, *4* Barcelona2, *5* Cáceres, *6* Cartagena, *7* Ceuta, *8* Córdoba, *9* Granada1, *10* Granada2, *11* Huesca, *12* León, *13* Madrid, *14* Orense, *15* Oviedo, *16* Palma de Mallorca, *17* Pamplona, *18* Plasencia, *19* Salamanca, *20* Santander, *21* Santiago de Compostela, *22* Sevilla, *23* Toledo, *24* Úbeda, *25* Valencia, *26* Zaragoza.

number of species or indeed a single species (*e.g. Quercus* in Santiago, *Cupressus* in Zaragoza and Huesca, and *Platanus* in Madrid and Huesca); this was particularly the case of perimeter zones (Salamanca) and tree-lined avenues (Granada and Almería). While no significant correlation was observed between the surface area of these spaces and I_{UGZA}, a statistically-significant correlation was found between the index value and both tree density and total number of trees; this confirms the independence of the allergenicity index with regard to other traditional parameters for measuring the environmental quality of urban green spaces (Baykan-Levent and Nijkamp, 2009). The results also showed, in some cases, an inverse correlation between specific diversity and allergenicity (Cariñanos et al., 2016a), probably due to the reduced diversity of allergenic flora; the greater the diversity of species, the less likelihood there is of allergenic species.

The results also confirmed that both native (*Quercus, Pinus, Platanus, Betula*), and allochthonous taxa (several species of Cupressaceae, Oleaceae and Moraceae) contributed to the allergenicity index. Thus, when addressing potential corrective measures, there is no justification for replacing non-native species by native flora (Cariñanos and Casares-Porcel, 2011; Jianan et al., 2007). It is recommended that appropriate measures be taken to implement nature-based solutions (NBS) at various levels: in planning and design, in handling and management, and when reinforcing green infrastructure elements in cities.

Use of the index as a tool for designing new green spaces, since it enables their maximum allergenicity to be estimated from the outset, remains a fundamental measure in order to prevent the formation of new sources of allergen emission in urban areas (Cariñanos et al., 2016a). In addition to existing measures aimed at increasing the number of female specimens (Ogren, 2000, 2002), introducing species with a short pollen season, and achieving greater species diversity (Cariñanos and Casares-Porcel, 2011), the introduction of shrubs is recommended in those areas where the effect of cooling and shade do not represent a major ecosystem service for the welfare of local residents (Bowler et al., 2010). Further recommendations at this level include the introduction of insect-pollinated tree species, with a view to reducing pollen emission, and the strengthening of regulatory ecosystem services, such as pollination by bees (Kremen et al., 2007).

A second set of measures might be taken with regard to the management and maintenance of the green spaces themselves and of the species growing in them. Given that tree species are regarded as a major source of allergen emission, action is required to minimize the volume of allergen production. Since in many wind-pollinated species floral organs develop in the axillary buds of stems resulting from the natural growth of earlier shoots (Castillo-Llanque and Rapoport, 2011; Frankel and Galun, 2012), one of the most effective measures is the control of flower production. Pruning is widely recognised as the key action for this purpose, since directed pruning can both limit the vegetative growth of the tree and reduce the induction of floral buds (Alejano et al., 2008; Connor et al., 2014; Koutinas et al., 2010). The effect of pruning on pollen emissions has already been studied in plane trees, in two areas with similar bioclimatic conditions but subjected to pruning regimes of differing intensity; increased directed pruning was found to prompt a significant drop in pollen emissions (Sánchez-Reyes et al., 2009). Similar findings have been reported for Cupressaceae (Galán et al., 1998). Positive results could be obtained with species of the genus *Ligustrum*, where the selective pruning of inflorescences during the reproductive period could reduce both proximity-allergy reactions and cross-reactivity with other Oleaceae (Cariñanos et al., , 2002a; Vara et al., 2016).

Controlled irrigation may be regarded as a further management measure, since reduced intensity and frequency of watering in parks and gardens can limit flower production in certain species, even those which are physiologically adapted to summer drought conditions (Fam et al., 2008; Bacelar et al., 2012). This measure is also applicable for the control of other major allergens such as grasses, not studied here (D´

Amato et al., 2007). Frequent watering of the meadows and lawns favours flowering and limits the water available to species sharing the same space. If maintenance mowing is not adequate, large areas of grassland in some parks may become a source of allergens. Given the incompatibility of heavy watering with the xeriscaping techniques increasingly necessary in the Mediterranean area (Ochoa et al., 2009; Asgarzadeh et al., 2014), it essential to ensure they can be properly maintained before implementation.

Nature-based solutions (NBS) for building green infrastructure should focus on reducing the airborne allergen load, so that poor biological air quality does not impair the quality of life and the health of local residents (Cariñanos et al., 2001, 2016a). While the measures outlined earlier are intended to address the processes of pollen production and emission, reduction of airborne pollen counts involves addressing pollen transport and deposition. Once pollen grains have been released into the atmosphere, they behave like any other aerosol, and are subject to the same atmospheric dynamics (Oke, 2002). In urban environments, too, the formation of microclimate conditions plays an important role in pollen dispersal (Cariñanos et al., 2002b; Nazridoust and Ahmadi, 2006; Rodriguez-Rajo et al., 2010a). In an urban context, trees can actively mitigate air pollution through the depositing of gases and particles on the leaf surface (Grote et al., 2016). Like other particulate matter, BPM (Biological Particulate Matter, including pollen grains larger than 10 μm) can be immobilized on the leaf surface, thanks to their larger size and weight (Elimelech et al., 2013), through the presence of exine ornaments (Zhou et al., 2008) or of pollenkitt which increases its adhesiveness to the leaf surface (Pacini and Hesse, 2005). Therefore, the installation of scavenging populations of BPM in strategic areas of the city may be an effective mitigation measure, but it must be implemented judiciously, since many of the species with a known ability to capture pollen are themselves important sources of allergens (Yang et al., 2015).

Finally, reinforcement using elements of blue infrastructure may improve air quality in two ways: first, given their harmomegathic nature, increased humidity favours the hydration of pollen grains, leading to faster deposition (Rodriguez-Rajo et al., 2010b); and secondly, because the presence of permeable sediment or of water substrates hinders resuspension of pollen grains once deposited on the ground (Kadurupokune and Jayasuriya, 2009). In this respect, a further possibility to be explored in the near future is the generation of artificial rain from clouds formed by certain molecules released by trees. Recent research suggests that α-pinenes of plant origin, present in a large number of gymnosperms, can seed clouds, acting as water steam condensers (Castelvecchi, 2016; Pelley, 2016). This would lead to atmospheric washout, decreasing appreciably the airborne pollen load (Akyüz and Çabuk, 2009).

7. Conclusions

The results obtained by applying the I_{UGZA} index to parks of different types and characteristics throughout Spain highlight its value as a management tool; given the lack of correlation with other conventional variables used in landscape design (surface area, species richness, biodiversity), it could be incorporated as a tool for environmental analysis. At the same time, the information derived from the application also facilitates the planning and implementation of NBS to address the enormous problems posed by that allergen emissions to public health. Finally, it should be stressed that the index complies with the principle of scalability, central to current and horizon scientific research.

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