



Original article

Allergenic pollen of ornamental plane trees in a Mediterranean environment and urban planning as a prevention tool



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ABSTRACT

Green spaces and urban green infrastructure are new concepts in urban planning, and lately, the influence of green spaces in cities and how this presence affects local climate change have been taken into account. Moreover, some of the ornamental trees most used in cities provoke allergic symptoms in sensitized people. Due to the importance the plane trees in our parks and cities have as ornamental trees, this article assesses the urban *Platanus* airborne pollen concentration in the air of five cities of the SW Iberian Peninsula and tries to determine the differential factors that its distribution has by means of combining continuous monitoring of the air using volumetric spore traps and the geolocation of plane trees. They were counted separately according to the direction (Q1 NE, Q2 SE, Q3 SW, Q4 NW) around the spore trap location in circles of 100, 200, 300, 400, 500, 1000, 1500, 2000 and 2500 m in diameter. Pollen sums were distributed according to the predominant wind direction for each day. The highest concentrations for *Platanus* pollen were recorded in Don Benito. Differences amongst pollen stations were found and were mainly related to their degree of maturity and their proximity to spore traps, and finally, with the number of plane trees. Furthermore, other factors, as the pruning, which is different in each city and even in a more local way, affects pollination and is frequently unknown to aerobiological studies. The geolocation of ornamental trees can be a useful tool for providing summarized information about their behavioral differences amongst cities, which can be used to create healthy itineraries, minimizing the natural hazards in human health (allergic diseases) and could be implemented into a model to help policy-makers to create measures to improve green urban development.

1. Introduction

Green spaces and urban green infrastructure have recently been developed as a new concept in “Urban Planning and Development”. They include ornamental trees in urban environments and natural or semi-natural vegetation, both of which improve the quality life of citizens (Breuste et al., 2015; Taylor and Hochuli, 2017). Urban green spaces have been analysed from several perspectives. Green infrastructure sources, concerning the spatial identification and its diversity in distribution as well as their functional diversity in relation to urban zones, have been studied in cities (Długonski and Szumanski, 2015). Land use significantly affects the distribution of urban green spaces (Li et al., 2015), avian abundance (Rega et al., 2015) and urban heat islands (Schwarz and Manceur, 2015).

An increase in the global average temperature occurred between 1880 and 2012, and it has been anticipated that this trend continues according to IPCC reports (2013). Urban areas will be most affected due to the heat island effect (Chen et al., 2017). Because of their importance to the climatic ecosystem, urban green areas have an important role in this process (Henseke and Breuste, 2015). On the other hand, resilience has become an important objective for cities in order to avoid the effects of climate change. The majority of the world's population live in urban areas and the trend is increasing. Furthermore, they have become laboratories for resilience (Meerow et al., 2016). Carriñanos et al. (2016b) have confirmed that pollen emissions are a valuable biological indicator for estimating the adaptive response of various species and the resilience of the forest mass to climate-change events.

Consequently, ornamental trees play an outstanding role in any

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Fig. 1. Maps of locations of spore traps.

urban, *peri*-urban and rural environment and in their landscape designs (Read and Bavougian, 2014). Several factors should be considered for the designs: aesthetics (Sadeghi et al., 2014), the mortality of trees (Lu et al., 2010), childhood asthma (Gern, 2010) and allergenic index in each species (Cariñanos et al., 2017). Architectonic barriers can also play an important role in impeding the air renovation and accumulating the pollen grains content if the air cannot flow freely through long and narrow avenues, creating isolated points with high concentrations if tall buildings are frequent (Cariñanos et al., 2002). This has been studied in air pollution, being known as building downwash effect (Thompson, 1993), but it remains as a blurred factor referring to biological pollution in aerobiological studies.

Plane trees, such as *Platanus hispanica* (*P. acerifolia*) and *Platanus orientalis* (López, 1998; Rocha-Afonso, 1990), are chosen due to their tolerance to water shortages and high levels of pollution, rapid growth and the development of a wide shadow. Plane trees are deciduous, monoecious, with unisexual flowers in globose inflorescences, wind-pollinated, and *Platanus orientalis* has high pollen production ($3.3 \times 10^6 \pm 0.2 \times 10^6$), which was the highest amount per inflorescence in a study of pollen production in trees (Damialis et al., 2011). Tormo et al. (1996) recorded a pollen production per tree of more than 1×10^{11} in *Platanus hispanica*. Pollen released by urban flora contributes to the airborne allergen content during the pollen season, and it has a considerable adverse impact on human health (Cariñanos et al., 2016a). In spite of their growing advantages, the pollen of ornamental plane trees is a major causes of respiratory allergies in Mediterranean countries such as Greece (Gioulekas et al., 2004), Italy (Bedeschi et al., 2007), France (Caillaud et al., 2015), Portugal (Ribeiro and Abreu, 2014) and Spain (Alcázar et al., 2004, 2015; Fernández-González et al., 2013). The ability of *Platanus* pollen to trigger immediate hypersensitivity reactions has been known since the 1970s (Anfosso et al., 1997). *Platanus* pollen was cited as an important cause of pollinosis in Spain in the early 1990s (Subiza et al., 1994). However, there is a great disparity in the prevalence of sensitisation to this pollen among the various published studies, ranging between 5% and 59% depending on geographical areas. Effects of cross-reactivity within *Platanus* genus have been reported (Pazouki et al., 2008), but also with other species such as *Artemisia vulgaris* or *Corylus avellana* (Miralles et al., 2002). The prevalence of this sensitisation has been increasing awareness in relation to the number of trees planted in cities (D'Amato and Lobefalo, 1989; Subiza et al., 1994; Varela et al., 1997). In a study conducted in Spain in 2003, the highest prevalence of *Platanus* pollen sensitisation was found in cities with higher concentrations of this

pollen, such as Barcelona, Madrid and Zaragoza, which was above 30% (Pola et al., 2015). Clinical symptoms most often associated with *Platanus* pollen allergies are seasonal rhinoconjunctivitis and asthma (Subiza et al., 1994). Some patients also report symptoms during the months of September and October, which could be explained by the re-floating of pollen attached to the leaves at the time of the leaf fall (Valero et al., 1999). Sensitisation to *Platanus* pollen is a significant additional risk factor for asthma among patients allergic to grasses, probably because it is associated with a greater degree of atopy (Varela et al., 1997).

There is a high disparity between *Platanus* pollen records, sensitization to this pollen, and clinical involvement. This could be explained by the low percentage of patients who are monosensitized to *Platanus* and the association of sensitization to other more relevant pollens, complicating the direct link between pollen and symptoms present in patients (Enrique et al., 2002; Varela et al., 1997). Other factors which can influence in a major production and pollen release and the creation of these geographical gradients are: differences between species, growing spontaneously in the eastern Mediterranean (*Platanus orientalis*) and as ornamental tree in the western Mediterranean (*Platanus hispanica*), human management (Cariñanos et al., 2017; Gabarra et al., 2002), which is different depending on the site, the predominant wind direction pattern and its persistence, which disperses differently aerobiological particles from anemophilous trees (Damialis et al., 2005) and influences in the pollen loads for each city, causing a random effect in aerobiological results (Maya-Manzano et al., 2017a).

Other factors that can be cited are the differences in altitude (Damialis et al., 2017; Fernández-Rodríguez et al., 2014b); and air temperature (Moore et al., 1991), which tends to be higher in cities than rural locations, moving the flowering season forward and decreasing the differences between day and night temperatures. As a result, the characteristics of MPS can be modified and longer exposures to pollen along the year and at night can be possible in a climate change scenery (Grewling et al., 2016; Mimet et al., 2009).

The major allergen of *Platanus* is Pla a 1, 18 kDa (Asturias et al., 2002). The presence in the atmosphere of Pla a 1 is independent of the amount of total *Platanus* pollen existing in the same period. Pla a 1 is detected in the atmosphere after the presence of *Platanus* pollen, so it would lengthen the periods of risk for *Platanus* pollen allergy, due to the positive influence that rainfall periods have over the allergens release (Fernández-González et al., 2013).

Due to this problem, recent papers on urban areas have studied the relationship between urban green zones and pollen allergies in order to

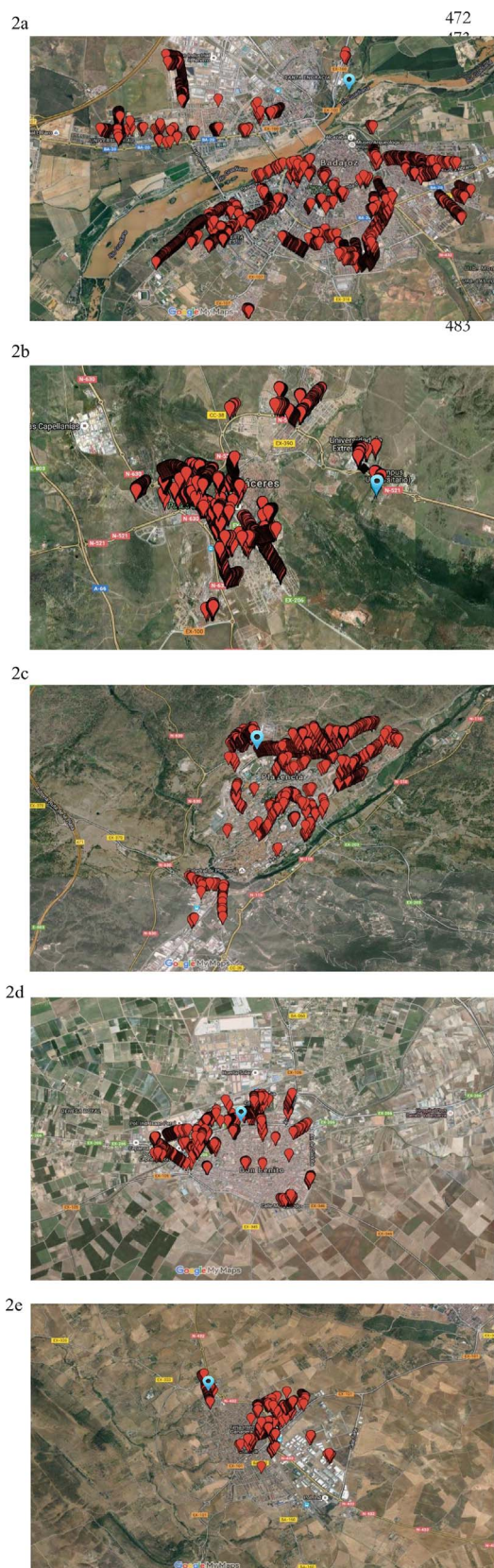


Fig. 2. Plane trees in BA (2a), CC (2b), PL (2c), DB (2d) and ZA (2e) and their spore trap positions (dots in blue color). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

provide guidelines for the design of spaces with low allergy impact (Cariñanos and Casares-Porcel, 2011) and have estimated the allergenic potential of urban green spaces (Cariñanos et al., 2014). Therefore, it is worth noting the allergological problems induced by an inaccurate design of the ornamental vegetation in the parks and streets of the cities (Vara et al., 2016). *Platanus* pollen has been measured in order to estimate the potential allergy risk (Rojo et al., 2016).

Given the increase in the number of pollen allergy sufferers in built-up areas, new strategies are required to improve the biological urban air quality (Cariñanos et al., 2016a). Fischer and Amekudzi (2011) have reported on the chance to improve the quality of life, sustainable civil infrastructure, and sustainable development. A hazard-based analysis of travel distance in urban environments has been conducted by Anastasopoulos et al. (2012). The use of new techniques, such as remote sensing technology (El-Gafy et al., 2011) and GPS have been used in urban planning and development (Korpilo et al., 2017; Wang et al., 2014). All ideas could help in planning routes free of allergenic pollen for pedestrians in the city.

The aims of this study are 1) to analyse the urban *Platanus* airborne pollen concentration in the air using volumetric spore traps and 2) to geolocate the pollen sources in public streets, avenues, squares, etc., in order to detect different behavioral patterns and assess the relevance of pollen source distribution in relation to records.

2. Materials and methods

2.1. Sampling site

Extremadura (Fig. 1) is an agricultural region (41,635 km²) in southwestern Spain with a population of 1,092,997 inhabitants (NSI, 2015). This study has been developed in five cities: Badajoz (BA), population 149,892; Cáceres (CC), 95,617; Plasencia (PL), 40,755; Don Benito (DB), 36,971; and Zafra (ZA), 16,857 (NSI, 2015). Atmospheric sampling was undertaken in those cities located latitudinally in the region, i.e., BA in the west, CC in the middle, PL in the north, DB in the east and ZA in the south (Fig. 1). Their respective heights above sea level are 184 m, 459 m, 415 m, 280 m and 508 m. The maximum distance of 182 km separated PL and ZA. Near PL and CC, there are holm oak and cork oak trees and extensive grazing. Irrigated crops (corn-fields, fruit trees and other vegetable crops) and dried crops (wheat and oats) are present in BA. The most frequent land cover around DB is irrigated crops (e.g., fruit trees, corn, tomato, rice). In the vicinity of ZA there is an influence from livestock production, olive trees and holm oak trees. Orography indicates a region that is quite flat, except for a mountain range with an altitude of a few hundred metres laid in an east-west direction between PL and DB (Sierra de San Pedro).

2.2. Climate and meteorological data

The Extremadura region has a Mediterranean climate affected by a degree of continentality, with an annual mean temperature between 15.8 °C and 17.1 °C (ZA 15.8 °C, PL 16.1 °C, CC 16.3 °C, BA and DB 17.1 °C). The highest temperatures are reached in the summer, mainly in July and August. The total annual rainfall varies depending on latitude (DB 460 mm, BA 447 mm, CC 551 mm, ZA 619 mm and PL 694 mm). Average data for the 1981–2010 period were provided by the Regional Meteorological Centre (AEMET, 2016). Prevailing winds are from the west (Silva-Palacios et al., 2007) in a region that has a nearly flat topography.

The distance between meteorological stations and Hirst type 7-day recording volumetric traps (Hirst, 1952) were 12.95 km (BA), 2.66 km (CC), 2.24 km (PL), 0.95 km (DB) and 0.53 km (ZA). The hourly meteorological data used, including rainfall (R), relative humidity (RH),

Table 1

Characterization of each city studied through the number of inhabitants per tree, the perimeter (km), urban surface (km²), number of trees, inhabitants (NSI 2015), number of inhabitants per km² and number of trees per km².

city	Inhabit./tree	Perimeter (km)	Urban surface (km ²)	Number trees	Inhabitants (NSI 2015)	Inhabit./km ²	Trees/km ²
DB	51.4	8.7	4.3	719	36,971	8,558.1	166.4
BA	48.3	21.8	15.4	3104	149,892	9,733.2	201.6
CC	42.8	27.7	13.6	2235	95,617	7,030.7	164.3
ZA	35.9	8.5	3.5	469	16,857	4,775.4	132.9
PL	23.3	11.1	4.8	1748	40,755	8,455.4	362.7

and maximum (Tmax), mean (Tmean) and minimum temperatures (Tmin), for BA, CC, PL, DB and ZA were provided by the AEMET (Agencia Estatal de Meteorología). Moreover, available meteorological data including wind direction were provided for BA and CC, including

the number of daily hours for each quadrant. For PL, DB and ZA, data were provided as the main daily wind direction in tenths of degrees. The comparison between daily pollen data and wind direction was performed in two ways depending of the type of meteorological data

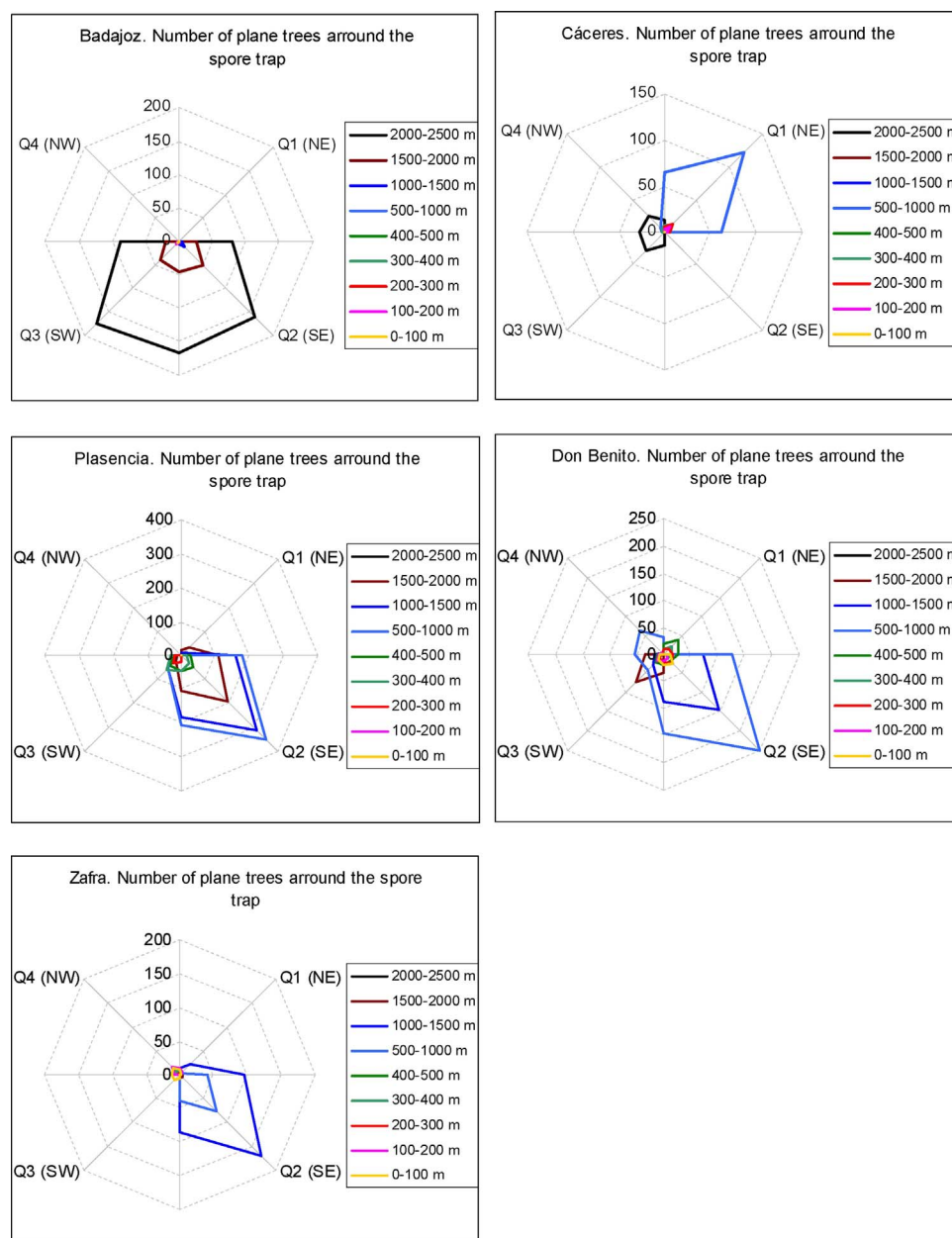


Fig. 3. Plane tree distribution in relation to the four quadrant (Q1 NE, Q2 SE, Q3 SW, Q4 NW) and separate in circles around the spore trap location.

Table 2
Number of trees and densities in the main urban areas.

City	Main urban areas planted with plane trees	Trees	Trees/km ²
BA	Paseo de San Francisco	25	278
	Paseo Condes de Barcelona	190	1152
	Calle Remigio Cordero	50	1136
	Calle Jacobo Rodríguez Pereira	40	1290
	Calle Salvia	38	1288
CC	Río Calamón	118	226
	Parque del Perú	129	617
	Avda. de Paris	62	350
	Parque avda. Pablo Naranjo Porras	60	1662
PL	Avda. de Portugal	240	349
	Barrio de la Esperanza	30	112
DB	Avda. Alonso Martín	52	426
	Plaza de Extremadura	26	861
	Avda. Europa	43	801
ZA	Alrededores Hospital	30	238
	Parque Avda. Adolfo Díaz Ambrona	44	191

provided. For BA and CC, the product of the daily pollen concentration and the number of hours of wind for each quadrant was calculated, after the sum of daily values for each quadrant was calculated. For PL, DB and ZA, sums of the daily pollen concentration were calculated for each of the four quadrants separately. In all cases, only data from March and April (60 days) were used.

2.3. Plane trees location

All of the streets, squares, gardens and open urban spaces in the five localities were explored during the period of this study, and ornamental plane trees were identified, counted and georeferenced on a map of each study site, together with its spore trap location. Private ornamental areas are quite small in the localities studied, and they are not estimated. However, plane trees on streets, squares, gardens and public places were georeferenced in the study sites. They were counted separately according to the four quadrants (Q1 NE, Q2 SE, Q3 SW, Q4 NW) around the spore trap location in circles of 100, 200, 300, 400, 500, 1000, 1500, 2000 and 2500 m in diameter. 500 m were chosen because according to Bricchi et al. (2000), the pollen from plane trees decreases quickly at a distance greater than 400 m. By choosing 500 m we have more precision, which allows to specify all the trees included in this distance. Moreover, a previous work published in the same study area have been carried out with *Platanus* assuming this distance (Maya-Manzano et al., 2017b) and a general deep study dealing with the main airborne pollen (Fernández-Rodríguez et al., 2014a).

2.4. Aerobiological monitoring

Pollen grains have been collected using Hirst type spore trap samplers (Hirst, 1952) in each city; BA (1997–2015), CC (1997–2001), and PL, DB and ZA (2011–2014). The traps were situated on the terrace of the Agricultural Engineering School of the University of Extremadura in BD (38°53' N, 6°58' W), on the terrace of the meteorological centre in CC (39°48' N, 6°20' W), on the terrace of the Hospital Virgen del Puerto building in PL (43°10' N, 2°25' W), on the terrace of the Donoso Cortés Secondary School in DB (38°58' N, 5°50' W) and on the terrace of the town's hospital building in ZA (38°25' N, 6°25' W). Standardized data management procedures for capturing and counting airborne pollen were used, following those described by the Spanish Aerobiology Network (REA) (Galán et al., 2007). Pollen concentrations were expressed

as the number of pollen grains per cubic metre of air [pollen grains m⁻³]. Values are usually provided as daily concentrations or as the average for a period of time (year or the whole period studied). In this paper, values are mostly given as the average pollen concentration for the whole period studied in each locality. The main pollen seasons (MPS) of *Platanus* were defined using the 90% method, whereby the season started when 5% of the total annual catch was achieved and ended when 95% was reached (Nilsson and Persson, 1981). The characteristics of *Platanus* pollen seasons were described by the start and end dates of the airborne pollen season, the duration (number of days), the date and value of the maximum daily mean *Platanus* pollen concentration, and the sum of daily average airborne *Platanus* pollen concentrations recorded in the season (Seasonal Pollen Index or SPI). Pollen sums were also separated in quadrants according to the predominant wind direction for each day.

2.5. Statistical analysis

The normal distribution of the data was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. These tests showed that the daily data did not follow a normal distribution. The tests also showed that the log10-transformed data also did not follow a normal distribution. A Spearman correlation test was used to analyse associations between selected variables. A correlation analysis was performed with the data of pollen types, which included trees with ornamental representations in the localities studied, to assess whether the amount of pollen recorded is related to the number of trees that produce the pollen. The statistical analysis included the entire daily dataset and was performed with the SPSS 15.0 statistical package. Furthermore, meteorological parameters, rainfall (R), relative humidity (RH), maximum (Tmax), mean (Tmean) and minimum temperature (Tmin), have been analysed for the *Platanus* MPS using MATLAB. We have not taken into account the possible reduction in pollen records that rain may drive.

3. Results

3.1. Plane tree location

Fig. 2 shows the location of ornamental plane trees in each city: BA (Fig. 2a), CC (Fig. 2b), PL (Fig. 2c), DB (Fig. 2d) and ZA (Fig. 2e), and their spore trap locations for each city. The density of ornamental plane trees per inhabitant for each city is shown in Table 1. The ratio of inhabitants per km² and the tree ratio per km² are shown in Fig. 3.

The plane tree distribution around the spore traps according to quadrants and distance (Fig. 3) presents a marked heterogeneous distribution. BA plane trees appeared towards the south and at least 1500 m distant. For CC, they were located mainly to the northeast. For DB, there were a relevant number of plane trees close to the spore trap, mainly to the south. For PL, plane trees were located chiefly to the south and mainly from 200 m. For ZA, plane trees were situated in the southeast from 500 m, but there is an important number close to the spore trap to the northwest. The tree density in some selected areas of the locations studied, where the highest values of abundance of plane trees were found. The highest values reach 1660 trees/km² (Table 2). Those values corresponded to parks with a marked abundance of plane trees and streets where plane trees were planted over both sidewalks.

3.2. Aerobiological monitoring

The characteristics of the *Platanus* pollen season for all periods studied in each city were analyzed and shown in Fig. 4.

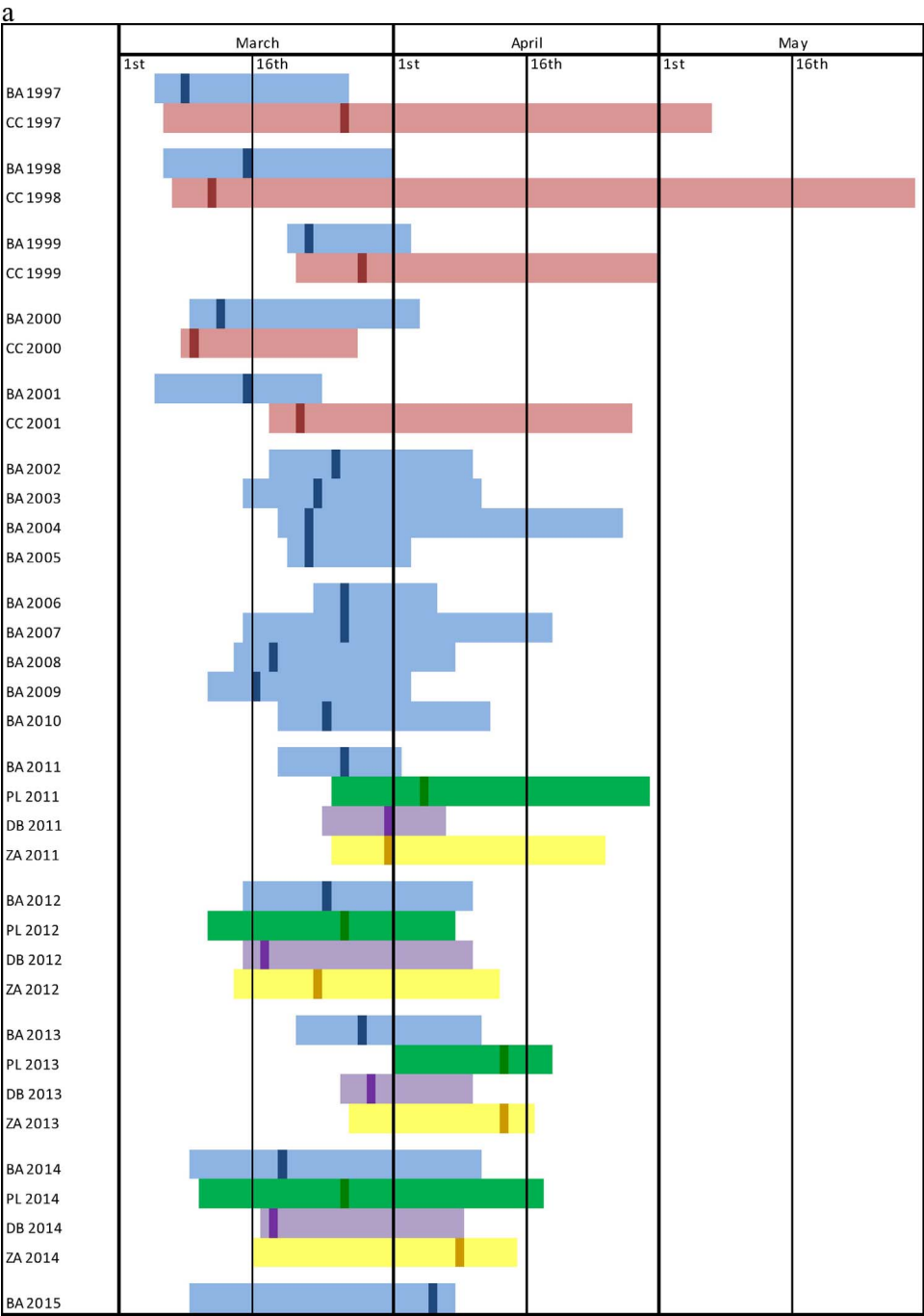


Fig. 4. Main pollen season (MPS) representation. (a) Main days of MPS: day of start, day end and day of maximum (colored in strong color). (b) Number of days of the MPS and (c) values of Seasonal Pollen Index (SPI).

The daily pattern of each city along the year appears in Fig. 5, this was calculated using 5-days running average and vertical scale is different for DB stations.

3.3. Relationship with meteorological variables

The first analysis performed was a Spearman correlation analysis of the relationship between the *Platanus* SPI and the selected meteorological variables. Table 3 shows the results obtained in each year. Temperature (maximum, minimum and mean) and relative humidity were the meteorological variables with the highest positive correlation coefficients with the SPI. The correlation with relative humidity,

rainfall and temperatures (maximum, minimum and mean) fluctuated between positive and negative values. Temperatures (maximum, minimum and mean) were the meteorological parameters with more significant years for all cities and the period studied. However, rainfall was the least statistically significant correlation obtained.

Fig. 6 shows a graphical relationship between the number of plane trees and airborne pollen recorded according to quadrants. Airborne pollen generally had a non-homogenous distribution. From BA, CC, DB and PL, winds from Q3 carried the highest pollen concentration, while for DB, it was Q2. Nevertheless, for PL, winds from Q1 were nearly as relevant as those from Q3.



Fig. 4. (continued)

4. Discussion

The high amount of plane trees in all the cities studied, considering their pollen as one of the most allergenic ones, provided evidence for informational and sensitization deficits on the subjects of environmental risks, urban planning and the design of green spaces and human health (related with allergic diseases of ornamental flora in human beings) at a local level in these locations.

In a city in southeastern Spain, Adinolfi et al. (2014) confirmed that the main function of green spaces is to enhance the well-being of local citizens, improving their quality of life. The greening potential in C-CSRAs (climate change-sensitive residential areas) in order to reduce the problems related to the urban heat island effect is still not sufficiently valued by decision-makers and inhabitants, and adaptation strategies in urban development are lacking in many countries. Nevertheless, some studies related to this issue have been done in Austria (Henseke and Breuste, 2015) or the USA (Lu et al., 2008). By studying the differences in behavior in one pollen type (*Platanus*) amongst different cities, it seems to be clear that the differences in the size of the buildings and in the width of the streets, together with the isolated points in squares or big parks, can create more exposed

points to meteorological parameters (wind, rainfall, incoming solar radiation, etc.). This fact and the differences in topography and slopes within the cities, can create microclimatic conditions capable of affecting to plants phenology and consequently, to pollen patterns (Mimet et al., 2009).

The outstanding role played by ornamental trees in any environmental urban design is well known (Cariñanos and Casares-Porcel, 2011). Proper environmental urban design can be essential in order to avoid immunological cross-reactivity between some pollen types (Vara et al., 2016), reducing the urban heat island effects in cities, and consequently, decreasing the effects of allergies (D'Amato and Liccardi, 2002). Cariñanos et al. (2016a) quantified the potential pollen allergenicity of anemophilous plant species growing in urban green zones. They showed the importance of not only the allergenicity of each pollen but also the amount of pollen released for each species, which is especially important in *Platanus* according to previous studies (Damialis et al., 2011; Tormo et al., 1996).

Platanus is also important because of its abundance in cities, and it is advisable to progressively substitute it for other non-allergenic species, or use selective pruning, among other corrective measures, to prevent high allergen levels and thus improve the biological air quality in cities.

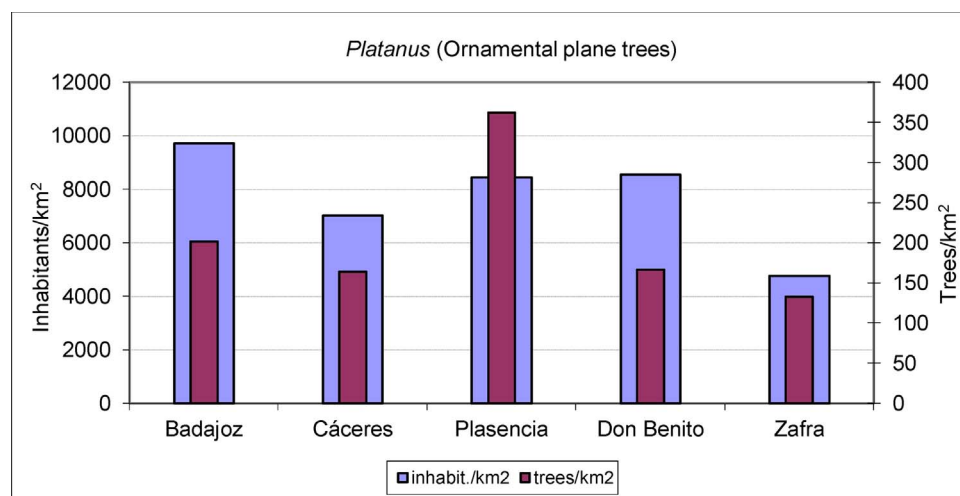


Fig. 5. Relationship between inhabitants and ornamental plane trees per unit area for each city.

Table 3

Correlation coefficients between daily MPS and meteorological parameters. *in italics: significance at the 95% level.

City	Year	Tmax	Tmin	Tmean	Rain	RH
BA	1997	−0,08	−0,22	−0,20		0,5*
	1998	0,47*	−0,51*	−0,02	−0,19	−0,24
	1999	0,52	−0,18	0,54*	−0,11	−0,64*
	2000	−0,08	0,25	0,10	−0,16	0,25
	2001	−0,22	−0,22	−0,42	0,27	0,35
	2002	0,69*	0,12	0,67*	−0,48*	−0,51*
	2003	0,09	0,41*	0,4*	0,16	0,32
	2004	0,04	0,15	0,08	−0,16	0,10
	2005	0,06	0,67*	0,22	0,04	−0,32
	2006	−0,15	0,08	0,02	0,22	0,51
	2007	0,00	−0,22	−0,03	−0,07	−0,04
	2008	0,13	0,42*	0,31	0,15	0,28
	2009	0,63*	0,34	0,54*		0,6*
	2010	−0,42	0,07	−0,33	0,49*	0,77*
	2011	0,09	−0,08	0,04	0,13	0,01
CC	2012	0,20	0,59*	0,4*	0,20	0,12
	2013	0,28	0,26	0,42	−0,03	0,17
	2014	0,13	−0,52*	−0,01	−0,16	−0,46*
	2015	0,10	0,05	0,07	0,26	−0,02
	2016	0,10	0,05	0,07	0,26	−0,02
PL	1997	−0,06	−0,32	−0,15	−0,02	−0,22
	1998	0,35*	0,00	0,29*	−0,29*	−0,47*
	1999	0,11	−0,41*	−0,08	−0,39*	−0,36*
	2000	0,6*	−0,05	0,52*	−0,44*	−0,6*
	2001	−0,32*	0,23	−0,13	0,26	0,4*
DB	2011	0,54*	0,21	0,57*	−0,37*	−0,58*
	2012	0,52*	0,49*	0,66*	−0,36	0,08
	2013	0,55*	0,27	0,48*	−0,08	0,00
	2014	0,08	0,08	0,13	−0,07	−0,13
ZA	2011	0,80*	0,54*	0,76*	−0,10	−0,68*
	2012	−0,15	−0,25	−0,22	−0,01	−0,12
	2013	0,67*	0,69*	0,76*	0,16	0,53*
	2014	0,04	−0,31	−0,11	−0,21	−0,45
ZA	2011	0,42*	0,21	0,44*	−0,23	−0,36*
	2012	0,53*	0,46*	0,61*	−0,26	−0,17
	2013	0,26	−0,44	0,05	−0,53*	−0,48*
	2014	−0,19	−0,47*	−0,33	−0,01	−0,04

Consequently, according to the pollen behavior detected in our work, selective pruning would be especially advisable in areas with mature specimens, such as DB, CC and BA, due to the potential high concentrations that can be reached in these areas, together with the main

wind direction pattern. ZA would not be problematic in this area, and we can propose the progressive substitution of sick and dying trees for other non-allergenic species. We can mention PL, where in the future, higher pollen amounts could be recorded, due to the growth of current immature specimens (located mostly to the SE and E of the pollen trap). Selective pruning causes a disturbance in pollination, avoiding to some specimens achieve maturity (Skjøth et al., 2013) and influencing in the length of the main pollen season. In Extremadura is frequently the practice of pruning, but is difficult try to do comparisons between cities because the method can vary widely from one location to another, even within the same city. Some examples of this can be appreciated in the differences between the number of plane trees found in CC (Q1 and Q4), BD (Q2), DB (Q1 and Q2), PL(Q1) and ZA (Q1) and their respective pollen sums.

Other point to be taken into account should be water availability, because in cities the ornamental trees can be watered differently in parks with respect to streets, and it provokes an intervention in the process of pollen production and release (Gabarra et al., 2002; Fam et al., 2008; Firon et al., 2012).

Concerning to the MPS characteristics, CC showed a longer length than BA during four out of the first five years of study (1997–2001, except for 2000). It can be due to lower temperatures in CC, doing its pollination seasonality longer. During this period, BA started first the *Platanus* MPS and finished before than CC, except for the year 2000, when happened on the contrary. BA had a more narrow MPS, and during all the period studied, it seems to been put forward in the year, reflecting changes in its phenology. With respect to the last period that we have multiple pollen dataset (2011–2014), the peak days happened firstly in BA and DB, with less altitude, and later, in PL and ZA, with a more pronounced topography and with more altitude. Finally, for all the cases in stations and cities that were studied (36), the pattern more frequent was to start the MPS on the first fortnight of March and to finish on the first fortnight of April. The peak days were found more frequently on the second half of March.

Comparisons between the distribution of plane trees and the pollen recorded according to four quadrants showed correspondence depending on the distance considered. This is a key point of this work that barely has been previously in urban environment, because studies at regional scale, or even considering long distance, are more frequent that at micro and local scales (Sofiev et al., 2013). For BA plane trees, which appeared mainly at 1500 m, the nearest 6 trees (200 m) appeared to be the most relevant for pollen records. For CC, the main source is Q1. For DB, the most pollen was recorded from Q3;

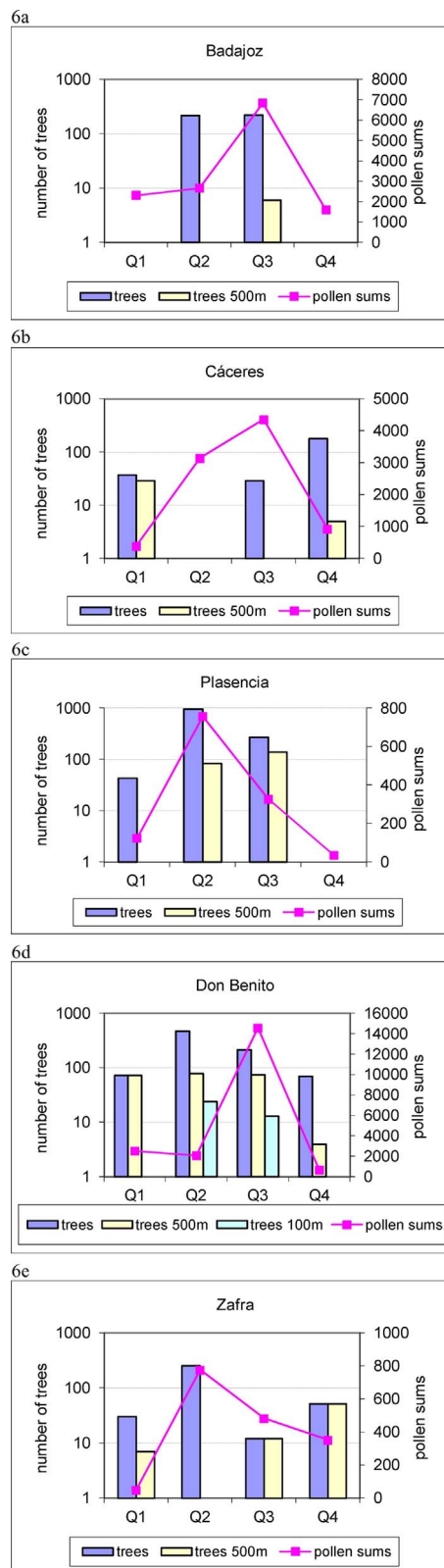


Fig. 6. Relationship between the number of plane trees and *Platanus* pollen sums for BA (a), CC (b), PL (c), DB (d) and ZA (e), with data separated according to the four quadrants Q1 (NE), Q2 (SE), Q3 (SW), Q4 (NW).

nevertheless, trees appeared more abundant at Q2, notwithstanding there are four plane trees very close to the spore trap (30 m) at Q3, and those trees may be the responsible for the high amounts of pollen

recorded at this location. For PL, there is a great correspondence between tree distribution and pollen records, and there no plane trees within 200 m of the spore trap. For ZA, the situation was similar to PL. The *Platanus* airborne pollen concentration is related not only to the number of specimens in each city or near the spore trap, but also to the wind direction within the city and to the trunk diameter and branch development degree shown by each tree (Maya-Manzano et al., 2017b). Consequently, despite the fact that BA and CC were the cities with the most plane trees, 4 and 3 times the quantity of trees in DB, respectively, they do not show the highest amount of *Platanus* pollen, which was recorded in DB. It is necessary to add that general seasonal pattern of airborne plane pollen distribution between places studied is similar (Fig. 7), only DB is remarkable for the high levels of pollen recorded.

The main results of this study in cities with problems of allergies to *Platanus* pollen could be of interest to allergologists for recommending healthy spaces in the studied cities of Extremadura to their patients. This fact highlights the importance of some factors, such as proximity of trees to spore traps and the growth rate of specimens (Fernández-Rodríguez et al., 2014a; Velasco-Jiménez et al., 2013), which should also be taken into account when we want to analyze the influence of some ornamental trees on the airborne content, and due to this, its risk as a natural hazard (Fernández-Rodríguez et al., 2016) for sensitized people in cities. Preferences for urban green spaces and peri-urban forests through an analysis of stated residential choices have been published (Tu et al., 2016). On the other hand, Litvak et al. (2017) have indicated that for the design of healthy cities, empirically substantiated metrics are necessary. Future related studies could consider producing healthy itineraries in local urban environments to avoid natural hazards due to allergenicity of some pollen types, such as *Platanus*. Recent studies have included *Platanus* spp. as trees suitable for urban heat management (Woodruff and BenDor, 2016), as suitable species in urban green areas (García-García et al., 2016), as included genera inside a database, with almost 400 woody plants, for supporting tree selection for urban areas in temperate climates (Vogt et al., 2017) and as guidance proposed to integrate ecosystem services into plants (Woodruff and BenDor, 2016). Our results could be considered as a decision-making tool for the development of the built environment (Abdalla et al., 2016; Breuste, 2004) with the goal of building in the short-term, taking into account green infrastructure (Breuste et al., 2015) and its allergenic potential (Cariñanos et al., 2014) in future Smart Cities (Zubizarreta et al., 2016).

5. Conclusions

This research highlights the need for the geolocation of ornamental plane trees to be included in the green infrastructure of urban areas in order to detect local patterns in the behaviour of plane trees and their pollen. It was evidenced that proximity and wind direction play an essential role in the pollen capture. Differences between pollen stations, in relation to the total pollen amount recorded, were correlated with the number of plane trees, maturity degree, sources distribution and mainly proximity to spore traps. Plane tree density of 100–300 (–1500) trees/km² in urban environment may produce annual sums (SPI) from some hundreds up to more than ten thousands, depending mainly on the proximity of the trap to the sources. Knowledge of *Platanus* pollen concentration reduces the natural risk hazard of organic aerosols from plane trees and increases the quality of life in urban areas for allergy sufferers. The distribution of pollination sources could be implemented in a model in order to provide citizens summarized information to citizens through healthy itineraries, and it is also helpful for policy-makers, who have to make decisions to improve the green urban development.

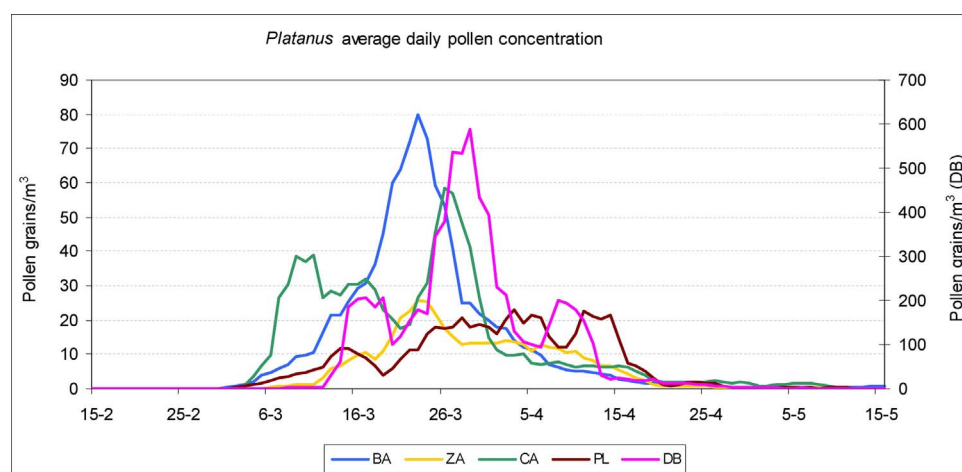


Fig. 7. Average daily *Platanus* pollen concentrations for each city (5-days running average, notice different vertical scale for DB).

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