

Perspective Essay

Distribution of ornamental urban trees and their influence on airborne pollen in the SW of Iberian Peninsula



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HIGHLIGHTS

- Urban ornamental trees cause allergenic ailments when airborne pollen is produced.
- Distribution and abundance of pollen sources reflect spore trap pollen records.
- The nearest ornamental trees explain most of airborne pollen recorded from samplers.
- Plane trees and cypress trees provide most of the allergenic pollen in urban areas.
- Designing urban green spaces should consider ornamental trees as allergenic sources.

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ABSTRACT

Ornamental trees in urban environment are a relevant cause of illness due to allergenic pollen airborne dispersed. The work presented here analyses the importance of ornamental tree distribution and investigates airborne pollen records using volumetric spore traps. Three localities in the southwest of Spain were studied: Don Benito (DB), Plasencia (PL), and Zafra (ZA), in the Extremadura region. Volumetric Hirst type spore traps recorded pollen levels continuously for three years. Ornamental street trees in the study area were identified, counted and mapped. Airborne pollen records were found to be related to the number of trees, the proximity of the trees to traps, the different pollination systems and wind direction. A total of 17635 trees, from all localities were counted, belonging to 67 species, 58% anemophilous, 22% entomophilous, and 20% both pollination systems. Five species represented more than 50% of the total number of ornamental trees: *Platanus hispanica*, *Olea europaea*, *Ulmus minor*, *Acer negundo* and *Melia azedarach*. The average total pollen concentration in g m^{-3} was 102 (DB), 93 (PL), and 99 (ZA). . . Omitting the data for *Quercus* pollen, a statistically significant correlation between the number of trees at 0.5 km around the spore traps and the types of pollen recorded was found. Some measures to decrease the amount of potential allergenic airborne pollen in urban environments were identified, such as reducing trees with anemophilic pollination systems, eliminating male trees and employing suitable pruning practices. In any case, the closer the source of ornamental pollen, the greater the allergenic risks.

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1. Introduction

Urban green infrastructure is a concept that includes ornamental street trees and all other vegetation in urban environments. It

is a concept that has been developed in the last two decades, and it is clear that urban green infrastructure can improve the quality of life for citizens (Breuste, Artmann, Li, & Xie, 2015). The benefits from ornamental street trees and urban green spaces are widely alleged in literature (Mullaney, Lucke, & Trueman, 2015; Tyrväinen, Pauleit, & Seeland, 2005) for the following reasons: (a) providing aesthetic beauty and visual relief (Shackleton, Chinyimba, Hebinck, Shackleton, & Kaoma, 2015), (b) the protection of pedestrians from the sun (Gillner, Vogt, Tharang, Dettmann, & Roloff, 2015), (c)

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offering habitats for birds and other animals in urban landscapes (Idilfitri, Sulaiman, & Suriani-Salleh, 2014), (d) lowering urban temperatures and mitigating the intensity of urban heat island effects (Ashby, 2001; Flatley, 2001; Norton et al., 2015; Yu & Nyuk, 2006), (e) acting as noise filters (Fang & Ling, 2005) and capturing particulate matter, carbon dioxide, ozone and other air pollutants (Whittinghill, Bradley, Schutzki, & Cregg, 2014), (f) improving the willingness to work and work performance (Kaplan, 1993; Wolf, 2003), (g) regulating ecosystem services by increasing water infiltration (Haase & Nuissl, 2007), (h) crime reduction in cities with more developed green zones (Kuo & Sullivan, 2001), and (i) in some countries, providing economic benefits for residents; for example, in Lisbon, for every \$1 invested in tree management, residents receive \$4.48 in energy savings (Soares et al., 2011).

Nevertheless, in spite of the numerous beneficial aspects of ornamental plants in urban landscapes, the pollination of these plants generates allergies in an increasing number of people each year (Cariñanos & Casares, 2011). Although there are differences among countries, the incidence and prevalence of asthma and rhinitis is increasing worldwide (Pawankar, Canonica, Holgate, Lockey, & Blaiss, 2013; Pawankar, 2014). The prevalence of allergies in the world population is between 10 and 40% as estimated by the WAO (World Allergy Organization). It has been noted that people living in urban environment suffer more pollen allergies than that from rural areas (D'Amato et al., 2007; Ogren, 2002) and it has been suggested that this may be originated by the interaction of air pollutants with airborne pollen (Cariñanos et al., 2002; Cariñanos, Galán, Alcázar, & Domínguez, 2007). Pollens from ornamental trees such as *Olea europaea*, *Cupressus* and *Platanus* are highly allergenic in the Mediterranean area (D'Amato et al., 2007). The impact on humans needs to be considered from two perspectives: the town design and the choice of ornamental species (Staffolani, Velasco-Jiménez, Galán, & Hruska, 2011). In that regard Cariñanos, Casares, and Quesada (2014) proposed an allergenicity index to manage the design of urban green spaces. That useful index is calculated for a determined area and shows the relationship between a product of different values and the surface analysed. The product includes the number of trees, allergenic potential based on 5 categories, type of pollination (separated into 4 categories), the length of the main pollen season period (separated into 3 categories) and a measure of the canopy volume to estimate pollen production. The index is named I_{UGZA} (Urban Green Zone Allergenicity Index).

Because of the demographic trends of populations moving from rural to urban areas, cities are becoming bigger (Schmidheiny & Suedekum, 2015), and the development of green areas is a growing concern for urban planning designers (Rupprecht, Byrne, Garden, & Hero, 2015). This means that more people may be affected by ornamental tree pollen allergies. When thinking about this concern, it is relevant to consider the criteria for the selection of urban trees because the issue of allergies from ornamental trees is rarely discussed in this context. According to Sæbø et al. (2005), it should be considered that trees with allergy-inducing pollen could be avoided. To assess that problem correctly, it is necessary to take into account the abundance of ornamental trees, their distribution, and spore sampler locations because the location of the pollen source is essential for the interpretation of airborne pollen records. Although some work has been performed on a larger scale (Fernández-Rodríguez et al., 2014b; Oteros et al., 2015; Rojo, Rapp, Lara, Fernández-González, & Pérez-Badía, 2015) there are no studies that take into account the distance of the pollen sources from the spore samplers.

In this regard, several works have been performed on a large scale, more than 20 km, using back trajectories as a tool (Fernández-Rodríguez, Skjøth et al., 2014; Fernández-Rodríguez et al., 2015; Hernández-Ceballos, García-Mozo, & Galán, 2014a; Hernández-Ceballos, Skjøth, García-Mozo, Bolívar, & Galán, 2014; Oteros et al.,

2015; Rojo et al., 2015). Some studies have compared the results of sensors separated between 1 and 3 km (Fernández-Rodríguez, Tormo-Molina, Maya-Manzano, Silva-Palacios, & Gonzalo-Garijo, 2014; Giorato, Bordin, Gemignani, Turatello, & Marcer, 2003; Irdi, Jones, & White, 2002; Khattab & Levetin, 2008; Tormo-Molina, Maya-Manzano, Fernández-Rodríguez, Gonzalo-Garijo, & Silva-Palacios, 2013), and other studies have used distances between 5 and 20 km (Arobba et al., 2000; Velasco-Jiménez, Alcázar, Domínguez-Vilches, & Galán, 2013). However, few studies have taken into account the distance of spore samplers from pollen sources over short distances in cities (Fernández-Rodríguez, Tormo-Molina et al., 2014b,c; Velasco-Jiménez et al., 2013, 2014). Ornamental street trees play a minor role in atmospheric phenomena such as urban heat islands or climate change (Endlicher, 2011) in urban areas, where more than 50% of the world population lives (Heilig, 2012). These ornamental trees also receive a comparable attention among urban green infrastructure studies and urban aerobiological papers that are related mainly to the study of local source airborne pollen and its transport over short distances (Fernández-Rodríguez, Tormo-Molina et al., 2014b; Velasco-Jiménez et al., 2014). The study area has been aerobiologically monitored from 2011 using volumetric spore samplers. Natural or cultivated pollen sources are the main focus of the study and this paper deals with urban green areas as they are the closest to the majority of the population and the pollen traps used.

The aims of the present study were to analyse the relationship between the density or abundance of ornamental trees and airborne pollen records from three urban environments in the SW of Iberian Peninsula, and to assess the relationship between the distance of pollen sources from spore samplers and the pollen count captured. Furthermore, we emphasize the relevance of selecting tree species for ornamental purposes in designing urban environments considering their pollen allergenicity as a selection criterion with the intention of providing better air quality.

2. Material and methods

2.1. Study area

The study was conducted in three cities located in the southwest of the Iberian Peninsula: Plasencia (PL), Don Benito (DB) and Zafra (ZA), which were separated by a maximum distance of 182 km (PL-ZA), and a minimum of 77 km (DB-ZA), they are located in three main different environments in the region of Extremadura (Spain). The respective heights above sea level appear in Table 1. The general vegetation, or the most frequent land cover around the cities, was holm oak and cork oak trees, extensive grazing land and some forestal and timber plantations of pines (PL), irrigated crops such as fruit trees, corn, tomato, and rice (DB), and livestock production, olive trees and holm-oak trees (ZA). The urban areas for the study sites and their populations in 2014 (<http://estadistica.gobex.es>) appear in Table 1. Orography indicates a region that is quite flat except for a mountain range with a few hundred metres laid in a west-east direction between PL and DB (Sierra de San Pedro). Those localities were treated in this study because they are the rural localities from the regional aerobiological network in Extremadura (Spain) and their pollen sources distribution offer a good opportunity to study the relationship with airborne pollen records. The situation of locations studied appears in Figs. 6–8. Meteorological data appear in Table 1. The study area supports a Mediterranean climate affected by a point of continentality. The highest temperatures were reached in the summer, mainly in July and August. Prevailing general winds blew from the West (Silva-Palacios, Tormo-Molina, & Muñoz-Rodríguez, 2007).

Table 1
Locations studied (DB Don Benito, PL Plasencia, ZA Zafra) with general information.

	(DB)	(PL)	(ZA)
Height above sea level (m)	280	415	508
Urban area (ha)	336.5	415.2	296.1
Population (inhabitants)	40 892	37 011	16 828
Main vegetation	irrigated crops	holm/cork oak	holm oak, olive groves
Distance from meteorology station (km)	0.95	2.24	0.53
Mean temperature (°C)	17.1	16.1	15.8
Annual rain (mm)	460	694	619
Average wind speed range (km/h)	25.2–30.1	24.5–32.6	31.0–32.2
Average wind direction	W	SE	N-SW
Average pollen concentration (g m ⁻³)	102	93	99
Spore sampler height over ground (m)	6	17	6

2.2. Ornamental trees location

All of the streets, squares, gardens and open urban spaces in the three localities were explored during the period of this study, and ornamental trees were identified, counted and located on a map. The surrounding areas of the urban towns (approximately 100 m around) were also visited to assess the distribution of two relevant species from the aerobiological point of view: *Olea europaea*, often cultivated as a crop, and *Cupressus sempervirens* in cemeteries. Private ornamental areas are quite reduced in the localities studied, trees from these areas were not counted because of its inaccessibility. Moreover, the number of ornamental trees around the spore samplers were counted in concentric areas with a radius of 50 m, up to a distance of 500 m. The Urban Green Zone Allergenicity Index (I_{UGZA}) was calculated for each species using the values provided by Cariñanos and Casares (2011) or estimated for related species when those species were not included in the reference work.

2.3. Aerobiological monitoring

Pollen grains were collected continuously for three years (1/3/2011 to 28/2/2014) using Hirst (1952) spore samplers. The traps were situated 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 Hospital building in ZA (38° 25'N, 6° 25'W).

Standardised data management procedures for capturing and counting airborne pollen were used, following those described by the Spanish Aerobiology Network (REA) (Galán, Cariñanos, Alcázar, & Domínguez-Vilches, 2007). Slides were examined along two longitudinal transects according to previous studies (Tormo-Molina, Muñoz-Rodríguez, & Silva, 1996, 2013). Pollen concentrations were expressed as the number of pollen grains per cubic metre of air [g m⁻³]. The records can give hourly concentrations; however, 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 average pollen concentration for the whole period studied in each locality.

2.4. Pollen types and index of allergenicity

In general, pollen morphology does not allow species level identification, apart from isolated cases (*Alnus glutinosa*, *Casuarina cunninghamiana*, *Juglans regia*, *Olea europaea*). Therefore, genus or family names are used to name pollen types and they include the species present in the study area. For some tree species, no airborne pollen was recorded, because of some of the following reasons: they are insect pollinated species, or they have a low pollen production, or there is a low number of trees, or they are distant from the spore sampler location. Nomenclature of species (or pollen types) is in accordance with the work *Flora Iberica* (<http://www.floraiberica.es/>). The index of allergenicity I_{UGZA} (Cariñanos et al., 2014), although

originally described for urban green spaces, it was used in this work for the whole urbanized area studied in each locality.

2.5. Meteorological data

Meteorological data were provided by the Spanish Meteorological Center (AEMET). The distances between meteorological stations and spore samplers appear in Table 1. The meteorological data that were provided included temperature (°C), rain (mm), and wind speed (km h⁻¹) and direction (degrees). Climatic values from the average meteorological data were calculated for the period of 1961–1990. Wind direction was used to analyse tree pollen source distribution and airborne pollen records. This graphical analysis was performed with hourly data for days around pollen peaks' concentration of the period of study when it was necessary to explain results from non-homogenous pollen sources distribution.

2.6. Statistical analysis

Pearson correlation coefficients were calculated comparing the number of ornamental trees and pollen concentrations. Normalization was performed using square root transformation. The level of $p < 0.01$ was taken into account for statistical significance. SPSS package (v.15.0) was used for statistical analysis. A correlation analysis was performed with the data from pollen types that included trees with ornamental representation in the localities studied, to assess if the amount of pollen recorded was related to the number of trees producing that pollen.

3. Results

3.1. Ornamental trees

A total of 17635 trees were counted, belonging to 67 species (Table 2). The density of ornamental trees per inhabitants for each locality was 0.17 (DB), 0.15 (PL), and 0.30 (ZA). The density of inhabitants per tree was 5.9 (DB), 6.6 (PL), and 3.3 (ZA) [values of trees per 1000 inhabitants: 171 (DB), 152 (PL) and 300 (ZA)]. The 20 most abundant ornamental species of trees appear in Fig. 1; those include 86% of the total number of trees. Five species represent more than 50% of the total number of ornamental trees: *Platanus hispanica*, *Olea europaea*, *Ulmus minor*, *Acer negundo* and *Melia azedarach*.

According to the type of pollination, 57.5% of all trees showed a clear anemophilous pollination system. Additionally, 20.4% of trees showed an amphiphilous pollination system. The rest, 20.4%, were pollinated by insects (entomophilous). A total of 21 ornamental tree species were not of interest from an aerobiological point of view because they had an evident entomophilous pollination system or their representation as ornamentals was scarce. These ornamentals include some species from different families: Anacardiaceae (*Schinus molle*), Bignoniaceae (*Catalpa bignonioides*,

Table 2

Number of ornamental tree species identified from the localities studied (DB Don Benito, PL Plasencia, ZA Zafra), pollen type (n: no recorded from spore trap), system of pollination (Pol: A anemophilic, E entomophilic, AE amphiphilic) and sexuality (Sex: h hermaphrodite, m monoecious, d dioecious).

Species (Family)	DB	PL	ZA	Total	Pollen type	Pol	Sex
<i>Abies alba</i> (Pinaceae)			1	1	Pinaceae	A	m
<i>Acacia dealbata</i> (Mimosaceae)	8	16	19	43	Acacia	E	h
<i>Acer negundo</i> (Aceraceae)	153	507	410	1070	Acer	A	d
<i>Acer platanoides</i> (Aceraceae)		31		31	Acer	E	h
<i>Acer pseudoplatanus</i> (Aceraceae)		30		30	Acer	E	h
<i>Aesculus hippocastanum</i> (Hippocastanaceae)		1		1	n	E	h
<i>Ailanthus altissima</i> (Simaroubaceae)		10	31	41	n	A	h
<i>Albizia julibrissin</i> (Mimosaceae)	6	51	51	108	Acacia	E	h
<i>Alnus glutinosa</i> (Betulaceae)		205		205	Alnus	A	m
<i>Betula alba</i> (Betulaceae)		18		18	Betula	A	m
<i>Brachychiton populneus</i> (Malvaceae)	3	16	34	53	n	E	h
<i>Brossenettia papyrifera</i> (Moraceae)			8	8	Morus	A	d
<i>Calocedrus decurrens</i> (Cupressaceae)		10		10	Cupressaceae	A	m
<i>Casuarina cunninghamiana</i> (Casuarinaceae)	169	3	7	179	Casuarina	A	d
<i>Catalpa bignonioides</i> (Bignoniaceae)	63	189	114	366	n	E	h
<i>Cedrus atlantica</i> (Pinaceae)	34	26	36	96	Pinaceae	A	m
<i>Cedrus deodara</i> (Pinaceae)	10	7		17	Pinaceae	A	m
<i>Celtis australis</i> (Cannabaceae)	53	192		245	n	A	h
<i>Ceratonia siliqua</i> (Caesalpiniaceae)			8	8	n	AE	d
<i>Cercis siliquastrum</i> (Caesalpiniaceae)	11	30	45	86	n	E	h
<i>Citrus aurantium</i> (Rutaceae)	167	135	146	448	n	E	h
<i>Crataegus monogyna</i> (Rosaceae)		6		6	n	E	h
<i>Cryptomeria japonica</i> (Cupressaceae)		3		3	Cupressaceae	A	m
<i>Cupressocyparis leylandii</i> (Cupressaceae)	29	32	49	101	Cupressaceae	A	m
<i>Cupressus arizonica</i> (Cupressaceae)	26	12	87	125	Cupressaceae	A	m
<i>Cupressus macrocarpa</i> (Cupressaceae)	14	36	10	60	Cupressaceae	A	m
<i>Cupressus sempervirens</i> ^a (Cupressaceae)	389	68	192	649	Cupressaceae	A	m
<i>Eriobotrya japonica</i> (Rosaceae)	14		13	27	n	E	h
<i>Eucalyptus camaldulensis</i> (Myrtaceae)		33	42	75	Eucalyptus	E	h
<i>Fraxinus angustifolia</i> (Oleaceae)	40	251	1	292	Fraxinus	A	h
<i>Fraxinus ornus</i> (Oleaceae)	53	9	10	72	Fraxinus	A	h
<i>Gleditsia triacanthos</i> (Caesalpiniaceae)	76	8	3	87	n	AE	m
<i>Jacaranda mimosifolia</i> (Bignoniaceae)	79		18	97	n	E	h
<i>Juglans regia</i> (Juglandaceae)	2	4	2	8	Juglans	A	m
<i>Ligustrum lucidum</i> (Oleaceae)	187	59	445	691	Ligustrum	E	h
<i>Liquidambar styraciflua</i> (Altingiaceae)	10	14		24	Platanus	A	m
<i>Magnolia grandiflora</i> (Magnoliaceae)	14		13	27	n	E	h
<i>Melia azedarach</i> (Meliaceae)	116	203	501	820	n	E	h
<i>Morus alba</i> (Moraceae)	101	75	49	225	Morus	A	m
<i>Olea europaea</i> ^a (Oleaceae)	2112	114	524	2750	Olea	AE	h
<i>Paulownia tomentosa</i> (Malvaceae)	47			47	n	E	h
<i>Phoenix canariensis</i> (Arecaceae)	215	65	77	357	Arecaceae	A	d
<i>Phoenix dactylifera</i> (Arecaceae)	132	2	17	151	Arecaceae	A	d
<i>Photinia serratifolia</i> (Rosaceae)		8	1	9	n	E	h
<i>Pinus halepensis</i> (Pinaceae)	174		52	226	Pinaceae	A	m
<i>Pinus pinaster</i> (Pinaceae)	14	113	103	230	Pinaceae	A	m
<i>Pinus pinea</i> (Pinaceae)	345	149	15	509	Pinaceae	A	m
<i>Platanus hispanica</i> (Platanaceae)	753	1698	563	3014	Platanus	A	m
<i>Platycladus orientalis</i> (Cupressaceae)	126	8	98	232	Cupressaceae	A	m
<i>Populus alba</i> (Salicaceae)	213	155	36	404	Populus	A	d
<i>Populus nigra</i> (Salicaceae)	13	149	23	185	Populus	A	d
<i>Populus simonii</i> (Salicaceae)	18	3	7	28	Populus	A	d
<i>Prunus cerasifera</i> (Rosaceae)	126	34	105	265	n	E	h
<i>Prunus dulcis</i> (Rosaceae)			1	1	n	E	h
<i>Quercus rotundifolia</i> (Fagaceae)	1	18	15	34	Quercus	A	m
<i>Quercus suber</i> (Fagaceae)		26	1	27	Quercus	A	m
<i>Robinia pseudoacacia</i> (Fabaceae)	94	393	157	644	n	E	h
<i>Salix atrocinerea</i> (Salicaceae)		2		2	Salix	AE	d
<i>Salix babylonica</i> (Salicaceae)	3	20		23	Salix	AE	d
<i>Schinus molle</i> (Anacardiaceae)	6		4	10	n	E	h
<i>Sequoia sempervirens</i> (Cupressaceae)		1		1	Cupressaceae	A	m
<i>Sophora japonica</i> (Fabaceae)	7	9	3	19	n	E	h
<i>Tilia platyphyllos</i> (Tiliaceae)	3	1		4	Tilia	E	h
<i>Trachycarpus fortunei</i> (Arecaceae)	7	9	1	17	Arecaceae	A	d
<i>Ulmus minor</i> (Ulmaceae)	159	319	790	1268	Ulmus	A	h
<i>Washingtonia filifera</i> (Arecaceae)	564	5	99	668	Arecaceae	AE	h
<i>Washingtonia robusta</i> (Arecaceae)	25	19	13	57	Arecaceae	AE	h
Total	6984	5610	5041	17635			

^a Data includes 100 m around the urban perimeter. For exclusively urban perimeter: data for *Cupressus sempervirens* (149 DB, 68 PL, 92 ZA) and for *Olea europaea* (63 DB, 114 PL, 24 ZA).

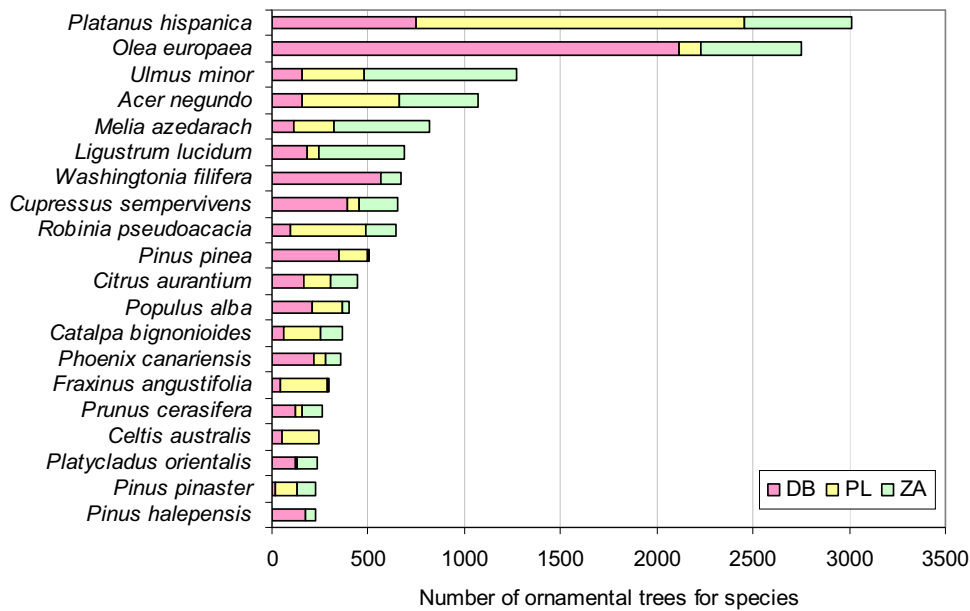


Fig. 1. The 20 most abundant ornamental trees in the localities studied.

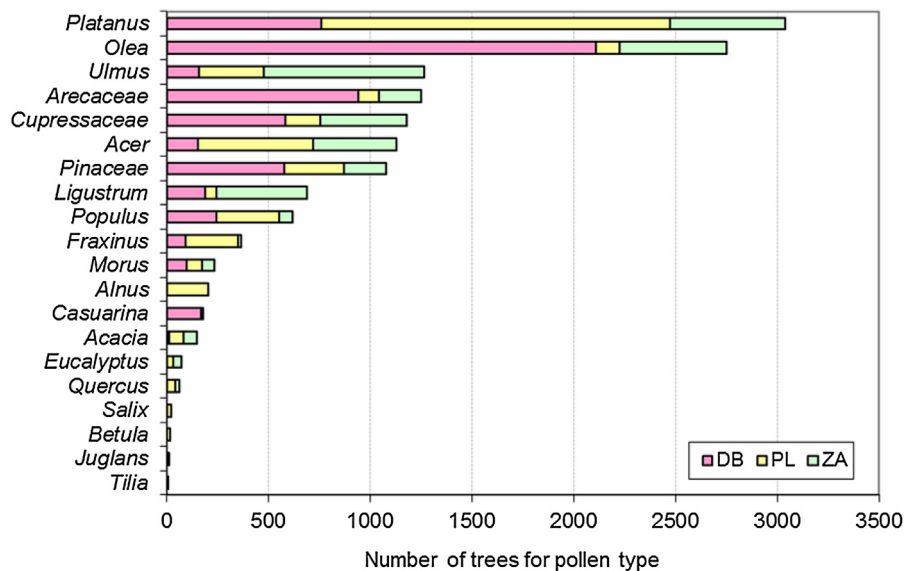


Fig. 2. Pollen types and number of trees for each locality studied.

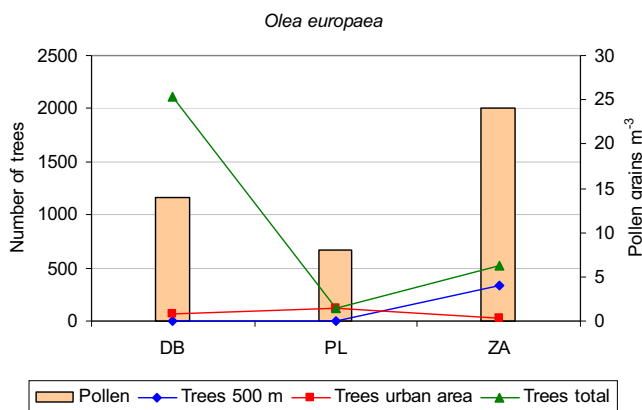


Fig. 3. *Olea europaea* number of trees and average airborne pollen concentration, around spore trap in a radius of 500 m, for only urban area, and for urban area including the 100 m surroundings.

Jacaranda mimosifolia), Caesalpiniaceae (*Cercis siliquastrum*, *Cercatonia siliqua*, *Gleditsia triacanthos*), Fabaceae (*Robinia pseudoacacia*, *Sophora japonica*), Hippocastanaceae (*Aesculus hippocastanum*), Magnoliaceae (*Magnolia grandiflora*), Malvaceae (*Brachychiton populneus*), Meliaceae (*Melia azedarach*), Paulowniaceae (*Paulownia tomentosa*), Rosaceae (*Crataegus monogyna*, *Eriobotrya japonica*, *Photinia serratifolia*, *Prunus cerasifera*, *Prunus dulcis*), Rutaceae (*Citrus aurantium*), Simaroubaceae (*Ailanthus altissima*), and the genus *Celtis* (Ulmaceae). Trees from those taxa represent 18.6% of the total number of trees.

Fig. 2 includes 20 pollen types that are of aerobiological interest, ordered by the number of ornamental trees counted in the localities studied. Five of them include more than 50% of the total number of trees. In decreasing order, they are *Platanus*, *Olea*, *Ulmus*, *Arecaceae* and *Cupressaceae* (Fig. 2). Two pollen types from tree species did not have representation as ornamental trees in the studied areas: *Castanea* and *Corylus*. Four pollen types had no airborne pollen records or they were insignificant: *Acacia*, *Acer*, *Betula* and *Tilia*.

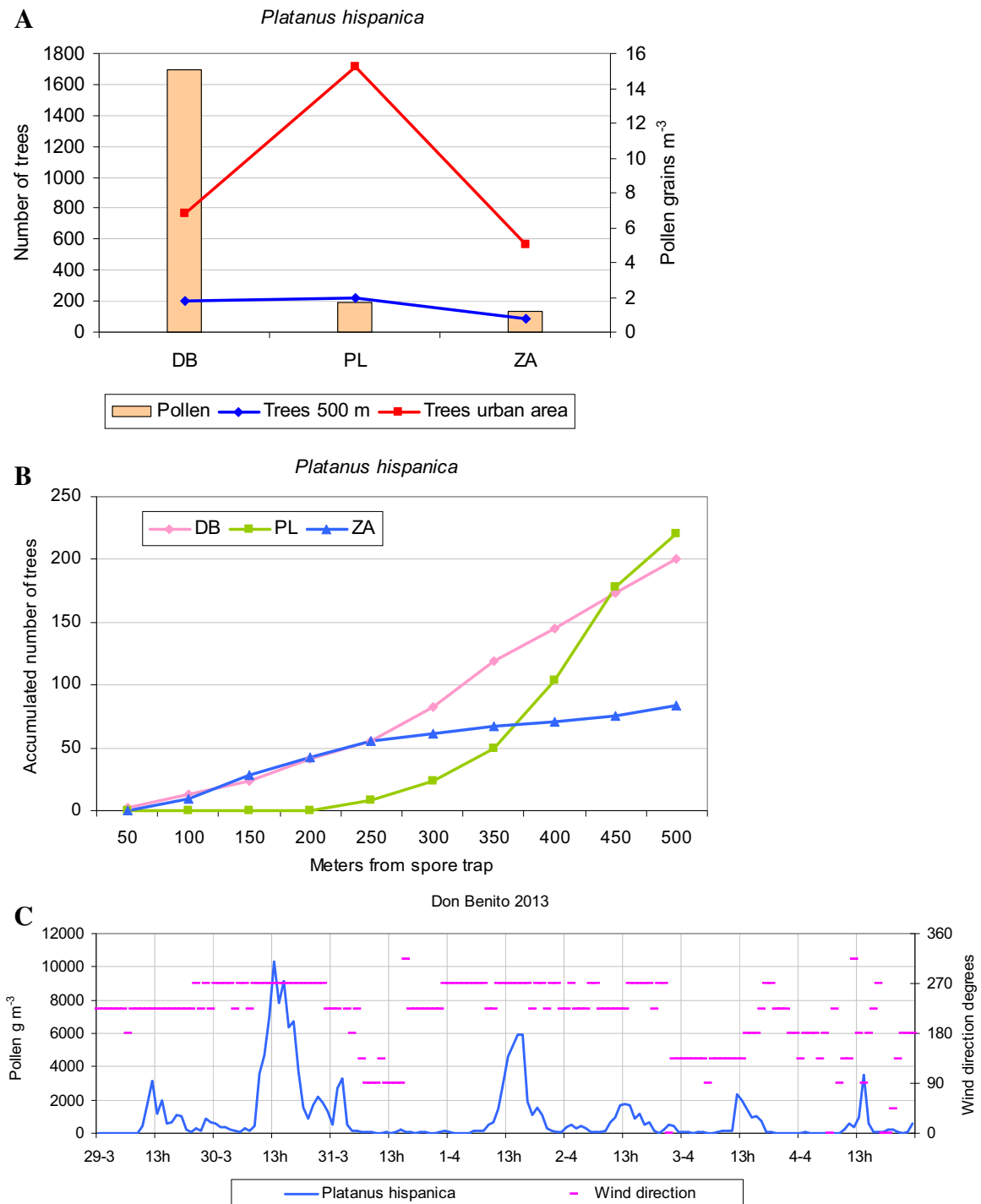


Fig. 4. A *Platanus hispanica* number of trees and average airborne pollen concentration. B *Platanus hispanica* number of trees from spore trap location. C Hourly pollen concentration in Don Benito in 2013 for the days with peak of concentration and wind direction.

3.2. Airborne pollen concentration

Average pollen concentrations for the whole period studied were, in g m⁻³: 102 (DB), 93 (PL) and 99 (ZA). Herbaceous pollen types, such as *Poaceae*, *Plantago*, *Rumex*, and *Urticaceae*, accounted for 22–25% of the total pollen recorded, and those data were not analysed in this study. A total of 32 pollen types showed pollen concentrations of at least 0.1 g m⁻³ in one of the localities studied (Table 3). Fourteen of those pollen types included were herbaceous or shrub species, and 18 were tree species.

The most abundant airborne pollen type was *Quercus*. Pollen sources for this pollen type come mainly from tree species that are abundant in landscapes: *Q. rotundifolia* (holm oak), *Q. suber* (cork oak) and *Q. pyrenaica* (Pyrenean oak), but they are rarely planted as ornamentals. Only two species were found as ornamentals, holm oak and cork oak, but they represent just 0.3% of the total of ornamental trees. The place where the most *Quercus* airborne pollen was recorded (PL), presented the highest number of these trees planted as ornamentals. Nevertheless, DB, with only one *Quercus* tree planted as an ornamental, did not show a proportional reduc-

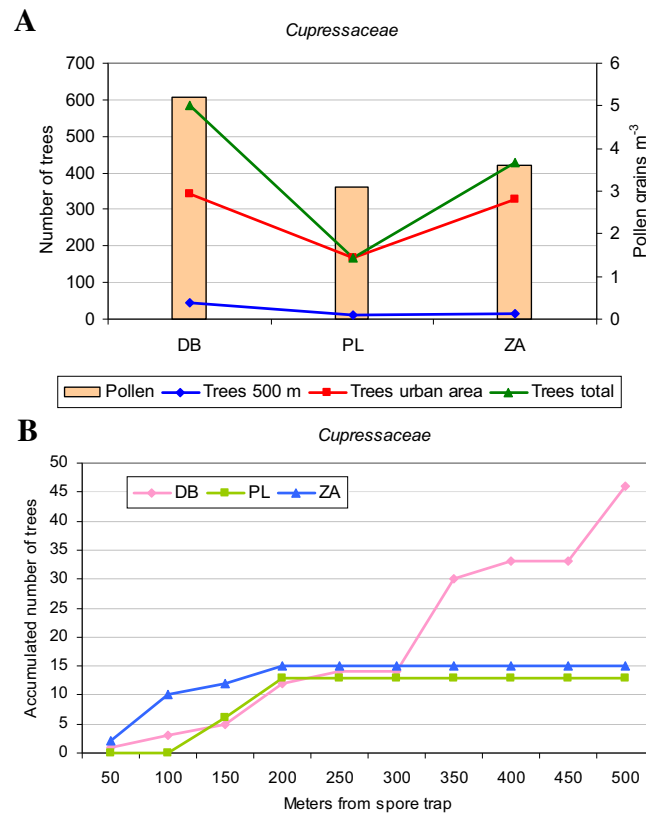


Fig. 5. A *Cupressaceae* number of trees and average airborne pollen concentration. B *Cupressaceae* number of trees from spore trap location.

Table 3

Annual average airborne pollen in g m⁻³ for pollen types with concentration >0.1 for the whole period of study in the localities studied (DB Don Benito, PL Plasencia, ZA Zafra). Growing habit from sources (T tree or shrubs, H herbaceous).

Pollen type	DB	PL	ZA	Habit
<i>Alnus</i>	0.3	0.6	0.2	T
<i>Amaranthaceae</i>	0.9	0.4	0.7	H
<i>Anthemideae</i>	0.3	0.3	0.2	H
<i>Arecaceae</i>	0.5	0.2	0.2	T
<i>Brassicaceae</i>	0.1	0.0	0.1	H
<i>Castanea</i>	0.2	1.6	0.2	T
<i>Casuarina</i>	0.3	0.0	0.2	T
<i>Corylus</i>	0.1	0.1	0.0	T
<i>Cupressaceae</i>	5.2	3.1	3.6	T
<i>Echium</i>	0.5	0.5	0.5	H
<i>Erica</i>	0.1	0.2	0.1	T
<i>Eucalyptus</i>	0.7	0.1	0.2	T
<i>Fraxinus</i>	0.5	1.6	0.4	T
<i>Helianthus</i>	0.1	0.0	0.0	H
<i>Juglans</i>	0.0	0.1	0.1	T
<i>Ligustrum</i>	0.0	0.0	0.1	T
<i>Morus</i>	0.4	0.0	0.1	T
<i>Olea</i>	13.9	8.0	24.1	T
<i>Pinaceae</i>	2.0	2.4	1.0	T
<i>Plantago</i>	3.1	3.0	2.8	H
<i>Platanus</i>	15.1	1.7	1.2	T
<i>Poaceae</i>	15.3	16.5	16.4	H
<i>Populus</i>	0.2	0.1	0.1	T
<i>Quercus</i>	32.0	43.5	39.7	T
<i>Rumex</i>	1.2	2.2	1.1	H
<i>Salix</i>	0.3	0.4	0.2	T
<i>Senecio</i>	0.1	0.1	0.1	H
<i>Typha</i>	0.1	0.0	0.0	H
<i>Ulmus</i>	0.4	0.2	0.5	T
<i>Urtica membranacea</i>	0.5	0.4	0.4	H
<i>Urticaceae p.p.^a</i>	1.0	0.6	0.6	H
<i>Xanthium</i>	0.1	0.0	0.0	H

^aThis pollen type includes all species from the family except *Urtica membranacea*.

tion in the pollen recorded; and ZA, with one third the number of ornamental *Quercus* trees in relation to PL, showed a weak reduction on airborne pollen records.

The second most abundant airborne tree pollen type was *Olea*. Olive trees are usually cultivated, but for the last few years they have also been planted as ornamentals in urban environments. The results showed great differences between locations and tree abundance (Fig. 3). The total number of trees, including surrounding areas, was greatest in DB. For the urbanized areas only, PL was the town with the most trees. Nevertheless, ZA was the locality with the most airborne pollen, and this finding was related to the presence of trees in the 500 m radius around the spore sampler: 0 (DB), 4 (PL) and 337 (ZA).

The third most abundant airborne tree pollen type represented only a single species in the three localities studied, *Platanus hispanica*. Plane trees appear only as ornamentals; they are rarely found to be spontaneous. The location with the most plane trees in total was PL (Fig. 4). Nevertheless, DB was the locality with the most airborne pollen recorded, probably due to the number of trees close to the spore sampler and wind directions (Fig. 4B). Fig. 6 shows the location for the urban area in DB and the distribution of plane trees. Fig. 4C shows that peak concentrations were reached when winds from the Southwest (180–270°) were dominant (plane trees were located at this direction, Fig. 6). In ZA, the position of plane trees was similar to DB (Figs. 6, 8). Nevertheless, winds blew from the North and South. Moreover, those trees in ZA were younger and smaller than the ones in DB, so their pollen production was lower.

The fourth most abundant tree pollen type was *Cupressaceae*, which included nine species, all growing only as ornamental, with three of them being the most frequent: *Cupressus sempervirens* (55%), *Platycladus orientalis* (20%) and *Cupressus arizonica* (11%). The amount of airborne pollen is related to total tree abundance and tree position in relation to the spore sampler. DB was the loca-

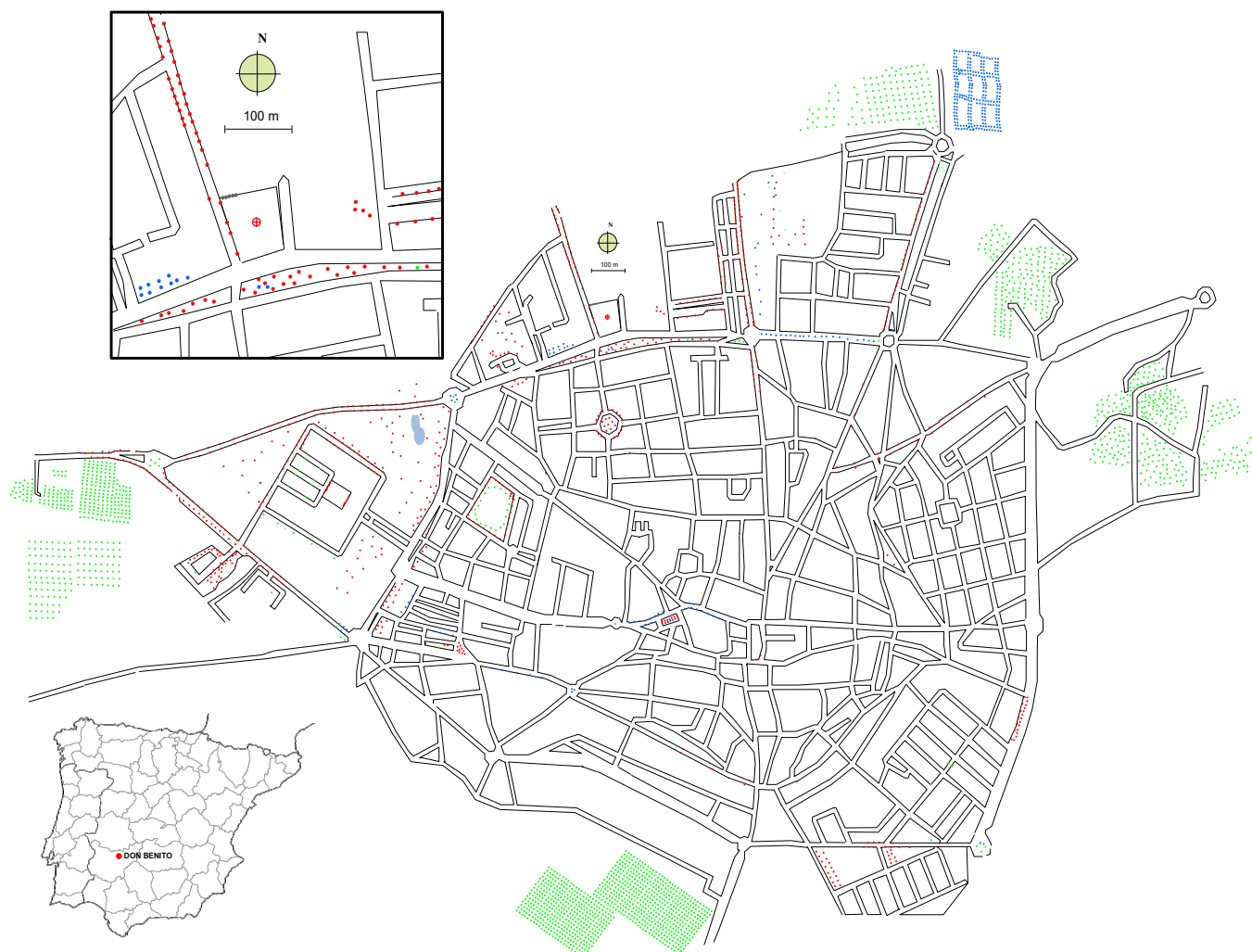


Fig. 6. Don Benito (DB) urban area showing the location of spore trap (encircled red cross), *Olea europaea* trees (green dots) *Platanus hispanica* trees (red dots), and Cupressaceae trees (blue dots) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

tion that had more Cupressaceae trees and pollen, whereas PL had less (Fig. 5A). The number of trees located within 200 m around the spore sampler was the same in the 3 cities, but at 500 m was higher in DB (Figs. 5B, 6).

Pinaceae showed low pollen concentrations ($<3\text{ g m}^{-3}$) in the three localities; nevertheless, the total number of these ornamental trees represents a relevant amount. The most frequently found trees were *Pinus pinea* (47%), *Pinus pinaster* (21%) and *Pinus halepensis* (21%). Interpretation of the data should take into account that those trees are often cultivated for timber, and they were found more frequently in the surrounding areas of PL. This may explain the highest records for this pollen type in PL in spite of being more abundant as ornamentals in DB (577) than in PL (295) or ZA (207), even at the 500 m area around the spore sampler.

The palm family (Arecaceae) had a more noticeable presence as an ornamental in DB (943) with respect to PL (100) and ZA (207). The palm species most frequently planted were *Washingtonia filifera* (53%), *Phoenix canariensis* (29%) and *Phoenix dactylifera* (12%). DB is the locality that had the most palm pollen recorded, neatly corresponding with having the most abundant amount of palms planted as ornamentals.

Three abundant species of ornamental trees, *Ulmus minor* (elm), *Celtis australis* (honeyberry tree) and *Acer negundo* (ashleaf maple), did not show significant pollen records in spite of their system of pollination through the air. This may be explained by the fact that

they have had low pollen production and a pruning manipulation that does not allow for a high level of flower production. For elm trees, there is correspondence between their abundance close to the spore samplers and their recorded pollen concentrations, where ZA (790 trees) is the locality with the highest pollen concentration in relation to PL (319 trees) and DB (159 trees), despite being a natural species growing frequently on river banks. For honeyberry trees, a monoecious species, 192 trees were found in PL, 53 in DB, and its pollen did not appear in any studied locality. Finally, for ashleaf maple, a dioecious species, airborne pollen records were completely irrelevant.

Fraxinus, *Salix*, *Populus* and *Alnus* pollen types include ornamental tree species, but are often spontaneous or cultivated on river banks. Their pollen records were low and concentrated mainly during winter or early spring. For *Fraxinus*, *Salix* and *Alnus* there was a correspondence between the total number of ornamental trees and pollen records, and PL was the locality with more ornamental trees and pollen records. *Populus* trees were more abundant closer to the spore sampler position in DB (45), compared with PL (14) and ZA (0), in correspondence with the airborne pollen records.

The rest of the pollen types analysed showed low airborne pollen records, but a correspondence was found between tree abundance and the pollen records. Those include *Casuarina*, *Ligustrum* and *Morus*. *Eucalyptus*, however, showed the highest pollen records in DB, with no trees as ornamental but extensively planted as fore-

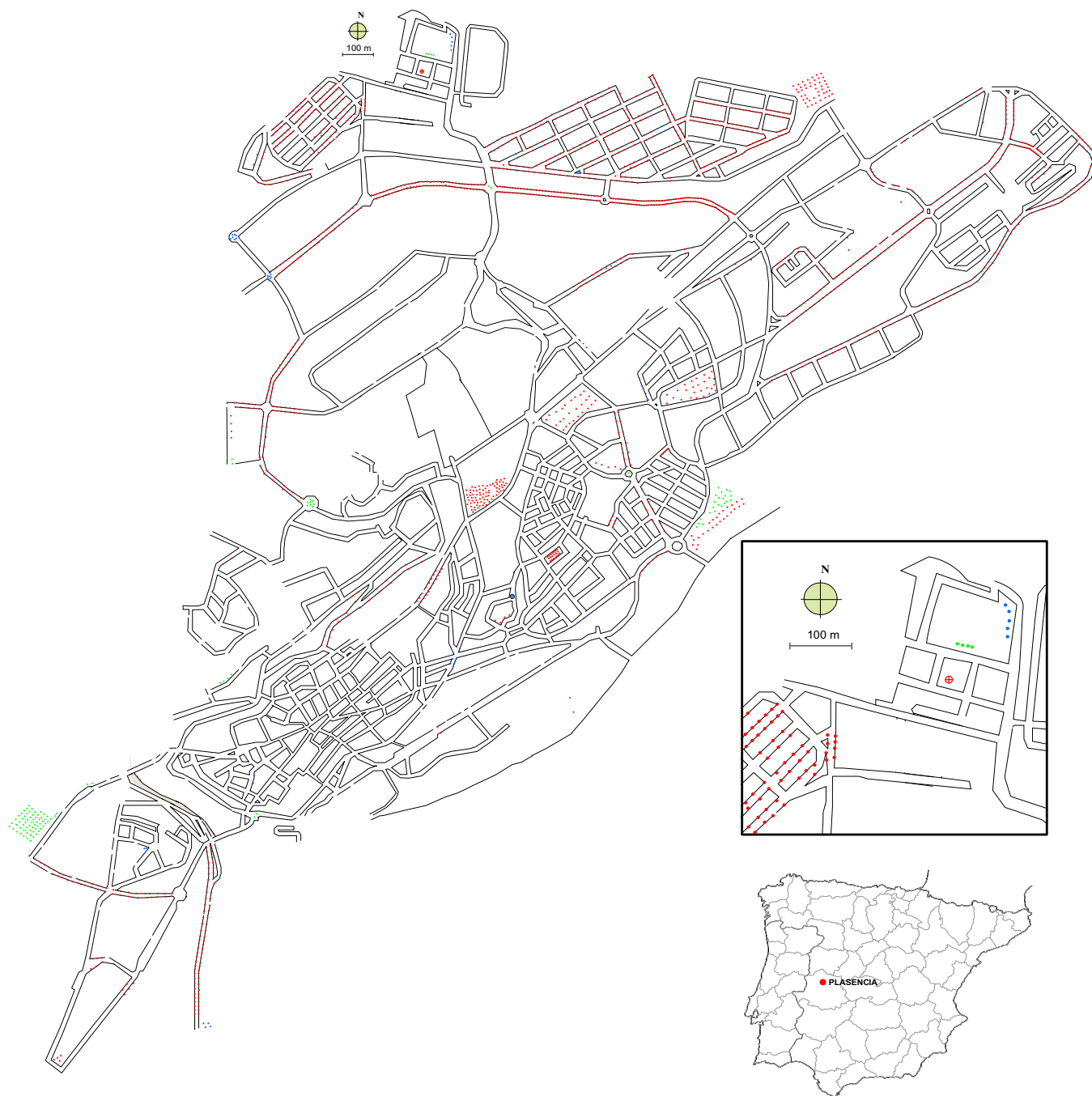


Fig. 7. Plasencia (PL) urban area showing the location of spore trap (encircled red cross), *Olea europaea* trees (green dots) *Platanus hispanica* trees (red dots), and Cupressaceae trees (blue dots) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

stalls at 5–10 km. Finally, *Juglans* showed both a very low tree presence and airborne pollen records.

The maximum value of I_{UGZA} (Cariñanos et al., 2014) was obtained for *Platanus hispanica* (0.0234 DB, 0.0652 PL, 0.0246 ZA), while the rest of values obtained were always below 0.0100, and only eight species reached a level above 0.0010, at least in one locality (*Acer negundo*, *Catalpa bignonioides*, *Olea europaea*, *Cedrus atlantica*, *Pinus pinaster*, *Pinus pinea*, *Platycladus orientalis*, and *Ulmus minor*).

Correlation between pollen concentration and total number of trees was analysed for 16 pollen types and the three localities ($n=48$), results appear in Table 4. Two of the tree pollen types did not have representation in the urban environment (*Castanea*

and *Corylus*), and four pollen types did not have pollen records or were anecdotic (*Acacia*, *Acer*, *Betula* and *Tilia*), so those pollen types were not included in the analysis. The results did not show statistical significance, even when considering exclusively ornamental urban trees (avoiding olive and cypress trees around the localities). Using the data on tree distribution around the spore sampler (up to 500 m radius), the total data did not show a significant correlation either. When *Quercus* data were removed, statistical significance ($r=0.466$, $p=0.001$) was obtained. This significant correlation was also obtained with data from the tree distribution at the 400 m radius ($r=0.392$, $p=0.008$), but no significance was obtained with source distribution data from less than 400 m.



Fig. 8. Zafra (ZA) urban area showing the location of spore trap (encircled red cross), *Olea europaea* trees (green dots) *Platanus hispanica* trees (red dots), and Cupressaceae trees (blue dots) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

Table 4

Results from correlation analysis. Relation between airborne pollen average concentration and number of trees around spore trap at circles of 50–500 m, all trees in the urban area (Urban) and including the surrounding (Total). Including all the pollen types and excluding *Quercus* type. Statistical significance when $p < 0.01$ appears in bold.

	All pollen types		Excluding Quercus	
	r	p	r	p
50 m	−0.057	0.703	0.075	0.622
100 m	−0.023	0.875	0.076	0.618
150 m	−0.077	0.604	0.049	0.751
200 m	−0.090	0.543	0.058	0.705
250 m	−0.024	0.872	0.057	0.710
300 m	0.032	0.831	0.235	0.120
350 m	0.061	0.679	0.345	0.020
400 m	0.075	0.613	0.392	0.008
450 m	0.081	0.585	0.432	0.003
500 m	0.092	0.532	0.466	0.001
Urban	−0.055	0.712	0.297	0.048
Total	−0.047	0.750	0.320	0.032

4. Discussion

The relation between inhabitants, or population, and the number of ornamental trees is a measure that can be compared in different cities. In this study the localities had a higher number of trees per inhabitant than in other cities in the Iberian Penin-

sula or United States (0.13 Beja, 0.07 Lisbon, Albuquerque 0.04), lower (Berkely 0.35, Santa Monica 0.32), or similar (Charlotte 0.14) (Fernandes & Carvalho, 2004; Flatley, 2001; Soares et al., 2011). Compared with the average values from Europe measured as trees per 1000 inhabitants, values from the localities studied here were clearly higher (Pauleit et al., 2002). Nevertheless, it is necessary to take into account that the European study included cities much larger than ones analysed in this study.

In relation to species diversity, comparative results should take the size of the area studied into account. Nevertheless, results from this study are similar to those seen in Hong Kong, with 70 species (Jim & Zhang, 2013), the South African cities of Port Alfred, Grahamstown and Somerset East, with 61 species (Kuruner-Chitepo & Shackleton, 2011), and Lisbon with 78 species (Soares et al., 2011). Additionally, it is clear that the diversity of species should be considered in relation to their relative representation, as it has been accepted by authors that the most dominant species should not surpass 10% (Muratet, Pellegrini, Béatrice-Dufour, Arrif, & Chiron, 2015; Nagendra & Gopal, 2010). In our study, only one species, *Platanus hispanica*, represented more than this 10% in the three studied localities; this value is lower than some found in other cities, such as Lisbon, where *Celtis australis*, *Tilia* spp. and *Jacaranda mimosifolia* all reach that percentage (Soares et al., 2011).

In relation to the *Quercus* pollen type, the most abundant airborne pollen recorded, it came from trees from the three places

analysed and were scarce as ornamentals. Therefore, it is clear that airborne *Quercus* pollen came from natural vegetation, and species of this genus represent one of the major contributors to airborne pollen in the Centre and South of the Iberian Peninsula (García-Mozo et al., 2008). The airborne *Quercus* pollen record was greater in PL because sources, mainly cork oak, were closer and more profuse at the surroundings of the city. In the case of DB, holm oak dehesas were further from the spore sampler because irrigated crops cover most of landscapes around the city.

Olive trees have usually been planted as crops. Nevertheless, the trend to use them as ornamental trees is making their presence in the urban environment more frequent, often because those trees were transplanted from crops to the city. The *Olea* pollen type is one of the main causes of allergies (Feo-Brito et al., 2011). As urban olive trees represented only 7.3% of the total trees, including areas surrounding the localities studied, airborne *Olea* pollen records may come mainly from outside the city. Notwithstanding, it is clear that the proximity to the spore sampler is the main factor in explaining their abundance (Galán, Vázquez, García-Mozo, & Domínguez, 2004).

The most abundant ornamental tree planted in the three localities studied was *Platanus hispanica*. Their pollen has been clearly identified as a cause of allergy (Fernández-González, Guedes, Abreu, & Rodríguez-Rajo, 2013; Varela et al., 1997). Due to its easy growth, it has been extensively planted as an ornamental tree in many cities across Europe. Airborne *Platanus* pollen records were explained not only by the tree presence close to the spore sampler but also by wind direction and the age of the trees. DB and ZA had similar values of tree abundance close to the spore sampler, in similar positions; nevertheless, trunk diameter and branch development degrees showed relevant differences between both places. The results from this work support the observation of Bricchi, Frenguelli, and Mincigrucci, 2000, who said that most of the airborne pollen from this tree only reaches an area of 800 m around the sources. Pruning, often applied to this species, should also be taken into account to explain airborne pollen records (Iglesias, Rodríguez-Rajo, & Méndez, 2007).

The Cupressaceae pollen type includes mainly trees species, and one of them, *Cupressus sempervirens*, is not only the most abundant but the largest pollen producer (Hidalgo, Galán, & Domínguez, 1999, 2003). In our study, although the number of Cupressaceae trees was similar at 300 m around the spore sampler for the three localities studied (Fig. 5B), in DB there were twice as many trees at 500 m, and their positions were more favourable to pollen being pulled by wind, as was the case of *Platanus*. Those results evidence the strong relationship between the source distribution of cypresses and airborne pollen records, as it has been revealed by other studies (Díaz de la Guardia, Alba, de Linares, Nieto-Lugilde, & López Caballero, 2006; Galán, Fuillerat, Comtois, & Domínguez, 1998).

The rest of the pollen types showed low concentrations, so it is not possible to generate relevant conclusions. The Pinaceae pollen type includes species that are often planted as forestal crops, mainly in Plasencia (Pulido et al., 2007); this may explain why more airborne Pinaceae pollen was found in PL than in DB, where there were more Pinaceae ornamental trees, even close to the spore sampler. The Arecaceae pollen type includes only ornamental palm species. In this case, the relationship between recorded amounts of pollen and palm abundance in DB is clear. In this family, it is necessary to mention that dioecy is abundant, and male palm distribution should be taken into account to properly interpret the results because sensitization to palm pollen is a cause of allergy (Huertas, López-Sáez, & Carnés, 2011). The results from examining the *Ulmus* pollen type are a bit astonishing because this pollen type includes a rather abundant species planted as an ornamental tree that is also spontaneously grown on river banks. In

spite of this abundance, pollen records are very low. This finding may be explained because this pollen is only dispersed at a short distance, as has been found in other closely related species (Venturas, Nanos, & Gil, 2014). Moreover, the pollen production was confirmed to be low in relation to other anemophilous trees (Tormo-Molina, Muñoz, Silva, & Gallardo, 1995), and a degree of sterility and vegetative reproduction has been observed (López-Almansa, Pannell, & Gil, 2003). The presence of the *Acer* pollen type in pollen records was anecdotal. Three species were identified, but *Acer negundo* was clearly the most abundant. *Acer negundo* is a dioecious and anemophilous species, contrary to *A. platanoides* and *A. pseudoplatanus*, with hermaphrodite flowers and an entomophilous pollination system. Although male and female trees from this species were not counted separately, we estimate that male trees were less frequent, and this may be the explanation for the low level of found airborne pollen. *Castanea* and *Corylus* are present in natural vegetation near PL, and scarcely represented as ornamentals in PL and DB, this may explain their presence in pollen records in both localities.

Assessing the potential allergenic capacity of an urban area is a useful tool to establish more clean areas from this point of view. The allergenic index created by Cariñanos et al. (2014) is suitable to compare different areas, but only species by species. Using the sum values obtained for each species as a general index for the entire surface studied, the localities studied appeared in this order: PL (0.0866), ZA (0.0555) and DB (0.0525), meaning that PL was potentially the locality with more problems with allergens. From our point of view, that index underestimates the allergenicity of pollen and overestimates the canopy volume. This is because the total value of the index is a result from a product of values with the same weight or relevance in the formula. In this way, for instance, *Platanus hispanica* and *Cedrus deodara*, the second species allergenically irrelevant, reached similar values of allergenicity, and *Olea europaea* obtained values several times lower, when it is a clear allergenic species. Thus, the allergenic categories (0–4) should increment their effect to obtain more suitable results. It is necessary to point out that the allergenic index was originally designed to be used from specific urban green areas and in this paper is used in the whole urban area, thus this may distort real comparisons with other studies. Moreover, epidemiologic studies should be performed to assess the relation between allergy and ornamental trees abundance in urban environment.

Long distance pollen transport has been an issue long reported in the literature (Gregory, 1978). In addition, there are studies comparing the position of sources in relation to traps over a great distance, v.g. 50–100 km (Oteros et al., 2015), and an intermediate distance, approximately 3 km (Fernández-Rodríguez, Tormo-Molina et al., 2014b). Nevertheless, to properly assess the relationship between airborne pollen production and shedding, it is necessary to take into account accurate source position and predominant winds that transport those particles when assessing their record in a spore sampler. In any case, it is obvious that wind direction should be considered when a shorter distance is taken into account (Rojo et al., 2015). We accept that a suitable comparison from a mapped area should be aerobiologically sampled in the centre of that area, but this is not the case for our study. Spore sampler situation is a compromise between the availability of places and methodological procedures. Nevertheless, a previous study comparing two sampling points nearly in opposite positions in a city twice the size of the study presented here revealed that aerobiological records were quite similar under such conditions (Fernández-Rodríguez et al., 2014b).

Finally, we want to emphasize that to reduce pollen allergies, pollination characteristics of ornamental trees should be considered as selection criteria by government officials (Conway & Vander Vecht, 2015; Goldberg, Confino-Cohen, & Waisel, 1998; Jianan,

Zhiyun, Hua, Xiaoke, & Hong, 2007). Different strategies may be considered, such as planting more entomophilous species, selecting female trees when dioecy is present, selecting species with low pollen production or even pruning practices being performed at suitable times to avoid or reduce pollen production and shedding (Cariñanos et al., 2014). We recognize that some species have a long tradition in urban green spaces designing, as cypresses and plane trees, both highly allergenic, but with low growing requirements. Nevertheless, for olive trees the use for gardening is a new trend in Mediterranean countries. Pruning is mainly a practice in order to avoid litter from deciduous trees or topiary on evergreen species, and it could be considered to reduce pollen production. Those ideas should be borne in mind in the design of urban street trees for obtaining sustainable development of cities.

5. Conclusions

The average concentration of airborne pollen did not show great differences between the three localities studied, ranging 93–102 g m⁻³. It is not possible to properly estimate the amount of pollen from ornamental trees separately from natural vegetation. Notwithstanding, pollen from exclusively ornamental sources (Arecaceae, *Casuarina*, Cupressaceae and *Platanus*) represented approximately 10% of the total pollen recorded. Moreover, the most abundant tree pollen (*Quercus*) came mainly from natural sources. In urban environments, proximity to tree pollen sources is a main factor that explains airborne pollen records. The distribution of sources in an area of 400–500 m around the spore sampler provides most of the airborne pollen captured. Furthermore, wind directions play a relevant role when sources are not homogeneously distributed. This finding was demonstrated in the case of plane trees, one of the most abundant ornamental trees. Other frequent ornamental anemophilous trees, such as *Ulmus minor*, *Acer negundo* and *Celtis australis*, did not show relevant airborne pollen records. We want to emphasize that to reduce pollen allergies, pollination characteristics of ornamental trees should be considered as selection criteria by government officials. This idea should be taken into account in the design of urban street tree areas for obtaining sustainable development of cities.

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