

Comparative study of the effect of distance on the daily and hourly pollen counts in a city in the south-western Iberian Peninsula

Santiago Fernández-Rodríguez · Rafael Tormo-Molina ·
José María Maya-Manzano · Inmaculada Silva-Palacios ·
Ángela Gonzalo-Garijo

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Abstract The airborne pollen concentration in the city of Badajoz was measured in two locations 2.9 km apart. The measurements were taken from January to June between 2009 and 2012 using Hirst-type volumetric aerobiological samplers. One sampler was placed at the Faculty of Science (FS) and the other at the Agricultural Engineering School (AES) of the University of Extremadura, Spain, on terraces located 16 and 6 m above ground, respectively. The two sets of hourly and daily pollen concentrations were compared regarding the meteorological parameters and the distribution of local pollen sources. A total of 46 pollen types were counted, with a mean total concentration of 43 pollen grains/m³ in the winter and 336 pollen grains/m³ in the spring. In the winter,

pollen grains from (in decreasing order) Cupressaceae, *Fraxinus-Phillyrea*, Urticaceae spp., *Alnus glutinosa* and *Urtica membranacea* types represented 77 % of the total. In the spring, 89 % of the total was represented by pollen grains from (in decreasing order) *Quercus*, Poaceae, *Olea*, Pinaceae and *Plantago*. The FS/AES ratio was 0.57 in the winter and 1.31 in the spring. While a Wilcoxon test applied to the daily total concentration data showed statistically significant differences between the two sites, a correlation study based on the Spearman coefficient showed statistically significant correlations in both the winter and spring. The results were similar when comparing the separate pollen types, except for Urticaceae spp., which showed no statistically significant correlation. The meteorological data studied showed a statistically significant correlation with the daily concentrations. A comparison of the hourly concentration data showed no correspondence with the time of maximum concentration. The local distribution of pollen sources explained some of the differences found between the two sites. Overall, the results indicate that a single aerobiological sampler may be sufficiently representative to register the daily pollen grain data of an urban area of approximately 3 km or greater in diameter, although it underestimates the influence of heterogeneity in the distribution of the local flora.

S. Fernández-Rodríguez (✉) · R. Tormo-Molina ·
J. M. Maya-Manzano
Department of Plant Biology, Ecology and Earth
Sciences, Faculty of Science, University of Extremadura,
Avda. Elvas s/n, 06071 Badajoz, Spain
e-mail: santiferro@unex.es

I. Silva-Palacios
Department of Applied Physics, Engineering Agricultural
School, University of Extremadura, Badajoz, Spain

Á. Gonzalo-Garijo
Department of Allergology, Hospital Universitario Infanta
Cristina, Badajoz, Spain

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1 Introduction

Knowledge of the spectrum of airborne pollen in town centres has contributed to improving the identification of potential allergens for people living or working in those urban areas. Furthermore, pollen calendars and recent airborne pollen forecasting models constitute very useful tools for planning any preventive and palliative treatments for patients with allergy problems (D'Amato et al. 1998, 2007; Gioulekas et al. 2004; Abreu and Ribeiro 2005; Docampo et al. 2007).

The relative importance of the pollen type depends not only on the flowering period but also on factors that affect the pollen dispersion and abundance. Among other factors, these include the latitude and the climate, as well as locally specific factors such as the type of vegetation in the surrounding area, the land use, and the selection and distribution of ornamental plants (Emberlin et al. 1994, 1999, 2000; Galán et al. 1995). In order to increase the precision of predictive models at a regional or local level, it is important to understand the relationship between the dependent variables (the concentrations of airborne pollen types over time) and the independent variables (the meteorological parameters and pollen sources) in different places (Sánchez-Mesa et al. 2003). The human impact also needs to be considered from two perspectives, the town design and the choice of ornamental species (Staffolani et al. 2011).

Table 1 lists the literature consulted relating to the evaluation of differences at distances of at most 20 km

in aerobiological sampling. Five of these studies compare the results of sensors separated by between 1 and 3 m (Eversmeyer and Kramer 1987; Pedersen and Moseholm 1993; Irdi et al. 2002; Giorato et al. 2003; Khattab and Levetin 2008), while the remaining studies used distances between 5 and 20 km (Kramer and Eversmeyer 1984; El-Ghazaly et al. 1993; Fornaciari et al. 1996; Frenz et al. 1997; Gottardini and Cristofolini 1997; Arobba et al. 2000; Velasco-Jiménez et al. 2012). Other papers comparing distances between 20 and 100 km were also considered (Strandhede and Wihl 1981; Palmas and Cosentino 1990). Most of these studies are of European or North American origin, with the sampling lasting between 2 and 3 years.

Considering the study of pollen concentrations at the local level, two papers were of particular interest. Gonzalo et al. (2006) studied the variations in the pollen concentrations in Badajoz, comparing the urban and peripheral zones of the city. They concluded that it might be useful to know the distribution (often highly variable) of ornamental plants whose pollen is potentially allergenic to indicate which areas of the city are likely to have a greater or lesser incidence of potential pollinosis. Silva et al. (2007) studied the importance of the interactions of weather conditions on *Plantago* and *Brassicaceae* pollen concentrations. The NE winds had a positive effect, while the SW winds had a negative effect on the concentrations of both pollen types. These effects were not explained by the location of the sources because both species groups were abundant around the sampling site.

Table 1 Comparative studies between sites separated by at most 20 km

Reference	City (Country)	Sampler	Distance (km)	Height (m)
Kramer and Eversmeyer (1984)	Manhattan (USA)	2 BST	10	1.5
Eversmeyer and Kramer (1987)	Kansas (USA)	15 Rot	0.001	1, 2, 3
Pedersen and Moseholm (1993)	Copenhagen (Denmark)	2 BST	0.003	15
El-Ghazaly et al. (1993)	Huddinge, Estocolmo (Sweden)	2 BST	15	
Fornaciari et al. (1996)	Perugia (Italy)	3 LST	5	10, 20, 30
Frenz et al. (1997)	St. Paul, Minnesota (USA)	2 Rot	5.6	
Gottardini and Cristofolini (1997)	Trento, S. Michele all'Adige (Italy)	2 BST	20	10, 15
Arobba et al. (2000)	Génova (Italy)	2 LST	10	15, 20
Irdi et al. (2002)	Pittsburgh (USA)	2 BST	0.001	10
Giorato et al. (2003)	Padova (Italy)	2 LST	0.002	20
Khattab and Levetin (2008)	Tulsa (USA)	2 BST	0.001	1.5, 12
Velasco-Jiménez et al. (2012)	Córdoba (Spain)	2 BST	9	15, 22

BST Burkard spore trap; Rot rotorod; LST Lanzoni spore trap

There are papers that analyse intradiurnal variations in a city (Trigo et al. 1997; Ribeiro et al. 2008; Pérez Badía et al. 2010), but most of the comparative studies consulted did not consider the hourly variations in the meteorological conditions or the pollen concentration, nor did they examine in any detail the distribution of the pollen sources in explaining the observed variations in pollen counts. However, the overall conclusion to be drawn from these distance comparisons is that the phenology of the sources and the variations in the meteorological parameters explains the pollen count variability (Tormo et al. 2013).

Badajoz is located 184 m above sea level. It has a population of 151,565 and is the second largest borough in extension (1,470 km²) (NSI 2012) in Extremadura, a rural, agricultural region of Spain. Surrounding Badajoz, there are zones of irrigation farming (e.g. orchards, maize and tomatoes) and olive groves, as well as the somewhat more distant holm oak woodland and areas for extensive grazing. The average climatic values (1971–2000) provided by the state meteorological agency (AEMET) show an average annual temperature of 16.6 °C and a total rainfall of 463 mm.

The objective of the present study was to analyse and compare the results of aerobiological sampling in a city between two samplers a few kilometres apart, considering the local distribution of pollen sources and the meteorological parameters. The purpose of the study

was to determine the influence of the distance and the surrounding vegetation on the hourly and daily pollen concentration data, as this information could be useful in developing predictive models for a specific city.

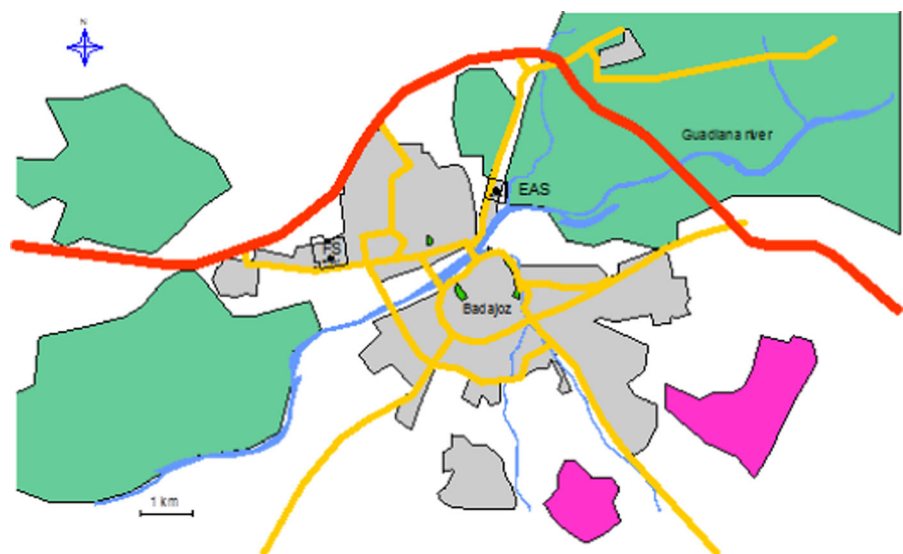
2 Materials and methods

2.1 Study area

The pollen-monitoring samplers in Badajoz were situated 16 m above ground in the Faculty of Science (FS) (38°53'87"N, 7°00'87"W) and, 2.9 km away, 6 m above ground in the Agricultural Engineering School (AES) (38°53'45"N, 6°58'07"W), both belonging to the University of Extremadura (Fig. 1).

Separate maps were made of all the trees and shrubs of aerobiological interest within an area of approximately 500 m in diameter around the two samplers. The clearly entomophilous species were not considered. The most frequent vegetation found around spore traps, beyond the closed area studied, is ornamental areas (gardens and streets: Platanaceae, Oleaceae, Pinaceae, Cupressaceae, Fagaceae, Poaceae, Rosaceae, Rutaceae), irrigated crops (mainly tomato, corn, fruit trees) and their weeds (Amaranthaceae–Chenopodiaceae, Poaceae, Asteraceae, Urticaceae), and river vegetation (Cyperaceae, Typhaceae, Poaceae, Ulmaceae, Salicaceae, Juncaceae).

Fig. 1 Locations of the University of Extremadura's Faculty of Science (FS) and Agricultural Engineering School (AES). *Grey* built-up area; *green* irrigation farming; *pink* semi-natural holm oak and shrub vegetation; *white* uncultivated or fallow fields or irrelevant small crop areas. (Color figure online)



2.2 Meteorological data

The meteorological data were taken from the “AT Delta-T DL2” fixed weather station located in the Botany experimental garden on the Faculty of Science campus (38°52′59″N, 7°00′28″W) 16 m from the FS sampler. The meteorological parameters measured included wind speed (Ws), wind direction (Wd), hours of sun per day (Sh), relative humidity (Rh), rainfall (R), solar radiation (Sr), maximum air temperature ($T_{\max}$), mean air temperature (T_{mean}) and minimum air temperature ($T_{\min}$).

2.3 Pollen data

The sampling lasted in spring from 20 March to 30 June during 2009, 2010 and 2011 and in winter from 1 January to 19 March during 2010, 2011 and 2012. The daily average and diurnal (hourly) pollen counts were obtained using Hirst-type volumetric aerobiological samplers (spore traps, Burkard Seven-Day Volumetric Spore-Trap®) (Hirst 1952). The samplers were located on open terraces with an intake of 1.5 m above ground. The standardised data management procedures used were similar to those described by the Spanish Aerobiology Network (REA) (Galán et al. 2007). The slides were examined along two or four longitudinal transects, depending on the number of pollen grains (Tormo et al., 1996). The daily mean (00:00–24:00 h) pollen counts and diurnal variations (UTC hourly counts) are expressed as pollen grains/m³. The seasonal time distribution model of the predominant pollen types (*Quercus*, *Poaceae*, *Olea*, *Plantago* and *Cupressaceae*) was calculated from the data from the main period of pollination, according to Nilsson and Persson (1981).

The daily pollen concentrations were compared for the five most abundant pollen types in each season: spring—*Quercus*, *Poaceae*, *Olea*, *Pinaceae* and *Plantago*; winter—*Cupressaceae*, *Fraxinus*–*Phillyrea*, *Urticaceae* spp., *Alnus glutinosa* and *Urtica membranacea*. The hourly concentrations were compared for the *Quercus*, *Poaceae*, *Olea*, *Plantago* and *Cupressaceae* pollen types, selecting the 5 days of the highest peak concentrations. These 5 days represent 14.4–52.1 % of the total pollen analysed depending on pollen type and they mean a more selective method than previously ones used (Galán et al. 1991; Trigo et al. 1997; Ribeiro et al. 2008; Pérez-Badía et al. 2010) that include more days

and consequently more randomness in the information analysed. The FS/AES ratio of the daily mean total concentrations between the two sites was calculated for the spring and the winter.

The Shapiro–Wilk (W) test did not show the normal distribution of any of the data, even after the application of a logarithmic transformation. Therefore, comparisons of the daily and hourly data between the two locations were made using the Wilcoxon (Z) test, while the Friedman (χ^2) test was used to compare the concentrations in the season studied. Spearman's correlation coefficient (r) was used to study the possible correlations between the pollen concentrations and between the pollen concentrations and the meteorological parameters. The confidence level was set at 95 %.

3 Results

3.1 Nearby pollen sources

There were a total of 4,904 individual ornamental trees and shrubs on the FS campus and 828 on the AES campus. Table 2 lists the numbers corresponding to the most abundant pollen types. The remaining individuals (54 and 24 % for FS and AES, respectively) were not recorded in the aerobiological samples because they were clearly entomophilous species. The most abundant species included *Brachychiton populneus*, *Catalpa bignonioides*, *Citrus aurantium*, *Cistus ladanifer*, *Cortaderia selloana*, *Crataegus monogyna*, *Melia azedarach*, *Nerium oleander*, *Prunus avium*, *Prunus cerasifera*, *Prunus dulcis* and *Viburnum tinus*. The distributions of the most relevant individuals are shown in Figs. 2 and 3.

3.2 Pollen grains registered

The total numbers of pollen grains counted for the entire study period were 162,969 (FS) and 107,060 (AES). These numbers correspond to 46 pollen types with a mean total concentration of 43 pollen grains/m³ in the winter (the greatest concentration in the winter of 2011 and the least in that of 2010) and 336 pollen grains/m³ in the spring (Fig. 4) (the 2009 mean spring concentration was lower than that of 2010). The greatest spring concentration was that of 2011. Neither season's daily mean pollen concentration data were

Table 2 Inventory of species grouped into the most common anemophilous pollen types, including the number of individuals (trees and shrubs) on the campuses of the FS and the AES

Pollen type	FS	EAS	Species	Pollen type	FS	EAS	Species
<i>Acacia</i>	4	3	<i>Acacia dealbata</i>	<i>Juglans</i>	15	8	<i>Juglans regia</i>
<i>Acer</i>	60	20	<i>Acer negundo</i> , <i>A. monspessulanum</i> , <i>A. platanoides</i> ,	<i>Morus</i>	102	1	<i>Morus alba</i>
<i>Alnus glutinosa</i>	21	0	<i>Alnus glutinosa</i>	<i>Olea</i>	60	1	<i>Olea europaea</i>
<i>Erica</i>	11	3	<i>Erica arborea</i>	<i>Platanus</i>	208	14	<i>Platanus hispanica</i> , <i>P. orientalis</i>
<i>Castanea</i>	106	3	<i>Castanea sativa</i>	Pinaceae	538	6	<i>Pinus pinea</i> , <i>P. halepensis</i> , <i>P. radiata</i>
<i>Corylus</i>	10	0	<i>Corylus avellana</i>	<i>Populus</i>	79	4	<i>Populus alba</i> , <i>P. nigra</i>
Cupressaceae	170	138	<i>Cupressus arizonia</i> , <i>C. macrocarpa</i> , <i>C. sempervivens</i> .	<i>Quercus</i>	338	9	<i>Quercus ilex</i> , <i>Q. rotundifolia</i> , <i>Q. robur</i> , <i>Q. faginea</i>
<i>Eucalyptus</i>	157	106	<i>Eucalyptus camaldulensis</i>	<i>Salix</i>	58	1	<i>Salix babylonica</i> , <i>S. atrocinera</i>
<i>Fraxinus</i>	110	308	<i>Fraxinus angustifolia</i> , <i>F. ornus</i>	<i>Ulmus</i>	208	4	<i>Ulmus minor</i>
Urticaceae spp.			<i>Urtica urens</i> , <i>Parietaria judacia</i>	<i>Plantago</i>			<i>Plantago afra</i> , <i>P. coronopus</i> , <i>P. major</i> , <i>P. lagopus</i>

normally distributed, even after applying a logarithmic transformation: the three winters ($W = 0.984$, $p = 0.069$; $W = 0.982$, $p < 0.035$; $W = 0.954$, $p < 0.001$) and the three springs ($W = 0.946$, $p < 0.001$; $W = 0.982$, $p < 0.001$; $W = 0.980$, $p < 0.001$). The Friedman test showed statistically significant interannual differences between the three winters ($\chi^2 = 12.023$, $p = 0.002$) and the three springs ($\chi^2 = 46.595$, $p < 0.001$).

In the winter, 77 % of the pollen grains corresponded to five pollen types: (in descending order) Cupressaceae, *Fraxinus-Phillyrea*, Urticaceae spp., *Alnus glutinosa* and *Urtica membranacea*. In the spring, 89 % of the pollen grains also corresponded to five pollen types: (in descending order) *Quercus*, Poaceae, *Olea europaea*, Pinaceae and *Plantago*. The greatest daily mean concentrations were 2,300 pollen grains/m³ at the FS site and 1,556 pollen grains/m³ at the AES site, both registered on 8 April 2011. The FS/AES ratio of the daily mean total concentrations was 0.57 in the winter and 1.31 in the spring. There were statistically significant differences between the two sites in the total mean concentration in the winters of 2010 ($Z = 2.667$, $p = 0.008$), 2011 ($Z = 2.549$, $p = 0.011$) and 2012 ($Z = 3.214$, $p = 0.001$), and in the springs of 2009 ($Z = 1.956$, $p = 0.050$), 2010 ($Z = 2.327$, $p = 0.020$) and 2011 ($Z = 4.578$, $p < 0.001$) (Fig. 5). Nonetheless, despite these

differences, statistically significant positive correlations were obtained for the daily mean total concentrations between the two sites in the winters of 2010 ($r = 0.704^{**}$), 2011 ($r = 0.801^{**}$) and 2012 ($r = 0.495^{**}$), and the springs of 2009 ($r = 0.745^{**}$), 2010 ($r = 0.848^{**}$) and 2011 ($r = 0.878^{**}$), with the significance level in all cases being $p < 0.001$. There were statistically significant differences between the two sites in the daily mean concentrations of the principal pollen types in both the winter and the spring, except for *Alnus glutinosa* (Table 3). There were also significant correlations between the major pollen types between the two sites in both the winter and the spring (Table 4).

For the meteorological parameters, in both the winter and the spring, the strongest correlations of the daily mean concentrations were between the maximum, mean and minimum temperatures, and the total solar radiation, while the weakest was between the wind speeds.

Figure 6a–f shows the temporal variation in the FS and AES of the concentrations of the most relevant pollen types: *Quercus*, Poaceae, *Olea*, Pinaceae, *Plantago* and Cupressaceae, respectively. In the spring, the greatest peak concentrations of *Quercus*, Poaceae, *Olea* and *Plantago* did not occur on the same days. Table 5 shows all cases of statistically significant correlations, comparing the maximum hourly concentrations of pollen types (*Quercus*, Poaceae and

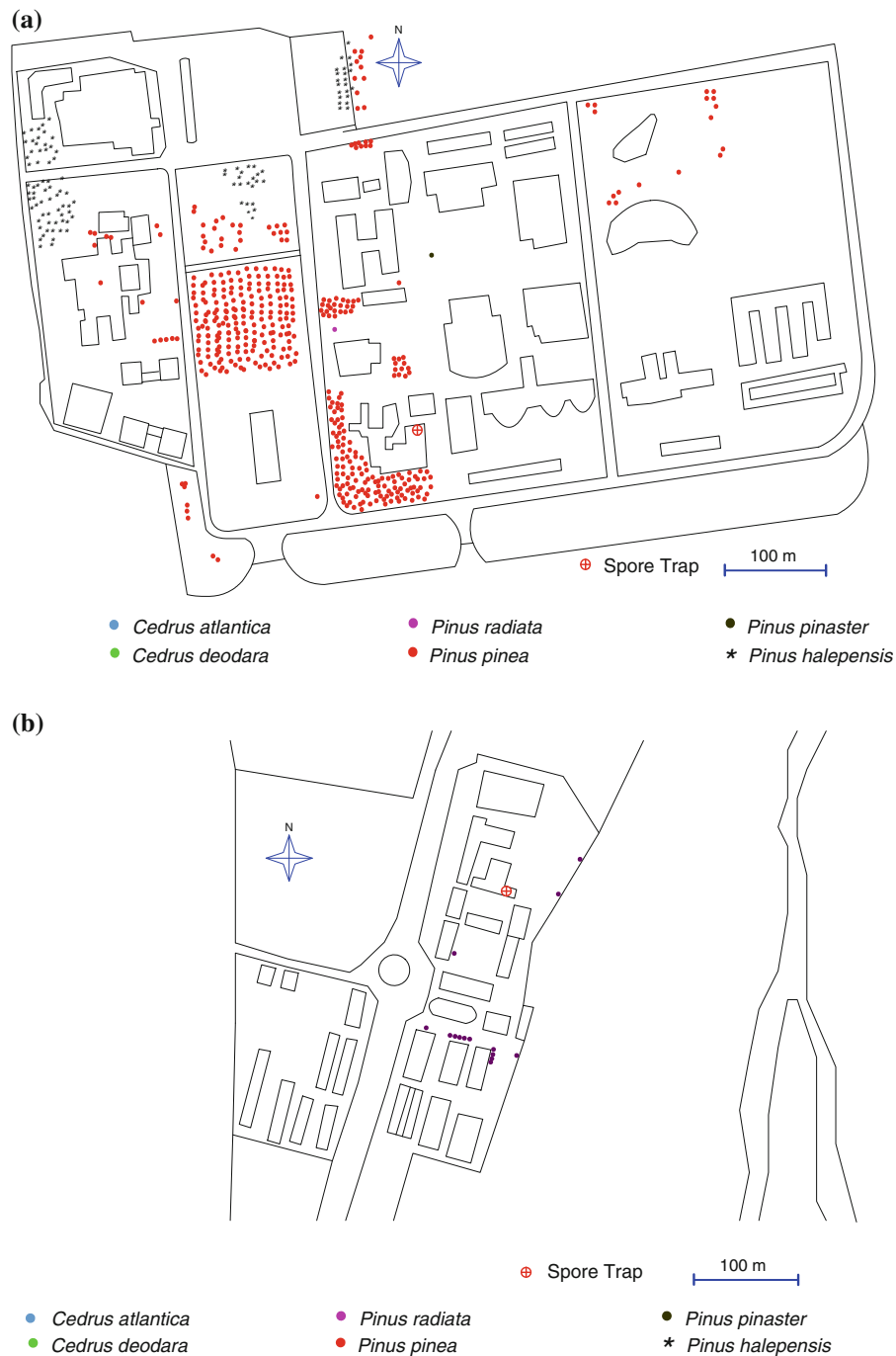


Fig. 2 Distribution of Pinaceae on the campuses of **a** The FS and **b** The AES

Cupressaceae) and the meteorological parameters in both sites, and Fig. 7a–e includes only the most relevant results. There was a difference of 14 h between the *Olea* peaks on 11 May 2011 (Fig. 7e).

The mean peak concentrations of all the pollen types studied occurred between 11:00 and 15:00 h, although some peak concentrations occurred at other times of the day, even during the night, as with *Quercus* on 3

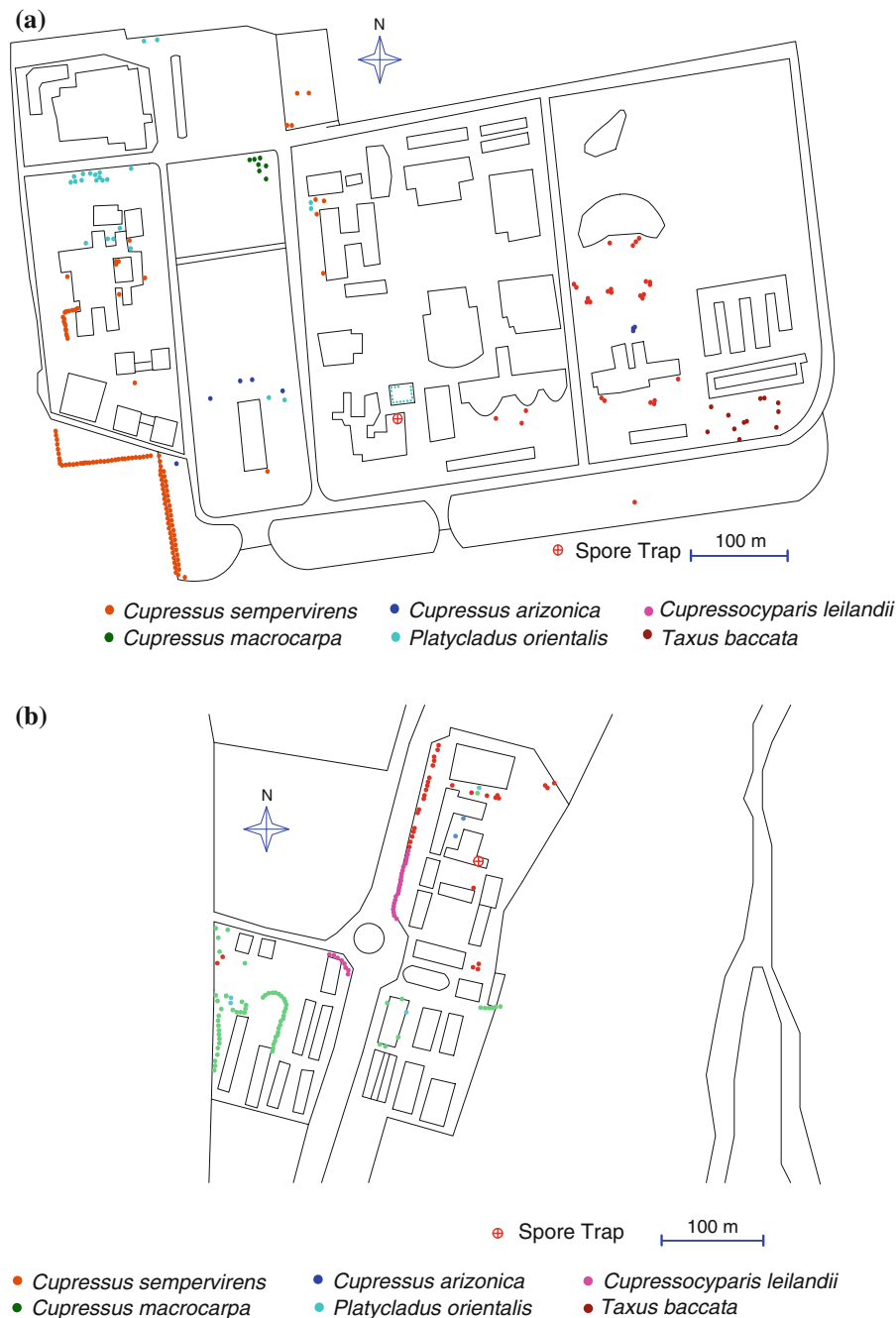


Fig. 3 Distribution of Cupressaceae on the campuses of **a** The FS and **b** The AES

April 2009 at the FS site (Fig. 7b). On average, the peak concentrations of all the pollen types appeared at the AES site first at 12:48 h and then at 13:54 h at the FS site. A coincidence of peak concentrations at both samplers occurred on only two occasions: for *Quercus* on 31 March 2009 at 17:00 h (Fig. 7b) and for *Olea* on

20 May 2010 at 10:00 h. With respect to the temporal variation, the average difference in the timing of the peak concentrations between the two samplers varied between 2.8 and 3 h, with the greatest difference being 14 h. Although the comparison of the timing of the *Quercus*, *Poaceae*, *Olea* and *Plantago* concentrations

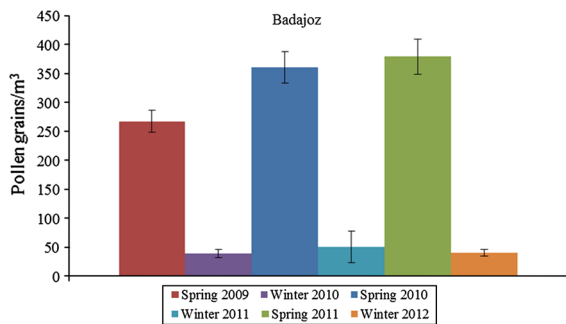


Fig. 4 Daily mean total pollen concentration (pollen grains/m³), with standard error bars, in Badajoz during the spring and the winter study periods; bars represent standard errors

Fig. 5 Daily total pollen concentration (pollen grains/m³) on the FS and AES sites during **a** The spring and **b** The winter study periods

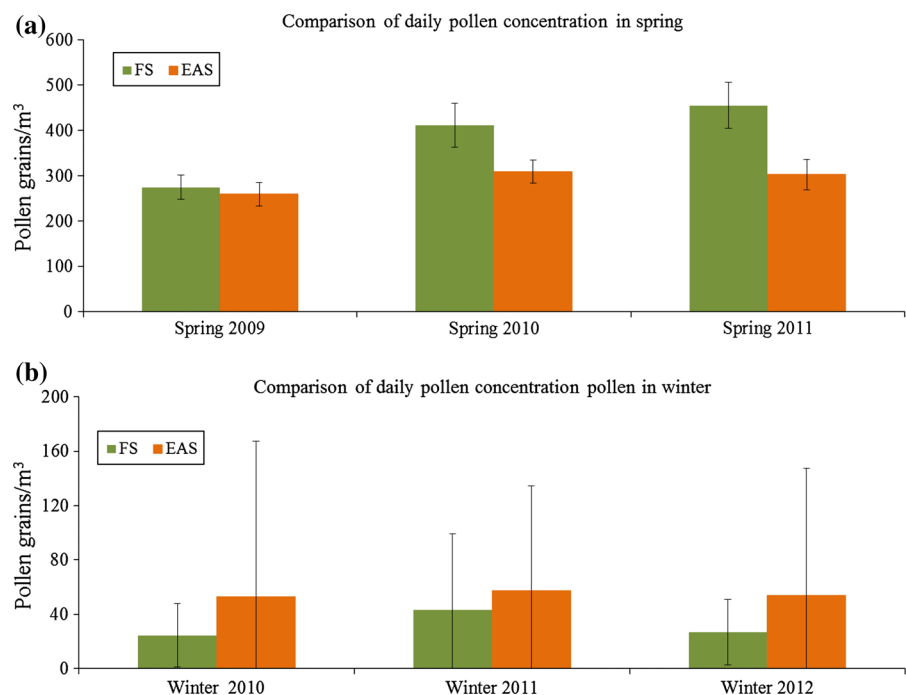


Table 3 Wilcoxon test results comparing the daily concentrations of the predominant pollen types between the FS and the AES sites from 2010 to 2012

Period	Statist	Pollen type				
		Cupressaceae	<i>Fraxinus–Phillyrea</i>	Urticaceae spp.	<i>Alnus glutinosa</i>	<i>Urtica membranacea</i>
Winter 2010–2012	Z	−5.466	−2.895	−8.032	−1.855	−3.519
	p	<0.001	0.004	<0.001	0.064	<0.001
Period	Statist	<i>Quercus</i>	Poaceae	<i>Olea</i>	Pinaceae	<i>Plantago</i>
Spring 2009–2011	Z	−2.896	−4.360	−5.953	−10.207	−4.371
	p	0.004	<0.001	<0.001	<0.001	<0.001

Z values are in bold when $p < 0.05$

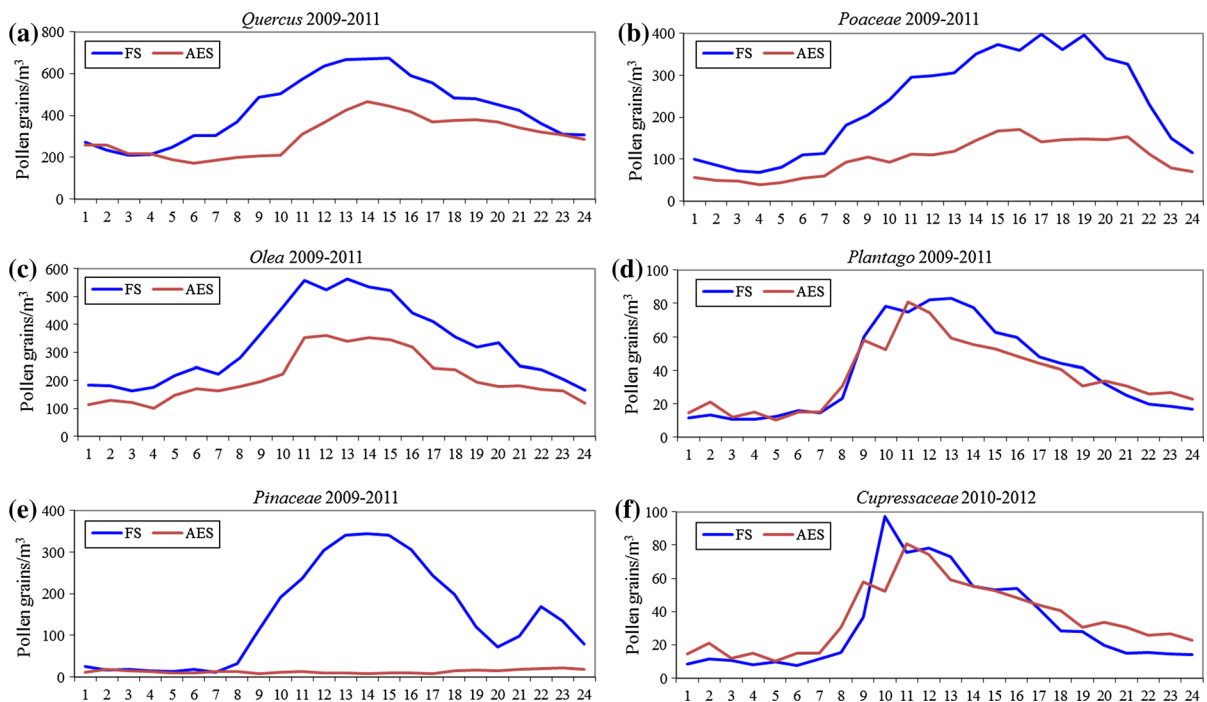
showed statistically significant differences (Table 6), the spring peak hourly concentrations were significantly correlated for all the pollen types studied (Table 7; Fig. 7b–e).

In the winter, the peak concentrations of Cupressaceae were also not registered on the same day (Fig. 7a). On average, the maximum concentrations appeared first 6 m above ground at the AES site at 12:42 h and then 16 m above ground at the FS site at 12:54 h. Some of the peak concentrations also occurred at night. A coincidence of peak concentrations at both samplers occurred on only three occasions: on 27 February 2010 at 10:00 h, on 19

Table 4 Spearman correlation test results comparing the daily concentrations of the predominant pollen types between the FS and the AES sites from 2010 to 2012

Period	Statist	Pollen type				
		Cupressaceae	<i>Fraxinus-Phillyrea</i>	Urticaceae spp.	<i>Alnus glutinosa</i>	<i>Urtica membranacea</i>
Winter 2010–2012	<i>r</i>	0.729**	0.344**	0.251**	0.447**	0.253**
	<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001
Period	Statist	<i>Quercus</i>	Poaceae	<i>Olea</i>	Pinaceae	<i>Plantago</i>
Spring 2009–2011	<i>r</i>	0.911**	0.850**	0.896**	0.558**	0.775**
	<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001

r values with ** when $p < 0.001$

**Fig. 6** Hourly variation of the concentration of **a** *Quercus*, **b** *Poaceae*, **c** *Olea*, **d** *Plantago*, **e** *Pinaceae* and **f** *Cupressaceae* pollen types on the FS and AES sites

February 2011 at 12:00 h and on 4 March 2012 at 13:00 h. With respect to the temporal variations, the average difference in the timing of the peak concentrations between the two samplers was 2.9 h, with the greatest difference being 13 h. Although there were statistically significant differences in the days of maximum hourly concentrations ($Z = -9.003$, $p < 0.001$), statistically significant correlations were also found ($r = 0.414^{**}$, $p < 0.001$) (Table 7; Fig. 7a).

Using the daily meteorological data, we found statistically significant correlations with the hourly

concentration of *Cupressaceae* for relative humidity, which was negatively correlated, and solar radiation, mean temperature, and wind speed, which were positively correlated (Fig. 7a). The wind direction, however, showed no statistically significant correlations. For the spring pollen types, the relative humidity also showed statistically significant negative correlation with the hourly concentrations of *Quercus*, *Poaceae*, *Olea* and *Plantago* (Fig. 7d), while the solar radiation, mean temperature (Fig. 7c) and wind speed (Fig. 7b) showed statistically significant positive correlations.

Table 5 Spearman test results, with all cases of statistically significant correlations, comparing the maximum hourly concentrations of *Quercus*, *Poaceae* and *Cupressaceae*, and the

meteorological parameters between the FS and the AES sites during the spring of 2009–2011 and the winter of 2010–2012, respectively

Pollen type	Parameters meteorological	Statist	Site studied					
			FS Spring 2009	AES	FS Spring 2010	AES	FS Spring 2011	AES
<i>Quercus</i>	Rh.	<i>r</i>	−0.432**	−0.547**	−0.430**	−0.325**	−0.310**	−0.427**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.001	<0.001
	T mean	<i>r</i>	0.693**	0.726**	0.210*	0.276**	0.327**	0.453**
		<i>p</i>	<0.001	<0.001	0.021	0.002	<0.001	<0.001
Poaceae	Rh.	<i>r</i>	−0.644**	−0.506**	−0.612**	−0.607**	−0.542**	−0.693**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Sr	<i>r</i>	0.582**	0.622**	0.461**	0.529**	0.532**	0.407**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	T mean	<i>r</i>	0.663**	0.547**	0.614**	0.589**	0.490**	0.564**
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Ws	<i>r</i>	0.459**	0.506**	0.495**	0.530**	0.237**	0.214*
		<i>p</i>	<0.001	<0.001	<0.001	<0.001	0.009	0.018
			Winter 2010		Winter 2011		Winter 2012	
Cupressaceae	Sr	<i>r</i>	0.409**	0.311**	0.659**	0.654**	0.646**	0.597**
		<i>p</i>	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
	T mean	<i>r</i>	0.213*	0.308**	0.557**	0.438**	0.602**	0.619**
		<i>p</i>	0.020	0.001	<0.001	<0.001	<0.001	<0.001

r values with ** when *p* < 0.001

4 Discussion

In the spring, 89 % of pollen grains corresponded to 5 predominant pollen types. This number of predominant pollen types is similar to those reported by other studies comparing spatially separated samplers: 5 (Galán et al. 1995), 4 (Gottardini et al. 1997), 6 (Alcázar et al. 1998), 7 (Arobba et al. 2000), 10 (Chakraborty et al. 2001), 6 (Thibaudon and Sulmont 2002), 4 (Jato et al. 2006) and 6 (Velasco-Jiménez et al. 2012). The remaining 11 % of pollen grains corresponded to minor pollen types, including those of typically entomophilous species, such as *Echium*, *Anthemidae* and *Lactuceae*, which release less pollen and therefore have a lower presence in the pollen spectrum (Kasprzyk 2004).

The statistically significant differences found in the interannual total mean concentrations in the winter and the spring could reflect the different weather conditions each year. The high rainfall in 2010 most

likely led to the delayed appearance of the principal pollen types as well as increases in their concentrations. A similar explanation has been invoked in the literature for such interannual differences (Fornaciari et al. 1996). Of the winter months, January had the lowest concentrations. Of the spring months, May had the maximum and June had the lowest concentrations. These results are consistent with other studies conducted in Mediterranean countries with similar climatic conditions, including Perugia in Italy (Fornaciari et al. 1996) and Évora in Portugal (Caeiro et al. 2007).

Although the daily values at the two sites were correlated, the differences in the two sets of concentrations were statistically significant. Other comparative studies involving distance have also reported similar differences (Fornaciari et al. 1996; Gottardini and Cristofolini 1997; Frenz et al. 1997; Arobba et al. 2000; Trigo et al. 2000; Velasco-Jiménez et al. 2012). Such differences in pollen counts could not be

Fig. 7 Hourly distribution of the peak concentrations of pollen types with some meteorological parameters: **a** *Cupressaceae* with wind speed; **b** *Quercus* with wind speed; **c** *Poaceae* with mean temperature; **d** *Plantago* with relative humidity; and **e** *Olea* with wind direction

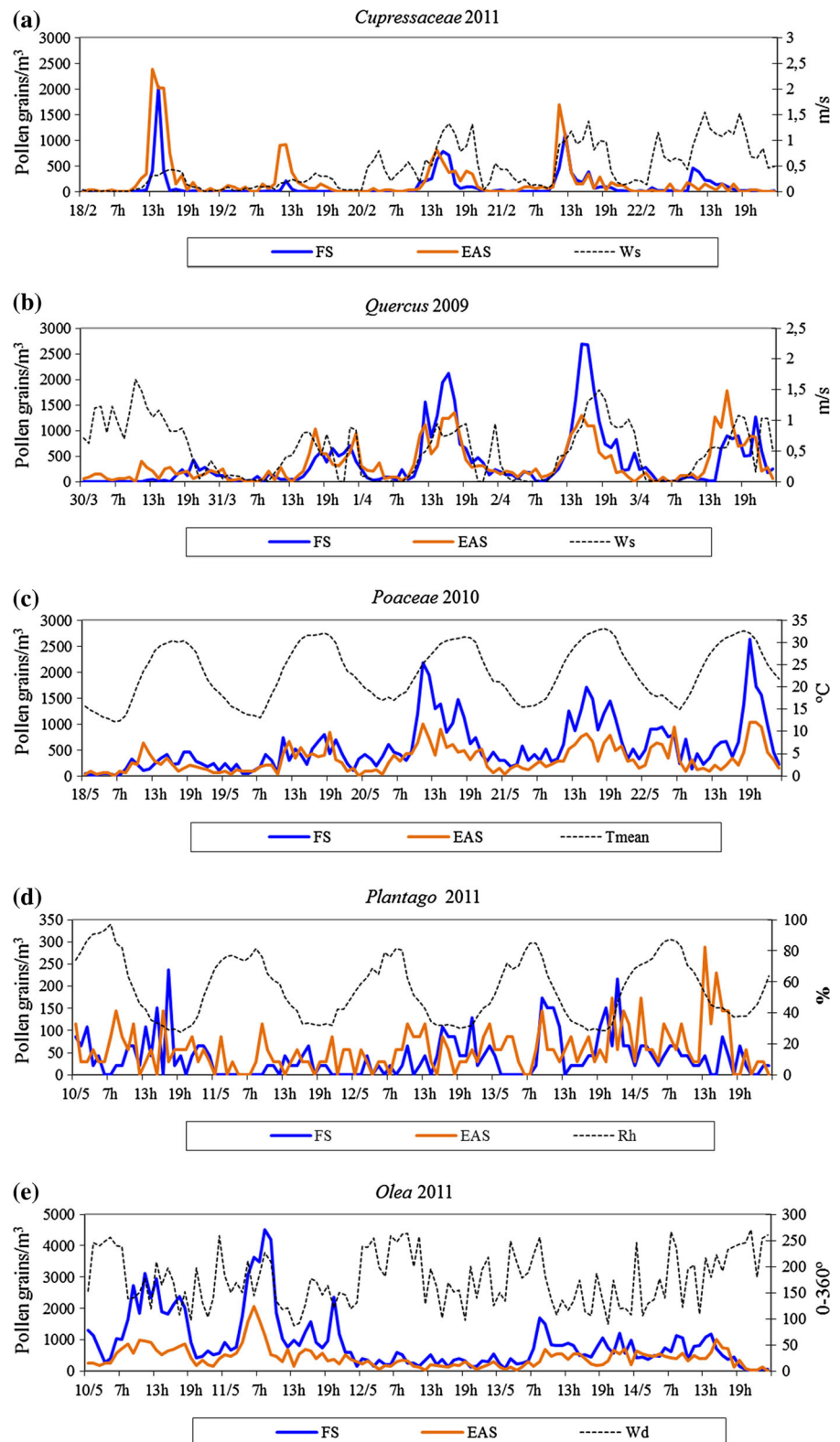


Table 6 Wilcoxon test results comparing the maximum hourly concentrations of the Cupressaceae, *Quercus*, Poaceae, *Olea* and *Plantago* pollen types between the FS and the AES sites during the maximum concentration peaks from 2010 to 2012

Statist	Pollen type				
	Cupressaceae	<i>Quercus</i>	Poaceae	<i>Olea</i>	<i>Plantago</i>
Z	−9.003	−2.761	−5.628	−11.544	−1.073
p	<0.001	0.006	<0.001	<0.001	0.283

Z values are in bold when $p < 0.05$

Table 7 Spearman test results comparing the maximum hourly concentrations of the *Quercus*, Poaceae, *Olea* and *Plantago* pollen types between the FS and the AES sites during the spring of 2009–2011

Statist	Pollen type			
	<i>Quercus</i>	Poaceae	<i>Olea</i>	<i>Plantago</i>
r	0.780**	0.746**	0.746**	0.346**
p	<0.001	<0.001	<0.001	<0.001

r values with ** when $p < 0.001$

explained by any weather differences between separate sites only a few kilometres apart and must instead be attributed to the different plant species or genera close to the sites.

In both the winter and the spring, except for *Alnus glutinosa*, the pollen types studied showed statistically significant differences in the mean concentrations between the two sites. These differences can be attributed to the heterogeneous distribution of the flora in the site surroundings, such as a greater presence of individuals of *Pinus* sp. and *Cupressus* sp. around the FS site than around the AES site (Figs. 2 and 3). In a similar comparative study, Trigo et al. (2000) found no statistically significant differences in *Olea*, Myrtaceae and Pinaceae and just a few differences in *Quercus* and Poaceae but found statistically significant differences in *Amaranthaceae*–*Chenopodiaceae*, *Plantago*, *Parietaria* and *Urtica membranacea*. Velasco-Jiménez et al. (2012) found differences in the *Platanus*, *Populus* and *Urticaceae* pollen types. Neither study, however, included a detailed analysis of the pollen sources.

Nonetheless, the statistically significant correlations found for all the major pollen types both in the spring and in the winter may indicate the similarity of the daily pollen concentration patterns in both parts of the city, a similarity that has also been reported in other studies (Gottardini and Cristofolini 1997; Frenz et al. 1997; Arobba et al. 2000; Velasco-Jiménez et al. 2012).

It is generally considered that peak pollen concentrations occur in the middle of the day (Galán et al. 1991). The present results record the maxima between 10:00 and 12:00 h for *Plantago* pollen, with *Quercus* and *Olea* pollen peaking between 13:00 and 15:00 h, and Poaceae pollen peaking between 15:00 and 17:00 h. Therefore, the mean of the maximum concentrations occurred between 10:00 and 17:00 h, although some maxima appeared at other times of day, even during the night. The winter pollen type studied, Cupressaceae, presented a maximum concentration between 10:00 and 11:00 h on the FS site and between 13:00 and 14:00 h on the AES site. These results are consistent with those reported by Galán et al. (1991), in which the maximum concentrations recorded in Córdoba (Spain) occurred in the afternoon (12:00 to 18:00 h).

Regarding the mean timing of the four spring pollen types studied (*Quercus*, *Olea*, Poaceae and *Plantago*), the maximum hourly concentrations appeared first on the AES site 6 m above ground and later on the FS site 16 m aboveground. The pollen of the winter-pollinating Cupressaceae also appeared in this order between the two sites, possibly due to the maximum concentrations occurring later with increasing height. The lag in the AES maximum hourly concentrations relative to those recorded by the FS sampler was, on average, 2.9 h in the winter and between 2.8 and 3 h in the spring. The greatest lags were 13 and 14 h in the winter and spring, respectively. The spatial separation may have an effect through the differences in the pollen sources and through the meteorological conditions being reflected in the seasonal and phenological behaviour of the pollen (Piotrowska 2004; Alcázar et al. 2009). The maximum hourly concentrations occurred at the same time on 3 occasions for Cupressaceae pollen in the winter and on 2 occasions for *Quercus*, *Olea*, Poaceae and *Plantago* in the spring.

Although the maxima of the hourly data were significantly different between the two sites, there were also statistically significant positive correlations between the two samplers. An explanation for these results could be that, although slight hourly variations in the concentrations can lead to statistically significant differences, these variations occur in the same way at both sites. The results may also be influenced by the phenology of the sources and by the wind transporting the pollen grains, as have been noted in other studies (Silva et al. 2007; Velasco-Jiménez et al. 2012). Indeed, the wind speed affected the maximum hourly concentrations of the pollen types studied, with statistically significant positive correlations in most cases; therefore, the wind is likely the driving factor. Similar correlations were found with solar radiation and mean temperature. The relative humidity presented statistically significant negative correlations. The other potential causes of the hourly variations are the pollen sources distributed around the samplers. *Quercus*, *Olea* and Cupressaceae trees are, however, distributed around both sites fairly uniformly. Thus, it would be difficult to consider their distribution as the cause of the temporal differences in the maximum concentrations observed. Furthermore, in the cases of *Quercus* and *Olea*, the pollen had to have been transported from distant areas and could therefore arrive at any time, thereby either contributing to enhancing the contributions of more local sources during the day or giving rise to high concentrations at night (Skjøth et al. 2009). There are never two sites with the exact same meteorological data. While the distance between the sites studied may be enough to affect the pollen record, we only have data from one site and should not extrapolate to the other. We consider the wind to be the most variable parameter in the spatial distribution.

Our results, therefore, are very similar to what was first indicated by Arobba et al. (2000) and subsequently supported by Velasco-Jiménez et al. (2012) in that a single sampling site measuring airborne pollen concentrations is sufficiently representative of large urban areas, even for sites more than 10 km apart, as long as only daily data are considered. Nonetheless, there are local variations in some pollen types with major differences in the timing of the peak concentrations that may be highly relevant allergologically.

5 Conclusions

We have analysed the variations in the measurements taken by two samplers 2.9 km apart in the city of Badajoz, including the influence of weather conditions and of the distribution of the pollen sources. The sampling of either one of the samplers can be considered representative of the entire city and its surrounding areas for the daily pollen concentrations. The hourly concentrations, however, presented major variations, and the timing of the peaks differed markedly between the two samplers. The heterogeneous distribution of the flora in different areas around the city can lead to differences in the pollen spectrum, particularly of the Pinaceae, Cupressaceae and *Alnus glutinosa* pollen types.

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