

Assessment between pollen seasons in areas with different urbanization level related to local vegetation sources and differences in allergen exposure

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Abstract Pollen data recorded by a single sampler in any given city often fail to reflect particular events occurring in surrounding areas. This is frequently overlooked when interpreting aerobiological results, and therefore pollen data obtained in urban areas may not necessarily be representative of the situation in more rural areas of the same city. Our purpose is to assess differences between allergenic pollen concentrations recorded in an urban area (Eskulap) and a rural/suburban (Morasko) of the same city from 2005 to 2007. Anova-Manova Scheffe, Spearman correlation and Mixed-design ANOVA within-subjects effects tests were applied. The results obtained have showed longer pollen seasons, earlier starts of flowering and later conclusion in the urban area. The participation of arboreal pollen in the pollen fall of both sites had enough significative similarities to determine that is linked to regional conditions, while differences in the atmospheric pollen content of herbaceous plants between sites should be due to local conditions.

Keywords Arboreal · Herbaceous · Pollen · Rural · Urban · Aerobiology

1 Introduction

The remarkable clinical impact of pollen allergies all over Europe has increased in recent years (D'Amato et al. 2007), and there is now considerable evidence to suggest that climate change will have a further substantial effect on the presence of aeroallergens, with higher pollen counts, greater pollen allergenicity and longer pollen seasons (Beggs 2004). Environmental conditions greatly affect the residents' quality of life (Cariñanos et al. 2002), and changes in vegetation composition and land use may increase the emission of airborne allergenic pollen grains (Hyde 1959), prompting a decline in the quality of life of allergy-sufferers as well as giving rise to higher socioeconomic costs (Cariñanos et al. 2002; Ring et al. 2001). Air pollution, which includes airborne allergens, is a key environmental determinant of asthma (Eder et al. 2006).

Aerobiological data are drawn largely from stations located in city centres, since most aerobiological research is concerned with allergies, and most city-dwellers live in or near city centres (Šikoparija et al. 2006). Few studies have addressed suburban or rural environments, or compared locations with differing

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levels of urbanization (Cariñanos et al. 2002; Kasprzyk 2006; Šikoparija et al. 2006; Oliveira and Ribeiro 2009). Nonetheless, a number of authors (Frenz 2000; Raynor et al. 1975; Emberlin and Norris-Hill 1991) have shown that pollen originating from outlying vegetation may have a significant effect on the urban pollen spectrum. Pollen data recorded by a single sampler in any given city often fail to reflect particular events occurring in surrounding areas (Cariñanos et al. 2002). This is frequently overlooked when interpreting aerobiological results, and therefore, pollen data obtained in urban areas may not necessarily be representative of the situation in more rural areas of the same city.

In towns, floral biodiversity is reduced, and pollen sources are relatively scarce (Kasprzyk 2006), although pollen types from a number of tree and shrub species may be quite abundant (Nitiu and Mallo 2002; Mimet et al. 2009). Moreover, particular pollen deposition and dispersal patterns occur in towns, due to the so-called urban heat island phenomenon, characterized by higher temperatures, reduced levels of relative air humidity and more specific thermal winds than in open spaces, giving rise to a longer vegetative period (Unger 1999; Mimet et al. 2009). Additionally, increased turbulence in cities caused by the characteristic thermal wind patterns can transport pollen grains from suburban areas into the town centre (Emberlin and Norris-Hill 1991), delaying intradiurnal pollen peaks. Comparisons of pollen counts at stations located in a town, in a village and in a rural area (e.g. Kasprzyk 1999) have noted minor differences in taxonomic composition but considerable quantitative differences, especially in the case of herbaceous pollen content (Emberlin and Norris-Hill 1991; Hart et al. 1994; Spieksma et al. 2000; Cariñanos et al. 2002; Kasprzyk 2006; Šikoparija et al. 2006). On the basis of these findings, the generally accepted conclusion is that the contribution of tree pollens to the overall pollen count reflects regional conditions, while the contribution of herbaceous plant pollen reflects local conditions (Hicks 1991).

In order to ascertain to what extent observed differences in airborne pollen counts between two sites in the same city might influence the performance of predictive models and/or the allergenic risk to which inhabitants of different parts of a city are exposed, it is essential to estimate the level of

confidence that should be applied when records from only one sampling site are used to represent other sites. The aim of this study was to assess the strength of the correlation between pollen sampler location and airborne pollen counts obtained from an urban and a rural/suburban area in the city of Poznan (Poland).

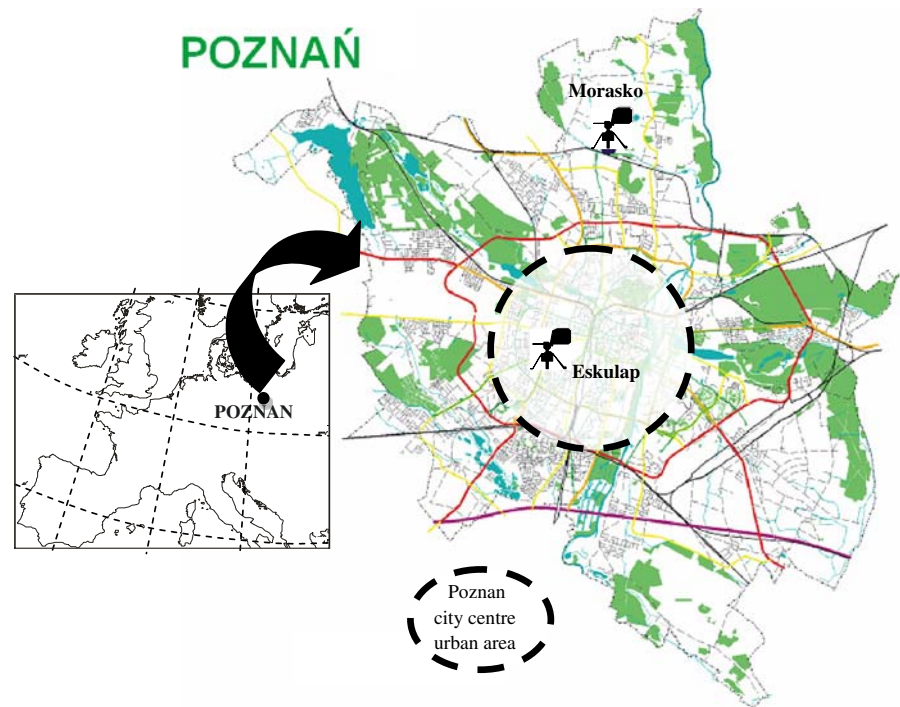
2 Materials and methods

Poznan is located in Western Poland (52°25' north, 16°53' east) situated 80 m above sea level. The city presents a population of 578,235 inhabitants and is the capital of Wielkopolska (population 3,350,437), a region situated in midwestern Poland. The mean annual precipitation is below 500 mm, and the average yearly temperature is 8.5°C. Average January and July temperatures are −1.4 and 19.2°C, respectively. Prevailing wind directions are from the west and southwest. The Institute of Meteorology and Water Management supplied Poznan meteorological data from a station located 1.5 km west of the aerobiological station at Ławica Airport (52°25'N 16°49'E).

Daily average pollen concentrations were collected at two sites in Poznan using Hirst type Burkard volumetric spore traps (Hirst 1952). The first sampler was sited in a representative urban area of the city centre, Eskulap, on the roof of a 13 storey university students' dormitory (52°24'N, 16°53'E) at a height of about 33 m (Corden et al. 2002). It is surrounded by 4–8 storey buildings, roads and two small parks with ornamental and no-ornamental trees, shrubs and herbaceous species. The second trap was placed in a representative rural/suburban area of the city northern outskirts (52°27'N, 16°55'E), on the roof (height 22 m) of a building in the new university Morasko campus. The sampler is surrounded by some small buildings or greenhouses. Morasko is situated in an open area that is a mixture of green grassland, small crop producing fields and coniferous woodland with isolated stands of deciduous trees. The distance between Eskulap and Morasko is approximately 8 km (Fig. 1).

The study was conducted during the years 2005–2007, by selecting 6 pollen types considered as the most common sources of pollinosis in the area of Poznan (Obtułowicz et al. 1991; Obtułowicz 1994;

Fig. 1 Location of the sampling points in the city of Poznan. The urban area is marked with a discontinuous circle



Piotrowska and Weryszko-Chmielewska 2006). Three of them correspond to arboreal taxa (*Alnus*, *Corylus* and *Betula*) and the rest herbaceous pollen types (*Poaceae*, *Rumex* and *Artemisia*). In the temperate climatic zone of the Northern Hemisphere, trees belonging to *Betulaceae* family are important sources of allergenic pollen (Matthiesen et al. 1991; D'Amato and Spieksma 1992). Exposure to the pollen of hazel and alder, which are the earliest of the *Betulaceae* family to flower, can effectively extend the pollen season of an important aeroallergen as birch (Emberlin et al. 1997; Adams-Groom et al. 2002). Grass pollen is the major cause of pollinosis in many parts of the world, inducing severe clinical hypersensitivity over 50 grains/m³ (Davies and Smith 1973). *Rumex* could induce allergy episodes even with low atmospheric pollen concentrations as some species of this family are holders of higher allergenic capacity than *Poaceae* (Lewis et al. 1983). Finally, mugwort is an anemophilous genus included in the *Compositae* family, considered as one of the main causes of pollinosis in Poland (Piotrowska and Weryszko-Chmielewska 2006).

The data of these selected taxa were organized in two time period sets with the aim to analyse similarities and differences related to the intradiurnal

and seasonal airborne pollen behaviour between both sampling sites. The pollen grains were counted following the model proposed by the Spanish Aero-biological Network based on four longitudinal transects along the slides (Domínguez et al. 1991).

The method described by Andersen (1991) was taken into account to obtain the main pollen season. It includes 95% of the total pollen collected, eliminating the initial period until 2.5% is attained and the final period once 97.5% has been attained. It was considered necessary to eliminate the long tails of low values at the start and the end of the seasons that may introduce bias to the results during statistical analysis (Sanchez-Mesa et al. 2003). With the aim to define the characteristics of the main pollen season, several parameters were considered such as start, end and length, the maximum mean daily pollen concentration recorded for each pollen type and year as well as the day in which the maximum was reached, the number of days with concentration higher than 50 pollen grains/m³ (value suggested by Davies and Smith (1973) as the threshold for many taxa to detect severe clinical pollinosis episodes among sensitized people) and the annual total pollen index.

In order to know the variations of the pollen concentration throughout the day, we followed the

model proposed by Galán et al. (1991), which select during the three years studied the days on which the pollen concentration is greater than the annual mean of the main pollen season and, within such, the days without rainfall. The resulting days were used to calculate the mean concentration every 2 h, thereafter expressing the data as percentages.

Anova-Manova Scheffe and Mixed-design ANOVA within-subjects effects tests were performed with the aim to assess the magnitude of differences between samples sites, considering as variables the aforementioned parameters selected to describe the pollen season as well as the shape of the pollen curves. The sphericity assumption of the Mixed-design ANOVA within-subjects effects test shows that the standard deviation of each of these sets of difference variables (1 vs. 2, 1 vs. 3, etc.) is a constant, and a significant value implies that all variables are not independent. The Greenhouse-Geisser and Huynh-Feldt corrections index are two ways to adjust downwards the degrees of freedom to correct for violations of the sphericity assumption.

Spearman nonparametric correlation test was used to detect possible relationships between daily mean airborne pollen levels and the main weather-related factors: rainfall (mm), relative humidity (%), maximum, minimum and mean temperatures (°C) and wind speed (m/s). Weather conditions may affect pollen release and dispersion directly or indirectly. Therefore, this study also determined the correlation between pollen counts for a given day and the main weather-parameter values for the previous five days. Significance was calculated for $P \leq 0.05$ and $P \leq 0.1$, respectively. Finally, the correlations coefficients obtained were analysed by means Anova-Manova Scheffe test in order to highlight which meteorological variables could be used to show differences between pollen records in both sampling sites. All statistical analyses were performed by means the SPSS 15.0 statistical software package.

3 Results

Pollen data obtained from monitoring stations located at sites differing in terms of local vegetation, degree of urbanization and microclimate were evaluated. Table 1 provides an overview of the key features of the main pollen season. The pollen season started

earlier in the urban area of Eskulap than in the rural/suburban area of Morasko, for all pollen types and in all years. The most similar start-dates between the two areas were found for arboreal taxa with the exception of *Corylus*, due to the anomalous flowering recorded in 2006 in the Eskulap area compared with the average. In general terms, pollen-season end-dates varied widely, although the closest dates between areas were recorded for tree species. The pollen season tended to last longer in the Eskulap area than in the Morasko area, for most pollen types and years. Pollen-count peaks were generally higher in the rural area than in the urban area for most pollen types and years, with the exception of *Corylus* in 2006. Nonetheless, pollen-peak dates were very similar in the two areas for tree pollen types, whereas considerable differences in peak dates were found for herbaceous pollens (as much as 8 days' difference in the case of *Artemisia*). With regard to pollen-season severity, there were more days with counts of over 50 pollen grains/m³ in the rural area (Morasko) for all herbaceous pollen types and years. Results for tree pollens were similar for the two areas. Finally, the annual pollen index was mostly higher in the Morasko area than in the Eskulap area for most pollen types and years, with the exception of *Corylus* in the year 2005 (Table 1). The annual pollen indices for the two areas were more similar for tree species than for herbaceous plants (Figure 2).

In order to assess the magnitude of differences between samples sites in terms of the parameters established for the main pollen season, Anova-Manova Scheffe tests were performed (Table 2). The results indicated highly significant differences in the aerobiological behaviour of *Rumex* between the two areas for four features of the main pollen season; the only significant difference in the case of *Betula* was for pollen-season length. A similar analysis (Table 3) was performed taking into account the shape of the pollen curve plotted using average daily mean pollen counts (Fig. 3). Differences between sites for average daily variations in pollen counts displayed highly significant differences not only for *Rumex* (both for each year and for the whole three-year period) but also for *Artemisia* in the three-year period as a whole. Differences in tree pollen-curve shapes between areas were not significant; only herbaceous pollen curves displayed significant inter-site differences.

Table 1 Characteristics of the main pollen season of the selected taxa in the urban area of Eskulap and the rural/suburban of Morasko

	<i>Alnus</i>		<i>Corylus</i>		<i>Betula</i>		Poaceae		<i>Rumex</i>		<i>Artemisia</i>	
	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko
Date start pollen season												
2005	16-Mar	17-Mar	25-Jan	6-Mar	14-Apr	15-Apr	28-May	30-May	28-May	30-May	19-Jul	22-Jul
2006	27-Mar	27-Mar	27-Mar	27-Mar	20-Apr	21-Apr	26-May	9-Jun	22-May	30-May	15-Jul	23-Jul
2007	17-Feb	18-Feb	10-Jan	12-Jan	9-Apr	11-Apr	20-May	21-May	17-May	20-May	20-Jul	23-Jul
	10-Mar	11-Mar	9-Feb	24-Feb	14-Apr	15-Apr	24-May	30-May	22-May	26-May	18-Jul	22-Jul
Date final pollen season												
2005	8-Apr	7-Apr	17-Apr	16-Apr	9-May	5-May	8-Aug	16-Aug	7-Sep	4-Sep	7-Sep	3-Sep
2006	10-Apr	13-Apr	12-Apr	9-Apr	14-May	12-May	6-Sep	14-Aug	4-Sep	7-Sep	24-Sep	17-Sep
2007	28-Mar	27-Mar	26-Mar	25-Mar	5-May	30-Apr	7-Aug	24-Jul	26-Aug	5-Sep	24-Aug	26-Aug
	5-Apr	5-Apr	8-Apr	6-Apr	9-May	5-May	17-Aug	7-Aug	2-Sep	5-Sep	8-Sep	5-Sep
Length pollen season												
2005	24	22	83	42	26	21	73	79	103	98	51	44
2006	15	18	17	14	25	22	104	67	106	101	72	57
2007	40	38	76	73	27	20	80	65	102	109	36	35
	26	26	59	43	26	21	86	70	104	103	53	45
Maximum concentration												
2005	607	1,111	49	50	506	583	327	363	35	83	49	59
2006	648	985	138	108	2,167	4,205	135	214	53	125	45	83
2007	223	318	26	27	1,045	1,269	250	378	43	52	136	137
	492	804	71	62	1,239	2,019	237	318	44	86	77	93
Day of the maximum concentration												
2005	26-Mar	26-Mar	27-Mar	19-Mar	17-Apr	17-Apr	25-Jun	28-Jun	13-Jul	22-Jun	3-Aug	22-Aug
2006	29-Mar	1-Apr	29-Mar	29-Mar	22-Apr	22-Apr	26-Jun	26-Jun	15-Jun	26-Jun	14-Aug	18-Aug
2007	7-Mar	7-Mar	18-Feb	18-Feb	17-Apr	17-Apr	21-Jun	21-Jun	6-Jun	7-Jul	8-Aug	8-Aug
	20-Mar	21-Mar	15-Mar	12-Mar	18-Apr	18-Apr	24-Jun	25-Jun	21-Jun	28-Jun	8-Aug	16-Aug
Number of days with concentrations up to 50 pollen/m ³												
2005	18	18	0	0	15	17	34	34	0	5	0	1
2006	10	11	3	3	22	20	17	20	1	12	0	5
2007	8	7	0	0	16	17	26	37	0	2	12	16
	12	12	1	1	18	18	26	30	0	6	4	7

Table 1 continued

	<i>Alnus</i>		<i>Corylus</i>		<i>Betula</i>		<i>Poaceae</i>		<i>Rumex</i>		<i>Artemisia</i>	
	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko
Annual pollen index												
2005	3,849	5,243	391	335	3,206	3,232	5,252	5,364	1,154	1,913	772	1,185
2006	3,469	4,993	369	397	16,514	25,345	2,586	2,587	1,152	2,137	849	1,129
2007	1,306	1,477	276	317	5,896	6,406	3,943	5,816	1,163	1,901	1,549	2,076
	2,875	3,904	345	350	8,539	11,661	3,927	4,589	1,156	1,984	1,057	1,463

Calculated according the 95% method (Andersen 1991)

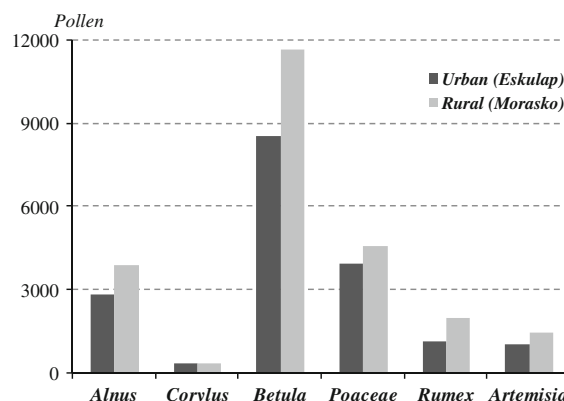


Fig. 2 Average total pollen index value (2005–2007) in the urban area of Eskulap and the rural/suburban of Morasko

Daily pollen counts throughout the season were also analysed by means of R-squared values in order to ascertain the degree of association between the records obtained at Eskulap and Morasko (Fig. 4). The coefficients confirmed the results obtained previously with the Anova-Manova Scheffe test. The degree of association obtained from urban/rural areas accounted for the behaviour of pollen counts for tree species to a greater degree (93–87%) than for herbaceous taxa (*Poaceae* 76%, *Artemisia* 71%). Once again *Rumex* recorded the lowest degree of association (55%).

Variations in intradiurnal pollen counts are compared in Fig. 5. A general model is presented, calculated using mean bi-hourly values for the 3 study years, since the behaviour pattern was fairly constant throughout the study period. Intradiurnal variations displayed greater inter-site similarity for tree species than for herbaceous species. The disparity in intradiurnal pollen peaks was more marked in herbaceous plants, and especially in *Rumex* and *Poaceae*: peak counts were reached earlier in Morasko, with a rapid increase in counts for all pollen types, and especially for herbaceous taxa. Therefore, values for average kurtosis of the shape of the intradiurnal pollen curve in the rural area were higher (kurtosis = 0.38) than those recorded in Eskulap (kurtosis = 0.61). Average values for skewness, indicating the asymmetry of the pollen curve, were lower in the rural areas (skewness = −0.45) than in the urban area (skewness = −0.67), suggesting that the rise and fall in pollen counts occurred more gradually in the urban area.

Table 2 Values of the Anova-Manova Scheffe test coefficients to show differences between populations, taking into account the characteristics of the main pollen season (* $P < 0.05$, ** $P < 0.01$)

<i>Alnus</i>	<i>Corylus</i>	<i>Betula</i>	Poaceae	<i>Rumex</i>	<i>Artemisia</i>
Date start pollen season					
39517.33	39576.00	39601.67	39590.33	39647.00	39592.67
0.969	0.5794034	0.809	0.4001445	0.041*	0.366
Date final pollen season					
39641.33	39624.67	39617.00	39623.67	39679.00	39637.67
0.342	0.762	0.771	0.498	0.548	0.186
Length pollen season					
26.33333	58.66667	26.00000	103.6667	53.00000	85.66666
0.974	0.593	0.004**	0.789	0.565	0.213
Annual pollen index					
2875.667	346.3333	8542.333	1061.000	1165.667	3976.000
0.517	0.934	0.713	0.306	0.000**	0.650
Number of days with concentrations up to 50 pollen/m ³					
14.00000	3.000000	22.66667	23.66667	25.33333	40.33333
1.000	1.000	0.786	0.125	0.012*	0.739
Maximum concentration					
804.4333	61.72000	2019.073	93.01667	86.30000	318.3267
0.329	0.833	0.555	0.689	0.122	0.346
Day of the maximum concentration					
26383.33	39519.33	103.3333	39624.00	104.0000	39618.00
0.374	0.888	1.000	0.718	0.070	0.858

Table 3 Values of the Anova-Manova Scheffe test coefficients to show differences between populations, taking into account the average daily pollen concentrations for each year separately and considering the three years altogether (* $P < 0.05$, ** $P < 0.01$)

	<i>Alnus</i>	<i>Corylus</i>	<i>Betula</i>	Poaceae	<i>Rumex</i>	<i>Artemisia</i>
2005–2007	15.50000	1.388889	46.38492	18.24735	7.916667	5.972222
	0.310	0.932	0.305	0.269	0.000**	0.023*
2005	22.69697	1.454545	14.51948	8.246032	8.341991	23.30303
	0.484	0.736	0.907	0.910	0.002**	0.271
2006	18.30769	1.454212	92.69231	9.487180	7.868132	4.575091
	0.493	0.907	0.306	0.995	0.004**	0.116
2007	5.861111	1.454545	25.42857	23.10317	7.579365	8.246032
	0.763	0.736	0.861	0.100	0.001**	0.271

The Anova-Manova Scheffe test performed with hourly data showed no difference between sample sites, either for herbaceous or for arboreal taxa.

Finally, Spearman's correlation test was applied to mean daily pollen counts in order to test for correlations between pollen counts and major weather-related parameters. The results are summarized in Table 4, which indicates the correlation

coefficient for the two sampling locations. Correlations between pollen counts and weather parameters over the previous 1, 2, 3, 4 and 5 previous days are also included. Correlations were significant in a large number of cases; Spearman coefficient values were higher for *Rumex* in the Morasko area, and no significative correlations were found for *Artemisia* in the Morasko area. The Anova-Manova Scheffe test

Fig. 3 Average daily mean pollen concentration of the six more allergenic taxa of Poznan during the years studied

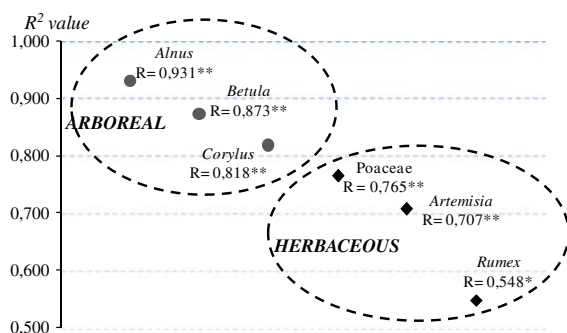
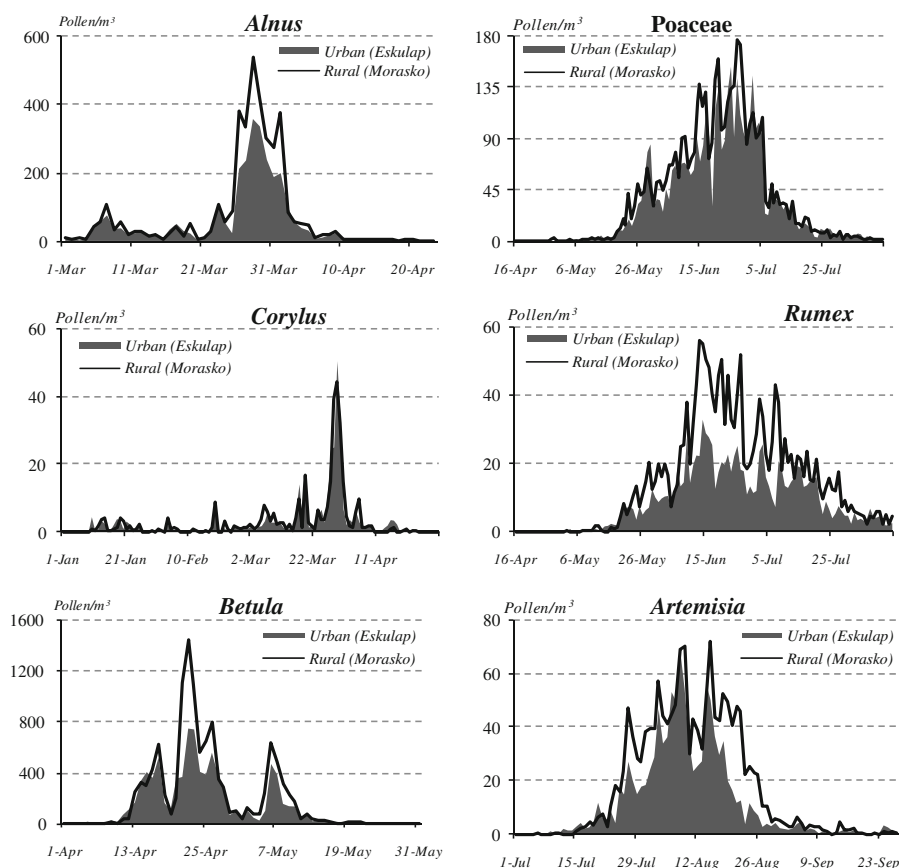


Fig. 4 R-square coefficient values between pollen data of the urban and rural locations (* $P < 0.05$; ** $P < 0.01$)

applied to correlation coefficient data, to check for possible inter-site differences in correlations between daily pollen counts and major weather parameters detected considerable differences in correlations between pollen counts and temperature for *Alnus* and *Artemisia*, although not for *Corylus*, *Betula* and *Rumex* (Table 5). *Corylus* appeared to be the only pollen type strongly and variously affected by

differences in humidity between sites. The most significant inter-site differences for wind speed were found for *Betula*, *Poaceae* and *Rumex*.

4 Discussion

Most aerobiological information comes from stations located within urban areas. In allergy-related research, pollen data are sometimes extrapolated to nearby areas with similar weather conditions but different types of vegetation and different levels of urbanization. This may be misleading, since the pollen spectrum recorded by a single sampler in a given city frequently fails to reflect particular events that may occur in surrounding areas, given that pollen from nearby vegetation may exert a profound local influence. A mixed-design ANOVA within-subjects effects test applied to all study data (Table 6) revealed no difference between pollen counts as a function of the urban or rural location of the sampler.

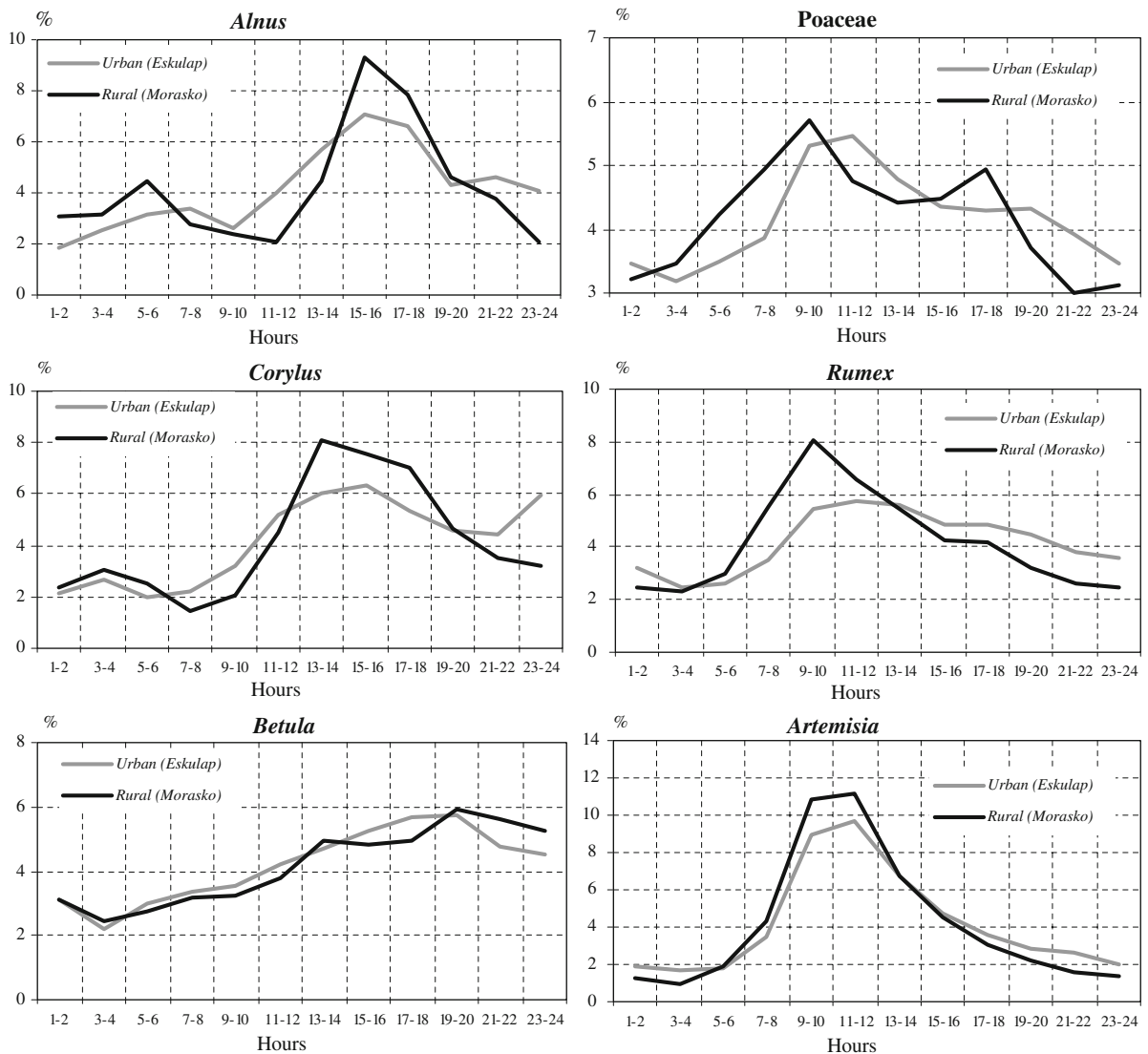


Fig. 5 The evolution of the average pollen concentrations followed throughout the day for all taxa expressed as percentage

However, significant differences were observed when comparing sampler location, pollen counts and year-on-year variations; this was due largely to variations in pollen counts prompted by the influence of temperature (Glassheim et al. 1995).

Nevertheless, as the results obtained here show, careful analysis of pollen-count behaviour reveals differences between rural and urban environments, despite their physical proximity, due mainly to differences in local vegetation and microclimate. Previous studies have detected, directly or indirectly, an interaction effect of urbanization on pollen-season

timing and pollen counts (Cariñanos et al. 2002), daily pollen cycles (Kasprzyk 1999; Cariñanos et al. 2002; Kasprzyk 2006; Šikoparija et al. 2006; Hicks 1991), plant growth and productivity (Ziska et al. 2003; Ziska et al. 2004) in rural or suburban areas. The so-called urban heat island effect, caused by a combination of factors such as accumulated heat irradiation (e.g. from tarmac and concrete structures), reduced levels of relative air humidity and specific thermal winds, gives rise to longer vegetative periods (Glassheim et al. 1995; Mimet et al. 2009; Ziska et al. 2004; Oliveira and Ribeiro 2009). The present results

Table 4 Correlation coefficients between pollen concentration and meteorological parameters during the pollen season considering the 3 years altogether in the urban area of Eskulap and the rural/suburban of Morasko (Spearman's coefficients * $P < 0.05$, ** $P < 0.01$). Correlations with the meteorological values of one, two, three, four and five preceding days were considered

	<i>Alnus</i>		<i>Corylus</i>		<i>Betula</i>		<i>Poaceae</i>		<i>Rumex</i>		<i>Artemisia</i>	
	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap
<i>Rainfall</i>												
Rainfall-1	-0.014	-0.128	-0.221*	-0.060	0.072	0.051	-0.116	-0.127*	-0.144*	-0.074	-0.241*	-0.079
Rainfall-2	-0.015	-0.188	-0.173	-0.127	0.052	0.093	-0.091	-0.108	-0.109	-0.040	-0.160	-0.083
Rainfall-3	0.005	-0.223	-0.065	-0.162	0.139	0.111	-0.068	-0.056	-0.111	0.023	-0.136	-0.151
Rainfall-4	0.034	-0.125	0.066	-0.058	0.028	0.034	-0.083	-0.069	-0.116	-0.012	-0.153	-0.114
Rainfall-5	0.051	-0.020	0.122	0.042	0.012	0.017	-0.063	-0.083	-0.140*	0.003	-0.135	-0.113
<i>Humidity %</i>												
Humidity-1	0.003	0.020	0.019	0.023	-0.023	-0.001	-0.093	-0.055	-0.067	0.015	-0.084	-0.129
Humidity-2	0.041	-0.080	-0.231*	-0.329**	-0.306**	-0.247**	-0.423**	-0.477**	-0.462**	-0.462**	-0.046	-0.058
Humidity-3	0.115	0.009	-0.017	-0.132	-0.283**	-0.197*	-0.365**	-0.418**	-0.399**	-0.383**	-0.030	-0.040
Humidity-4	0.174	0.107	0.133	-0.088	-0.189	-0.100	-0.275**	-0.282**	-0.329**	-0.299**	0.022	0.022
Humidity-5	0.211*	0.143	0.121	-0.116	-0.155	-0.004	-0.201**	-0.257**	-0.304**	-0.234**	0.045	0.081
<i>Mean Temp</i>												
Mean T-1	0.162	0.143	0.085	-0.063	0.006	0.124	-0.127*	-0.227**	-0.281**	-0.166**	-0.031	0.013
Mean T-2	0.192*	0.144	0.068	0.006	-0.027	0.147	-0.046	-0.187**	-0.234**	-0.114	0.001	0.049
Mean T-3	0.051	0.341**	0.338**	0.243**	0.161	0.268**	0.262**	0.210**	0.265**	0.373**	0.306**	0.160
Mean T-4	-0.016	0.237*	0.311**	0.224*	0.113	0.230*	0.209**	0.143*	0.184**	0.278**	0.280**	0.110
Mean T-5	-0.066	0.078	0.228*	0.141	0.044	0.120	0.095	0.057	0.092	0.159*	0.243**	0.052
Mean T-6	-0.179	-0.039	0.167*	0.109	-0.002	-0.005	0.067	0.024	0.083	0.095	0.159	-0.022
Mean T-7	-0.230*	-0.078	0.076	0.078	-0.081	-0.186	0.058	-0.010	0.076	0.037	0.118	-0.031
Mean T-8	-0.276**	-0.099	0.007	0.002	-0.117	-0.297**	0.059	-0.022	0.024	0.004	0.076	-0.069
<i>Maximum Temp</i>												
Max T-1	0.080	0.369**	0.362**	0.268**	0.210*	0.347**	0.274**	0.257**	0.312**	0.404**	0.245**	0.171
Max T-2	0.003	0.246*	0.296**	0.219*	0.159	0.293**	0.210**	0.188**	0.226**	0.306**	0.219**	0.112
Max T-3	-0.037	0.104	0.200*	0.114	0.100	0.165*	0.082	0.087	0.115*	0.179**	0.191*	0.019
Max T-4	-0.171	-0.028	0.128	0.104	0.046	0.051	0.087	0.070	0.107	0.131*	0.122	-0.048
Max T-5	-0.174	-0.025	0.081	0.105	-0.038	-0.127	0.084	0.029	0.113	0.072	0.116	-0.033
Max T-6	-0.253**	-0.080	-0.034	0.001	-0.057	-0.274**	0.067	0.020	0.075	0.037	0.067	-0.089
<i>Minimum Temp</i>												
Min T-1	0.066	0.188	0.283**	0.196*	0.026	0.011	0.131	0.029	0.073	0.188**	0.265**	0.075
Min T-2	-0.041	0.059	0.232*	0.148	-0.055	-0.052	0.054	-0.039	-0.032	0.070	0.233**	0.079
Min T-3	-0.060	-0.002	0.225*	0.089	-0.078	-0.111	0.013	-0.082	-0.085	0.013	0.213*	0.052
Min T-4	-0.165	-0.081	0.170	0.062	-0.090	-0.189	-0.018	-0.120	-0.068	-0.039	0.107	0.037
Min T-5	-0.205*	-0.091	0.084	0.027	-0.057	-0.250**	-0.021	-0.134*	-0.083	-0.091	0.065	-0.040
Min T-6	-0.230*	-0.091	0.037	-0.021	-0.117	-0.257**	0.019	-0.122	-0.127*	-0.111	0.055	-0.006

Table 4 continued

	<i>Alnus</i>		<i>Corylus</i>		<i>Betula</i>		<i>Poaceae</i>		<i>Rumex</i>		<i>Artemisia</i>	
	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap	Morasko	Eskulap
<i>Wind velocity</i>	0.073	-0.017	0.110	0.014	0.025	-0.090	0.073	0.086	0.021	-0.016	-0.137	-0.075
<i>Wveloc-1</i>	-0.084	-0.128	-0.134	-0.167	-0.007	-0.111	0.001	0.057	-0.031	-0.102	-0.166*	-0.163
<i>Wveloc-2</i>	-0.129	-0.171	-0.133	-0.158	-0.044	-0.227*	0.038	0.069	-0.024	-0.096	-0.141	-0.113
<i>Wveloc-3</i>	-0.090	-0.086	-0.105	-0.133	-0.097	-0.160	0.096	0.095	-0.001	-0.052	-0.153*	-0.135
<i>Wveloc-4</i>	-0.082	-0.013	-0.172	-0.252**	-0.108	-0.167	0.068	0.121*	0.036	0.014	-0.117	-0.141
<i>Wveloc-5</i>	0.012	0.139	-0.039	-0.131	-0.057	-0.008	-0.043	0.102	0.017	-0.001	-0.129	-0.066

Table 5 Values of the Anova-Manova Scheffe test coefficients, taking into account the values of the Spearman coefficient correlation coefficients (* $P < 0.05$, ** $P < 0.01$)

	Temperature	Rainfall	Humidity	Wind speed
<i>Alnus</i>	-0.091052 0.036*	-0.040195 0.093	0.2104183 0.830	-0.059263 0.961
<i>Corylus</i>	0.1415851 0.105	-0.046416 0.945	0.1740818 0.007**	-0.034577 0.429
<i>Betula</i>	-0.235680 0.120	-0.062382 0.789	-0.043699 0.539	-0.025965 0.012*
<i>Poaceae</i>	0.0094477 0.580	-0.034819 0.754	-0.237077 0.302	0.1160381 0.068*
<i>Rumex</i>	-0.032604 0.111	-0.039348 0.859	-0.311772 0.159	-0.025640 0.005**
<i>Artemisia</i>	0.0741408 0.045*	-0.000343 0.896	-0.009447 0.934	-0.077252 0.500

confirm that trend: pollen seasons were longer in the urban area of Eskulap than in rural area of Morasko, for all pollen types in almost all years. Pollen seasons started earlier and ended later, suggesting that the conditions for pollen production and release were achieved earlier in the urban area and were also kept up for longer periods of time (Hyde 1959; Cariñanos et al. 2002; Kasprzyk 2006).

Considerable quantitative differences have been reported between sites, especially for herbaceous pollens, even when differences in taxonomic composition are minor (Kasprzyk 1999). Here, the total amount of pollen recorded over the three years, the number of days with concentrations higher than 50 pollen/m³ and the statistical results showed higher concentrations of pollen in the rural area than in the urban area, especially in the case of herbaceous taxa. Similarly, a number of authors (Unger 1999; Ziska et al. 2003, 2004) have reported the interaction effect of higher temperatures and CO₂ concentrations in urban areas on increasing growth rates in plants. Studies by Kasprzyk (2006) and Hicks (1991) have shown that in towns, where floral biodiversity is reduced and pollen sources are relatively scarce, the contribution of tree pollen to airborne pollen counts appears to reflect regional conditions, while the contribution of herbaceous pollens reflects local conditions. Here, the presence of Poaceae in urban green areas constitutes an important source of pollen, matching the concentrations observed in the rural area (mostly covered by forest).

Table 6 Values of the tests of within-subjects effects (* $P < 0.05$, ** $P < 0.01$)

		<i>df</i>	Mean square	<i>F</i>	<i>P</i> <
Location/pollen/year	Sphericity assumed	10	6,609	4.3	0.000**
	Greenhouse-Geisser	2	27,763	4.3	0.010**
	Huynh–Feldt	3	26,346	4.3	0.009**
Pollen/year	Sphericity assumed	10	85,623	4.5	0.000**
	Greenhouse-Geisser	3	331,307	4.5	0.006**
	Huynh–Feldt	3	314,293	4.5	0.005**
Location/pollen	Sphericity assumed	5	274	0.2	0.971
	Greenhouse-Geisser	1	1,150	0.2	0.718
	Huynh–Feldt	1	1,091	0.2	0.731
Pollen/average <i>T</i> .	Sphericity assumed	5	63,254	3.3	0.005**
	Greenhouse-Geisser	1	244,755	3.3	0.056
	Huynh–Feldt	1	232,186	3.3	0.054

The effect of urbanization on intradaily dynamic pollen concentration cycles has been stressed by several authors (Emberlin and Norris-Hill 1991; Spieksma et al. 2000; Cariñanos et al. 2002). Their findings point to a delay in intradiurnal pollen peaks in urban areas compared to rural areas, caused by increased turbulence in cities as a result of thermal wind systems, which would transport pollen grains from suburban areas into the town centre (Emberlin and Norris-Hill 1991). The results obtained here showed that delays in reaching diurnal pollen peaks were more marked for herbaceous plants than for tree species, and particularly for *Rumex* and Poaceae. This situation reinforces the idea that the pollen counts for these two herbaceous plants reflect local conditions and that the importance of their presence in the area might be overlooked if only records from urban sampling sites are taken into account (Cariñanos et al. 2002).

Although peaks may be less elevated in urban than in rural areas, the patterns illustrating hourly variations suggest that the number of hours in the day that sensitized people are exposed to allergenic pollen levels is still higher in urban areas (Cariñanos et al. 2002). Recent studies have noted the “priming effect” by which the concentration thresholds triggering allergenic symptoms in sensitized people decrease as the period of exposure to the allergens increases (Connell 1969; Subiza 2001). The results suggesting longer pollen seasons and prolonged high levels of pollen throughout the day in the urban area suggest that sensitization by overexposure could potentially reduce the quality of life of allergy-

sufferers (Cariñanos et al. 2002; Ring et al. 2001). This situation is particularly worth highlighting in the case of *Rumex*, since this pollen type could induce allergy episodes even at low airborne pollen counts; some species of the *Rumex* family are considered to hold higher allergenic capacity than Poaceae (Lewis et al. 1983). Resuspension and transport could contribute to this effect, although evening counts in the rural area were considerably lower than in the urban area, and transport from those areas in the evening probably plays a minor role (Emberlin and Norris-Hill 1991).

5 Conclusions

The results obtained here suggest that pollen counts recorded by a single sampler in the city centre (Eskulap) failed to reflect particular occurring in the suburban/rural area (Morasko). This situation was largely due to differences in local vegetation, microclimate or degree of urbanization. The contribution of tree species to the pollen counts at both sites was similar enough to suggest that it was linked to regional conditions, while inter-site differences in airborne pollen counts for herbaceous species were likely to reflect local conditions. These findings should be taken into account when using airborne pollen data from a single sampling point to construct predictive models or to prevent allergenic risk in various areas of a given city, in order to avoid overestimating or underestimating potential exposure to pollen allergens.

Urbanization creates an environment different from that of suburban–rural areas; considerable modification of local flora may prompt changes in the characteristics of the main pollen season, e.g. causing the prolongation of the pollen season, which starts earlier and ends later. New data to be recorded over the coming years will help to confirm or reject this hypothesis. The results obtained from the small number of years analysed here may not be wholly stable; consequently, greater importance should be attached to those results displaying higher statistical significance values.

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