

The weak effects of climatic change on *Plantago* pollen concentration: 17 years of monitoring in Northwestern Spain

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Abstract *Plantago* L. species are very common in nitrified areas such as roadsides and their pollen is a major cause of pollinosis in temperate regions. In this study, we sampled airborne pollen grains in the city of León (NW, Spain) from January 1995 to December 2011, by using a Burkard® 7-day-recording trap. The percentage of *Plantago* pollen compared to the total pollen count ranged from 11 % (1997) to 3 % (2006) in the period under study. Peak pollen concentrations were recorded in May and June. Our 17-year analysis failed to disclose significant changes in the seasonal trend of plantain pollen concentration. In addition, there were no important changes in the start dates of pollen release and the meteorological parameters analyzed did not show significant variations in their usual trends. We analyzed the influence of several meteorological parameters on *Plantago* pollen concentration to explain the differences in pollen concentration trends during the study. Our results show that temperature, sun hours, evaporation, and relative humidity are the meteorological parameters best correlated to the behavior of *Plantago* pollen grains. In general, the years with low pollen concentrations correspond to the years with less precipitation or higher temperatures. We calculated the approximate *Plantago* flowering dates using the cumulative sum of daily maximum

temperatures and compared them with the real bloom dates. The differences obtained were 4 days in 2009, 3 days in 2010, and 1 day in 2011 considering the complete period of pollination.

Keywords Aerobiology · Climatic change · *Plantago* pollen · Pollen season · Flowering date

Introduction

In the city of León, the genus *Plantago* of the family Plantaginaceae is mainly represented by the species *Plantago lanceolata* L., *Plantago coronopus* L., and *Plantago major* L. The species are abundant in nitrified areas where there is animal transit or near-fertilized soil. These plants have anemophilous pollination, reduced corollas and stamens with developed filaments that expose the anthers to the action of the wind (Damme 1992).

Plantago was selected for this study because its pollen is a relevant cause of pollinosis in temperate regions. The incidence of allergy to *Plantago* has been described in Australia (Krilis et al. 1985) and in the Mediterranean area (D'Amato and Lobefalo 1989), where a high prevalence of the pollen has also been reported in Spain (García-González et al. 1998; Subiza et al. 1995). In general, the atmospheric pollen spectra reflects the composition of local vegetation, but also, it depends on other factors such as meteorological conditions, pollen grain dispersal capacity, plant numbers, and pollen production per individual (Hidalgo et al. 2003). Meteorological conditions influence pollen emission, transport, permanence in the atmosphere, and deposition on surfaces. Different studies have analyzed the impact of meteorological

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parameters on *Plantago* airborne pollen concentration (García-Mozo et al. 2007; Gutiérrez et al. 1999; Puc 2009; Stennett and Beggs 2004; Tormo Molina et al. 2001; Trigo et al. 1997). The common parameters used in airborne pollen studies are maximum, minimum and mean temperature, rainfall, relative humidity, sun hours, evaporation, wind speed, and direction. Several studies have described different temperature-based methods to determine the start and end of the pollen season in different plant species (Frenguelli et al. 1989; Fuertes-Rodríguez et al. 2007; García-Mozo et al. 2000, 2009; González-Parrado et al. 2006; Larsson 1993; Rodríguez-Rajo et al. 2003). Temperature influences many aspects of reproductive growth, including floral initiation, release of bud dormancy, and anthesis (Kramer and Kozłowski 1979). So, an increase in the number of daily sun hours causes a rise in pollen concentration: sun hours produce dehydration in the wall of anthers and consequently, the release of pollen (Bricchi et al. 1992). The flowering time of the same species in a given location also varies from year to year because of temperature differences (Frenguelli et al. 1989; García-Mozo et al. 2010). Climate change has given rise to numerous studies on the effects such change will have on atmospheric pollen levels of many species. Some species have tended to increase in recent decades, leading to changes in the pollination period of several plants (Jato et al. 2013; Recio et al. 2009; Tedeschini et al. 2006; Ziello et al. 2012). Moreover, a general increase in pollinosis has also been detected (Stennett and Beggs 2004; Cecchi et al. 2010; Jackson 2001).

The main objective of this paper was to analyze changing trends in the behavior of *Plantago* pollen concentration in the atmosphere of León (Northwestern Spain).

Material and methods

Study area

The city of León is located in the northwestern part of the Iberian Peninsula (latitude 42°34'N, longitude 5°35'W), at 830 m above sea level. The city's climate is continental Mediterranean. It has an average annual temperature of around 11 °C. Summers are relatively short and warm (maximum temperature: 39 °C, minimum temperature: 10 °C) and winters are long and cold (maximum temperature: 12 °C, minimum temperature: −6 °C). Differences between winter and summer are very high: daily temperature variations in July and August can reach 25 °C, while in winter they do not exceed 18 °C. Moreover, frost are common from November to March, while rainfall of Atlantic origin is abundant during the winter, but almost absent in spring and summer due to the Mediterranean influence. The winter precipitation quite often occurs in the form of snow. The annual rainfall is around 500 mm.

Aerobiological survey

To determine the start of the *Plantago* pollen season, airborne pollen counts were monitored from 1 January of 1995 to 31 December of 2011 using a Burkard® 7-day-recording volumetric spore trap sampler. Samples were prepared and analyzed using the method developed by the Spanish Aerobiology Network (Galán Soldevilla et al. 2007). We examined the tendency of the start date and end date of the pollination periods, using two methods: the main pollination period (MPP) corresponding to 90 % of the total pollen catch, proposed by Nilsson and Persson (1981) and the complete period of pollination (CPP), which we consider the period from the first grain of pollen of *Plantago* appears in the air to the time of the last grain of pollen. These methods were chosen as they are the ones that yielded the best results in the past.

Weather data

The studied meteorological parameters were maximum, minimum, mean temperature, temperature measures to 15 cm above ground (an important factor in herbaceous plants), dew point, rainfall, relative humidity, sun hours, evaporation, and wind speed and direction. Meteorological data were supplied by Meteorology State Agency from the weather station at León airport.

Statistical analysis

Linear regression models were developed in order to detect possible trends in the main pollen behavior characteristic and meteorological parameters during the study period. We used Spearman's Rank Correlation Coefficient for nonparametric data to analyze the correlations between meteorological parameters and pollen concentration during the MPP and the CPP for each year from 1995 to 2011. The level of significance was assessed between $P < 0.01$ and $P < 0.05$. SPSS statistical software, version 18.0 (SPSS Inc, Chicago, IL) was used for all statistical analyses.

Predicting the start of pollen season

We predicted the flowering date using the cumulative sum of the maximum, minimum, and average temperatures and sunshine hours per day. These meteorological parameters were chosen as the parameters yielding the best correlations for other plant species (Fuertes-Rodríguez et al. 2007; Galán et al. 2005; González-Parrado et al. 2006; Recio et al. 2010). We summed the annual values of temperature and sun hours from 1 January to the start of the MPP and CPP from 1995 to 2008. Then, we calculated the mean of the cumulative sum of these parameters throughout the study period. The 3 years: 2009, 2010, and 2011 were used to validate the forecast start pollen season dates obtained by this method.

Table 1 Seasonal Pollen Index (SPI) of *Plantago* from 1995 to 2011, percentage relative to the total of pollen in each year, date, and maximum concentration of pollen in the peak day in pollen/m³

Year	SPI	Percentage	Peak day	Maximum <i>Plantago</i> pollen
1995	557	7.4	22 May	15
1996	922	5.2	19 Apr	36
1997	1,415	11	8 Aug	43
1998	977	6.2	20 Jun	46
1999	1,334	10.4	17 Jun	60
2000	1,067	6.3	8 Jun	44
2001	524	3.6	29 May	24
2002	624	4.8	15 May	26
2003	723	5.4	21 May	34
2004	494	3.6	19 May and 3 Jun	27
2005	333	3.7	7 Jun	14
2006	299	3.1	2 May	11
2007	602	5.4	17 May	34
2008	948	4.8	2 Jun	51
2009	492	3.9	1 Jun	16
2010	648	3.9	31 May	25
2011	1,047	5.2	21 May	43

ranged between 329 mm in 2005 to 735 mm in 1996. During this period, the percentage of *Plantago* pollen grains, with regard to all other pollens, ranged from 3.1 % (2006) to 11 % (1997). The seasonal pollen index (SPI) of *Plantago* ranged from 299 (2006) to 1,415 (1997) (Table 1). The highest values of *Plantago* pollen concentration were recorded in late May and early June. The highest value of daily pollen concentration was recorded on 17 June 1999, with 60 pollen/m³ (Table 1). Some years presented two periods with peak plantain pollen concentration, the first in May or June and the second in July. The years with SPI low values are 2001, 2004, 2005, and 2009 and correspond to the years with the lowest precipitations, except 2006, which had the lowest concentration of pollen (299 SPI) with regular rainfall, but with higher evaporation values throughout the *Plantago* flowering season (Fig. 1). The start of the MPP varied from 19 April (1996) to 20 May (1999) while CPP fluctuated from 7 March (2004) to 20 April (2000). End dates of MPP are between 8 August and 14 September, while the CPP range from 20 September to 26 October. The average length of pollination, calculated as MPP, was 112 days, while that computed as CPP, was 188 days (Table 2).

Results

Aerobiological survey

During the study period, the mean maximum temperature in the warmest month (July) was 27 °C, the mean minimum temperature in the coldest month (January) was −0.5 °C and the mean annual temperature was 11 °C. The annual rainfall

Statistical analysis

No significant increasing or decreasing trend of the annual total *Plantago* pollen count was observed in León (Fig. 2). Taking into account the start of pollen season, no trend towards an earlier or later start or end of the pollen season was observed (Fig. 3). Likewise, there was no significant change in the seasonal trend of any of the weather parameters analyzed but only a slight tendency of pollen to decrease on days with calm wind

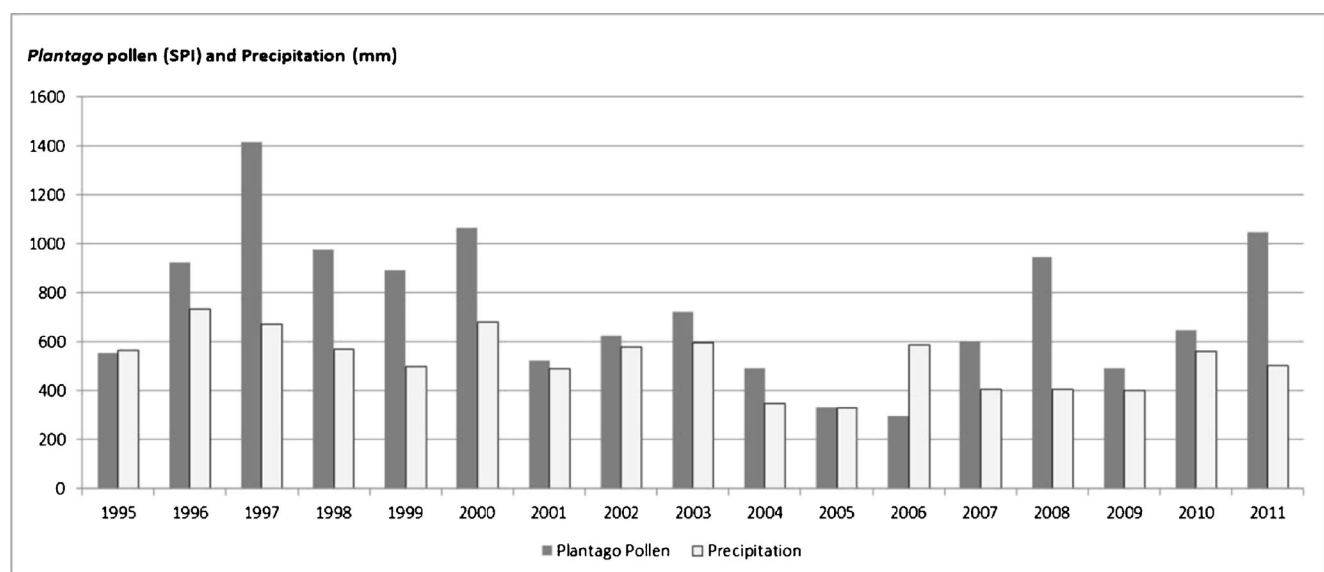
**Fig. 1** Seasonal Pollen Index of *Plantago* pollen, SPI (white square) and annual precipitation, mm (gray square)

Table 2 Characteristics of main pollination period (MPP) and the complete pollination period (CPP)

Year	MPP			CPP		
	Start date	End date	Length (days)	Start date	End date	Length (days)
1995	24 Apr	29 Aug	128	27 Mar	9 Oct	197
1996	19 Apr	31 Aug	135	14 Apr	26 Oct	196
1997	8 May	14 Sep	130	22 Mar	6 Oct	199
1998	14 May	22 Aug	100	19 Apr	25 Sep	160
1999	20 May	22 Aug	95	31 Mar	8 Oct	192
2000	13 May	9 Aug	89	20 Apr	26 Sep	160
2001	28 Apr	23 Aug	118	15 Mar	29 Sep	199
2002	30 Apr	19 Aug	112	1 Apr	29 Sep	182
2003	2 May	22 Aug	113	1 Apr	20 Sep	173
2004	3 May	9 Aug	99	7 Mar	27 Sep	205
2005	1 May	18 Aug	110	8 Apr	28 Sep	176
2006	27 Apr	29 Aug	125	4 Apr	26 Sep	176
2007	26 Apr	3 Sep	131	9 Apr	21 Oct	196
2008	4 May	8 Aug	97	14 Mar	6 Oct	207
2009	2 May	21 Aug	107	22 Mar	11 Oct	204
2010	30 Apr	15 Aug	108	19 Apr	16 Oct	181
2011	3 May	25 Aug	115	2 Apr	17 Oct	199
Mean			112			188

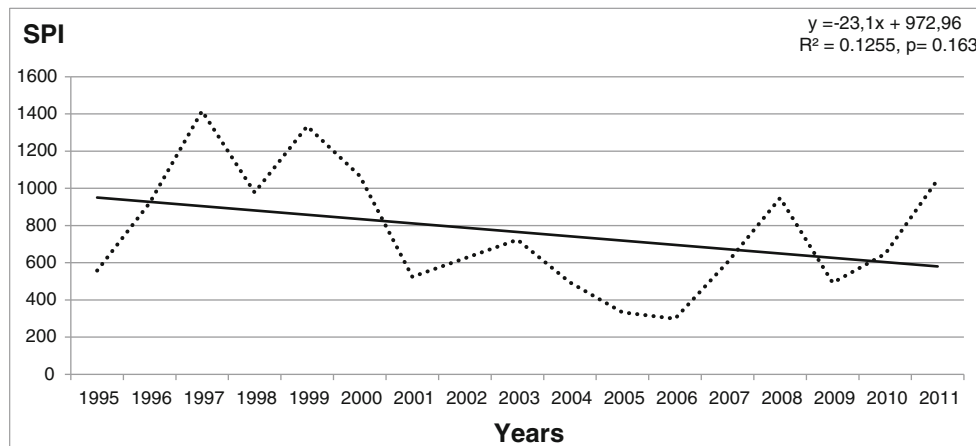
and precipitation (Fig. 4). Spearman's correlation coefficients obtained comparing *Plantago* pollen concentration and meteorological parameters showed the highest correlations with CPP except for wind-related parameters (Tables 3, 4, and 5). A positive significant correlation was observed with all temperatures. In general, maximum temperature was the parameter with the highest correlation values, except in 1997, 1998, 2000, 2007, 2008, 2010, and 2011 when the highest values correlated with the mean temperature (Table 3).

Negative correlation coefficients were obtained in terms of daily rainfall and relative humidity for most of the years in the studies. These values were, in general, lower, the highest

values being -0.40 in 1996 (MPP) for rainfall and -0.71 in 2002 (CPP) for relative humidity (Table 4). Sun hours and evaporation yielded positive and significant correlations with complete years. In general, significant wind-related values were few and low (Table 5).

Predicting the start of pollen season

The mean of the cumulative sums from 1995 to 2008 were 1,443 and 903 °C for maximum temperature, 191 and 52 °C for minimum temperature and 818 and 479 °C for mean temperature, and 746 and 480 h for sun hours during the

Fig. 2 Annual *Plantago* pollen trend and linear regression

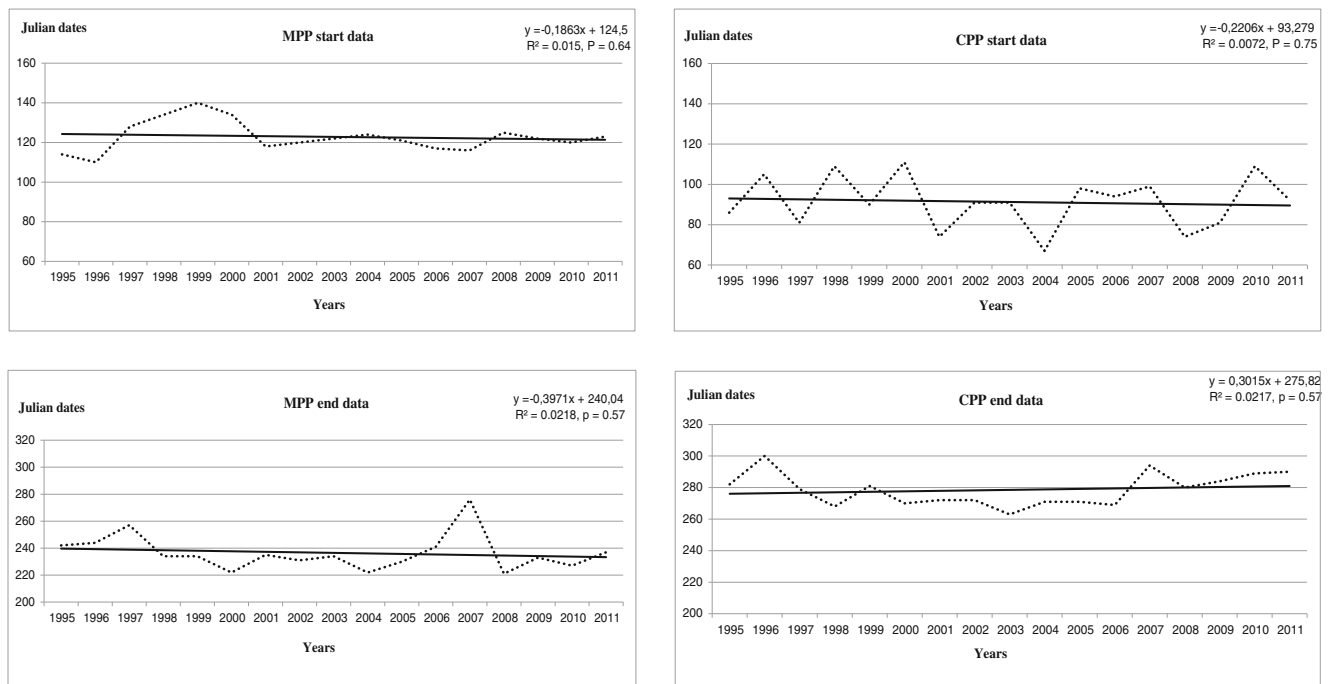


Fig. 3 Trends of the annual start and end dates of *Plantago* pollination periods (MPP and CPP) and linear regressions

MPP and CPP, respectively. Finally, the mean cumulative sum of different temperatures and sun hours used to predict pollen season start dates for 2009, 2010, and 2011 served to validate

models (Table 6). The best results were obtained with the cumulative sum of maximum and mean temperatures and taking account the CPP (Table 7).

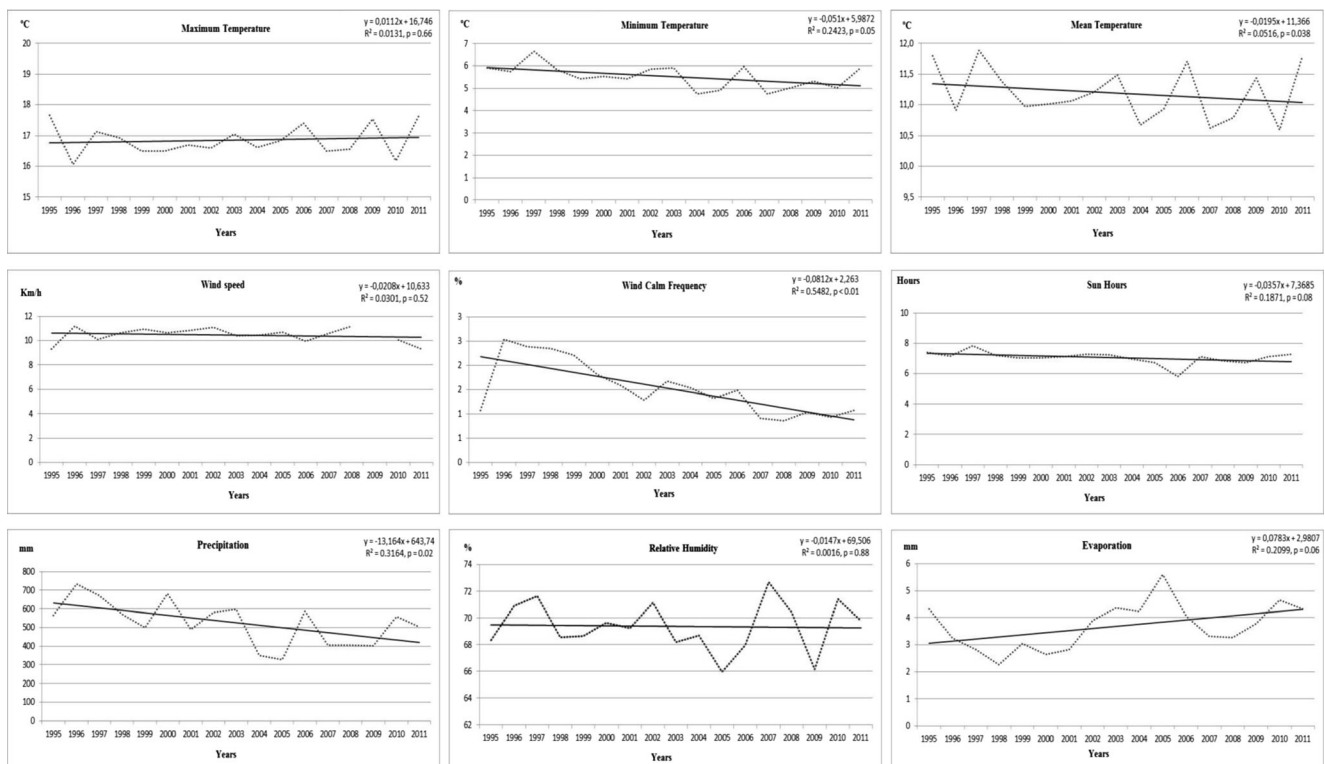


Fig. 4 Trends 1995–2011 for meteorological parameters (maximum, minimum, and mean temperatures, wind speed and frequency of calms, sun hours, precipitation, relative humidity, and evaporation) and linear regressions

Table 4 Spearman's correlation coefficients between *Plantago* pollen concentration and rainfall, relative and absolute humidity, sun hours and evaporation, considering MPP and CPP

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	1995–2011
Precipitation																		
MPP	-0.27**	-0.40**	-0.07	-0.11	-0.20	0.04	-0.12	-0.04	-0.11	-0.10	0.20*	-0.03	-0.01	0.01	-0.22*	-0.19	0.05	-0.07**
CPP	-0.22**	-0.29**	-0.08	-0.20**	-0.17**	-0.15**	-0.21**	-0.21**	-0.25**	-0.05	-0.08	-0.21**	-0.05	-0.03	-0.21**	-0.24**	-0.13*	-0.16**
Relative humidity																		
MPP	-0.47**	-0.37**	-0.28**	0.24*	-0.20	0.02	-0.36**	-0.38**	0.02	-0.05	0.21*	-0.16	-0.32**	0.16	-0.20*	-0.15	0.07	-0.07**
CPP	-0.66**	-0.68**	-0.42**	-0.55**	-0.58**	-0.56**	-0.65**	-0.71**	-0.60**	-0.46**	-0.41**	-0.61**	-0.52**	-0.50**	-0.52**	-0.57**	-0.53**	-0.55**
Sun hours																		
MPP	0.36**	0.47**	0.37**	-0.03	0.21*	0.02	0.29**	0.15	0.16	0.27**	-0.07	-0.00	0.30**	-0.09	0.20*	0.13	-0.06	0.14**
CPP	0.59**	0.63**	0.43**	0.50**	0.56**	0.57**	0.58**	0.59**	0.63**	0.44**	0.48**	0.54**	0.51**	0.42**	0.50**	0.54**	0.45**	0.52**
Evaporation																		
MPP	0.54**	0.27**	0.42**	0.66**	0.15	0.02	0.32**	0.30**	-0.12	-0.05	-0.20*	0.52**	0.26**	-0.34**	0.07	0.05	-0.17	-0.01
CPP	0.76**	0.54**	0.27**	0.41**	0.68**	0.66**	0.69**	0.66**	0.71**	0.57**	0.51**	0.61**	0.72**	0.68**	0.69**	0.66**	0.68**	0.59**

*95 % significance level; **99 % significance level

Discussion

Aerobiological survey

The total *Plantago* pollen counts obtained in this study were similar to those reported in other Spanish cities (Gutiérrez et al. 1999). The higher *Plantago* pollen concentration found during the first years of the study may be due to the presence of fewer urbanized areas at that time. In general, the changes in annual pollen concentrations during the 17 years studied were caused by meteorological variations. Years with a low *Plantago* pollen concentration (2001, 2004, 2005, and 2009) corresponded to years with less precipitation during the previous months. According to Trigo et al. (1997), the growth of herbaceous plants such as *Plantago* appears to be influenced by accumulated rainfall in the 3 months before the pollination period. However, the year with the lowest *Plantago* pollen concentration was 2006, even though this year had similar precipitations. Year 2006 presented higher temperatures than other years and this could have caused high evaporation rates and the same effects as a period of drought.

In 2008, the *Plantago* pollen concentration was higher although rainfall was not abundant. This may have been due to rains occurring at a favorable time for plant development. The different periods of higher *Plantago* pollen concentration found in some years can be interpreted as the successive flowering of different *Plantago* species. The first period (in May and June) is produced by *P. lanceolata* and the second period (in July) by *P. coronopus* (observation in phenological survey). However, variations in the timing of peak pollen concentrations may also be related to variable weather conditions as noted by Tormo Molina et al. (2001) in other Spanish localities, and Puc (2009) in Poland. *Plantago* had a long pollination period with a mean duration similar to that described by Gutiérrez et al. (1999) in other localities of Northern Spain, but longer than the pollination period in Southern Spanish localities. According to Gutiérrez et al. (1999), these differences may be due to biogeographic characteristics.

Statistical analysis

Several studies have reported changes in airborne pollen counts across Europe (Jato et al. 2009, 2013; Recio et al. 2009; Ziello et al. 2012) that may be linked to climate change. By contrast, no clear decrease or increase in the annual total pollen count was noted for *Plantago* in León, in agreement with the findings of Ziello et al. (2012). Most studies focused on the possible effect of climatic change on the start of flowering are based on spring pollination species (Corden and Millington 1999; Emberlin et al. 2002; Recio et al. 2010; Van Vliet et al. 2002) where the pollen season has tended to start progressively earlier in recent years. On the other hand, a different behavior has been observed in

Table 5 Spearman's correlation coefficients between *Plantago* pollen concentration and parameters related to the wind, considering MPP and CPP

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	1995–2011
Wind speed																		
MPP	-0.26**	-0.44**	0.03	-0.21*	-0.19	-0.19	-0.22*	-0.34**	-0.07	-0.27**	0.14	0.10	-0.33**	-0.08	-0.36**	-0.27**	-0.19*	-0.19**
CPP	-0.05	-0.12*	0.05	-0.05	0.01	-0.03	-0.00	0.13*	0.07	0.07	0.05	0.08	0.15**	0.03	-0.01	-0.03	0.20**	0.04**
1st Quadrant north–north–east																		
MPP	0.24**	0.15	0.05	-0.06	0.26*	-0.06	0.25**	0.16	-0.10	0.27**	0.03	0.06	0.40**	0.30**	0.35**	-0.13	0.19*	0.15**
CPP	0.26**	0.30**	0.10	0.15**	0.07	0.27**	0.14**	0.24**	0.09	0.13*	0.07	0.20**	0.14**	0.04	0.11*	0.07	0.20**	0.16**
2nd Quadrant north–east–south																		
MPP	0.29**	0.29**	-0.14	0.16	0.26*	0.36**	0.24**	0.46**	0.13	0.30**	-0.02	0.01	0.20*	0.06	0.44**	0.11	0.10	0.15**
CPP	0.07	0.14**	-0.04	0.13*	0.16**	0.16**	0.04	-0.15**	0.08	0.10*	0.15**	0.08	0.01	0.11*	0.10	-0.01	-0.12*	0.06**
3rd Quadrant south–south–west																		
MPP	0.07	-0.20*	-0.10	0.14	-0.14	0.08	-0.22*	-0.04	0.04	-0.41**	-0.05	-0.07	-0.23**	-0.08	-0.36**	0.17	-0.15	-0.09**
CPP	-0.09	-0.06	0.09	0.05	0.14**	-0.08	-0.06	-0.01	0.14**	-0.05	0.07	-0.04	0.02	0.04	0.13*	0.04	0.08	0.02
4th Quadrant south–west–north																		
MPP	0.08	-0.09	0.20*	-0.02	-0.28**	-0.26*	-0.15	-0.30**	-0.10	0.08	-0.03	0.01	-0.07	-0.30**	-0.33**	-0.07	-0.20*	-0.10**
CPP	0.13*	0.04	0.08	-0.13*	-0.11*	-0.11*	0.12*	0.13*	0.05	0.05	-0.01	0.10	-0.05	0.03	-0.08	0.09	0.09	0.02
Calm																		
MPP	0.31**	0.11	-0.03	-0.22*	-0.12	-0.22*	0.18	0.20*	0.02	0.08	-0.03	-0.02	0.23**	0.12	0.16	0.29**	-0.03	0.10**
CPP	0.05	-0.01	-0.08	0.11*	-0.01	-0.05	-0.03	-0.08	-0.11*	-0.11*	-0.02	0.04	-0.15**	-0.05	-0.09	0.01	-0.03	-0.01

*95 % significance level; **99 % significance level

Table 7 Real and predicted dates with different parameters (maximum, mean, minimum temperatures, and sun hours) of the onset of MPP and CPP in 2009, 2010, and 2011

Year	MPP						CPP					
	Real date			Predicted date			Real date			Predicted date		
	Max. T	Δ	Min. T	Δ	Mean T	S hours	Max. T	Δ	Min. T	Δ	Mean T	S hours
2009	2 May	0	30 May	+28	8 May	16 Apr	26 Mar	+4	10 May	+49	3 Apr	18 Mar
2010	30 Apr	+19	22 May	+22	6 Jun	8 May	16 Apr	-3	25 Apr	+6	19 Apr	6 Apr
2011	3 May	-1	21 Apr	-17	29 Apr	5 May	3 Apr	+1	31 Mar	-2	2 Apr	4 Apr

Δ Differences of days between the estimated date and the real date

These mean values were used to predict the pollen season onset

winter-flowering species, mainly trees (Frenguelli 2002; Rodríguez-Rajo et al. 2004).

We found no trend towards an earlier or later start or end of the *Plantago* pollination period, in agreement with the results of Recio et al. (2009) for Urticaceae, but a slightly delayed trend in the onset of the grass pollen season has reported (Jato et al. 2009; Recio et al. 2010). It could be that this effect is less noticeable in herbaceous plants that depend heavily on other factors such as the concentration of nutrients in the soil and water availability. We detected no trends in weather parameters, only a slight decrease in the frequency of wind calms as noted by Recio et al. (2009) in Málaga, whereas other authors found temperatures increases in different places, such as Perugia (Jato et al. 2013) and Málaga (Recio et al. 2010). The best correlation indexes were obtained taking into account our CPP data, indicating that *Plantago* depends on temperature, precipitation, and other year-round parameters influencing plant development and pollen production. Vega-Maray et al. (2003) reported the same results for Urticaceae.

Year-round data are best used to determine the effect of meteorological parameters on pollen concentration in herbaceous plants. Our results show that all temperatures, sun hours, evaporation, and relative humidity are the best

meteorological parameters to explain the behavior of *Plantago* pollen grains in the atmosphere of León. Maximum temperatures have been associated with peak *Plantago* pollen concentration in the air (Alcázar et al. 2009; Puc 2009; Stennett and Beggs 2004; Tormo Molina et al. 2001; Trigo et al. 1997): some authors (Mandrioli 1987; Vega-Maray et al. 2003) claim that higher temperatures speed up pollen release from anthers, although excessive increases may be harmful because they may cause plants to wither. The positive effect of sun hours on atmospheric *Plantago* pollen concentration was noted Trigo et al. (1997) who found that heat parameters such as temperature and sun hours have the greatest impact on *Plantago* pollen concentration at the beginning of the pollen season.

Evaporation exerts a positive effect on *Plantago* pollen concentration as it contributes to the partial drying of the anthers and the consequent release of pollen with its rapid dispersion in the atmosphere. Relative humidity has a greater impact on the presence of *Plantago* pollen in the atmosphere than precipitation. Both parameters are involved in the agglutination and deposition of atmospheric particles, and prevent the dehydration required for the anthers to open. The negative effects of relative humidity and precipitation have been shown by Alcázar et al. (2009), Stennett and Beggs (2004), and Tormo Molina et al. (2001).

Varying statistical results have been obtained for wind-related parameters. Hyde and Williams (1945) showed that low-wind speed leads to a reduction in pollen release by the anthers and its dispersion. Trigo et al. (1997) obtained positive correlations between wind conditions and pollen release in Málaga (Spain), explaining that the wind contributed to pollen dispersion. On the other hand, Tormo Molina et al. (2001) reported negative correlations between pollen release and wind speed. In our opinion, wind induced increases or decreases of pollen concentration in the atmosphere depending on the origin of this wind.

Predicting start pollen season

The effect of maximum and mean temperatures in *Plantago* pollen concentration is evident from the statistical analysis and further emphasized by the fact that the cumulative sum of maximum and mean temperatures was the best parameter for predicting the onset of the *Plantago* pollination period. Other authors used temperatures to predict the onset of the pollen season with good results (Frenguelli et al. 1989; Fuertes-Rodríguez et al. 2007; García-Mozo et al. 2000, 2009; González-Parrado et al. 2006; Rodríguez-Rajo et al. 2003) adopting different methods.

In conclusion, the SPI value of *Plantago* pollen in the atmosphere varies from year to year depending principally on weather and soil conditions. Low rainfall during the year and higher temperatures before the pollen season may cause a

drop in atmospheric pollen concentration. Our study failed to detect the effects of climate change on *Plantago*. Climate effects are probably less apparent in herbaceous plants, which are more susceptible to annual weather conditions, than woody plants that are more sensitive to climatic conditions. Certainly, it takes at least 30 years of data in order to establish a secure connection between climate change and the concentration of *Plantago* pollen in the air.

Our statistical analysis showed that meteorological parameters control the development, production, and emission of *Plantago* pollen. Heat parameters such as temperature, sun hours, and evaporation, contribute to increase the *Plantago* air pollen concentration, whereas relative humidity and precipitation exert a negative effect on the dispersion. The impact of maximum temperature on *Plantago* pollen concentration is evident from the statistical analysis and supported by the fact that the cumulative sum of maximum temperature was the best parameter for predicting the onset of the *Plantago* pollination period.

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