ORIGINAL ARTICLE

General Trends in Airborne Pollen Production and Pollination Periods at a Mediterranean Site (Badajoz, Southwest Spain)

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Abstract

Background: The aim of this study was to determine trends in the airborne pollen concentration and pollination period for the principal sources of pollen in Badajoz (southwest Spain) over 15 years of monitoring (1994-2008).
Methods: Airborne pollen was monitored by continuous sampling with a Hirst volumetric sampler. Pollen trends were investigated by linear regression and correlation analysis using mean annual and monthly pollen concentrations. The aerobiological results were compared with meteorological data (temperature and rainfall).
Results: During the study period, the mean total annual rainfall was 66.2 mm lower than normal and the mean annual temperature 0.8°C higher than normal. No temporal trend was found for total airborne pollen concentration, but differences were observed for monthly data, namely, an increase in January, February, and May and a decrease in March and June. For the different pollen types studied, there was a general trend toward increased values in the month with the highest values, and this trend seemed to be related to temperature. The beginning of the main pollen season occurred later, and the end occurred sooner; therefore, the main pollen season seems to be shorter.
Conclusions: Our data reflect trends in the response of plants to changing rainfall stress patterns in Mediterranean countries, and these trends seem to be different from those of temperate countries. Nonetheless, a longer study period will be required to confirm these preliminary conclusions.

Key words: Aerobiology. Airborne pollen trends. Climate change. Pollen.

Resumen

Introducción: El objetivo de este estudio era determinar si había alguna tendencia en la concentración de pólenes en el aire y en el período de polinización para las principales fuentes de polen en Badajoz (SW España) durante los años 1994-2008 (inclusive).
Métodos: Se realizó un muestreo aerobiológico continuo con un captador Hirst volumétrico. Las tendencias del polen fueron estudiadas mediante pruebas de regresión lineal y análisis de correlación usando las concentraciones de polen medias anuales y mensuales. Los resultados aerobiológicos fueron comparados con datos meteorológicos (temperatura y precipitación).
Resultados: Durante los años de estudio, la precipitación total anual fue inferior que los valores normales (valor medio de 66.2 mm menos) y la temperatura anual media más alta que el valor normal (valor medio de 0.8°C más). Aunque no se encuentra ninguna tendencia para la concentración de polen total, los datos mensuales muestran un aumento en enero, febrero y mayo y una disminución en marzo y junio. Para los diferentes tipos de polen estudiados, hay una tendencia general a incrementar las concentraciones en el mes con los valores más altos, lo cual parece estar relacionado con la temperatura. El inicio de la estación de polen principal ocurrió más tarde y el final más pronto, de modo que la estación de polen principal es más corta.
Conclusiones: Nuestros datos reflejan las tendencias en la respuesta de las plantas a la disminución de las precipitaciones que los países mediterráneos sufren en los últimos años y estas tendencias parecen ser diferentes de las de los países templados. Sin embargo, se requieren más años de estudio para confirmar estas conclusiones preliminares.

Palabras clave: Aerobiología. Tendencias. Cambio climático. Polen.

Introduction

The presence of airborne pollen in the atmosphere is directly affected by weather conditions, not only by daily changes, but also by general climatic trends. It is widely accepted that we are immersed in a process of climate change, which affects plants in different ways.

Changes in pollination due to variations in climate may also affect the prevalence and severity of allergic diseases. Indeed, there is evidence that climate change will influence aeroallergens by altering amounts, allergenicity, and pollen season, as well as the distribution and other attributes of pollen-releasing plants [1]. Shea et al [2] highlight the links between global climate change and respiratory allergies, showing that allergic disease is becoming increasingly prevalent, affecting the quality of life of many millions of individuals all over the world. Other authors, however, consider that there is still insufficient experimental evidence that climate changes can affect allergenicity [3]. Recent studies in Switzerland indicate that exposure to pollen has been declining since the early 1990s, whereas the prevalence of allergic rhinitis has basically remained unchanged, although it does show a slight decreasing tendency. Those studies argue that the pollen season is getting shorter and, as a result, people are exposed to pollen for shorter periods [4]. On the basis of experimental studies, Levetin et al [5] have shown that raised atmospheric levels of carbon dioxide directly increase plant productivity. This has affected the total amount of pollen produced by some species and could be responsible for earlier flowering of many spring-flowering species in various countries. Furthermore, increases in the seasonal cumulative totals of various pollen types may be explained by changes in plant distribution.

Aerobiologically, it would be interesting to understand the effect of climate change on airborne pollen by studying how climatic factors affect the amount of pollen in the air and the timing of its shedding. It is widely accepted that onset and peak abundance of certain pollen types should be explored as possible bioindicators of climate change [6]. Although several authors have examined the aerobiological aspects of pollen, findings differ from one part of the world to another. Most aerobiological or phenological studies have been carried out in temperate countries, and since biological responses to climate changes will depend on each country's general climate, the potential effects would not necessarily be the same in nontemperate areas [7]. In addition, no studies have analyzed whether trends vary with the season. The aim of the present work was therefore to evaluate the effects of climate change on airborne pollen data over a 15-year period at a Mediterranean site, Badajoz, in southwest Spain. The study analyzed not only the potential variation in the annual data, but also the monthly data in order to better distinguish any underlying pattern.

Material and Methods

Airborne pollen was collected using a Burkard volumetric sporetrap designed to the specifications described by Hirst [8]. It was located on the terrace roof of a 2-storey building (6 m above ground level) at the Agrarian Engineering School of the University of Extremadura, in Badajoz, Spain (38° 53'N, 6° 58' W), 184 m above sea level. Sampling began in May 1993. The present study used data from complete years (1994-2008).

Meteorological data (daily temperature and rainfall data) were provided by the Extremadura Meteorological Centre (station in Talavera la Real, 10 km from the trap) up to 2001 and from the university campus (2.5 km from the trap) from 2002 onwards.

The pollens selected for this study were the most abundant and most relevant as allergens in our area: *Poaceae*, *Quercus*, *Plantago*, *Olea*, *Platanus*, Cupressaceae, and Chenopodiaceae-Amaranthaceae. Together they account for more than 80% of total pollen. To determine the main pollen season, we applied the method proposed by Nilsson and Persson [9]. Thus, onset was established as the day when the accumulated daily counts reached 5% of the annual count, and the end as the day when the accumulated daily counts reached 95% of the annual count.

Pollen trends were studied by linear regression and correlation analyses (Pearson coefficient) using mean monthly and annual pollen concentrations. The means of the annual and monthly concentrations of each pollen type were compared between 2 subperiods, 1994-2001 and 2002-2008, using the *t* test. Differences were considered significant when $P<.05$. Data were normalized using logarithmic transformations. We also studied correlations using the parameters of the main pollen season for each pollen type: start, end, length, peak day, and peak concentration.

Results

Badajoz has a somewhat extreme Mediterranean climate, with rainfall concentrated in autumn and winter and a dry period in summer when the highest temperatures are recorded. The average values of the 1961-1990 meteorological data give normal meteorological values of 483.4 mm for total annual rainfall, 16.4°C for annual mean temperature, and November and December as the months with the greatest rainfall. During the study period (1994-2008), the average total annual rainfall was 66.2 mm less than the normal value, while the average annual mean temperature was 0.8°C higher than the normal value. Monthly meteorological data showed different trends, but in May, the month with the highest pollen concentrations (nearly one-third of the annual total), rainfall was lower and mean temperature higher than the normal values (Figure 1). There were no statistically significant temporal trends in temperature or rainfall during the study period.

According to our 15 years of daily pollen count data, the months with the highest values of airborne pollen were, in decreasing order, May, April, March, and June. These 4 months accounted for 82.8% of the annual total pollen. The annual mean of the total airborne pollen concentration showed no clear trend during the study period (Figure 2), but monthly data revealed a marked increasing trend in May (by more than 8 grains/m^3 per year) and a decreasing trend in the remaining months except January.

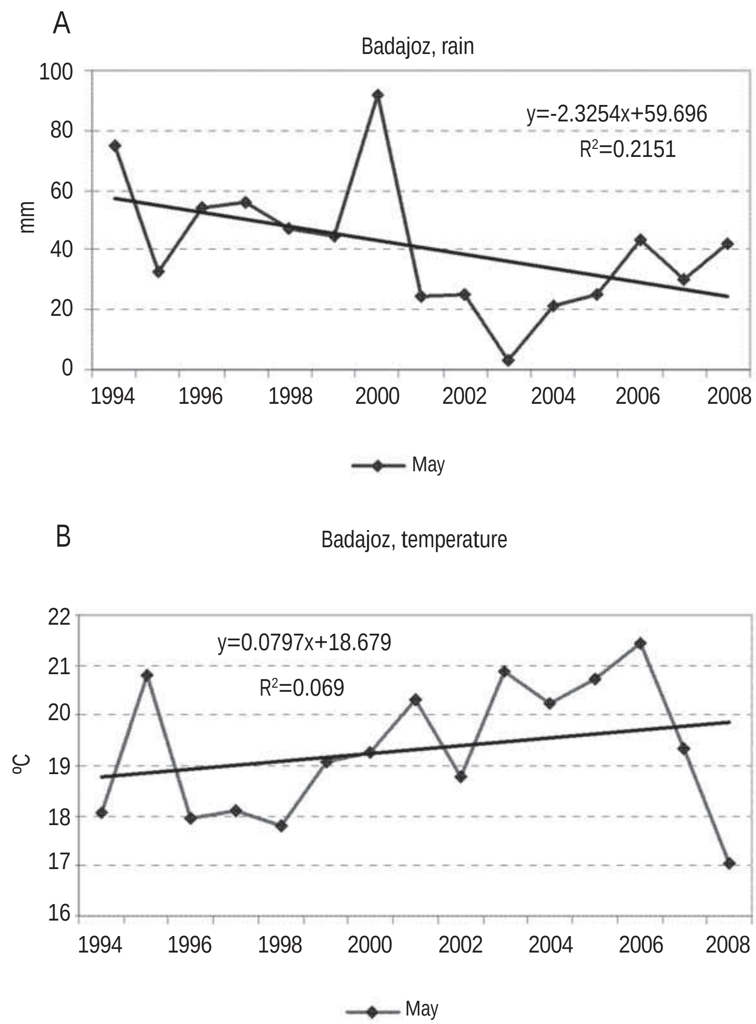

Figure 1. Meteorological values for May in 1994-2008: A, cumulative monthly rainfall. B, Mean monthly temperature.

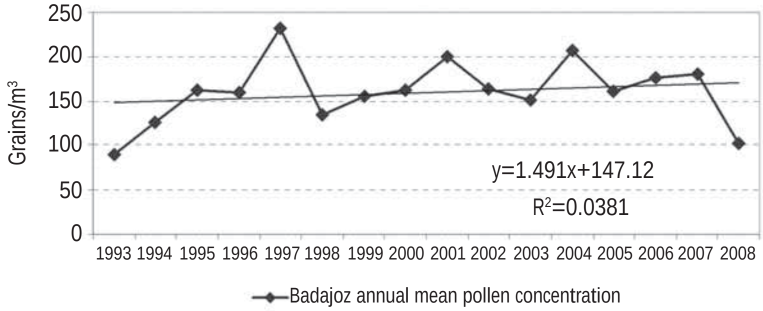

Figure 2. Annual mean of the total airborne pollen concentration during 1994-2008.

Table 1 presents the results of the regression analysis, giving for each pollen type the slope (b), which represents the possible trend and the monthly percentage of the annual total for that type. In the case of *Quercus*, Poaceae, and *Olea*, there was a decreasing annual trend, with an increasing trend in the months corresponding to the greatest amount of pollen captured (April for *Quercus* and May for Poaceae and *Olea*). Cupressaceae showed a weak increasing trend for both the annual data and the 3 months when it is most abundant (January, February, and March); however, the trend was not statistically significant. *Plantago* showed a decreasing trend in both the annual data and the 3 most abundant months (April, May, and June). *Platanus* showed a general increasing trend in both the annual data and the 2 most abundant months (March and April). Finally, Amaranthaceae-Chenopodiaceae showed a decreasing trend in the annual data and in 2 of the main months (June and July), but in May there was an increasing trend.

The statistical significance of these results was evaluated using the Pearson correlation coefficient. Only the results for *Quercus* in March (Figure 3A), *Platanus* in April (Figure 3B), and Amaranthaceae-Chenopodiaceae in June (Figure 3C) and July were statistically significant.

The comparison between the 2 subperiods (1994-2001 and 2002-2008) for the mean annual and monthly concentrations of each pollen type was performed using the *t* test. There was a statistically significant increase during the second of these periods for *Platanus* (Figure 4A) in March and a decrease for *Quercus* (Figure 3A) in March, Poaceae in June (Figure 4B), *Plantago* in May and June (Figure 4C), and Amaranthaceae-Chenopodiaceae in June and July (Figure 4D).

Table 2 presents the results of the regression analysis of the main pollen season (start, end, and length) of the pollen concentration for the peak day (Peak C) and of the date of this day (Peak D). For *Quercus* and *Olea* pollens, the start and the end of the main pollen season tended to appear later, and the season was longer for *Quercus* and shorter for *Olea*. For Poaceae, Cupressaceae, *Plantago, Platanus*, and Amaranthaceae-Chenopodiaceae, the start tended to appear later and the end sooner, so that the season was shorter. None of these results were statistically significant using the Pearson correlation coefficient, although the *Quercus* end (Figure 5A) and *Plantago* start (Figure 5B) results were close to statistical significance.

The pollen peak day showed no trend in the case of Poaceae pollen, although there was a delayed trend for *Quercus*, *Olea*, and *Platanus*, and an advanced trend for Cupressaceae, *Plantago*, and Amaranthaceae-Chenopodiaceae (Table 2). Of these results, only the trend for Amaranthaceae-Chenopodiaceae (advanced) was statistically significant (Figure 6).

Table 1. Monthly Analysis of the Pollen Types Studied

	January		February		March		April		May		June		July	
	b	%	b	%	b	%	b	%	b	%	b	%	b	%
Quercus	0.101	0.4	–0.155	0.4	–22.165	26.7	3.544	53.7	3.073	14.1	0.954	2.7	0.138	0.6
Poaceae	–0.075	0.2	–0.106	0.5	–0.506	2.7	–0.389	4.8	2.208	57.2	–6.749	25.9	–0.871	5.9
Olea	0.001	0.0	0.000	0.0	–0.019	0.1	-5.407	16.3	2.762	67.1	0.063	14.2	0.049	1.4
Cupressaceae	0.112	10.4	0.001	62.0	0.846	20.1	–0.132	1.2	0.000	0.6	–0.009	0.3	0.007	0.1
Plantago	–0.004	0.0	–0.005	0.0	–0.685	5.9	–0.291	34.7	–0.571	38.6	–1.414	16.4	–0.061	2.6
Platanus	0.000	0.0	0.001	0.0	1.975	77.2	0.521	17.0	0.026	4.5	–0.069	0.9	–0.010	0.3
Amar-Chen	–0.003	0.1	0.000	0.1	–0.015	0.4	–0.048	5.4	0.248	23.0	–0.344	17.2	–0.296	14.8

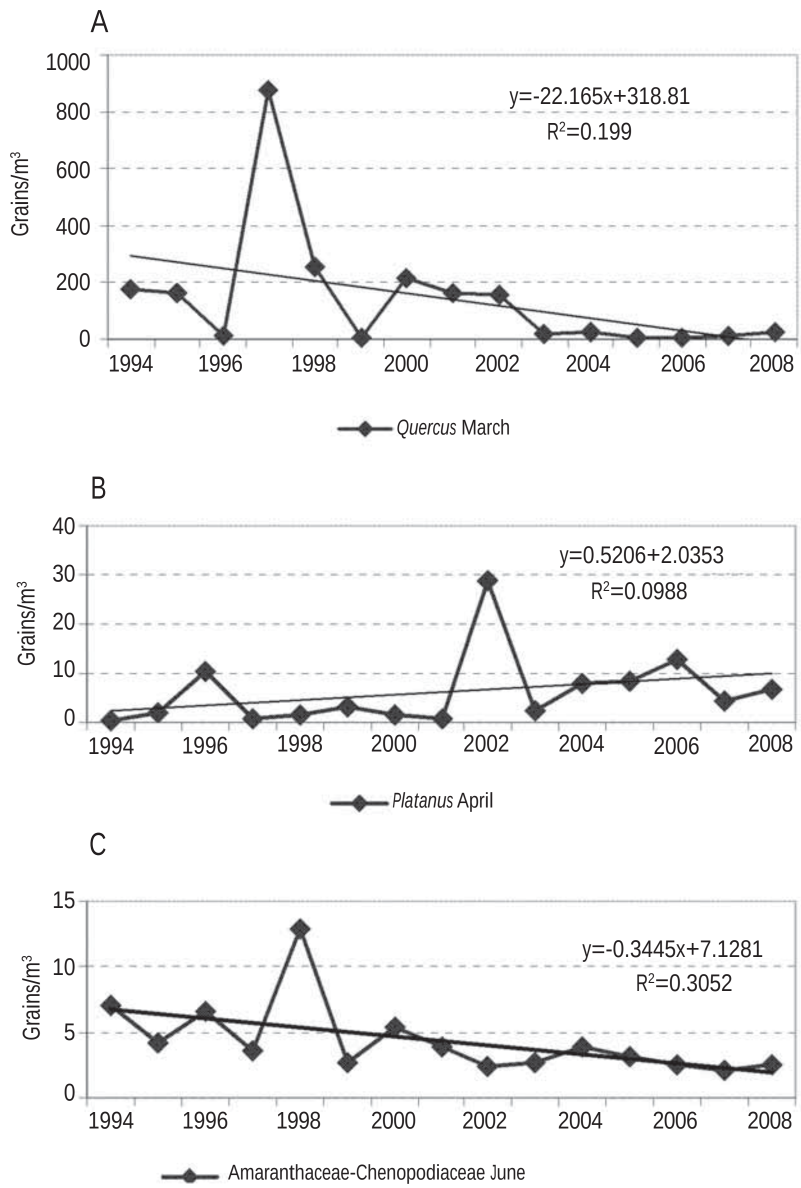

Figure 3. Statistically significant monthly pollen concentration trends for *Quercus* in March (A), *Platanus* in April (B), and Amaranthaceae-Chenopodiaceae in June (C).

The peak pollen concentrations showed an increasing trend for *Platanus* and Poaceae and a decreasing trend for the other pollen types, although none of these results were statistically significant.

The comparison of the data of each pollen type between the 2 subperiods using the *t* test showed a delayed start of the main pollen season in the second period for *Quercus* and *Platanus*, and an advanced end for *Platanus*. The peak concentrations were lower for Amaranthaceae-Chenopodiaceae and higher for *Platanus*. The peak day was delayed for *Quercus* and advanced for Amaranthaceae-Chenopodiaceae and *Plantago*.

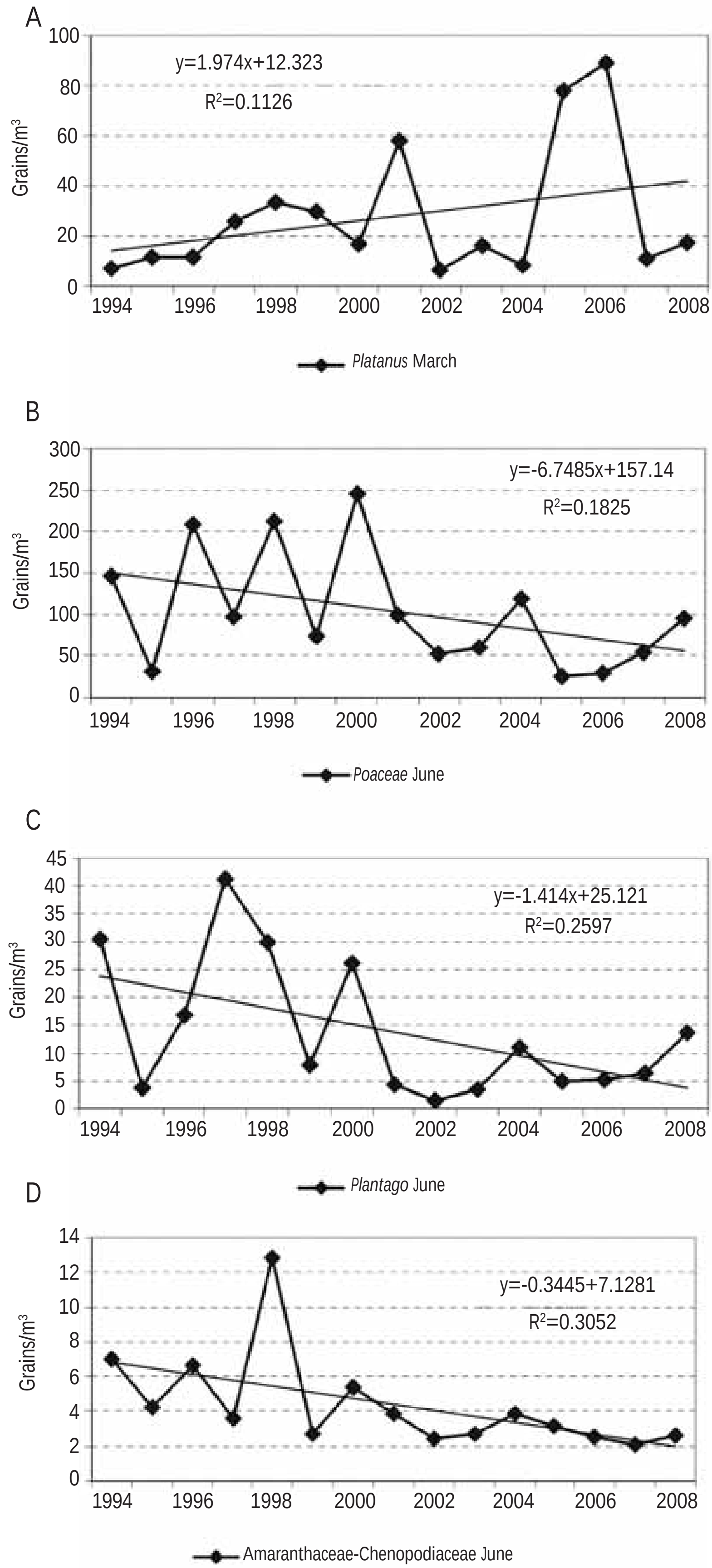

Figure 4. Pollen types with statistically significant differences in the means of the annual and monthly concentrations in 2 periods, 1994-2001 and 2002-2008, by the *t* test.

The results of the correlation analysis between the monthly pollen concentration data and the monthly temperature and rainfall data showed that temperature was positively correlated with 4 pollen types (*Quercus* in March and April, Poaceae in April, Cupressaceae in January, and *Olea* in May) and rainfall was negatively correlated with 3 pollen types (*Quercus* and Poaceae in April, and Amaranthaceae-Chenopodiaceae in May).

Table 2. Results of the Analysis of the Main Pollen Season (Start, End, and Length), Including the Peak Pollen Concentration (Peak C) and the Date of That Day (Peak D)

	Start	End	Length	Peak C	Peak D
Quercus	0.707	1.446	0.739	–15.768	1.125
Poaceae	0.879	–0.846	–1.725	3.275	0.000
Olea	0.586	0.371	–0.214	–9.439	0.861
Cupressaceae	0.211	–0.646	–0.857	–13.579	–0.289
Plantago	0.925	–0.250	–1.175	–2.643	–0.618
Platanus	0.286	–2.325	–2.611	26.793	1.554
Amar-Chen	0.125	–0.725	–0.850	–0.239	–10.814

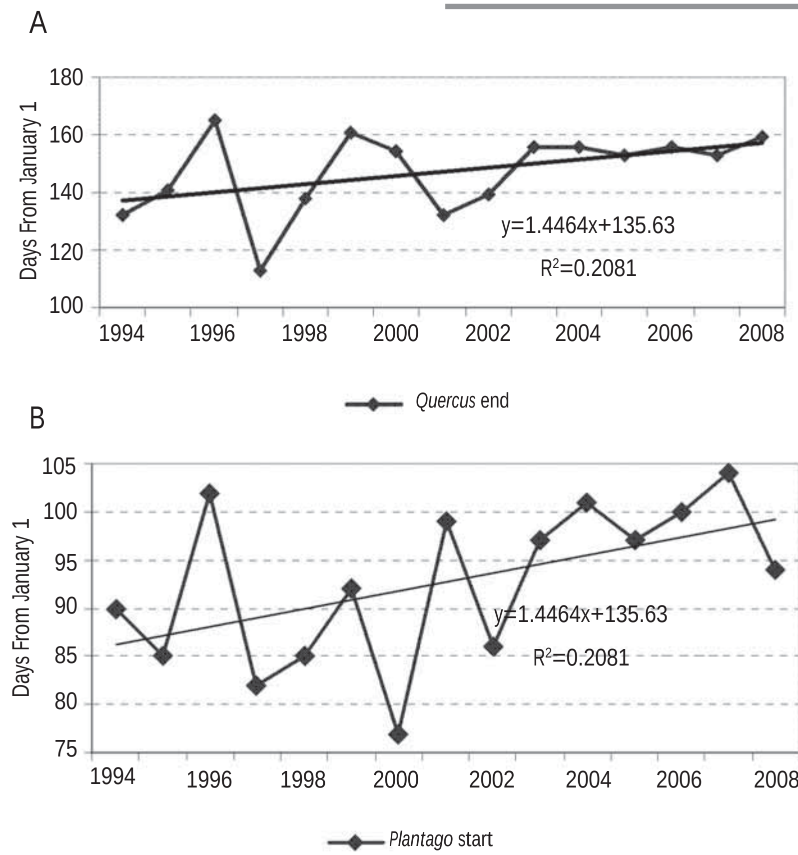

Figure 5. Statistically significant pollen season trends.

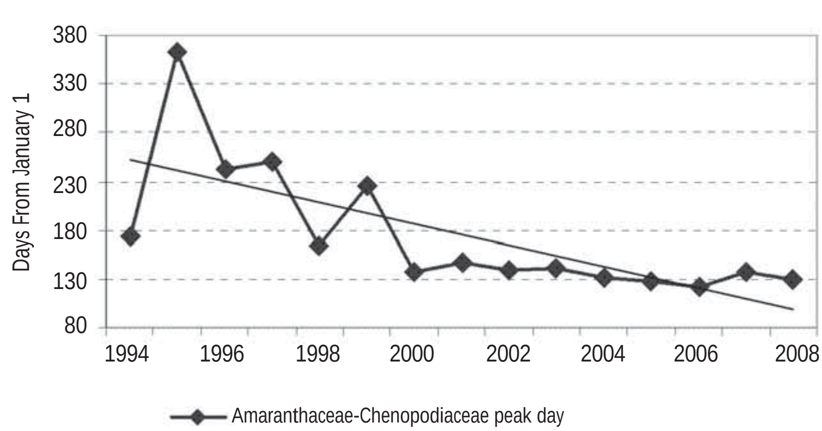

Figure 6. Peak day for Amaranthaceae-Chenopodiaceae.

Discussion

The aerobiological studies of trends in pollen production in Europe correspond to 15 European countries, 12 of which have a predominantly Euro-Siberian temperate climate (UK, The Netherlands, Belgium, France, Germany, Switzerland, Austria, Denmark, Sweden, Norway, Finland, and Poland) [10-24] and 3 with either a predominantly Mediterranean climate (Spain) [25-26] or a Mediterranean climate restricted mainly to Mediterranean coasts (Italy and Greece) [27-32]. The number of years covered by the studies ranges from 9 to 38 (1968 to 2008). The most analyzed pollen types in these studies were *Betula*, *Alnus*, *Corylus*, and Poaceae, the tree species studied being typical of Euro-Siberian vegetation. Nine of the studies reported increased pollen production [12,17,18,21,24,27,28,31,32], which doubled every 10 years in some cases [28]. Two studies reported a decrease for some types [12,32], although no trends were found in any of the pollen types analyzed in 6 cases [14,19,21,22,30,31]. An advance in the start of the pollen season was detected in 14 of these studies for some of the pollen types analyzed, varying from 3 to 22 days [10-13,15-18,20,23-26,29]. A correlation between temperature and pollen production was posited as a potential explanation of the results [10,29]. Finally, all the authors, even those who conducted the longest studies [21], agreed that longer periods of observation are needed for definitive conclusions to be drawn.

These studies are not fully comparable since the number of years involved ranged from 9 to 38, and most corresponded to temperate areas with a predominantly Euro-Siberian climate. Only the most recent works correspond to Mediterranean countries, but even then, not all the sites studied have a Mediterranean climate [25-30,32]. Another factor that could affect the results is that different methods are used to determine the pollen season. Jato et al [33] reviewed the criteria used to delimit the main pollen season; however, they did not recommend any in particular and concluded that the limits of the pollen season should be set in accordance with the aims of each survey. In the papers studied, the onset of the main season was established by taking into account either a fraction from the total pollen captured—1% [13,14,18,22], 2.5% [15,20,24,28,30], or 5% [12,29]—or a threshold pollen concentration reached consecutively for a certain number of days [23,25,26]. However, if the lowest limit is selected, there is a greater possibility of including pollens from distant sources.

We found no strong statistically significant evidence for any general trend in our data, at least for the annual values. The analysis of the monthly data, however, confirmed that climate trends are more observable seasonally, because production and shedding of pollen often depend on weather conditions, especially rainfall. In this sense, a recent report by the Intergovernmental Panel on Climate Change found that, in Mediterranean regions, a decline in rainfall of up to 20% may be attributable to climate change [34]. Positive correlations were found between pollen production and temperature, with higher temperatures seeming to lead to increases in airborne pollen levels. The negative correlations found between rainfall and pollen counts during the pollination period should be interpreted as a washing-out effect, because one would expect rainfall to have a positive effect when it occurs in earlier months, at least for the predominantly herbaceous pollen types.

May was the month with the highest airborne pollen grain concentrations in our study area, and it is also the period when the putative climatic trends are strongest, with increasing temperatures and decreasing rainfall. Moreover, the 2 months with the greatest mean rainfall values, November and December, show the strongest decreasing trends.

For most of the pollen types we studied, trends increased for the month with the highest pollen concentration. The exception was Cupressaceae, which essentially showed no trend. This could be because this type corresponds exclusively to ornamental plants; therefore, the impact of the weather may be different. Other studies, however, describe increasing trends for this pollen [12], as well as for *Olea* [32] and *Quercus* [26]. For Poaceae, some authors found no trend [15,16,21,31], but others reported a decreasing trend [32].

Considering the trends in the main pollen season, we observed that onset was later in all the cases studied by less than one day per year, while the end showed a delay in *Quercus* and *Olea* and an advance for the rest of the pollen types. The pollen season seemed to be shortening, except in the case of *Quercus*. Other authors report an advanced start for Poaceae [11], *Olea* [25], and *Quercus* [26], and, in the case of *Platanus*, the season has been reported to be significantly delayed if temperatures are lower and advanced if temperatures are higher [30].

No clear pattern was observed for the peak day and concentration, and only the delay for the Amaranthaceae-Chenopodiaceae peak day was statistically significant. In the second subperiod, we found lower peak concentrations for Amaranthaceae-Chenopodiaceae and higher concentrations for *Platanus*, and the peak day was delayed for *Quercus* and advanced for Amaranthaceae-Chenopodiaceae and *Plantago*.

We conclude that the climate in our region seems to be getting warmer and drier. There is probably a general increasing trend of airborne pollen concentrations, especially in the month with the highest values, and this increase seems to be related to the increasing temperature. With respect to the main pollen season, the pattern seems to be different from that reported in temperate countries: the start occurs later and the end earlier, so that the season seems to be getting shorter and perhaps more intense in terms of pollen production. This could reflect the response of plants to rainfall trends in Mediterranean countries. Nonetheless, longer study periods will be required to confirm these preliminary conclusions.

Acknowledgments

This work was made possible by research projects EIB94-12, PRI00A032, and PRI06A190 financed by the Regional Government, Junta de Extremadura (Spain).

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Manuscript received November 16, 2009; accepted for publication March 24, 2010.

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