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Quercus long-term pollen season trends in the southwest of the Iberian Peninsula



Santiago Fernández-Rodríguez^{a,*}, Pablo Durán-Barroso^a,
Inmaculada Silva-Palacios^b, Rafael Tormo-Molina^c,
José María Maya-Manzano^c, Ángela Gonzalo-Garijo^d

^a Department of Construction, Polytechnic School, University of Extremadura, Avda. de la Universidad s/n, Cáceres, Spain

^b Department of Applied Physics, Engineering Agricultural School, University of Extremadura, Avda. Adolfo Suárez s/n, Badajoz, Spain

^c Department of Plant Biology, Ecology and Earth Sciences, Faculty of Science, University of Extremadura, Avda. Elvas s/n, Badajoz, Spain

^d Section of Allergology, Hospital Infanta Cristina, Avda. Elvas s/n, Badajoz, Spain

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ABSTRACT

It is widely accepted the influence of meteorology to airborne pollen distribution, this concern is clearly affected by the issue of climate change. In the SW of Iberian Peninsula pollen from *Quercus* species is often the most abundant in the air and their flowering phenology show changes in seasonal pollination affected by meteorological parameters. This study aims to investigate airborne pollen data of *Quercus* from a city on the SW Iberian Peninsula over a 20 year period and to analyse the trends in these data and their relationship with meteorological parameters using time series analysis and propose a predictable model to forecast their concentration. Aerobiological sampling was conducted from 1994 to 2013 in Badajoz (SW Spain) using a 7-day Burkard spore trap. The main pollen season for *Quercus* pollen lasted, on average, 59 days, ranging from 31 to 80 days, from 28th March to 27th May. The model proposed to forecast the airborne pollen concentration is described by Eq. (1). This expression is composed of two terms: the first term represents the resilience of the pollen concentration trend in the air according to the average concentration of the previous 10 days; the second term is obtained from considerations of the actual pollen concentration value, which is calculated based on the most representative climatic variables multiplied by a fitting coefficient. In order to obtain the best fit the model was developed in four partial time series of 5 years, each of one with a high level of accuracy, although a general model was calculated.

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1. Introduction

The IPCC report (2013) indicated a rise of the global average temperature between 1880 and 2012 and it is anticipated that this trend will continue in the following years. The change of global warming has been studied (Root et al., 2003,

2005), being the phenology one of the most relevant aspects (Schwartz, 2003). Plants respond complexly to temperature changes, with the interaction of a wide range of local factors such as meteorological parameters (precipitation and wind mainly), photoperiod, diseases, soil factors, etc. (Ibáñez et al., 2010; Jato et al., 2014; Wielgolaski, 2001). Furthermore, the

* Corresponding author. Tel.: +34 924 289300; fax: +34 924289423.

E-mail address: santiferro@unex.es (S. Fernández-Rodríguez).
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distribution of allergenic pollen in relation to climate change has been previously analysed in Europe taking into account meteorological parameters (Zhang et al., 2013, 2014). The relation between *Quercus* pollen with to the climate change has been studied taking into account phenological trends in the Peninsula Iberian (García-Mozo et al., 2008) and with a statistical approach to bioclimatic trend detection (Fernández-Llamazares et al., 2014). The flowering phenophase (Tormo et al., 2011) found for two species of *Quercus* differences of 20–30 days in the southwest of Iberian Peninsula. The most frequent natural vegetation in Extremadura is the Mediterranean forest handling called as ‘dehesas’, being *Quercus* the main tree genera. Furthermore of their ecological importance, the acorn production of southern Mediterranean oak ecosystems is of vital economic importance, since acorns are a major component in the feeding systems of high-quality Iberian domestic pigs (Hernández-Ceballos et al., 2011b). *Quercus* pollen is an anemophilous genus producing high quantities of pollen (Tormo-Molina et al., 1996) and suitable for the atmospheric dispersion (Hernández-Ceballos et al., 2011a). In Extremadura five species are the most representative: *Quercus ilex* subsp. *ballota*, *Q. suber*, *Q. pyrenaica*, *Q. coccifera* and *Q. faginea*. Occasionally other species are planted as ornamentals, for instance *Q. robur*. Some papers about floral phenology of *Quercus* spp. have been published in Spain (García-Mozo et al., 2008; Jato et al., 2014). The temporal distribution of the *Quercus* pollen has been studied throughout the day (Hernández-Ceballos et al., 2014), the year (Pérez-Badía et al., 2013), comparatively in height (Charalampopoulos et al., 2013; Fernández-Rodríguez et al., 2014b) and distance (Fernández-Rodríguez et al., 2014a). Furthermore, meteorological parameters influence their presence (Grewling et al., 2014; Jung and Choi, 2013; Kasprzyk et al., 2014). The variations of *Quercus* pollen from local and faraway have been analysed with back-trajectory as tools to study the origin of airborne biological particles registered at a sampling station in Spain (Hernández-Ceballos et al., 2011b).

Airborne pollen have previously been published as air pollutant in papers related with the air quality (Cuinica et al., 2014; Mimura et al., 2014; Motreff et al., 2014). *Quercus* pollen is considered a moderate cause of pollinosis in different countries of Europe (Egger et al., 2008; Jato et al., 2014) and India (Bist et al., 2005). In EEUU have been confirmed the contribution to asthma morbidity (Darrow et al., 2012). In the north of Extremadura, 21% of patients studied with suspected respiratory allergy were sensitised to *Quercus* pollen. The authors believe that this figure is low, considering the large amount of *Quercus* pollen collected. This finding and the absence of monosensitized patients, supports the idea that *Quercus* pollen is little allergenic and rarely causes symptoms (Prados et al., 1995).

The acorn production forecast from airborne pollen data has been analysed in Spain (García-Mozo et al., 2007, 2012). For *Quercus* pollen the statistical tools used to analyse pollen season trends were correlation and regression analyses (Fernández-Llamazares et al., 2014; Jato et al., 2014; Myszkowska et al., 2011), linear regression equations forced through the origin and their root mean square error (RMSE) (García-Mozo et al., 2002) and multiple regression analysis (García-Mozo et al., 2012). A growing degree hour (GDH) model has been applied to establish a relationship between start/end dates and differential temperature sums using observed hourly temperatures from surrounding meteorology stations (Zhang et al., 2014). Phenological models were based in order to fit parameters to both start and peak dates (García-Mozo

et al., 2008). Other tools as HYSPLIT model were employed to analysis cluster with aerobiological data (Hernández-Ceballos et al., 2014). Spatial interpolation using ordinary kriging and longitudinal regression analysis with the purpose to estimate pollen concentration in places without pollen data were examined, this method incorporates weather and landcover characteristics that may provided reliable estimates of pollen concentration (Della Valle et al., 2012).

The aim of the present work is to model the *Quercus* pollen concentration in relation with the temporal distribution of five different meteorological variables for 20 years of continuous recording to model the *Quercus* pollen concentration by proposing a mathematical model calibrated with the Shuffle Complex Evolution Metropolis Algorithm (SCEM-UA) as optimisation tool.

2. Materials and methods

2.1. Sampling site

Aerobiological samples were collected from 1994 to 2013 in Badajoz (SW Spain) using a 7-day Burkard spore trap with an intake hole located 1.5 m above ground on an open terrace situated 6 m above ground at the Agricultural Engineering School of the University of Extremadura (38°53′45″ N, 6°58′07″ W). Petrolatum White (CAS number 8009-03-8) was used as adhesive. Standardised data management procedures were used as described by the Spanish Aerobiology Network (REA) (Galán et al., 2007). The main pollen season (MPS) was determined using the 5–95% range of the data (Nilsson and Persson, 1981), the number of days is defined as intensity. Seasonal pollen index (SPI) was calculated as the sum of the daily average pollen counts recorded in each MPS for *Quercus* pollen. *Quercus* trees and shrubs from an area of approximately 500 m around the spore trap location were counted and mapped.

2.2. Climate data and statistical analysis

Badajoz has a Mediterranean climate with the maximum rainfall in autumn (195 mm) (AEMET, 2015). The highest temperatures are recorded during the summer dry period. On average, the annual rainfall is 463 mm, and the annual temperature is 16.6 °C (1971–2000 mean). Climate data were obtained from Badajoz Airport (38°53′ N, 6°49′ W). The normal distribution of the data was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. These tests showed that the daily data did not follow a normal distribution. The tests also showed that the log 10-transformed data also did not follow a normal distribution. A Spearman correlation test was used to analyse associations between selected variables. The statistical analysis included the entire daily data set and was performed with the SPSS 15.0 statistical package. *Quercus* index (QI) is defined as the daily pollen concentration of this pollen type. The use of meteorological information to predict QI was evaluated with a mathematical model. The model was calibrated using the Shuffled Complex Evolution Metropolis Algorithm (SCEM-UA) with the root-mean-square error (RMSE) as the optimisation function. The suitability of the SCEM-UA has been previously verified in other areas of science, such as hydrodynamics (Efstratiadis and Koutsoyiannis, 2010; Vrugt et al., 2003). This algorithm is based on an automatic search of the feasible parameter space and starts by generating random samples of unknown calibration parameters. From this search, the set of solutions that optimises the goodness-of-fit

Table 1 – Pollen season characteristics (day start, day end, day maximum, number of days, daily average count and SPI). Start, end and maximum dates of the *Quercus* pollen season as day of the year (DOY).

	Day start (DOY)	Day end (DOY)	Day maximum (DOY)	Number of days (days)	Daily average count (pollen grains/m ³)	SPI (pollen grains)
1994	20–3	10–5	23–3	51	188	10,823
1995	27–3	19–5	13–4	53	406	24,203
1996	29–3	12–6	15–4	75	74	6,241
1997	14–3	22–4	20–3	39	828	36,038
1998	15–3	16–5	26–3	62	176	12,226
1999	20–3	14–5	27–3	55	221	13,580
2000	14–3	2–6	20–3	80	144	12,992
2001	15–3	10–5	31–3	56	238	14,964
2002	25–3	17–5	24–4	53	350	20,837
2003	28–3	3–6	7–4	67	145	10,887
2004	26–3	3–6	8–4	69	181	14,183
2005	6–4	31–5	28–4	55	352	21,486
2006	2–4	3–6	10–4	62	211	14,578
2007	25–3	3–6	16–4	70	105	8,422
2008	30–3	6–6	6–4	68	151	11,686
2009	20–3	14–5	27–3	55	221	13,580
2010	6–4	29–5	11–4	53	178	10,619
2011	31–3	1–5	7–4	31	441	15,797
2012	10–4	14–6	12–5	65	105	7,649
2013	4–4	29–5	19–4	55	86	5,379

criterion is found. Meteorological parameters measured and used were; rainfall (R), relative humidity (RH), maximum ($T_{\max}$), mean (T_{mean}) and minimum temperature ($T_{\min}$). To consider the effect of previous 10 days on the daily value of each variable (particularly for temperature and rainfall), the average mean of temperature and the cumulative sum of rainfall is added to the equation. There are another variables not evaluated in the present work by not being quantified, as global solar flux, or wind speed, which is neglected by its discontinuous spatio-temporal distribution.

3. Results

3.1. Nearby pollen sources

The ornamental trees and shrubs of *Quercus* in the vicinity of the spore trap were represented by five trees, three of *Q. suber* and two of *Q. robur*. Nevertheless, they were planted recently and represent young trees with an insignificant pollination. Except from some scattered trees 5 km around urban area the most important holm oak area appears in SE direction (Gonzalo et al., 1997; Silva et al., 1999).

3.2. Trends

Quercus MPS lasted on average 59 days, ranging from 31 to 80 days, from 28th March to 27th May (Table 1). Average pollen concentration for the MPS was 240 pollen grains/m³, with a range of 74–828 pollen grains/m³ (Table 1). Statistical significant trend was found in the start day of MPS ($r=643^{**}$, $p=0.002$), within number of days and the end day of MPS ($r=0.783^{**}$, $p<0.001$) and the day of maximum and start day of MPS ($r=0.772^{**}$, $p<0.001$) (Fig. 1). A statistically significant correlation was found between the SPI and daily *Quercus* pollen count ($r=-0.470^{*}$, $p=0.037$) (Fig. 2).

3.3. Relationship with meteorological variables

The first analysis performed was a Spearman correlation analysis of the relationship between the SPI *Quercus* and the

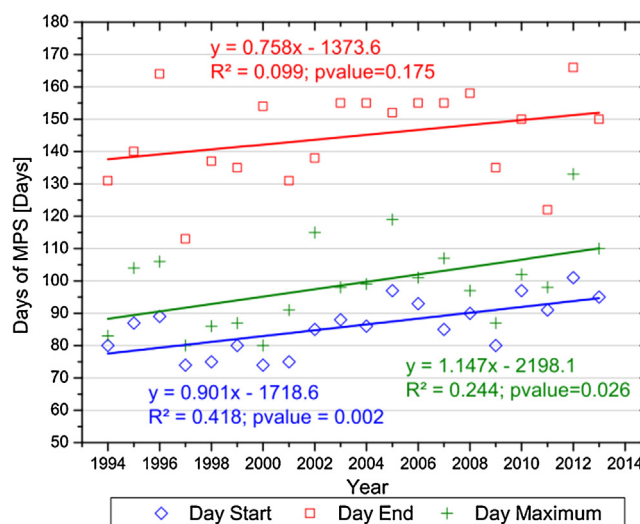


Fig. 1 – Trend in pollen season for *Quercus* pollen in Badajoz.

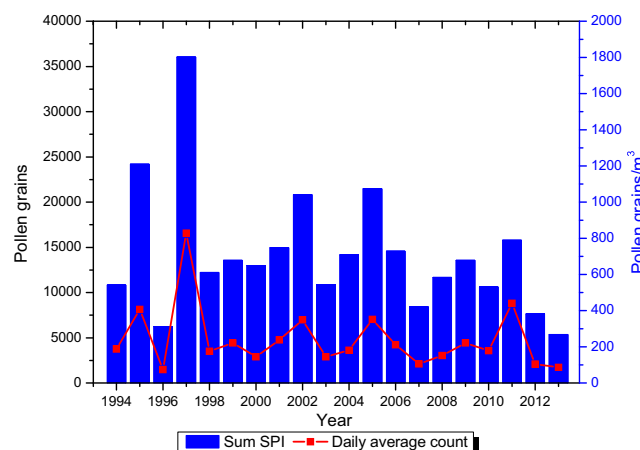


Fig. 2 – Relation between season pollen index (SPI) and daily *Quercus* pollen count.

Table 2 – Correlation coefficient between SPI and meteorological parameters.

	$T_{\max}$	T_{mean}	$T_{\min}$	Rain	RH	Rain (sum of 10 days before)	T_{mean} (average of 10 days before)
1994	0.422**	0.344*	0.015	−0.242	−0.237	−0.504**	0.286*
1995	0.276*	0.030	−0.256	−0.215	−0.531**	−0.527**	0.086
1996	0.218	0.160	−0.124	−0.337**	−0.222	−0.081	−0.071
1997	0.541**	0.085	−0.590**	−0.431**	−0.647**	−0.796**	−0.609**
1998	0.561**	0.439**	0.040	−0.263**	−0.423**	−0.380**	0.160
1999	−0.052	−0.105	−0.165	0.002	0.095	0.270*	−0.730**
2000	0.183	−0.067	−0.338**	−0.369**	−0.571**	−0.274*	−0.111
2001	0.549**	0.586**	0.376**	−0.496**	−0.368**	−0.282*	0.377**
2002	0.287*	0.242	0.044	−0.321*	−0.206	−0.283*	−0.011
2003	−0.082	−0.233	−0.412**	−0.087	−0.056	0.096	−0.370**
2004	−0.003	−0.096	−0.399**	−0.253*	−0.124	−0.273*	−0.214
2005	−0.160	−0.296*	−0.423**	−0.392**	−0.303*	−0.673**	−0.532**
2006	−0.547**	−0.534**	−0.430**	0.230	0.441**	0.422**	−0.677**
2007	0.484**	0.406**	0.231	−0.278*	−0.385**	−0.163	0.055
2008	0.529**	0.360**	−0.080	−0.387**	−0.202	−0.376**	0.048
2009	0.346*	0.215	−0.107	−0.468**	−0.459**	−0.603**	0.058
2010	−0.061	−0.053	−0.130	–	0.059	–	−0.176
2011	0.694**	0.723**	0.034	−0.751**	−0.763**	−0.785**	0.435*
2012	0.347**	0.317**	0.132	−0.162	−0.196	0.329**	−0.069
2013	0.433**	0.457**	0.372**	−0.240	−0.012	−0.391**	−0.005

* Significance at level 95%.

** Significance at level 99%.

selected meteorological variables. Table 2 shows the results obtained for each year. Temperature (maximum, mean and minimum) was clearly the variable with the highest positive correlation coefficient with the SPI. In most cases, the significance level was 99%. The correlation with rainfall fluctuated between positive and negative values and was significant for 8 years at level of 99% and 4 years at level 95%. Nevertheless, 6 years showed a significance level greater than 95% for the cumulative rainfall of the 10 previous days. No statistically significant correlations with the SPI were found with the annual or 3-month period for temperature and rain during the study period.

3.4. Model

The model proposed to forecast the airborne pollen concentration is described by Eq. (1). This expression is composed of two terms: the first term represents the resilience of the pollen concentration trend in the air according to the average concentration of the previous 10 days; the second term is obtained based on the actual pollen concentration value, which is composed of the most representative climatic variables multiplied by a fitting coefficient. Finally, to consider the effect of previous days on the daily value of each variable (particularly for temperature and rainfall), the average mean of these variables is added to the equation:

$$CQ^{t+1} = a \cdot \frac{\sum_{i=t-10}^{i=t} CQ^i}{10} + CQ^t \left(b \cdot T_{\max}^t + c \cdot T_{\text{mean}}^t + d \cdot T_{\min}^t + e \cdot \frac{\sum_{i=t-10}^{i=t} T_{\text{mean}}^i}{10} + f \cdot R^t + g \cdot \sum_{i=t-10}^{i=t} R^i + h \cdot RH^t \right) \quad (1)$$

where a , b , c , d , e , f , g and h are the coefficients to be calibrated for our time series of climatic and airborne pollen

concentration. It is composed by the integration of the different climatic variables for each time step regarding to the actual airborne pollen concentration value join to the mean concentration value of the previous 10 days for each time step. Beside the value of each variable is evaluated for every time step, it has been added the aggregated variables of the mean temperature for 10 previous days as well as the cumulative rainfall of the 10 previous days to analysis the influence of the temporal variation of these variables over the airborne pollen concentration. Regardless the degree of influence of some meteorological variables could be previously neglected by its apparently low relevance, it has been therefore considered appropriate to maintain them due the range of variations are different among them as well as its mean value. In Table 3 is shown the values obtained for each parameter for the 20 years analysed, and the value obtained of the coefficient of determination (R^2). It has been analysed the corresponding parameterisation for the whole serie (1994–2013) and for four partial series of 5 years (1994–1998, 1999–2003, 2004–2008 and 2009–2013) to evaluate the time dependency of the parameters adopted and the hypothesis of a similar parameter set for the whole serie. The model has been validated for the years considering in periods obtaining correlations for each of them (1994–1998, $R^2 = 0.74$; 1999–2003, $R^2 = 0.29$; 2004–2008, $R^2 = 0.69$; 2009–2013, $R^2 = 0.78$). Fig. 3 exposes the comparison between observed and predicted values in terms of pollen grains/ m^3 for the four periods evaluated, being added in correlative position all days of SPI for all years and for each time period. From a qualitative point of view, the trend of the pollen distribution is perfectly replicated by the model proposed. The partial serie with lower R^2 coefficient belongs to time serie from year 1999 to 2003. In this case, the trend of peak values is not so well characterised as in the others partial time series. It should be highlighted that peak values for this time serie are almost isolated concerning to the values from previous and next days. The fitting parameters for this model were estimated using the SCEM-UA. The resulting values are shown in Table 3. Parameter ‘a’ exposes a higher value than

Table 3 – Parameters of the model proposed to predict airborne pollen concentration obtained using the SCEM-UA algorithm.

Parameters from Eq (1)	Whole serie (1994–2013)	Partial time series (periods of time of 5 years each)				
		Years:	1994–1998	1999–2003	2004–2008	2009–2013
<i>a</i>	0.686		0.502	0.857	0.536	0.397
<i>b</i>	0.137		−1.816	0.158	0.182	0.054
<i>c</i>	0.108		−1.864	0.151	0.104	−0.014
<i>d</i>	−0.168		3.747	−0.208	−0.185	0.007
<i>e</i>	−0.081		−0.057	−0.139	−0.123	−0.060
<i>f</i>	−0.015		0.011	−0.032	0.011	−0.007
<i>g</i>	0.005		−0.002	0.003	0.003	−0.002
<i>h</i>	0.031		−0.364	0.863	0.170	0.428

others parameters in general terms, indicating the influence of the previously explained trend in the pollen concentration. Regarding to the parameters related to daily temperature, parameters 'b', 'c' and 'd', had close values for the whole serie and partial serie for periods 1999–2003 and 2008–2008. However, for periods 1993–1998 and 2009–2013, these parameters exhibit a deviation over and under the value related to the whole serie, respectively. Moreover, the sign of these parameters is also opposite. The influence of the average mean daily temperature of the 10 previous days was evident its close to the parameters related to daily values, with the exception of the period 1993–1998. The value of parameter 'g', linked to the average rainfall of the 10 previous days, was lower than parameter 'f', which is related to daily rainfall, due to the magnitude

of this variable (always higher or at least equal to daily rainfall). Finally, the value of parameter 'h', linked to daily relative humidity, fluctuate depending on the serie, not been constant in the four periods of time analysed.

Alternatively, the model proposed has been compared against the model analysed in (Sabariego et al., 2012). In Table 4 is shown the criterion R^2 obtained with both models appreciating that the present model is more accurate for the whole serie and for the different partial series evaluated. It is also compared the hypothesis of similar parameterisation for the whole serie, being examined for each partial serie individually. As it can be appreciated, there are not significant differences among considering a similar parameter set for the whole serie, or any different for each partial serie. Moreover, the model

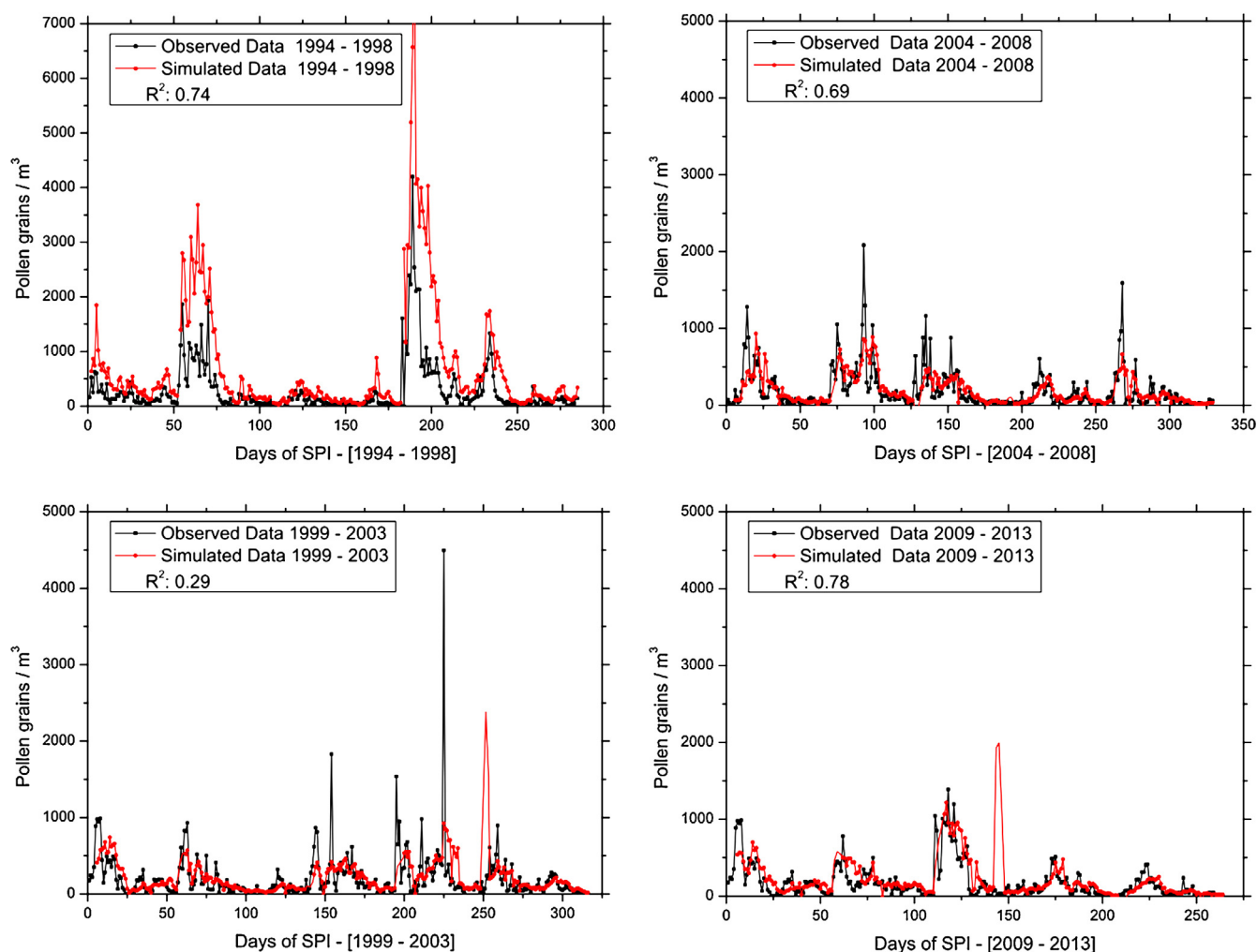
**Fig. 3 – Comparison between observed and simulated data the periods 1994–1998, 1999–2003, 2004–2008 and 2009–2013.**

Table 4 – Comparison of the criterion of R^2 between the model developed and the model proposed (Sabariego et al., 2012).

Whole serie 1994–2013	Developed model		Sabariego model
	0.58		0.46
Partial series			
1994–1998	0.74 ^a	0.72 ^b	0.66
1999–2003	0.29 ^a	0.23 ^b	0.10
2004–2008	0.69 ^a	0.66 ^b	0.50
2009–2013	0.78 ^a	0.74	0.70

^a R^2 obtained for each partial serie using an specific parameter set for each partial serie (columns 3–6 in Table 3).

^b R^2 obtained for each partial using the set parameter corresponding to the whole serie (column 2 in Table 3).

proposed in the present work is newly better despite considering a similar parameter set for the whole serie.

4. Discussion

As *Quercus* trees close to spore trap was irrelevant and their stage of development did not allow significant pollen production we consider that pollen records analysed had a medium to large origin (Fernández-Rodríguez et al., 2014a; Tormo et al., 2011; Velasco-Jiménez et al., 2014). The importance about the relation between distribution of the trees and the distance to the trap have been highlighted in UK (Skjæth et al., 2009) and Spain (Velasco-Jiménez et al., 2014).

A statistically significant trend was found with day start of pollen season. It seems there is a delay with the time nearly 1 day on average per year. It would be expected to obtain a positive correlation between total pollen recorded, defined as SPI, and the number of days of pollen season (MPS) (Fig. 1). These results are not consistent with other paper (García-Mozo et al., 2002), that has found in the 1982–1998 period an advance of the pollen season onset. Notwithstanding, we have found similar trend using hourly data for the period 1994–1998. A trend towards of the delay in the pollen season has been found in olive in southern Spain (García-Mozo et al., 2014), but this change was accompanied by an earlier onset of the season and, consequently, a longer MPS, implying that an increase in the mean temperature. The delay or advance in pollination differs from others studies and it is quite dependent on the years analysed. 2.5 days per decade were calculated for trees in Europe as the mean advance of Spring flowering dates (Menzel et al., 2006). Advances in the beginning of the pollen season were found in birch (Zhang et al., 2013) and in grasses (Stach et al., 2008). No statistical significant trend was found with total pollen or SPI, however this statistical significant relation was found in other study (Fernández-Llamazares et al., 2014). A negative statistically significant correlation was found between SPI and daily *Quercus* pollen count. It could be hypothesised that the cumulative chilling temperature might influence the pollen season, as occurs in *Quercus* pollen (García-Mozo et al., 2008). This fact could be explained due to the relation to the meteorology, there were statistically significant correlations with the maximum temperature (65% of the years) and the accumulated precipitation of 10 days (80% of the years).

The proposed model addressed the pollen trend over the past 10 days. Temperature was the main meteorological factor considered in terms of its effects on the daily pollen

forecast, and rain was a secondary factor that could modify this forecast. In their linear regression model, Jato et al. (2014) have proposed that temperatures to calculate the heat during December and January period were important factors to consider in the development of a forecasting model for *Quercus* pollen. The rain during 10 days was selected as the main variable for forecasting airborne grass pollen in a previous study of London (Smith and Emberlin, 2006), although they commented that rainfall has a significant negative effect on the release and dispersal of grass pollen from the plant. This effect may be specific to London and not applicable to Mediterranean locations. Neural network to forecast grass pollen have considered previous days as the most important source of information for developing predictive models (Sánchez-Mesa et al., 2002).

To test the accuracy of these results, the value of R^2 for this dataset was estimated for the multiple regression model proposed (Sabariego et al., 2012), and the value obtained was 0.58, against the value of 0.46 with the proposed model (Table 4). Subsequent to the analysis of the entire time period, the goodness-of-fit of the model was examined for the partial time series chosen (1994–1998, 1999–2003, 2004–2008 and 2009–2013), being calibrated the model parameters for each period. The R^2 values obtained were 0.74, 0.29, 0.69 and 0.58 for each period, which are greater than those previously found for the reference model (Sabariego et al., 2012). Even though the parsimoniousness of the reference model is higher by having a lower number variables, the efficiency of the model proposed is unquestionable due to all the variables used are commonly measured in any weather station. Hence, it is increased the model predictability without any additionally technical effort. Furthermore, by comparison of R^2 criterion, it is highlighted the advantage of using similar parameterisation for the whole serie despite a different parameter set for each partial serie. As consequence, it is eased the extension of the model proposed to different climatic scenarios, as well as it is possible to quantify the magnitude of climatic change over pollen distribution. These results also confirm the suitability of the proposed model.

5. Conclusions

In spite of airborne *Quercus* pollen presence nearly the whole year, its main pollen season lasted 2 months in the first half of Spring, with higher variations among years and a delay trend in the onset. With long-term pollen trends it has been developed an autoregressive parametric model to analyse the fitting degree for different 5-year partial time series. It could be appreciated that despite the global fit of the model is quite accurate this value is not constant for different partial time series due likely to the influence of meteorological variables.

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