

Regional forecast model for the *Olea* pollen season in Extremadura (SW Spain)

Santiago Fernández-Rodríguez¹ · Pablo Durán-Barroso¹ · Inmaculada Silva-Palacios² · Rafael Tormo-Molina³ · José María Maya-Manzano³ · Ángela Gonzalo-Garijo⁴

Received: 30 September 2015 / Revised: 26 January 2016 / Accepted: 31 January 2016
© ISB 2016

Abstract The olive tree (*Olea europaea*) is a predominantly Mediterranean anemophilous species. The pollen allergens from this tree are an important cause of allergic problems. *Olea* pollen may be relevant in relation to climate change, due to the fact that its flowering phenology is related to meteorological parameters. This study aims to investigate airborne *Olea* pollen data from a city on the SW Iberian Peninsula, to analyse the trends in these data and their relationships with meteorological parameters using time series analysis. Aerobiological sampling was conducted from 1994 to 2013 in Badajoz (SW Spain) using a 7-day Hirst-type volumetric sampler. The main *Olea* pollen season lasted an average of 34 days, from May 4th to June 7th. The model proposed to forecast airborne pollen concentrations, described by one equation. 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 was obtained from considering the actual pollen concentration value, which is calculated based on the most representative meteorological variables multiplied by a fitting coefficient. Due to the allergenic

characteristics of this pollen type, it should be necessary to forecast its short-term prevalence using a long record of data in a city with a Mediterranean climate. The model obtained provides a suitable level of confidence to forecast *Olea* airborne pollen concentration.

Keywords *Olea europaea* · Time series analysis · Forecasting · Temporal modelling

Introduction

If the occurrence of pollen in the atmosphere is related to the phenological state of flowering in wind-pollinated species (Tormo-Molina et al. 2011), then the variation of the vegetation to climate change can be studied from an aerobiological perspective (Fernández-Llamazares et al. 2014). In this respect, aerobiology has been applied to various pollen types such as *Artemisia* (Stach et al. 2007), *Betula* (Newnham et al. 2013) and *Olea* (Galán et al. 2005). The phenological response to climate change has been studied in Spain (García-Mozo et al. 2010), and microclimatic fluctuations have been found in the flower and pollen production of olive trees (Aguilera and Valenzuela 2012). In Badajoz, trends were found in response to changing rainfall patterns in Mediterranean countries (Tormo-Molina et al. 2010), which seem to be different from those of temperate countries.

The olive tree is a Mediterranean anemophilous (wind pollinated) species that is both native and cultivated (Fornaciari et al. 2005; Mazzeo et al. 2014). The temporal distribution of airborne pollen from anemophilous species is an important source of information for phenological and aerobiological studies (García-Mozo et al. 2014). Such studies allow observations of the relationship between the release of pollen and its presence in the atmosphere used

✉ Santiago Fernández-Rodríguez
santiferro@unex.es

¹ Department of Construction, Polytechnic School, University of Extremadura, Avda. de la Universidad s/n, Cáceres, Spain

² Department of Applied Physics, Engineering Agricultural School, University of Extremadura, Avda. Adolfo Suárez s/n, Badajoz, Spain

³ Department of Plant Biology, Ecology and Earth Sciences, Faculty of Science, University of Extremadura, Avda. Elvas s/n, Badajoz, Spain

⁴ Section of Allergology, Hospital Universitario Infanta Cristina, Avda. Elvas s/n, Badajoz, Spain

to identify the local source of airborne pollen (Rojo et al. 2015). Pollen release and its presence in the atmosphere occurs together in most pollen types (Torrighiani Malaspina et al. 2007), but the match is not always perfect. For example, airborne *Olea* pollen in Badajoz has been recorded before and after blooming (Tormo-Molina et al. 2011). *Olea* pollen may be relevant to climate change due to the intense flowering time and its relationship with the meteorological parameters (Aguilera et al. 2015a; Oteros et al. 2013a), and a number of studies related to the floral phenology of *Olea europaea* L. have been conducted in Mediterranean countries such as Italy (Orlandi et al. 2010) and Spain (Aguilera and Ruiz Valenzuela 2009).

The presence of airborne *Olea* pollen varies throughout the day (Galan et al. 1991), (Ribeiro et al. 2008b) and partly depends on meteorological parameters (García-Mozo et al. 2015). The bioclimatic factors (e.g., mean, maximum and minimum air temperature; rainfall; average relative humidity; sunlight hours; average wind speed; temperature and rainfall) that affect the daily flowering of *Olea* were studied in southwestern Spain (Vazquez et al. 2003). The variations of *Olea* pollen from nearby or remoter sources have been studied with back trajectories analysis to understand the origin of airborne biological particles registered at sampling stations in the Iberian Peninsula (Fernández-Rodríguez et al. 2014a; Hernández-Ceballos et al. 2011, 2014).

Olive pollen allergens are considered to be one of the most important causes of respiratory allergic disease in the Mediterranean region producing different symptoms in patients allergic to olive pollen (Feo-Brito et al. 2011). Several short-term effects of pollen species on hospital admissions in Spain were considered (Díaz et al. 2007). Both the diagnosis of the spectrum of olive allergens and its treatment have been studied (Villalba et al. 2014). Olive trees are being included as ornamentals in park landscaping (Staffolani et al. 2011). Due to the health problems that produce the allergens in urban environments, it is important to take this matter into account in the design of the public environments (Cariñanos and Casares-Porcel 2011; Cariñanos et al. 2014; Velasco-Jiménez et al. 2014).

Predicting the onset and duration of pollen season benefits allergy patients, providing information for forecasting pollen models and their levels at different spatiotemporal scales (Zhang et al. 2015). To forecast *Olea* pollen, it should consider daily values of airborne *Olea* pollen and the seasonal pollen index (SPI) (Fernández-Rodríguez et al. 2014b, c; Moriondo et al. 2001; Pérez-Badía et al. 2010), as well as trends in airborne related to climate change (Bonofiglio et al. 2013; Frenguelli et al. 2014; García-Mozo et al. 2014). A model for the time series of airborne Cupressaceae pollen produced by (Silva-Palacios et al. 2015), included meteorological parameters and it was verified by the close agreement between observed and predicted mean concentrations.

The statistical tools used to analyse pollen season trends have included time series analyses (Damialis et al. 2007), correlation and regression analyses with autoregressive integrated moving (ARIMA) for olive pollen (Oteros et al. 2013b) and stepwise multiple regression (Ribeiro et al. 2008a). A seasonal-trend decomposition procedure based on LOcal regrESSion or LOESS (STL) has also been applied to airborne pollen for modelling and forecasting (Aguilera et al. 2015b; García-Mozo et al. 2014). Other tools used include methods based on artificial intelligence (AI), e.g. neural or neuro-fuzzy models that have been used for olive pollen (Aznarte et al. 2007). The multi-layer perception (MLP) algorithms have been applied to *Olea* pollen (Voukantsis et al. 2010). A third tool used for forecasting olive crop yields is based on long-term aerobiological data series and bioclimatic conditions (Aguilera and Ruiz-Valenzuela 2014). Spatiotemporal analysis of olive flowering using geostatistical techniques have been recently developed by Rojo and Pérez-Badía (2015).

The main objective of this work is to model daily average *Olea* pollen concentrations from a city in the SW of the Iberian Peninsula, in relation with the temporal distribution of five different meteorological variables from 20 years of continuous recording. This was achieved using a combination with the shuffle complex evolution metropolis algorithm (SCEM-UA) using as an optimization function the root mean square error (RMSE).

Materials and methods

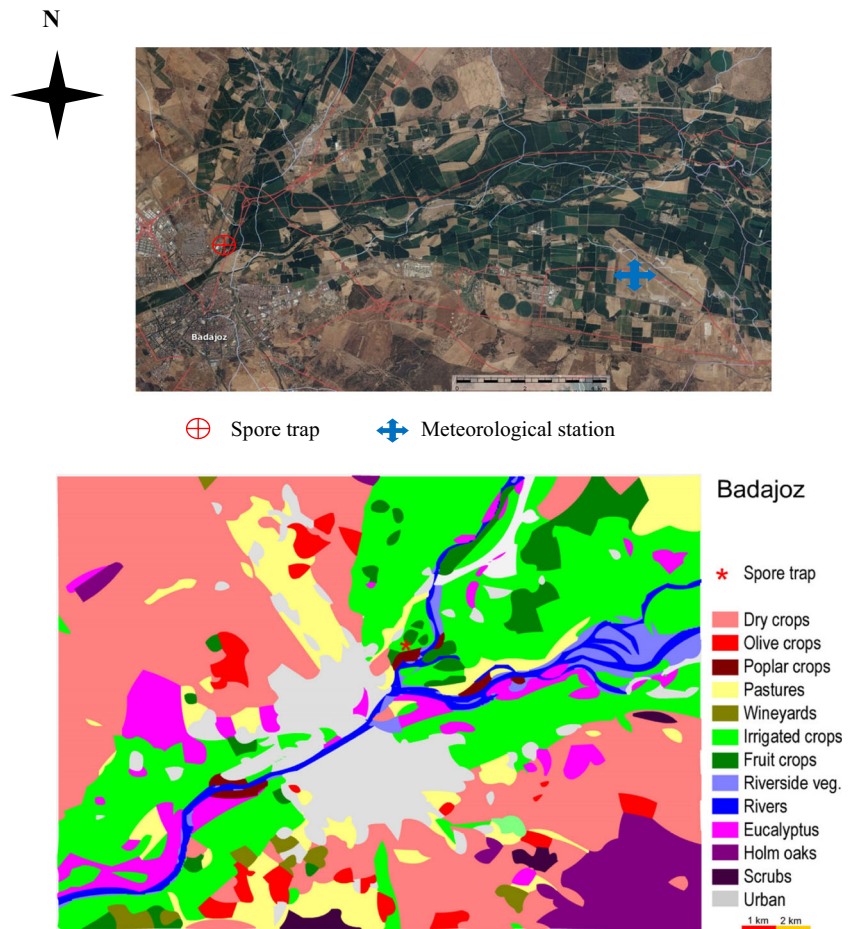
Sampling site

Aerobiological samples were collected from 1994 to 2013 in Badajoz (SW Spain) using a 7-day volumetric sampler of the Hirst design (Hirst 1952) 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 an 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 (Nilsson and Persson 1981) of the data. The data were used in the form of the seasonal pollen index (SPI), calculated as the sum of the daily average pollen counts recorded in each MPS for *Olea* pollen. Figure 1 includes a 12 × 10 km map with the main land uses located around the spore trap.

Climate data

Badajoz has a Mediterranean climate with the maximum rainfall in autumn and winter (AEMET 2015). The highest temperatures

Fig. 1 Maps of location of spore trap and meteorological station and land use



are recorded during the summer dry period. Annual values of rainfall (447 mm), mean temperature (17.1 °C) and relative humidity (64 %) were registered in the period 1981–2010. Wind data available (1993–2008) provides an average wind speed of 9.5 km/h with SW (35.4 %) and NW (26.4 %) winds being predominant. Climate data were obtained from Badajoz Airport (38° 53' N, 6° 49' W) (Fig. 1).

Statistical analysis

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 then 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. The use of meteorological information to predict the *Olea* pollen concentration 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 criterion is found. Meteorological parameters used were rainfall (R), relative humidity (RH), maximum (T_{max}), mean (T_{mean}) and minimum temperature (T_{min}).

Results

Trends

The *Olea* MPS lasted, on average, 34 days, ranging from 20 to 47 days, from May 4th to June 7th (Table 1). Not statistically significant correlation was found between the SPI and the number of days in the MPS ($r = -0.233$, $p = 0.322$) (Fig. 2). The mean daily average pollen concentration was 145 grains/

Table 1 *Olea* pollen season characteristics (day start, day end, day maximum, number of days, daily average count and SPI). Start, end and maximum dates of the *Olea* 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	29 April	6 June	3 May	38	111	4729
1995	24 April	3 June	3 May	40	105	4786
1996	14 May	28 June	23 May	45	74	3757
1997	10 April	1 May	14 May	21	578	14009
1998	2 May	14 June	6 May	43	53	2555
1999	3 May	30 May	6 May	27	160	4943
2000	13 May	15 June	15 May	33	129	4809
2001	28 April	11 June	20 May	44	104	5209
2002	9 May	12 June	19 May	34	124	4782
2003	9 May	16 June	28 May	38	133	5766
2004	10 May	17 June	11 May	38	166	7136
2005	5 May	15 June	23 May	41	121	5492
2006	9 May	2 June	16 May	24	282	7679
2007	10 May	5 June	18 May	26	88	2658
2008	25 April	12 June	3 May	48	78	4092
2009	3 May	30 May	6 May	27	160	4943
2010	14 May	5 June	21 May	22	172	4366
2011	26 April	21 May	2 May	25	131	3788
2012	12 May	8 June	16 May	27	90	2784
2013	9 May	22 June	13 May	44	58	2863

m³, with a range of 53–578 pollen grains/m³. Figure 2 shows a trend towards a shorter pollination period by delaying the start day and advancing the last day of the MPS. The day with maximum concentration (day maximum) is progressively closer to the day end, the correlation between the day maximum and day start ($r=0.696$, $p=0.001$) is

higher than between the day maximum and the day end ($r=0.491$, $p=0.028$) (Fig. 3).

Relationship with meteorological variables

The first analysis performed was a Spearman correlation analysis of the relationship between the *Olea* SPI and the selected meteorological variables. Table 2 shows the results obtained in each year. Temperature (maximum, mean and minimum) was the variable with the highest positive correlation coefficient with the SPI. In most cases, the significance level was 99 %. The correlation with rainfall and temperatures (maximum, mean and minimum) fluctuated between positive and negative values and was only significant for 2 years. Nevertheless, 6 years showed a significance level greater than 95 % for the cumulative rainfall of the 10 previous days.

Model

The model proposed to forecast the airborne *Olea* pollen concentration (CO) 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 by the most representative climatic

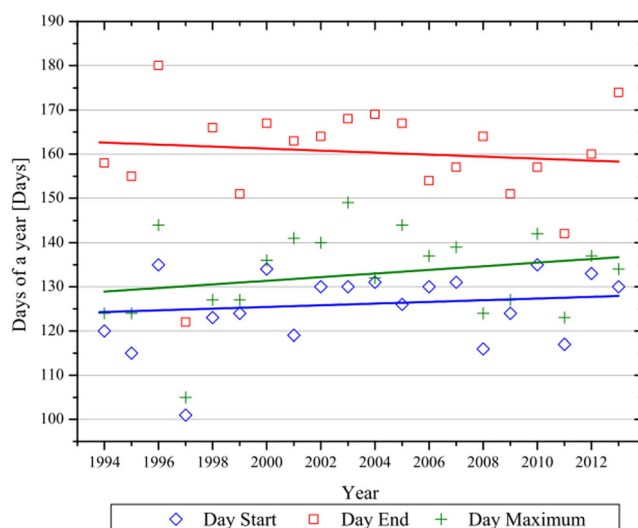
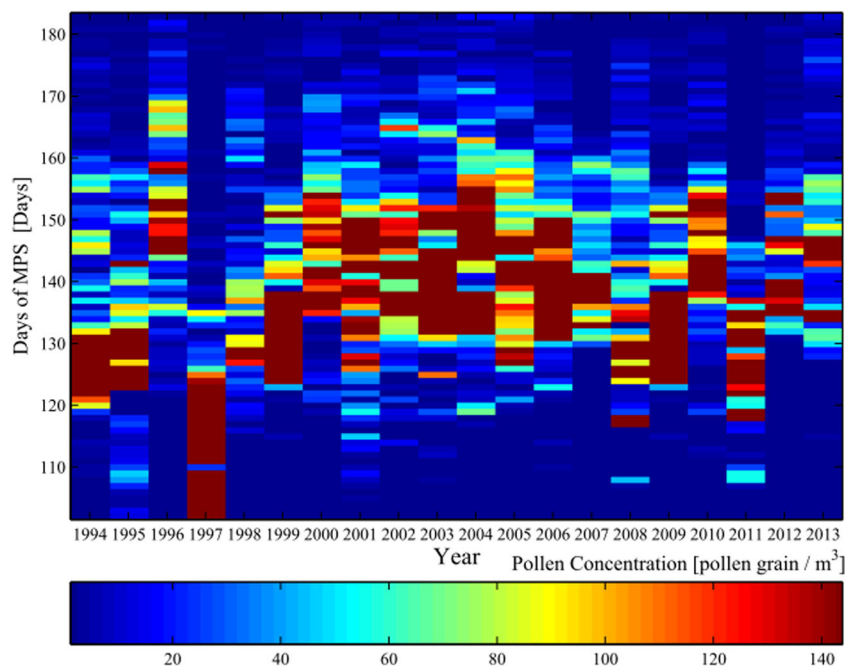


Fig. 2 Trends in the pollen season for *Olea* pollen

Fig. 3 *Olea* pollen season characteristics**Table 2** Correlation coefficient between daily SPI and meteorological parameters

	<i>T</i> max	<i>T</i> mean	<i>T</i> min	Rain	RH	Rain 10 days	<i>T</i> mean 10 days
1994	0.410 ^a	0.222	-0.322 ^b	-0.489 ^a	-0.643 ^a	-0.722 ^a	0.643 ^a
1995	0.063	0.171	0.387 ^b	0.168	0.005	0.413 ^a	0.148
1996	0.219	0.188	0.129	-0.083	-0.024	-0.157	-0.178
1997	0.450 ^b	0.429 ^b	-0.085	-0.475 ^b	-0.438 ^b	-0.344	0.355
1998	0.469 ^a	0.268	-0.043	-0.176	-0.244	-0.279	-0.165
1999	-0.370	-0.340	-0.160	0.321	0.418 ^b	-0.386 ^b	-0.257
2000	-0.133	-0.016	0.253	-0.132	0.542 ^a	-0.089	-0.350 ^b
2001	0.238	0.207	0.185	-0.307 ^b	-0.111	-0.081	-0.105
2002	0.183	0.168	0.101	0.091	-0.139	0.206	-0.461 ^a
2003	-0.004	-0.176	-0.300	0.029	-0.431 ^a	-0.496 ^a	-0.615 ^a
2004	-0.578 ^a	-0.662 ^a	-0.629 ^a	0.326 ^b	0.741 ^a	0.460 ^a	-0.658 ^a
2005	-0.128	-0.288	-0.486 ^a	-0.077	-0.196	0.131	-0.684 ^a
2006	-0.033	-0.170	-0.283	-0.283	-0.228	-0.563 ^a	-0.208
2007	0.022	-0.016	-0.066	-0.085	0.146	-0.219	-0.174
2008	0.339 ^b	0.383 ^a	0.257	-0.210	0.081	-0.175	0.075
2009	-0.054	0.059	0.053	-0.268	-0.050	-0.235	0.303
2010	0.260	0.334	0.215	–	-0.697 ^a	–	-0.375
2011	0.080	0.026	-0.299	-0.404 ^b	-0.231	-0.551 ^a	-0.554 ^a
2012	0.563 ^a	0.605 ^a	0.387 ^b	-0.115	-0.671 ^a	-0.235	0.305
2013	0.103	0.091	-0.143	-0.046	-0.391 ^a	-0.063	-0.571 ^a

^a Significance at level 99 %^b Significance at level 95 %

variables multiplied by a fitting coefficient. Finally, considering the effect of previous days on the daily value of each

variable the average temperature and the cumulative rainfall of the previous 10 days to the equation:

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

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 and Δt is the time step considered for the forecasting process, which is fixed at 1 day. It is composed by the integration of different climatic variables for each time step regarding the actual airborne pollen concentration value joined to the mean concentration value of the previous 10 days for each time step. Besides the fact that the value of each variable is evaluated for every time step, the aggregated variables of the mean temperature for 10 previous days as well as the cumulative rainfall of the 10 previous days have been included to analyse the influence of the temporal variation of these variables over the airborne pollen concentration. Regardless of the fact 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 to the fact that the range of variations are different among them as well as its mean value. The fitting parameters for this model were estimated using the SCEM-UA algorithm. In Table 3, the values obtained for each parameter for the 20 years analysed, and the value obtained from the coefficient of determination (R^2) are shown. The model has been validated for the last year considering the rest

of the data for the calibration process (Fig. 4), obtaining a correlation ($R^2=0.77$) between the observed data (1994–2012) and simulated data (2013).

Moreover, Table 3 also includes the results obtained with a forecast time step of 3 and 5 days to examine the suitability of the model to predict concentrations for longer time gaps. For this purpose, Eq. (1) is modified with Δt equal to 3 for a forecast time step of 3 days and 5 for a forecast time step of 5 days. As it is shown, parameter a had a high value, indicating the influence of the previously explained trend in the pollen concentration. Among the parameters related to daily temperature, parameter c , which is linked to the mean temperature, had a relatively high value. Such relationships were not observed for rainfall, which is the variable with lower parameters as well as maximum daily temperature (parameter b). The value of parameter g , linked to the average rainfall of the 10 previous days, was higher than the f parameter for a forecast time step of 1 and 3 days. However, it is lower in the case of 5 days. Finally, the value of parameter h , which is linked to daily relative humidity, was the second higher parameter for the two first time steps (1 and 3 days).

Discussion

In an area of 500 m around the volumetric sampler, only one olive tree was found and this is behind a building. We therefore

Table 3 Parameters and statistical analysis of the model proposed to predict airborne pollen concentration (D: previous day)

Parameters	Time prediction delay		
	1 Day	3 Days	5 Days
a	0.645	1.197	0.819
b	−0.003	0.014	0.071
c	0.123	0.026	−0.072
d	−0.085	0.001	0.046
e	−0.044	−0.05	−0.053
f	0.003	0.015	−0.012
g	−0.012	−0.017	−0.003
h	−0.176	−0.252	0.051
Comparison criteria			
R^2	0.623	0.574	0.476
RMSE	107.96	130.59	162.49
CCobs	127.84		
CCsim	131.04	128.02	112.8

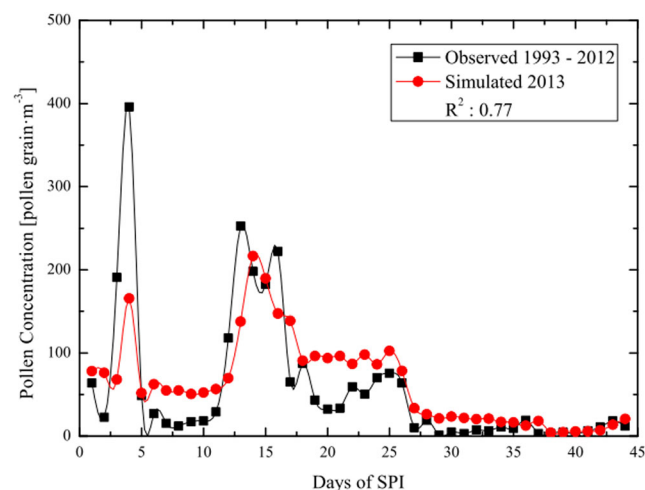


Fig. 4 Validation of the model for the last year

estimate that pollen recorded in this work comes from median and distant sources (Fernández-Rodríguez et al. 2014a; Rojo and Pérez-Badía 2015). This is because there are hardly any olive trees in the close surroundings of the sampler, but they are equally distributed in the 3–5 km area except the NE where trees are few. The frequency of winds from this direction is also low. Previous papers have estimated that pollen is recorded from an area of 100 km around the sampler (Domínguez et al. 1993; Fornaciari et al. 2000). Analysis of the phenology of wind-pollinated plants is a tool to study aerobiological results (Hidalgo et al. 2003; Oteros et al. 2015) and other papers have highlighted the relation between the temporal succession of phenological phases and the data recorded at the sampling site (Rojo and Pérez-Badía 2015; Tormo-Molina et al. 2011).

The MPS lasted about 1 month and, although trends are not statistically significant, it seems that there is a small delay trend in the pollination. This may be deduced because the number of MPS days is correlated with the end day. The delay or advance in pollination differs from other studies and it is quite dependent on the years analysed. Menzel et al. (2006) calculated for trees in Europe the mean advance of spring flowering dates at 2.5 days per decade. Advances at the beginning of the pollen season were found in *Betula* (Zhang et al. 2013), in Poaceae (Stach et al. 2008) and *Olea* (Aguilera et al. 2015b); however, a delay was found in airborne Cupressaceae pollen (Silva-Palacios et al. 2015). Peak of pollination and the onset, both correlated, tend to happen earlier. This may be in consonance with other phenological studies of trees that display a general advance in flowering but mainly in high altitudes or latitudes (Parmesan and Yohe 2003). It therefore seems reasonable to think that the phenological stage of *Olea* pollination could be sensitised to a future global climate change (Aguilera et al. 2015b).

We have not found any statistical significant trend in MPS length. In contrast, García-Mozo et al. (2014) found a lengthening mostly due to the advance of the pollen season start. We have noticed that the highest and lowest SPI values were found in two consecutive years, 1997 and 1998, and this may be related to rainfall before pollination, mainly in winter. Nevertheless, the rainfall during the MPS may effectively wash pollen-sized particles from the atmosphere and thereby influence the amount of pollen recorded. It is necessary to emphasise that the airborne pollen trend to increase in cultivated trees may occur due to the change in land use. In Extremadura, there was a clear general trend towards an increase in olive crops (MAFE 2013).

The positive relation between airborne olive pollen and temperature is clear, in accordance with previous papers (Galán et al. 2001; Oteros et al. 2013b). The increase of the temperatures produces anticipation of olive tree flowering and lower airborne pollen emission (Aguilera et al. 2015b). The effect of rain is not as clear as temperature, because previous rainfall is important for flower development in trees, mainly in

winter and early spring (Oteros et al. 2014). Rainfall during the MPS can mask airborne pollen records and in spring, the rainfall is frequent in Mediterranean regions. In this sense, the number of days with rain is more critical than total amount of rainfall, this could explain why 1997 recorded the highest SPI after 19 days with rain in March–May and 1998 recorded the lowest SPI after 34 days of rain in the same period.

The importance of producing models for predicting daily average concentrations of airborne *Olea* pollen has been previously addressed (Achmakh et al. 2015; Aguilera and Ruiz-Valenzuela 2014; García-Mozo et al. 2014). Temperature and rainfall have been used in other studies (Zhang et al. 2015). This study also takes into account pollen records from the 10 previous days, so the predictive value may be more accurate than using meteorological parameters alone. We have considered the more adjusted results to the real pattern of pollination. Average temperature of the previous 10 days was the main meteorological factor considered in terms of its effect on the daily pollen forecast, and rain was a secondary factor that could modify this forecast. This finding could be explained due to the fact that olive trees are resilient to increases in accumulated temperature, unlike herbs and grasses (Recio et al. 2010).

To test the accuracy of these results, R^2 value (0.77) was estimated for the multiple regression model proposed, being a value higher than reported for the same time series for Cupressaceae pollen in Badajoz (Silva-Palacios et al. 2015). Furthermore, for the analysis of the entire time period, the fit of the model was examined for a forecast horizon of 1, 3 and 5 days. The R^2 values obtained were 0.62, 0.57 and 0.48, respectively, which show a trend in decreasing order. These results also confirm the suitability of the proposed model.

Conclusions

Due to the allergenic characteristics of this pollen type, it should be necessary to forecast its short-term prevalence using a long record of data in a city with a Mediterranean climate. The model obtained provides a good level of confidence to forecast olive airborne pollen concentration with an R^2 of 0.62 and 0.57 for a forecast horizon of 1 and 3 days, respectively.

Acknowledgments This work was made possible by research projects PRI06A190 and PRI BS10008, and research groups aid GR15060 financed by the Regional Government, Junta de Extremadura (Spain) and the European Regional Development Fund.

References

- Achmakh L, Bouziane H, Aboulaich N, Trigo MM, Janati A, Kadiri M (2015) Airborne pollen of *Olea europaea* L. in Tetouan (NW Morocco): heat requirements and forecasts. *Aerobiologia* 31:191–199

- AEMET (2015) Climate statistics. Badajoz Airport (1971–2000). Agencia Estatal de Meteorología. Gobierno de España. <http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=4452&k=ext>
- Aguilera F, Ruiz Valenzuela L (2009) Study of the floral phenology of *Olea europaea* L. in Jaén province (SE Spain) and its relation with pollen emission. *Aerobiologia* 25:217–225
- Aguilera F, Ruiz-Valenzuela L (2014) Forecasting olive crop yields based on long-term aerobiological data series and bioclimatic conditions for the southern Iberian Peninsula. *Span J Agric Res* 12:215–224
- Aguilera F, Valenzuela LR (2012) Microclimatic-induced fluctuations in the flower and pollen production rate of olive trees (*Olea europaea* L.). *Grana* 51:228–239
- Aguilera F, Fornaciari M, Ruiz-Valenzuela L, Galán C, Msallem M, Dhiab A, Guardia C-D La, del Mar Trigo M, Bonofiglio T, Orlandi F (2015a) Phenological models to predict the main flowering phases of olive (*Olea europaea* L.) along a latitudinal and longitudinal gradient across the Mediterranean region. *Int J Biometeorol* 59:629–641
- Aguilera F, Orlandi F, Ruiz-Valenzuela L, Msallem M, Fornaciari M (2015b) Analysis and interpretation of long temporal trends in cumulative temperatures and olive reproductive features using a seasonal trend decomposition procedure. *Agric For Meteorol* 203:208–216
- Aznarte MJL, Benítez Sánchez JM, Lugilde DN, de Linares Fernández C, de la Guardia CD, Sánchez FA (2007) Forecasting airborne pollen concentration time series with neural and neuro-fuzzy models. *Expert Syst Appl* 32:1218–1225
- Bonofiglio T, Orlandi F, Ruga L, Romano B, Fornaciari M (2013) Climate change impact on the olive pollen season in Mediterranean areas of Italy: air quality in late spring from an allergenic point of view. *Environ Monit Assess* 185:877–890
- Cariñanos P, Casares-Porcel M (2011) Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. *Landsc Urban Plan* 101:205–214
- Cariñanos P, Casares-Porcel M, Quesada-Rubio JM (2014) Estimating the allergenic potential of urban green spaces: a case-study in Granada, Spain. *Landsc Urban Plan* 123:134–144
- Damialis A, Halley JM, Gioulekas D, Vokou D (2007) Long-term trends in atmospheric pollen levels in the city of Thessaloniki, Greece. *Atmos Environ* 41:7011–7021
- Díaz J, Linares C, Tobías A (2007) Short-term effects of pollen species on hospital admissions in the city of Madrid in terms of specific causes and age. *Aerobiologia* 23:231–238
- Domínguez E, Infante F, Galán C, Guerra FFV (1993) Variations in the concentrations of airborne *Olea* pollen and associated pollinosis in Córdoba (Spain): a study of the 10-years period 1982–1991. *J Investig Allergol Clin Immunol* 3(3):121–129
- Efstratiadis A, Koutsoyiannis D (2010) One decade of multi-objective calibration approaches in hydrological modelling: a review. *Hydrol Sci J* 55:58–78
- Feo-Brito F, Gimeno PM, Carnés J, Martín R, Fernández-Caldas E, Lara P, López-Fidalgo J, Guerra F (2011) *Olea europaea* pollen counts and aeroallergen levels predict clinical symptoms in patients allergic to olive pollen. *Ann Allergy Asthma Immunol* 106:146–152
- Fernández-Llamazares Á, Belmonte J, Delgado R, De Linares C (2014) A statistical approach to bioclimatic trend detection in the airborne pollen records of Catalonia (NE Spain). *Int J Biometeorol* 58:371–382
- Fernández-Rodríguez S, Skjøth CA, Tormo-Molina R, Brandao R, Caeiro E, Silva-Palacios I, Gonzalo-Garijo Á, Smith M (2014a) Identification of potential sources of airborne *Olea* pollen in the Southwest Iberian Peninsula. *Int J Biometeorol* 58:337–348
- Fernández-Rodríguez S, Tormo-Molina R, Maya-Manzano JM, Silva-Palacios I, Gonzalo-Garijo Á (2014b) Comparative study of the effect of distance on the daily and hourly pollen counts in a city in the south-western Iberian Peninsula. *Aerobiologia* 30:173–187
- Fernández-Rodríguez S, Tormo-Molina R, Maya-Manzano JM, Silva-Palacios I, Gonzalo-Garijo Á (2014c) A comparative study on the effects of altitude on daily and hourly airborne pollen counts. *Aerobiologia* 30:257–268
- Fornaciari M, Galán C, Mediavilla A, Domínguez E, Romano B (2000) Aeropalynological and phenological study in two different Mediterranean olive areas: Córdoba (Spain) and Perugia (Italy). *Plant Biosyst* 134:199–204
- Fornaciari M, Orlandi F, Romano B (2005) Yield forecasting for olive trees: a new approach in a historical series (Umbria, Central Italy). *Agron J* 97:1537–1542
- Frenguelli G, Ghitarrini S, Tedeschini E (2014) Climatic change in Mediterranean area and pollen monitoring. *Flora Mediterr* 24: 99–107
- Galán C, Tormo R, Cuevas J, Infante F, Domínguez E (1991) Theoretical daily variation patterns of airborne pollen in the southwest of Spain. *Grana* 30:201–209
- Galán C, Cariñanos P, García-Mozo H, Alcázar P, Domínguez-Vilches E (2001) Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalusia, Spain. *Int J Biometeorol* 45:59–63
- Galán C, García-Mozo H, Vázquez L, Ruiz L, de la Guardia CD, Trigo MM (2005) Heat requirement for the onset of the *Olea europaea* L. pollen season in several sites in Andalusia and the effect of the expected future climate change. *Int J Biometeorol* 49:184–188
- Galán C, Cariñanos P, Alcázar P, Domínguez-Vilches E (2007) Spanish aerobiology network (REA) management and quality manual, Servicio de Publicaciones Universidad de Córdoba. ISBN 978-84-690-6353-8
- García-Mozo H, Mestre A, Galán C (2010) Phenological trends in southern Spain: a response to climate change. *Agric For Meteorol* 150: 575–580
- García-Mozo H, Yaezel L, Oteros J, Galán C (2014) Statistical approach to the analysis of olive long-term pollen season trends in southern Spain. *Sci Total Environ* 473–474:103–109
- García-Mozo H, Oteros J, Galán C (2015) Phenological changes in olive (*Olea europaea* L.) reproductive cycle in southern Spain due to climate change. *Ann Agric Environ Med* 22:421–428
- Hernández-Ceballos MA, García-Mozo H, Adame JA, Domínguez-Vilches E, de la Morena BA, Bolívar JP, Galán C (2011) Synoptic and meteorological characterisation of olive pollen transport in Córdoba province (south-western Spain). *Int J Biometeorol* 55: 17–34
- Hernández-Ceballos MA, Skjøth CA, García-Mozo H, Bolívar JP, Galán C (2014) Improvement in the accuracy of back trajectories using WRF to identify pollen sources in southern Iberian Peninsula. *Int J Biometeorol* 58(10):2031–2043
- Hidalgo PJ, Galán C, Domínguez E (2003) Male phenology of three species of *Cupressus*: correlation with airborne pollen. *Trees - Struct Funct* 17:336–344
- Hirst JM (1952) An automatic volumetric spore trap. *Ann Appl Biol* 39: 257–265
- MAFE (2013) Survey areas and yields of crops. Analysis of olive groves in Spain. Ministry of Agriculture, Food and Environment of Government of Spain. <http://www.magrama.gob.es/es/>
- Mazzeo A, Palasciano M, Gallotta A, Camposeo S, Pacifico A, Ferrara G (2014) Amount and quality of pollen grains in four olive (*Olea europaea* L.) cultivars as affected by 'on' and 'off' years. *Sci Hortic* 170:89–93
- Menzel A, Sparks TH, Estrella N, Koch E, Aasa A, Ahas R, Alm-KÜbler K, Bissolli P, Braslavská OG, Briede A, Chmielewski FM, Crepinsek Z, Cumel Y, Dahl Å, Defila C, Donnelly A, Filella Y, Jatzek K, MÅGe F, Mestre A, Nordli Ø, Peñuelas J, Pirinen P, Remišová V, Scheffinger H, Striz M, Susnik A, Van Vliet AJH, Wielgolaski F-E, Zach S, Züst ANA (2006) European phenological

- response to climate change matches the warming pattern. *Glob Chang Biol* 12:1969–1976
- Moriondo M, Orlandini S, Nuntiis PD, Mandrioli P (2001) Effect of agrometeorological parameters on the phenology of pollen emission and production of olive trees (*Olea europea* L.). *Aerobiologia* 17: 225–232
- Newnham RM, Sparks TH, Skjøth CA, Head K, Adams-Groom B, Smith M (2013) Pollen season and climate: is the timing of birch pollen release in the UK approaching its limit? *Int J Biometeorol* 57:391–400
- Nilsson S, Persson S (1981) Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana* 20:179–182
- Orlandi F, García-Mozo H, Galán C, Romano B, de la Guardia CD, Ruiz L, del Mar Trigo M, Domínguez-Vilches E, Fornaciari M (2010) Olive flowering trends in a large Mediterranean area (Italy and Spain). *Int J Biometeorol* 54:151–163
- Oteros J, García-Mozo H, Hervás-Martínez C, Galán C (2013a) Year clustering analysis for modelling olive flowering phenology. *Int J Biometeorol* 57:545–555
- Oteros J, García-Mozo H, Hervás C, Galán C (2013b) Biometeorological and autoregressive indices for predicting olive pollen intensity. *Int J Biometeorol* 57:307–316
- Oteros J, Orlandi F, García-Mozo H, Aguilera F, Dhiab AB, Bonofiglio T, Abichou M, Ruiz-Valenzuela L, Del Trigo MM, Díaz De La Guardia C, Domínguez-Vilches E, Msallem M, Fornaciari M, Galán C (2014) Better prediction of Mediterranean olive production using pollen-based models. *Agron Sustain Dev* 34:685–694
- Oteros J, García-Mozo H, Botey R, Mestre A, Galán C (2015) Variations in cereal crop phenology in Spain over the last twenty-six years (1986–2012). *Clim Chang* 130:545–558
- Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37–42
- Pérez-Badía R, Vaquero C, Sardinero S, Galán C, García-Mozo H (2010) Intradial variations of allergenic tree pollen in the atmosphere of Toledo (central Spain). *Ann Agric Environ Med* 17:269–275
- Recio M, Docampo S, García-Sánchez J, Trigo MM, Melgar M, Cabezero B (2010) Influence of temperature, rainfall and wind trends on grass pollination in Malaga (western Mediterranean coast). *Agric For Meteorol* 150:931–940
- Ribeiro H, Cunha M, Abreu I (2008a) Quantitative forecasting of olive yield in Northern Portugal using a bioclimatic model. *Aerobiologia* 24:141–150
- Ribeiro H, Oliveira M, Abreu I (2008b) Intradial variation of allergenic pollen in the city of Porto (Portugal). *Aerobiologia* 24:173–177
- Rojo J, Pérez-Badía R (2015) Spatiotemporal analysis of olive flowering using geostatistical techniques. *Sci Total Environ* 505:860–869
- Rojo J, Rapp A, Lara B, Fernández-González F, Pérez-Badía R (2015) Effect of land uses and wind direction on the contribution of local sources to airborne pollen. *Sci Total Environ* 538:672–682
- Silva-Palacios I, Fernández-Rodríguez S, Durán-Barroso P, Tormo-Molina R, Maya-Manzano JM, Gonzalo-Garijo Á (2015) Temporal modelling and forecasting of the airborne pollen of Cupressaceae on the southwestern Iberian Peninsula. *Int J Biometeorol* 60(2): 297–306
- Stach A, García-Mozo H, Prieto-Baena JC, Czarnecka-Operacz M, Jenerowicz D, Silny W, Galán C (2007) Prevalence of *Artemisia* species pollinosis in western Poland: impact of climate change on aerobiological trends, 1995–2004. *J Investig Allergol Clin Immunol* 17:39–47
- Stach A, Smith M, Prieto Baena JC, Emberlin J (2008) Long-term and short-term forecast models for Poaceae (grass) pollen in Poznań, Poland, constructed using regression analysis. *Environ Exp Bot* 62:323–332
- Staffolani L, Velasco-Jiménez MJ, Galán C, Hruska K (2011) Allergenicity of the ornamental urban flora: ecological and aerobiological analyses in Córdoba (Spain) and Ascoli Piceno (Italy). *Aerobiologia* 27:239–246
- Tormo R, Silva I, Gonzalo Á, Moreno A, Pérez R, Fernández S (2011) Phenological records as a complement to aerobiological data. *Int J Biometeorol* 55:51–65
- Tormo-Molina R, Gonzalo-Garijo MA, Silva-Palacios I, Munoz-Rodriguez AF (2010) General trends in airborne pollen production and pollination periods at a Mediterranean site (Badajoz, southwest Spain). *J Investig Allergol Clin Immunol* 20:567–574
- Torrigiani Malaspina T, Cecchi L, Morabito M, Onorari M, Domeneghetti MP, Orlandini S (2007) Influence of meteorological conditions on male flower phenology of *Cupressus sempervirens* and correlation with pollen production in Florence. *Trees - Struct Funct* 21:507–514
- Vázquez LM, Galán C, Domínguez-Vilches E (2003) Influence of meteorological parameters on *Olea* pollen concentrations in Cordoba (south-western Spain). *Int J Biometeorol* 48:83–90
- Velasco-Jiménez MJ, Alcázar P, Valle A, Trigo MM, Minero F, Domínguez-Vilches E, Galán C (2014) Aerobiological and ecological study of the potentially allergenic ornamental plants in south Spain. *Aerobiologia* 30:91–101
- Villalba M, Rodríguez R, Batanero E (2014) The spectrum of olive pollen allergens. From structures to diagnosis and treatment. *Methods* 66: 44–54
- Voukantis D, Niska H, Karatzas K, Riga M, Damialis A, Vokou D (2010) Forecasting daily pollen concentrations using data-driven modeling methods in Thessaloniki, Greece. *Atmos Environ* 44: 5101–5111
- Vrugt JA, Gupta HV, Bouten W, Sorooshian S (2003) A shuffled complex evolution metropolis algorithm for optimization and uncertainty assessment of hydrologic model parameters. *Water Resour Res* 39: SWC11–SWC116
- Zhang Y, Isukapalli S, Bielory L, Georgopoulos P (2013) Bayesian analysis of climate change effects on observed and projected airborne levels of birch pollen. *Atmos Environ* 68:64–73
- Zhang Y, Bielory L, Cai T, Mi Z, Georgopoulos P (2015) Predicting onset and duration of airborne allergenic pollen season in the United States. *Atmos Environ* 103:297–306