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ORIGINALPAPER

Effect of the meteorological parameters on the *Olea europaea* L. pollen season in Bahía Blanca (Argentina)

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Abstract *Olea europaea* is one of the most prevalent aeroallergens causing allergenic reactions in the city of Bahía Blanca, Argentina. The aim of this study was to evaluate the influence of meteorological factors on the pollen season of *Olea europaea* L. The aerobiological analysis was performed over an 11-year period in the city. Sampling was carried out with a Rotorod model 40 volumetric impact sampler. The pollen season started in the middle of October and showed the highest values between 16 October and 24 November. A marked difference was noted over the years of this study, especially in 2005 and 2008, due to a significant decrease in the precipitation during the months prior flowering and high temperatures during the pollen season. A decreasing trend of pollen index during the study period coincided with a reduction in the precipitation from June to October (winter and spring). As expected, the air temperature prior to the onset of flowering is of great importance in determining the start of the pollen season.

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1 Introduction

The olive, which originated mainly in the Mediterranean Basin, is widely cultivated as a street tree in different towns in the center and east of Argentina, and there are also commercial plantations in northwest Argentina (Catamarca, La Rioja and San Juan), Mendoza, Córdoba and the southwest of Buenos Aires Province.

The olive tree is one of the major components of the urban trees in Bahía Blanca, Argentina, representing one of the 10 most abundant pollen types throughout the year (Murray et al. 2002, 2010). It is believed that the olive was introduced to the American continent in 1500 with the arrival of Spanish missionaries. The immigrants and their descendants were sometimes responsible for planting olive trees in the city. There are no reviews about plant varieties, their origin and/or age. Over recent decades, there has been a boom in the development of olive groves in the region, but these are more than 60 km from the city center of Bahía Blanca. However, this pollen source not really contribute to the pollen cloud dispersed in the city of Bahia Blanca, as has been observed prior by Murray et al. (2010). The olive pollen source is mainly local, and the major contribution is from the numerous olive plants present in the squares, gardens and streets in the city. Olive pollen is one of the most important causes of allergic diseases in Bahía Blanca, and 48 % of patients suffering from seasonal pollinosis are sensitive to this pollen (Ramón et al. 1995).

In the study zone, the climate is temperate/mesothermal with constant precipitation throughout the year and hot summers. A slight increase in precipitation during summer and a decrease in autumn have been detected during the last decades. On the other hand, the average annual temperature generally presented an increase of around 0.5–1.5 °C; the largest increases were observed during the spring and summer. Regarding future predictions, it is estimated that southern South America is undergoing a warming in all seasons, but minimal changes are projected for higher latitudes (south of 35°S). The changes in precipitation vary substantially from season to season and across regions in response to changes in the large-scale circulation. An increase in precipitation in central Argentina is projected for the summer and autumn (Nuñez et al. 2009; Stocker et al. 2013).

Some authors have observed an earlier occurrence of some phenological stages in plants associated with a marked increase in temperature (Galán et al. 2005; García-Mozo et al. 2015). The temperature is the most important meteorological parameter for winter and early flowering spring plants in temperate zones, chilling requirements provokes a break in bud dormancy, and heating requirements are important for flowering development. The plant needs accumulate heat units until flowering starts (Oteros et al. 2013c; Aguilera et al. 2014; Orlandi et al. 2014). The temperature not only affects the pollen season start, but also influences the daily airborne pollen concentrations, the peak intensity and the pollen season duration (Vázquez et al. 2003). The influence of meteorological factors on pollen emission and transport has been studied by several authors in the Mediterranean Basin (Vázquez et al. 2003; Bonofiglio et al. 2009; Orlandi et al. 2010; Hernádez-Ceballos et al. 2011; Avolio et al. 2012; Orlandi et al. 2014; Aguilera et al. 2015a). However, in Argentina, there are no published studies on the influence of meteorological variables in the olive pollen dynamics in the atmosphere.

As noted by Murray et al. (2010), the duration of the olive season shows marked fluctuations from year to year, changes that could be due to the influence of different meteorological variables although this aspect has not been studied yet in the city, neither in the region. For this study, it has been hypothesized that an increase in precipitation during the period previous to flowering season causes greater flowering intensity and then higher olive airborne pollen in the city of Bahia Blanca (located in the southwest of the province of Buenos Aires, in close proximity to the Atlantic coast). On the other hand, years with lower temperatures could provoke a delay in the pollen season start.

This is a first study to analyze the relationship between meteorological parameters and the olive pollen season in a temperate/mesothermal urban area in the South American region. The main goal of this study is to analyze the role of different meteorological parameters in the olive pollen season for both, timing and flowering intensity.

2 Materials and methods

Bahía Blanca City is located in the southwest of the province of Buenos Aires (38°44′S; 62°16′W), at 20 m above sea level, near to the Atlantic coast. Climate is temperate/mesothermal with constant precipitation throughout the year and hot summers (Kottek et al. 2006; Fig. 1). The annual mean temperatures are between 14 and 20 °C, being markedly different between seasons. Annual rainfall is between 500 and 600 mm, with a high degree of variability. The climate is influenced by the Atlantic Ocean, which has a particularly modulating effect on air temperature. However, the area is located on the edge of an estuary, and there are also continental features in the region (Verettoni and Aramayo 1974).

Olive airborne pollen was captured by a Rotorod model 40 volumetric impact sampler, located at 12 m above ground level in the town center (Fig. 2), during January 1, 2001, to December 31, 2011. The pollen collection and data analysis were carried out according to the operating manual of the Rotorod sampler (Brown 1993). Airborne pollen has been expressed as the daily average of pollen grains per cubic meter of air (pollen grains/m^3). The start of the pollen season was defined as the first day on which one pollen grains/m^3 was recorded, and subsequent days (at least five consecutive days) with one or more pollen grains/m^3. The end of the season was the last day on which one pollen grains/m^3 was recorded and the subsequent five

Fig. 1 Köppen-Geiger climate classification. *C* warm temperate; *f* fully humid; a hot summer

consecutive days with concentrations below this level (García-Mozo et al. 1999). Seasonal pollen index (SPI) has been considered as the sum of the daily averages during the pollen season.

The meteorological data were provided by the National Meteorological Service at "Comandante Espora" weather station, located at 6 km east of the sampling site (Fig. 2). The parameters that have been taken into account are daily maximum, minimum and mean temperature (T_{max}, T_{min} and T_{mean}), daily relative humidity (RH), daily wind velocity (WV) and daily rainfall (mm). For this study have been considered those variables with possible greatest influence on the vegetative and reproductive cycles of the olive: mean, maximum, minimum temperature in a ten-day moving average before flowering (August, September and October), in the previous summer (21 December to 20 March) and winter (21 June to 20 September) and the monthly value all year round; total rainfall in the two and six previous months, from 1 March to 31 July, 1 July to 31 December and monthly values.

Shapiro–Wilk's *W* test has shown that airborne pollen does not adjust to a normal distribution. Correlation analysis between meteorological parameters and airborne pollen has been carried out following nonparametric statistics with Spearman's test. Multiple regression analysis (forward stepwise) has been performed to produce forecasting models. Statistical analysis was carried out using the software package STATISTICA 10.

3 Results

3.1 Trends

The olive pollen was recorded in the atmosphere of Bahía Blanca city from the middle of October to the end of November, and it represents approximately 16 % of the total pollen recorded over the same period (Table 1; Fig. 3).

The start of the pollen season varied between 16 October (2003 and 2007) and 27 October (2009). The intensity and timing of the pollen peak also varied each year; the earliest peak date was 19 October (2008) and the latest the 2 November (2001); the daily peak concentration fluctuated between 9 and 84 pollen/m^3. The end dates varied from 4 November (2008) to 24 November (2002). The mean duration of the main pollen season (MPS) was 26 days, and it ranged between 17 days in 2008 to 33 days in 2006 (Table 2).

The peak day and end of the olive pollen season show a negative trend over the studied years, resulting in an advancement in both variables, whereas the starting day shows a positive trend, with a gradual delay over the years (Fig. 4).

3.2 Relation with the meteorological variables

The changes in mean monthly temperature and precipitation during vegetative growth and flowering (June–November) were compared to the mean values for the 1959–2000 period. It has been observed that the mean temperatures for June, September and October were very stable, and there were greater negative changes during July in 2007 and 2010 and during August in 2007, whereas important positive changes

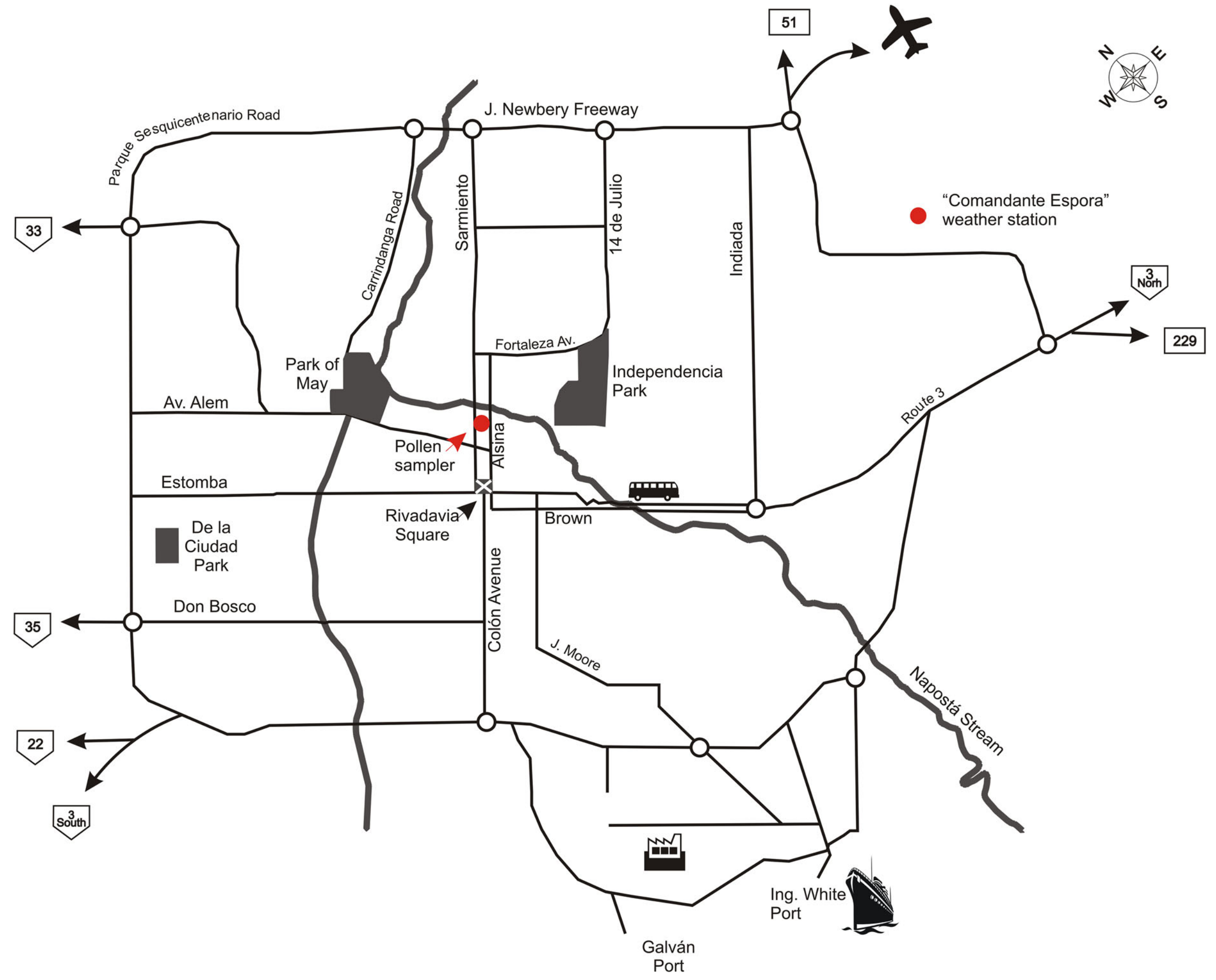

Fig. 2 Map of Bahía Blanca City. Pollen sampler and weather station locations

were observed for November in 2008 and 2011 (Fig. 5).

A clear downward trend in the winter precipitation has been observed over the study period. High positive values of changes during the months when the flowering of the olive occurs are also notable in the early study years (2001–2004 and 2006). It can be observed a generalized low water availability in October in 2005, 2008, 2009 and 2011 (Fig. 6).

The daily pollen concentration did not show a normal distribution, and the transformations of the pollen concentration, $\log_{10}(x+1)$; $\log_{10}((x \times 0.5)+1)$; $\ln((x \times 0.5)+1)$ and $\sqrt{x}$, did not improve the results. Therefore, the correlation analysis was not parametric (Spearman's Correlation). Table 3 shows the significant results obtained in the analysis.

The analysis of meteorological variables prior to the pollen season start was conducted with 111 variables, but only those with significant correlations with the pollen season variables are shown in Table 4. The start of the pollen season has shown a significantly positive correlation with the minimum temperature in the second ten-day period of September (1 month before the pollen season start) and a negative correlation with the mean temperature in the period before the start. The pollen season duration mainly shows a negative correlation with the mean temperature of the first month in the pollen season (October–November) and the maximum temperature of the first ten-day period of November. The seasonal pollen index depended highly on water availability during the months prior to flowering and during the initial period

Table 1 Pollen index of Bahía Blanca

Main pollen season	Olive pollen index	Total pollen index	%
2001	302	1722	18
2002	276	1692	16
2003	283	808	35
2004	293	3029	10
2005	52	894	6
2006	235	1809	13
2007	203	1334	15
2008	43	495	9
2009	139	525	26
2010	131	1127	12
2011	111	722	15
Mean			16
Minimum			6
Maximum			35

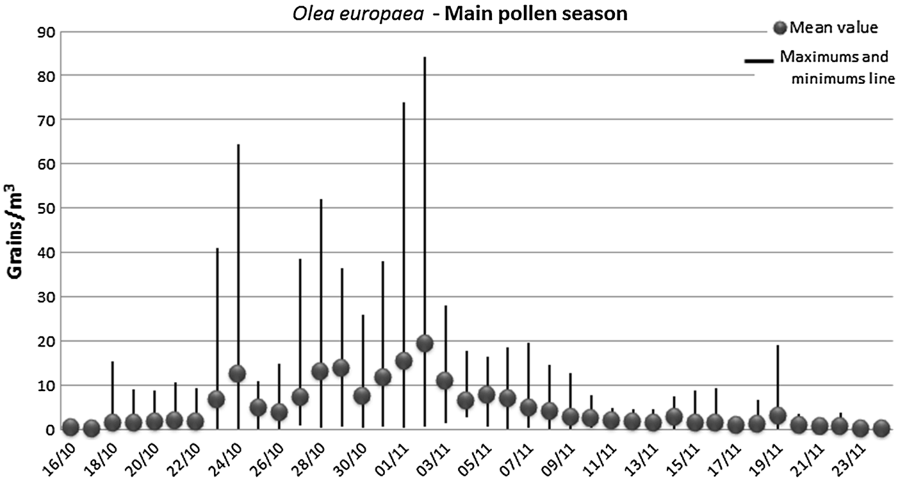

Fig. 3 Minimum, maximum and mean olive airborne pollen concentrations in Bahía Blanca, 2001–2011

(end of autumn, winter and beginning of spring), leading to an increase in the flowering intensity and therefore in the quantity of pollen dispersed in the atmosphere. The minimum temperature during the period close to the flowering start may positively influence the seasonal pollen index. The flowering intensity, measured as seasonal pollen index (SPI), is positively influenced by the precipitation in the months prior to the pollen season start (April to October), whereas the precipitation in the month prior to the start shows a significantly high correlation with the peak day. The maximum temperature in the second half of October and the first days of November negatively influence the date of the end of the season.

In order to improve the aerobiological variables (start, peak, end date, SPI and peak value), a forecast of the MPS multiple regression analysis was performed. Under the assumption that the least number of possible variables is included in the model to get the best fit, the best results obtained are presented. As can be seen in Table 5, variables related to temperature predominate in the models.

On the basis of these results, models that fit well have been found (R^2Adj. = 83–97 %) for the pollen season start, peak and end day, value of maximum peak and pollen index in Bahía Blanca. The model was elaborated with data from 2001 to 2010, and the 2011 was considered for validation; the real and the

Table 2 Parameters of the MPS of olive pollen

MPS	Start	End	Days	Peak date	Peak value	SPI
2001	22-Oct	17-Nov	27	02-Nov	84.21	302
2002	24-Oct	24-Nov	32	01-Nov	74.03	276
2003	16-Oct	08-Nov	24	24-Oct	58.30	283
2004	22-Oct	22-Nov	32	01-Nov	23.40	293
2005	21-Oct	14-Nov	25	3-Nov	8.65	52
2006	19-Oct	20-Nov	33	24-Oct	64.42	235
2007	27-Oct	20-Nov	25	30-Oct	25.96	203
2008	19-Oct	04-Nov	17	19-Oct	8.97	43
2009	27-Oct	15-Nov	20	29-Oct	30.45	139
2010	20-Oct	20-Nov	32	01-Nov	17.95	131
2011	23-Oct	14-Nov	23	29-Oct	29.81	111

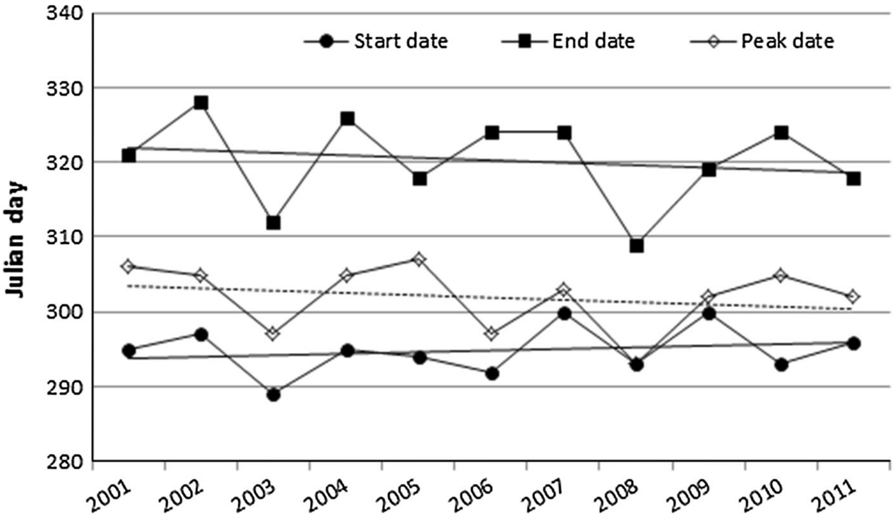

Fig. 4 Variation in the pollen season start, peak and end during the study period

forecasted value can be observed in the scatter plots (Fig. 7).

4 Discussion

Olive pollen is detected in the atmosphere of Bahia Blanca during October, November and December. The seasonal pollen index (SPI) from olive in urban spaces does not show an interannual variability in flowering intensity and seed production, phenomenon that characterize to olive crops, as has been observed before by Murray et al. (2002, 2010). This different behavior can be probably most related to the age of the trees, and also because the fruit is not harvested from 1 year to the next. The pollen season of the olive has been very variable; however, there has been a tendency toward a gradual decrease in its length (number of days) and abundance (SPI, peak value) over the years, and from 2005 and 2008 in particular.

The principal changes during the studied years are related to a decrease in pollen concentration in the air, resulting from a slight delay on pollen season start and an advanced on pollen season end. The pollen season start oscillated around 11 days during the second fortnight of October. In the case of an advance on the peak and end days of the season, it coincides with a report from Italy (Bonofiglio et al. 2009), but different behavior has been observed in the case of pollen season start, with a delay in Bahía Blanca and an advance in Spain and Italy (Galán et al. 2005; Bonofiglio et al. 2009; García-Mozo et al. 2014).

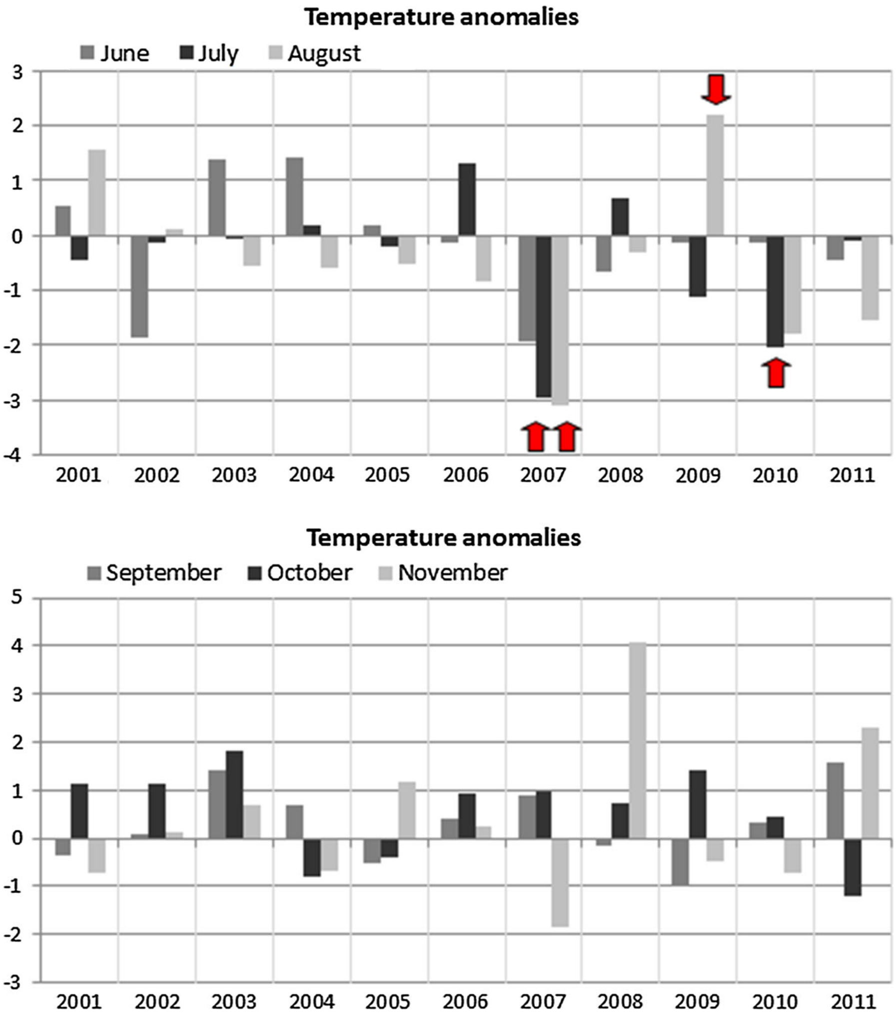

Fig. 5 Temperature change in Bahía Blanca City

These differences are consistent as response of olive to different bioclimatical areas and environmental conditions. On the other hand, differences also depend on the studied period of time.

Study on the influence of the meteorological variables during the pollen season is usually based on two different aspects. Knowledge on daily pollen behavior under different variables influencing local weather is essential for generating short-term forecasting models. On the other hand, studies based on the role of pre-seasonal meteorological factors on timing, length and intensity of the pollen season also offer important information for medium- or long-term forecasting models.

According to the statistics of the SMN (1961–2013), the variation in mean annual temperature did not increase in the Bahía Blanca region; however, it has been observed variations during the months of the year that influence the olive pollen season. The principal effects of climate change in the region show an increase in the mean temperature during spring and summer, whereas the precipitation shows a slight increase during the summer and a decrease in autumn (Servicio Meteorológico Nacional 2014).

Daily airborne pollen and meteorological variables barely showed a significant correlation in this study. In the case of temperature, a significant correlation with the accumulated average temperature has been only observed, supporting previous results in Spain (Recio et al. 1996, 1997; Vázquez et al. 2003). Rainfall and humidity did not show the same pattern during the studied period. Depending on the year in question,

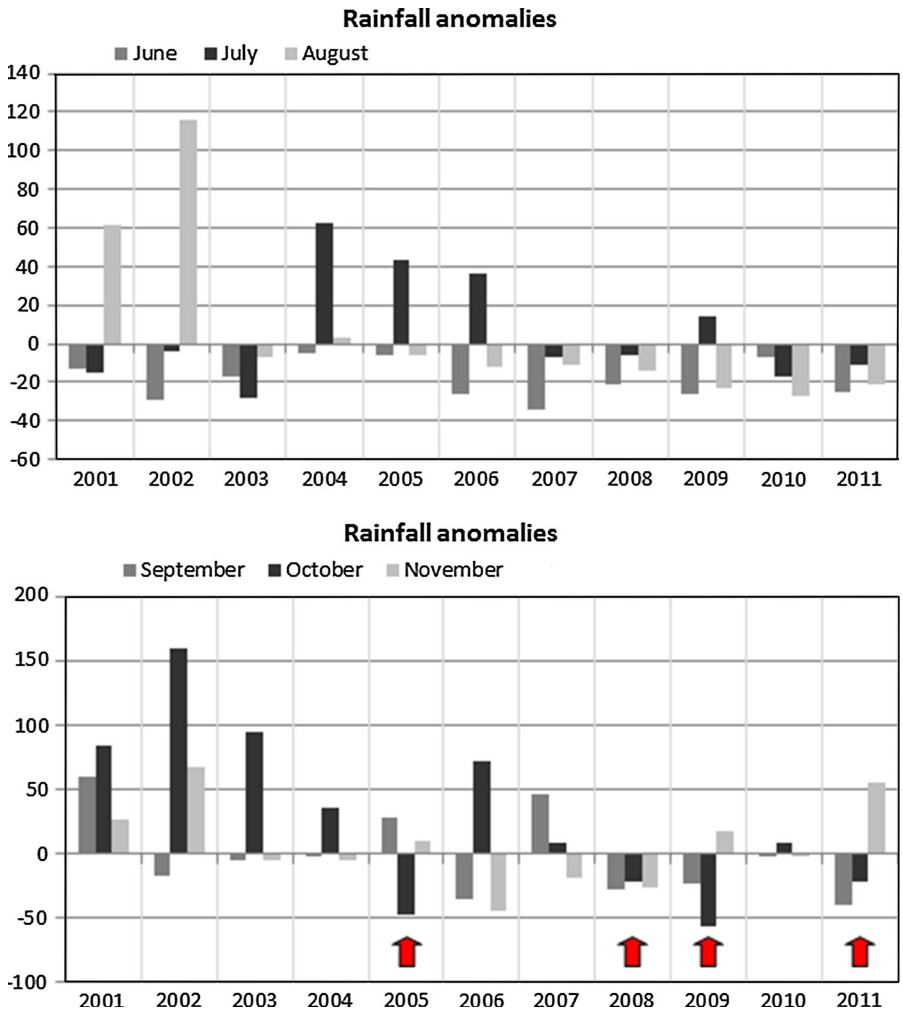

Fig. 6 Annual rainfall changes in Bahía Blanca City

different variables can affect the daily pollen concentration in the air in different ways (Oteros et al. 2013b). In wetter and warmer years during the pollen season, humidity and precipitation positively influence the daily pollen concentration. However, during colder years, the influence of these variables was negative. On the other hand, it is important to consider that during the flowering phenology phenomena, there are correlations with pollen from previous days, considering that moving average shows excellent results. These variables have been used for Poaceae and Cupressaceae airborne pollen with good results (Aboulaich et al. 2013; Silva-Palacios et al. 2015). These observations are important for future short-term forecasts. However, longer datasets could clarify and support these results in the future for defining which variables more affect airborne pollen during pollen season.

Regarding the role of different meteorological variables prior to pollen season, it has been shown that the temperature during the months prior to flowering (July, August and September) shows a significant correlation with some variables related to pollen season (Start and Peak day and Peak value), similar to other places in Europe (González-Minero and Cadau Fernández-Mensaque 1996; Moriondo et al. 2001; Galán et al. 2005; Oteros et al. 2013a, 2013c; Aguilera et al. 2014). The initiation of flowering was induced by the lower minimum temperatures during 1 month prior the pollen season start. In general, the evolution of the climate in the city at the beginning of spring is not gradual and there are

Table 3 Spearman correlation test

MPS	N	T_{accum}	T_{mean}	T_{max}	T_{min}	HR	W_{mean}	R_{accum}	Rainfall	T_{mean-1}	T_{max-1}	T_{min-1}	pollen-1	M_{Mov-3}
2001–	24	−0.53**	0.25	−0.07	0.45*	0.63**	−0.23	−0.55**	0.55**	0.37	0.24	0.46*	0.73**	0.74**
2002	32	−0.40*	0.06	−0.17	0.20	0.17	0.15	−0.42*	0.07	−0.07	−0.08	−0.02	0.62**	0.54**
2003	24	−0.29	0.01	−0.13	0.07	0.03	0.38	−0.28	0.25	−0.21	−0.27	−0.13	0.45*	0.54**
2004	32	−0.40*	0.31	0.36*	−0.16	−0.50**	−0.08	−0.41*	−0.31	0.12	0.21	−0.15	0.45**	0.45**
2005	25	0.23	0.13	0.09	0.33	0.03	0.02	0.30	0.12	0.33	0.23	0.26	−0.05	−0.05
2006	33	−0.36*	−0.03	−0.11	0.01	0.36*	0.00	−0.33	0.22	−0.21	−0.09	−0.21	0.30	0.30
2007	25	−0.43*	−0.06	0.01	−0.19	0.10	0.10	−0.38	−0.17	−0.12	−0.06	−0.07	0.35	0.35
2008	17	−0.28	0.46	0.27	0.11	−0.09	0.05	−0.32	0.16	0.09	0.33	−0.17	−0.07	−0.16
2009	20	−0.70**	0.13	0.06	0.30	0.12	−0.48*	−0.71**	0.41	0.18	0.21	0.36	0.65**	0.59**
2010	32	−0.17	0.10	0.23	−0.06	−0.17	−0.02	−0.17	−0.29	−0.07	−0.07	−0.28	0.25	0.39*
2011	23	−0.12	−0.09	−0.08	0.05	0.08	−0.10	−0.07	−0.06	−0.12	−0.15	−0.13	0.25	−0.32

T_{accum}, cumulative temperature; T_{mean}, mean temperature; T_{max}, maximum temperature; T_{min}, minimum temperature; HR, relative humidity; W_{mean}, mean wind velocity; R_{accum}, cumulative rainfall; T_{mean-1}, mean temperature of the previous day; T_{max-1}, maximum temperature of the previous day; T_{min-1}, minimum temperature of the previous day; pollen−1, pollen of the precious day; M_{Mov-3}, running mean of the three previous days; **–**, without outliers

** $p < 0001$; * $p < 0.05$

Table 4 Significant Spearman's correlations between olive pollen season variables and meteorological variables in the study period

Season pollen parameter versus meteorological factors	Spearman coefficient
Dependent variable: start date	
Minimum temperature in the second ten-day period of September	0.78**
Mean temperature in 4 months before start the season (15/6–14/7)	−0.78**
Mean temperature in the third 10-day period of September	−0.66*
Dependent variable: duration	
Maximum temperature in the first 10-day period of November	−0.69*
Minimum temperature in the last summer	−0.62*
Mean temperature in the first month of the season (15/10–14/11)	−0.62*
Dependent variable: SPI	
Minimum temperature in the first 10-day period of October	0.84**
Rainfall in 2 months before start the season (15/8–14/10)	0.70*
Rainfall in 6 months before start the season (15/4–14/10)	0.68*
Rainfall in April	0.68*
Rainfall in August	0.63*
Mean temperature in 3 months before start the season (15/7–14/8)	0.69*
Maximum temperature in April	−0.62*
Dependent variable: peak date	
Rainfall in the last autumn (1/3–31/7)	0.82**
Maximum temperature in July	−0.74**
Rainfall in September	0.72*
Dependent variable: peak value	
Minimum temperature in the first 10-day period of October	0.84**
Mean temperature in 3 months before start the season (15/7–14/8)	0.62*
Dependent variable: end date	
Maximum temperature in the first 10-day period of November	−0.92**
Mean temperature in the first 10-day period of November	−0.72*
Rainfall in the last autumn (1/3–31/7)	0.68*
Maximum temperature in the second 10-day period of October	−0.66*
Minimum temperature in February	−0.63*
Rainfall in April	0.60*

SPI seasonal pollen index

* $p < 0.05$; ** $p < 0.01$

alternately hot and cold weeks; moreover, late frosts are common at the beginning of September. The plants become adapted to the type of climate that characterizes the region (Aguilera et al. 2014). In those places with high maximum temperatures, plants generally respond to variations on minimum temperatures (Orlandi et al. 2013; Oteros et al. 2014). The peak day (timing) is positively related to water availability in the previous month of the pollen season start, as it has been observed in Spain and Italy (Orlandi et al. 2010), whereas the maximum temperatures during winter have a negative effect on this variable. The influence of the temperature at first month of the season on the end day is clear.

The increase in temperature as a consequence of climatic change influences floral development and specially pollen season start. It has been supported by different papers (Orlandi et al. 2013; Aguilera et al. 2015b; García-Mozo et al. 2015). In Bahia Blanca, a slight increase in temperature has not really affected in an advance of the olive pollen season start and peak day yet. Nevertheless, it has been observed an advanced in the start and peak day in those years characterized by high temperatures and low water availability during blooming period (October and November). Therefore, it is important to study what will occur in the future if increasing temperature continues.

Table 5 Relation between meteorological and aerobiological parameters

	Adjusted R^2	Model
Start date	0,897**	$y = 321.54 + 1.67\ (T_{2qSEP}) - 1.80\ (T_{mJ\text{-}Jl}) - 2.53\ (T_{m3dSEP})$
Peak date	0.826**	$y = 345.41 - 4.44\ (T_{maxJUL}) + 1.28\ (T_{minAUG}) + 1.07\ (T_{2qSEP})$
Peak value	0.912**	$y = -320.47 + 20.38\ (T_{min1dOCT}) + 13.83\ (T_{mS\text{-}O})$
SPI	0.944**	$y = -882.028 + 45.423\ (T_{min1dOCT}) + 50.115\ (T_{mSEP}) + 0.28\ (\text{Rf1/7–31/12})$
End date	0.972**	$y = 394.37{-}2.03\ (T_{max1dNOV}){-}1.42\ (T_{m2qOCT}){-}0.44\ (T_{min2dAUG})$

Multiple regression models

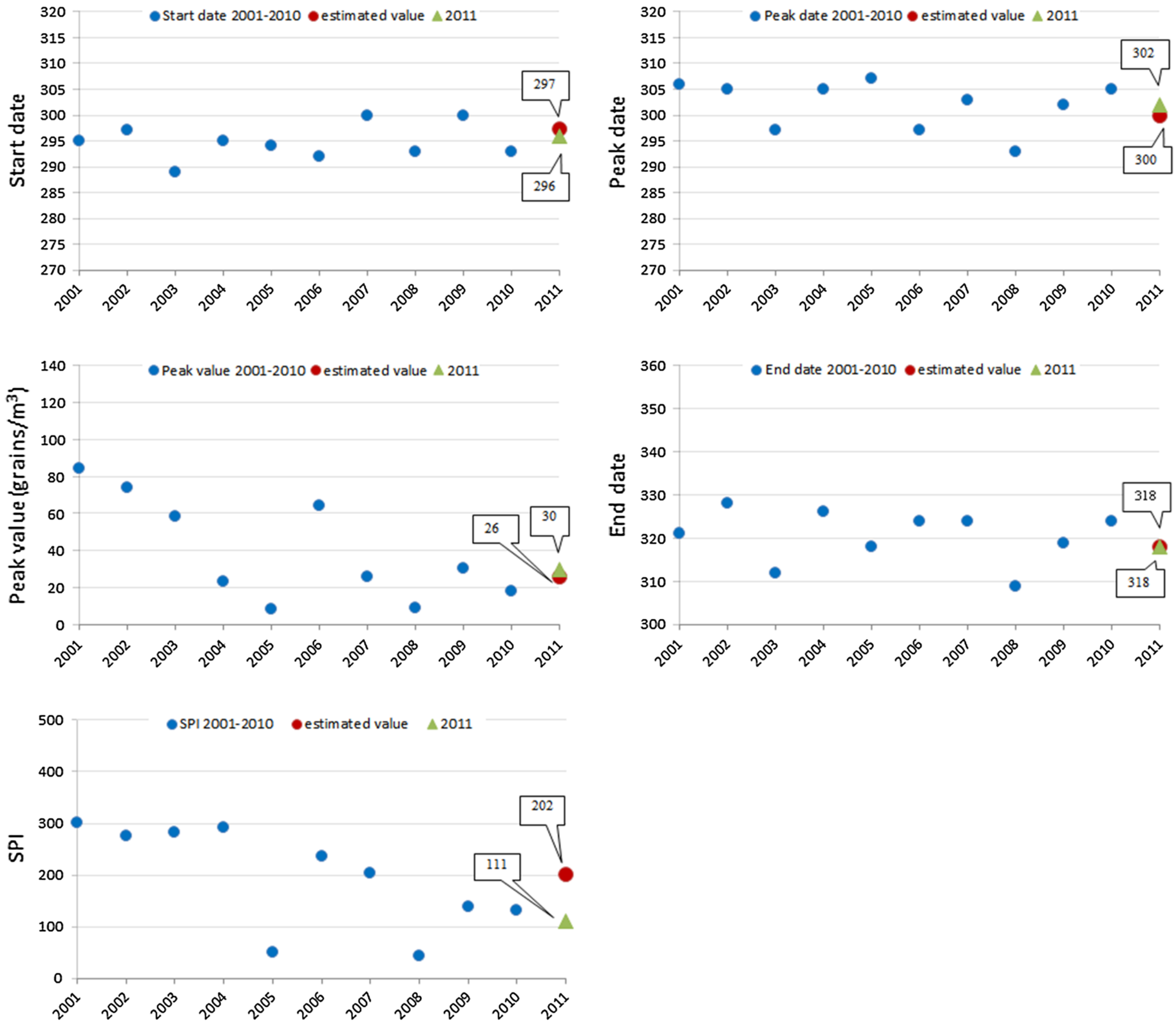

Fig. 7 Scatter plots show the relationships between selected pollen and meteorological variables

The maximum value (peak value) reached would be positively related to the minimum temperature during the season. The duration of the pollen season shows a correlation with the mean temperature in the first month of the season, and once the flowering of the olive is initiated, the mean temperature would be one of the variables that show most influence during the pollen season. On the other hand, the seasonal pollen index depended mainly on water availability in the previous period, in six and two months prior to the beginning of the season. Rainfall during the vegetative period notably has a positive effect on flowering intensity, as has been observed in southeastern France and Mediterranean region in general (Sicard et al. 2012; Oteros et al. 2014).

The seasonal pollen index also showed dependence with the previous minimum temperature to the pollen season start and mean temperature in the last winter; this close relationship between pollen index and temperature has been also reported by Oteros et al. (2013a) and Orlandi et al. (2014) in Mediterranean region. During 2005 and 2008, there was scarce airborne pollen with low values during the peak day and also during the SPI, coinciding with low water availability during the star season period.

The forecasting models produce a very good estimation for 2011 in all cases. The variables that more contributed to the model for the pollen season start and peak day are the early spring temperature and the coldest month during the year. Longer datasets and the application of the model would contribute to optimizing the model in the future. There are no studies on olives in the region or the country, or even in South America, that can be used to compare these results, but the models include similar variables than those obtained by Aguilera et al. (2015a) with more complex analysis. The forecasting models created in this study will be tested and adjusted in the next few years of research. Although these studies are preliminary, they lay the bases for the elaboration of more complex models of forecasting for the region.

5 Conclusions

This study has shown not clear trends in the olive pollen season start in Bahía Blanca. Air temperature prior flowering and also temperatures during the last 6 month are important variables in determining the pollen season start. Higher differences have been observed on seasonal pollen index and peak pollen emission. A decreasing trend in pollen index coincides with a decrease in the precipitation during June and August (winter). Dry years coincided with lower seasonal pollen index. Once the pollen grains are liberated, the variables that more contribute in short-term forecast models are related to pollen during previous days.

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