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Statistical approach to the analysis of olive long-term pollen season trends in southern Spain

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HIGHLIGHTS

- A long term olive airborne pollen analysis has been performed.
- Three types of statistical analysis were performed and compared: Linear Regression, Seasonal-Trend Decomposition procedure based on Loess (STL), and an ARIMA model.
- Olive Pollen Index is significantly increasing in South Europe.
- There is a lengthening of the Pollen season mostly due to the advance of the Pollen Season Start.
- The combination of the lengthening of the season with the increase in airborne pollen counts can play a negative effect on pollen-allergy sufferers in the Mediterranean area.

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ABSTRACT

Analysis of long-term airborne pollen counts makes it possible not only to chart pollen-season trends but also to track changing patterns in flowering phenology. Changes in higher plant response over a long interval are considered among the most valuable bioindicators of climate change impact. Phenological-trend models can also provide information regarding crop production and pollen–allergen emission. The interest of this information makes essential the election of the statistical analysis for time series study.

We analysed trends and variations in the olive flowering season over a 30-year period (1982–2011) in southern Europe (Córdoba, Spain), focussing on: annual Pollen Index (PI); Pollen Season Start (PSS), Peak Date (PD), Pollen Season End (PSE) and Pollen Season Duration (PSD). Apart from the traditional Linear Regression analysis, a Seasonal-Trend Decomposition procedure based on Loess (STL) and an ARIMA model were performed.

Linear regression results indicated a trend toward delayed PSE and earlier PSS and PD, probably influenced by the rise in temperature. These changes are provoking longer flowering periods in the study area.

The use of the STL technique provided a clearer picture of phenological behaviour. Data decomposition on pollination dynamics enabled the trend toward an alternate bearing cycle to be distinguished from the influence of other stochastic fluctuations. Results pointed to show a rising trend in pollen production.

With a view toward forecasting future phenological trends, ARIMA models were constructed to predict PSD, PSS and PI until 2016. Projections displayed a better goodness of fit than those derived from linear regression.

Findings suggest that olive reproductive cycle is changing considerably over the last 30 years due to climate change. Further conclusions are that STL improves the effectiveness of traditional linear regression in trend analysis, and ARIMA models can provide reliable trend projections for future years taking into account the internal fluctuations in time series.

1. Introduction

Reproductive phenology is now recognized as a major indicator of the impact of climate change (Menzel and Sparks, 2006). In the northern hemisphere, the growing season is becoming longer; spring is starting earlier, and autumn later (Ahas et al., 2002; Menzel, 2000). This trend is well documented in northern Europe and North America, but less is known about Mediterranean species (Peñuelas et al., 2002).

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Application of appropriate statistical techniques to long-term phenological data enables fluctuation patterns and overall trends to be analysed. One of the most widely-used techniques has traditionally been linear regression (Bradley et al., 1999; García-Mozo et al., 2010). Nevertheless, phenological data do not always fit a linear regression model, since frequent year-on-year variations give rise to non-linear patterns.

The present study analyzes olive flowering phenology on the basis of airborne pollen data for southern Spain over a recent 30-year period (1982–2011). The olive tree is a species well adapted to wind pollination which releases large amounts of pollen into the atmosphere. Airborne pollen from anemophilous species is an important phenological data. This data can be used not only for crop management purposes in agronomic or forestry species (García-Mozo, 2011), but also for the adoption of preventive measures in the case of allergenic pollen grains as is the case of olive species (Galán et al., 2013; Oteros et al., 2013a). Moreover these phenological data are key indicators of the impact of climate change (Bonofiglio et al., 2013).

The region of Andalusia (southern Spain) boasts the world's largest area of olive-groves that produces over 5 million tonnes of olive fruits per year. In this region, the province of Córdoba accounts for a third of all Andalusian cropland being the second largest producer province. The olive monoculture expansion and the high number of allergens present in olive pollen grains have given rise to atopy and asthma in a large proportion of the population throughout the Mediterranean area (Barber et al., 2008).

Research has confirmed that in wind-pollinated species, both pollination timing and also intensity, expressed by the Pollen Index (PI) as the annual sum of daily airborne pollen counts, vary considerably from year to year due not only to weather-related factors but also to a number of species-specific characteristics (Jäger, 1989). In the case of PI, regular alternate bearing cycles have been reported for several wind-pollinated tree species in northern Europe, including *Betula* and *Alnus* (Andersen, 1980; Nilsson and Persson, 1981) and *Quercus robur* (Emberlin et al., 1993). In the Mediterranean area, this cycle is much less common, due to the extreme year-on-year variations in temperature and rainfall typical of the Mediterranean climate. Alternate bearing cycle is well described in olive tree (Lavee, 2007) and research on *Olea europaea* pollination suggests the same alternate cycle (Domínguez et al., 1993; Galán et al., 2004; Barranco et al., 2008), although it can be interrupted due to extreme events like water-stress years (Díaz de la Guardia et al., 2003; Galán et al., 2008).

Analysis of fossil-pollen records has shown that such trends can indicate ecological or anthropogenic changes, albeit over periods of hundreds of years (Grimm, 1988). To date, few studies have focussed on long-term airborne pollen trends (Recio et al., 2009; Emberlin et al., 2002; Ziello et al., 2012). Continuous pollen monitoring started recently in most places; nevertheless, some papers so far reveal changes not only in annual pollen intensity but also in the timing of pollination, due to increasing temperatures and variations in rainfall patterns (Menzel, 2000; Ziello et al., 2012). In the case of *Olea* pollen, some studies have detected a general advance of the pollen season starting in the Mediterranean area (Aguilera et al., 2013; Avolio et al., 2012; Bonofiglio et al., 2009; Sicard et al., 2012; Orlandi et al., 2013a, 2013b), including different sites in South Spain where pollen detection started in 1982 in Córdoba city and from 1992 in other provinces (Díaz de la Guardia et al., 2003; Galán et al., 2005, García-Mozo et al., 1999).

The statistical techniques usually employed to study pollen-season trends are correlation and regression analyses, even though the interpretation of results is governed by the normality and linearity of the data used. The present study sought to explore other methods for analysing trends in olive pollen data, including a Seasonal-Trend Decomposition procedure based on Loess (STL) taking into account the olive's alternate reproductive pattern and ARIMA models which produce a forecasting model on the basis of autoregressive analysis. The main characteristics of the pollen season were analysed including start, peak, and end dates, duration of pollen season and the variations on annual intensity expressed as PI. Improving forecasting of the olive flowering intensity in southern Europe will be of great value for both crop-management and allergy-prevention purposes.

Long-term trends in olive flowering phenology were analysed using a 30-year database of *Olea* pollen records for Córdoba. The main aim of the study is to detect the potential trends on olive reproductive phenology in the last years in South Europe. For this purpose we have compared different statistic methods in order to offer the most reliable results: 1. to chart long-term trends in olive flowering phenology using linear regression; 2. to analyse long-term trends in pollen season using a Seasonal-Trend Decomposition procedure based on Loess; and 3. to forecast future trends in the annual pollen index, the pollen-season start date and the pollen-season duration using ARIMA models.

2. Material & methods

The study used a 30-year database (1982–2011) of pollen records for the city of Córdoba (southern Spain). The area has a Mediterranean climate with some continental features. The annual mean temperature is 17.8 °C and the annual average rainfall is 621 mm.

Phenological data on flowering intensity were measured by analysing airborne olive pollen counts, using a Hirst-type volumetric spore trap (Hirst, 1952) placed on the roof of the Educational Sciences Faculty, at 15 m above ground level. This sampler captures olive pollen over a radius of 100 km, thus providing a good indication of flowering phenology for the whole province of Córdoba (Hernández-Ceballos et al., 2010). Pollen counts were obtained using a standard protocol published by the Spanish Aerobiology Network (REA) (Galán et al., 2007). Data on the following phenological features were extracted for each study year: Pollen Season Start (PSS), Peak Date (PD), Pollen Season End (PSE), and Duration (PSD), as well as the annual Pollen Index (PI). The PSS was defined as the first day on which we record ≥ 1 pollen grain/m^3 and also in the following 5 days ≥ 1 pollen grain/m^3 per day are recorded (García-Mozo et al., 1999). The PSE was the last day on which 1 pollen grain/m^3 was recorded and counts on subsequent days were 1 or 0 pollen grain/m^3. The PI is defined as the sum of the daily average pollen counts per cubic metre throughout the year. The PD was defined as the day on which the highest daily pollen count was recorded.

Analysis of long-term trends in the olive reproductive cycle was performed using three approaches. Apart from linear regression, a Seasonal-Trend Decomposition procedure based on Loess (STL) technique was performed, taking into account olive reproductive patterns. An ARIMA model was also constructed for modelling and forecasting some pollen season features. ARIMA models enable long-term forecasting on the basis of autoregressive analysis, in which predicted values for the output variable are based on its own previous values, regardless of external factors such as potential weather patterns:

1 Linear regression analysis was used to study long-term trends displayed by the following phenological features: PSS, PD, PSE, PSD and PI.
2 A Seasonal-Trend Decomposition Procedure based on Loess (STL) was performed. STL is a filtering procedure for decomposing a time-series into additive components of variation (trend, seasonality and irregularity) by the application of loess smoothing models (Cleveland et al., 1990; Chaloupka and Limpus, 2001). This technique was applied to the daily-pollen time series with a view to analysing trends in daily pollen production over time, since some components of pollen time series produce distortions impeding our understanding of their long-term behaviour.

The daily-pollen time series was regarded as a mixture of several components: Trend (T), Seasonal (S) and Irregular (I). A decomposition technique was used to distinguish these components in study data, and to analyse only the Trend component, thus eliminating distortions in the interpretation of results, P being the daily-pollen time series:

$$P = T + S + I.$$

3 In order to forecast PI, PSS and PSD until 2016, ARIMA (Autoregressive Integrated Model of Running Mean) univariate seasonal and non-seasonal models (also known as "Box–Jenkins" models) were applied. Three parameters were tested: Autoregressive (p), Differentiation (d) and Running mean (q):

p Number of autoregressive terms. Each term measures the independent effect of the values with a specified lag. An order 2 autoregressive means that each value of the series is affected by the two preceding values (regardless of each other).

d Number of times that a time series was transformed calculating the differences between the values of the series and its predecessors.

q The order of the running mean of the process.

3. Results

3.1. Study of phenological and meteorological trends using linear regression models

Table 1 shows the results of the trend analysis performed to the climatic data of Córdoba city recorded during the studied period, 1982–2011. Slopes of the linear regression trend analysis of temperatures and rainfall show an increase of both parameters, overall in the case of spring temperature. Data for the PSS, PD and PSE of the pollen season are shown in Fig. 1. Both PSS and PD appear to have occurred earlier over recent years, while PSE has been occurring later; the delay in PSE is 0.8 day per year ($p = 0.01$). As the graphic shows, the result is that pollen season is lasting longer, largely due to delayed PSE. The advance in PSS is less significant than the trend shown by PSE. The combination of the two trends means that the pollen season has been lengthened by over one day per year. The PD for any given year is also expected to occur 0.75 day earlier than in the previous year ($p = 0.0017$).

Regression analysis (Table 2) indicated a significant increase in annual pollen count; the PI has been increasing on average by 699 per year. So, while the season may start slightly earlier, the peak is reached sooner, even though the season is lasting longer, and annual pollen output is rising lengthening in time and the annual pollen is increasing: i.e. there is more pollen over more days.

Table 1
Slopes of the linear regression trend analysis of Maximum (TMx), Minimum (TMin) and Mean Temperature (TMn) in °C, and rainfall (Rf) during the studied period (1982–2011) in the city of Córdoba.

Meteorological parameters	January–March	April–June	January–June	January–December
TMx	0.014	0.084*,**	0.050**	0.033**
TMin	0.007	0.071***	0.057**	0.043**
TMn	0.011	0.077***	0.054***	0.038***
Rf	8.139	0.516	2.982	4.176

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

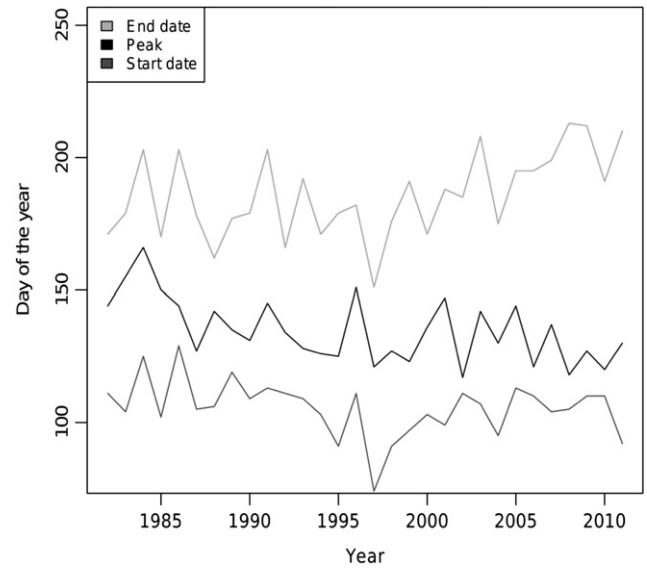

Fig. 1. Variation of Pollen Season Start, Peak Date, and Pollen Season End dates along the study period (1982–2011).

3.2. Seasonal-Trend Decomposition procedure based on Loess to study trends in pollen time series

The seasonal decomposition by loess, a method of regression with a weighted polynomial that is localized for different parts of the data, is shown in Fig. 2. By removing the seasonal trend, what is left is a much more obvious upward trend over time. The seasonal component shows variations in daily-pollen time series as a result of annual climate patterns. The reproductive cycles of organisms are usually adapted to the annual seasonality of the weather, and maintain annual patterns. The remainder component also shows variations due to random weather-related features which, in the Mediterranean region, display considerable year-on-year variability. Finally, the trend component charts the real long-term trend in atmospheric pollen content over time, clearly displaying a rising slope.

Fig. 3 shows trend with seasonality and randomness removed, together with a linear analysis of the trend component of the daily-pollen time series. This analysis confirms the positive trend in annual pollen production. Regression analysis shows that PI is increasing significantly ($p < 0.001$).

3.3. ARIMA models based on Box–Jenkins procedure

Linear regression and ARIMA analyses were applied to PI, PSS and PSD, as the most important variables on olive reproductive phenology. Based on the values of the auto-covariance function (ACVF) and the autocorrelation function (ACF) a Box–Jenkins model was constructed (Table 3). Log likelihood (Log lik.), the Akaike Information Criterium (AIC) and the Bayesian information criterion (BIC) were the adjustment criteria used for selecting the best model in each case. ARIMA analyses (Fig. 4) provided a more accurate model for PI and PSS. The AR1 parameter indicated that PI model was based on the existence of autocorrelation between the PI of a given year (t) and that of the previous year

Table 2
Linear regression summary: PSS, Pollen Season Start; PD, Peak Date; PSE, Pollen Season End; PSD, Pollen Season Duration; PI, Pollen Index.

	PSS	PD	PSE	PSD	PI
R^2	0.09	0.30	0.21	0.47	0.42
Slope	−0.36	−0.75	0.83	1.19	699
p	0.1071	0.0017	0.0112	0.0000	0.0001

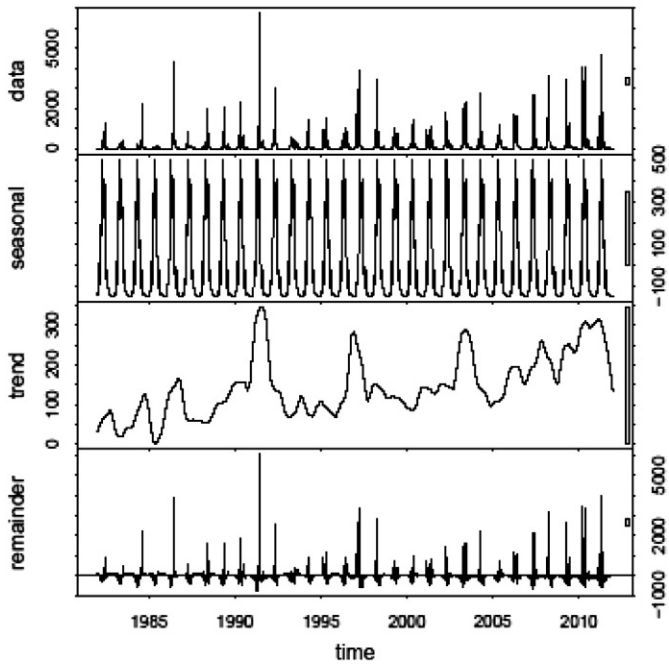

Fig. 2. Seasonal-Trend Decomposition procedure based on Loess. Daily pollen time series, seasonal component of time series, trend component of time series and remainder component of time series.

(t − 1). Similarly, the PSS model was based on the existence of autocorrelation between PSS_t and PSS_{t-1}. But the two models also had a SAR1 parameter, meaning that both variables display clearly seasonal behaviour. The PSD model also had AR1 and SAR1 parameters, but additionally presented an AR2 parameter meaning that the model was based on the existence of autocorrelation between PSD of a given year (t) and that of the year t − 2. Forecasting of future PSD by ARIMA (Fig. 5) confirmed the result obtained by linear regression, i.e. a rising trend.

The 5-year forecasts provided by the ARIMA models and by linear regression pointed to an increase in both PI and PSD, with an increasingly early PSS. However, ARIMA improved forecasting by enabling the modelling of other features of the time series, such as cycle patterns.

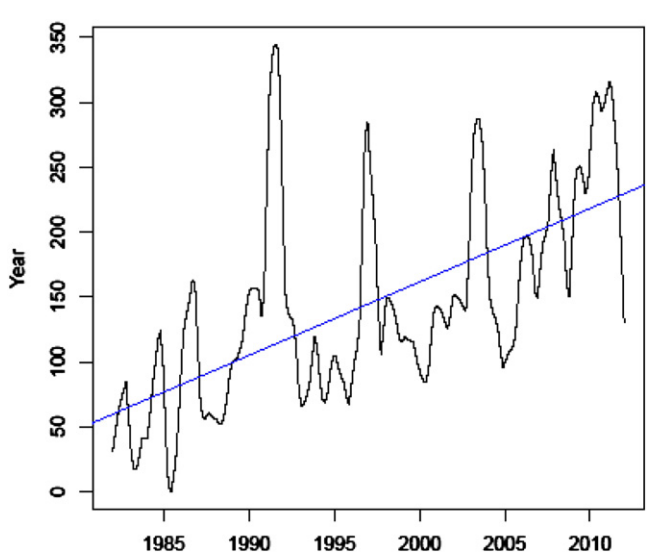

Fig. 3. Linear analysis of trend component of daily pollen time series.

Table 3
ARIMA summary. PSS, Pollen Season Start; PSD, Pollen Season Duration; PI, Pollen Index. Coef. (Coefficient), s.e. (Standard error), AR (Autoregressive), SAR (Seasonal Autoregressive), Log lik. (Log likelihood), AIC (Akaike Information Criterium), BIC (Bayesian information criterion).

Parameter	Model (PSS)		Model (PSD)		Model (PI)	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
AR1	−0.565	0.166	−0.884	0.196	−0.176	0.193
AR2			−0.476	0.192		
SAR1	−0.527	0.166	−0.764	0.135	−0.51	0.158
Model type	$(1,1,0)(1,1,0)_2$		$(2,1,0)(1,1,0)_2$		$(1,1,0)(1,1,0)_2$	
Log lik.	−109.67		−109		−290.37	
AIC	225.34		225.99		586.73	
BIC	229.23		231.17		590.62	

4. Discussion

The consequences of global climate change are evident from the observation of different climatic and biological manifestations which are directly or indirectly connected with the increase of the greenhouse effect (Bernstein et al., 2007). Many studies have confirmed the relationship between climate trends and various phenological phases in different plant and animal species (Sparks and Menzel, 2002; Beaubien and Freeland, 2000; Jaagus and Ahas, 2000; Kenda et al., 2000; Menzel and Sparks, 2006; Peñuelas et al., 2002; Chmielewski and Rötzer, 2001). Therefore, it can be assumed that a hypothetical future climate change will lead to changes in the range of the most sensitive species and a shift in the onset of different phenophases (Higgins and Richardson, 1999; Schwartz and Reiter, 2000). Research suggests that spring events in higher plants, leafing and flowering, have typically advanced, in some cases by several weeks (Bertin, 2008). Tree species are especially affected by climate warming, displaying in general an advance in flowering, leafing, and fruit ripening, particularly at high altitudes (Parmesan and Yohe, 2003).

In southern areas, the impact of climate change is being noticeable. According to the IPCC (Bernstein et al., 2007), Mediterranean ecosystems have certain vulnerabilities to climate change. Warmer and drier conditions will force species to shift. Land use, habitat fragmentation and intense human pressures will further limit natural adaptation responses, giving rise in many of these regions to a loss of biodiversity and of carbon sequestration services. The impact on plant response needs to be studied in greater depth. Most phenological research carried out in Europe provides few data on the Mediterranean region (i.e. Menzel, 2000; Vokou et al., 2012). The present findings confirm that olive phenology is being influenced by changes in climate. The annual pollen index is increasing, more pollen over more days, although the increase of Pollen Index could be partially explained by the increase of land surface devoted to olive cultivation suffered by the Córdoba province in the last years, around 20% from 1982 (SSYA, 2011). However, many scientific works have shown that temperature and water availability are highly correlated with the olive flowering intensity (Galán et al., 2001; Ribeiro et al., 2006a; Oteros et al., 2013b). In this sense, the increase of Pollen Index detected in our results can be also influenced by the increase of temperature during the study period. Regarding pollen season features, it is noticeable that the starting time is recorded earlier, pollen peak is being reached faster and the end is progressively later. Therefore pollen season is lengthening. These phenological changes can be attributed mainly to changes in temperature. The role of water availability on olive phenology is also important. Previous research has pointed out as water deficit can delay olive flowering phenology (Oteros et al., 2013c). Our results do not show this behaviour probably because the recorded rainfall is slightly increasing during the last 30 years, combined the fact of increasing temperatures (Galán et al., 2005; Ribeiro et al., 2006b; Orlandi et al., 2006; Aguilera et al.,

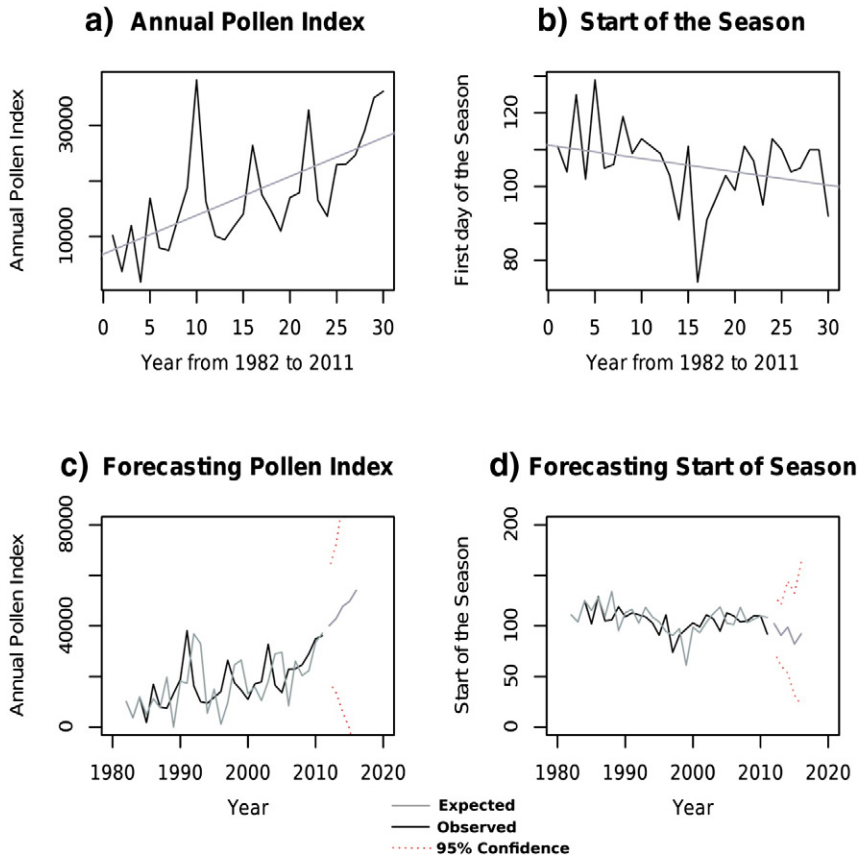

Fig. 4. Linear regression and ARIMA analyses for Pollen Index and the Start of Pollen Season. In a) and b) black line represents the real data and grey line represents the linear trend line in Linear regression analysis. The values forecasted by ARIMA models are represented in c) and d).

2013). Similar phenological changes, especially on flowering start, are also reported by other papers focussing on Spain and Italy (Galán et al., 2005; Bonofiglio et al., 2009, 2013; García-Mozo et al., 2010; Orlandi et al., 2013a, 2013b). Our results coincide in the fact of an olive flowering season advance although those related to the rest of phenological characteristics have been no possible to compare, due to the absence of works reporting this sort of results.

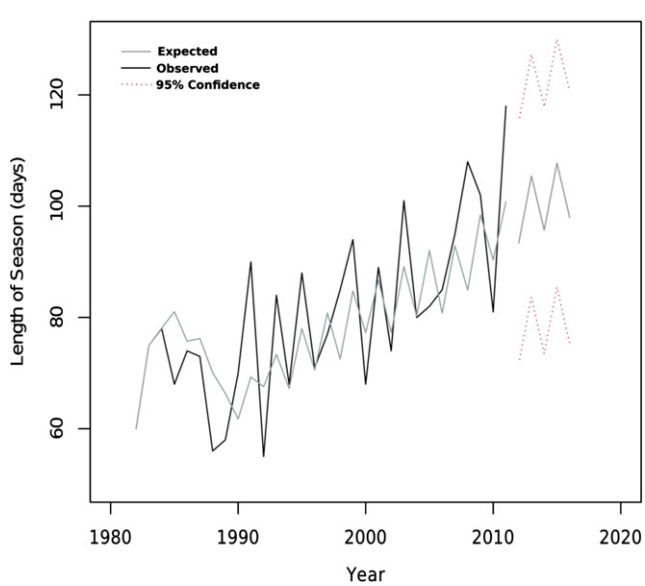

Fig. 5. Prediction of the length of the pollen season using ARIMA forecasting.

In anemophilous species of agricultural interest, like the olive, the study of flowering fluctuations provides valuable information on crop size (Galán et al., 2008). Changes in the length of the growing season influence the biochemical cycles of nitrogen, carbon and water, thereby affecting the productivity of natural terrestrial ecosystems and, in the case of the olive, agroecosystems (Ibáñez et al., 2010; Noormets et al., 2009). The Intergovernmental Panel on Climate Change (Bernstein et al., 2007) proposes several future climatic scenarios based on different estimations of humanity development and climate trends. The A1B emission scenario is the most accepted by scientific community, this future scenario assumes a rapid increase of greenhouse gas (having about 700 ppm of CO_2 concentration in 2100 year), increasing temperatures in the Mediterranean basin. More pollen grains produced by more flowers, due to climate warming and rising CO_2 levels; this could give rise to larger crops in future, on the other hand decreases in water availability could produce the opposite effect.

Shifts in olive flowering phenology involve agricultural economics both at the national and European community levels. Armed with improved knowledge of potential trends in olive flowering we can plan crop harvests and marketing, taking into account the influence of climate. Olive pollen research is also of particular interest for the general population, since pollen grains contain a number of different allergens that give rise to atopy and asthma in a large proportion of the population throughout the Mediterranean area (Barber et al., 2008).

Long-term trend analysis of phenological databases usually relies on linear regression techniques, although these are far from optimal because certain phenological features do not evolve linearly in time (i.e. Menzel, 2000; Dierenbach et al., 2013; Bartolini et al., 2013). Natural processes with a clear seasonal component, such as olive flowering, should be analysed using other kinds of statistical

technique, including Seasonal-Trend Decomposition procedure based on Loess (Verbesselt et al., 2010; Pomati et al., 2012). The present study pioneers the use of this technique in aerobiological research. By removing the seasonal component, which shows variations in daily-pollen time series due to annual weather patterns, and by removing the remainder component, which shows variations due to random features mainly linked to the considerable variability of the Mediterranean climate, the real rising trend in pollen output over time becomes much more obvious.

Although some attempts have been made to use ARIMA analysis for predicting daily pollen counts (Rodriguez-Rajo et al, 2006), it was not used hitherto as a means of forecasting annual phenological patterns. Usually phenological modelling, both from field or aerobiological data, has traditionally relied on linear regression (García-Mozo et al., 2010; Bradley et al., 1999; Peñuelas et al., 2002). Our results indicate ARIMA as an appropriate method for modelling nonlinear and auto-correlated series. In our case, it has been a more accurate forecasting method than linear regression, because olive reproductive cycle has several cyclical features, including a bi-annual pattern in flowering intensity, that impede effective predictions using linear methods.

5. Conclusions

Pollen-season duration is increasing in South Spain due to the fact that both the Start and Peak dates are occurring earlier, whereas the End date is occurring later. The annual Pollen Index is increasing significantly, which has consequences for olive crops. The lengthening of the season combined with the increase in airborne pollen counts can play a negative effect on pollen-allergy sufferers in the Mediterranean area.

With regard to the statistical analysis performed, apart from the Regression Analysis, the Decomposition analysis by Loess confirms a clear rising trend in pollen output, when only the trend component of daily-pollen time series is analysed. ARIMA models are more effective than linear regression techniques for nonlinear time series.

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