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Analysis and interpretation of long temporal trends in cumulative temperatures and olive reproductive features using a seasonal trend decomposition procedure

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ABSTRACT

The aim of the present study was to analyse long temporal trends in cumulative temperatures and olive (*Olea europaea* L.) reproductive features, including full flowering dates and daily pollen concentrations, in three Mediterranean areas. The study used a 19-year database (1993–2011) of pollen and temperature records from the sites of Perugia (Italy), Jaen (Spain) and Zarzis (Tunisia). The analysis of long-term trends in both temperatures and olive reproductive cycles was performed using two approaches. The first is a seasonal trend decomposition procedure based on locally weighted regression (Loess) smoothing (STL), which is a filtering procedure for decomposing seasonal time series into three components: trend, seasonal, and remainder. The second approach analyses the trend components using Mann–Kendall tests. Loess smoothing provides a good approach to study long-term meteorological and phenological trends. Removing both the seasonal and the remainder components, the real rising trends over time can be interpreted. In general, a significant and clear increasing trend in the spring cumulative temperature was revealed, with decreasing trends in the full flowering dates of the olive trees located in Perugia and Zarzis. Moreover, olive pollen emissions are decreasing, which is more evident for the highest and lowest latitudinal study sites. These data indicate that increasing temperatures result in both anticipation of olive tree flowering and lower airborne pollen emission. As a consequence, the lower atmospheric pollen levels will reduce human exposure to olive pollen in the Mediterranean area. These patterns are evident for the highest and lowest latitudes, but not clear in the intermediate latitudes of Jaen, where further analysis is needed.

1. Introduction

Plant phenology is sensitive to climate and local weather, with the main factors being the temperature and rainfall patterns (Aguilera et al., 2014a; Orlandi et al., 2014a; Osborne et al., 2000). Flowering is one of the most critical phases for every fructiferous plant (Barranco et al., 2008). For example, weather conditions prior to flowering, such as low temperatures and high precipitation, can promote the formation of flowers and contribute positively to increased pollen production of the olive tree (*Olea europaea* L.) (Aguilera and Ruiz-Valenzuela, 2012). In addition, cumulative rainfall during the olive flowering period can influence its length, and also the pollen release levels (Galán et al., 2008; Oteros et al., 2012).

Numerous studies have demonstrated that reproductive phenology is an important and useful indicator of the impact of climate change (Menzel and Sparks, 2006; Moriondo et al., 2013). The olive flowering period is considered a good bio-indicator for global warming, mainly due to its dependence on temperature and to its geographical distribution over one of the most high-risk areas for global warming on the Earth (Moriondo et al., 2008; Orlandi et al., 2014a; Osborne et al., 2000). However, there are rarely long time series of data available that can be used to detect significant phenological changes. For this reason, among the different types of phenological datasets that can be provided, measurements of pollen emissions into the atmosphere are generally the most used

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(Chuine et al., 1999). Many studies have thus used aeropalynological information to analyse the flowering phases in anemophilous species, with such airborne pollen data widely used as a well-proven tool for indirect evaluation of flowering periods (Aguilera and Ruiz-Valenzuela, 2009; Orlandi et al., 2010).

Nowadays, the olive tree is one of the most widespread arboreal cultivated species across the Mediterranean basin. This species is adapted to the climatic and environmental conditions of this region, and is the dominant tree crop throughout the Mediterranean areas (Barranco et al., 2008; Romero, 1998). Therefore, olive groves constitute a fundamental part of the Mediterranean environment, culture and economy, and the olive fruit and oil are among the oldest and most important products in these regions (Loumou and Giourga, 2003).

Over 750 million olive trees are cultivated worldwide, with 95% in the Mediterranean basin (International Olive Council, 2013). Spain is the largest olive-oil-producing country, followed by Italy, Greece and Tunisia. Together, these four countries cover 80% of the total world olive-oil production (International Olive Council, 2013).

Olive pollen represents the most abundant type within the pollen spectrum in the Mediterranean region. This is due to both the notable increase in the cultivation area and the flowering intensity of the olive, which releases large amounts of pollen grains into the atmosphere during spring (Aguilera and Ruiz-Valenzuela, 2012; García-Mozo et al., 2008). The pollen emitted by olive trees is considered one of the main causes of allergic respiratory diseases in the Mediterranean region (D'Amato et al., 2007). In Spain, Italy, Greece, Tunisia and Turkey, where commercial olive cultivation is concentrated, olive pollen is the most important cause of pollinosis, and it provokes seasonal allergic rhinitis and bronchial asthma among the populations.

Warming trends and spatial variability of rainfall regimes are both expected in the future (Giorgi and Lionello, 2008; Vergni and Todisco, 2011), and it is believed that global warming affects the timing of life-cycle events of the vegetation, which will also include pollen emission. According to Ziello et al. (2012), there is the need to determine the contributions of any changes in the weather patterns to increasing trends in allergic diseases. Indeed, these authors reported trends towards increases in atmospheric pollen of numerous allergenic taxa, which have occurred above all in northern Europe countries. However, few studies have been carried out in the warmest Mediterranean areas, such as Tunisia.

Application of appropriate statistical techniques to long-term phenological data enables fluctuations and overall trends to be analysed. Although linear regression is one of the most widely used techniques, phenological data do not always fit linear regression models, and consequently, other approaches are necessary. According to a previous pioneer study in aerobiology (García-Mozo et al., 2014), the seasonal trend decomposition procedure based on locally weighted regression (Loess) smoothing (STL) represents a good approach to study phenological trends.

The aim of the present study was the analysis and interpretation of long temporal trends in cumulative temperatures and olive reproductive features, including full flowering dates and daily pollen concentrations, in several Mediterranean areas using two complementary statistical approaches: STL and Mann–Kendall tests.

2. Materials and methods

2.1. Study area

Three Mediterranean areas were included in the present study, which are located at different latitudes (Table 1). The Mediterranean climate is characterised by cool, wet winters and hot, dry summers. This climate is also characterised by marked year-on-year variations in the weather patterns, and great spatio-temporal variability (Gasith and Resh, 1999). In the study areas, the annual mean temperatures ranged from 14.2 °C (Perugia, Italy) to 21.2 °C (Zarzis, Tunisia), and the annual rainfall from 170 mm (Zarzis, Tunisia) to 829 mm (Perugia, Italy).

2.2. Phenological and meteorological data

The study was performed using a 19-year database (1993–2011) of pollen and temperature records for each study site. The olive pollen sampling activities were carried out using the volumetric method, which is based on the capture of pollen and other biological particles present in the air (International Association for Aerobiology, 2011; Orlandi et al., 2014b). The monitoring traps were located inside or near to olive groves, for the detection of the pollen over wide olive-growing areas. This kind of sampling reflects the anthesis phenomenon, by reducing the subjectivity in the interpretation of the flowering period using field observations (Orlandi et al., 2010).

Two phenological features were calculated for each year and study site: (i) the date of maximum daily pollen concentration; i.e., the peak pollen emission date (day of the year; DOY); and (ii) the maximum pollen concentration (pollen grains/m^3 air). This information was extracted from the database through the calculation of the effective pollination period, which considers the pollen emission concentrations of the four days preceding the peak pollination date (Orlandi et al., 2005). These phenological variables correspond to the time when the majority of the olive trees are involved in full flowering, which thus indirectly represents the full flowering periods for the different study sites.

The annual olive yield data (tonnes olive fruit) were also analysed, as another agronomical variable. This information was provided by the local authorities in each region.

The daily mean temperatures were used to calculate the cumulative temperatures from 1 March to the end accumulation dates closely related to the peak pollen emission date in each study site: 20 April for the Zarzis site, 10 May for the Jaen site and 9 June for the Perugia site (Aguilera et al., 2014b). These dates were selected to detect patterns in the spring temperature trends linked to the biological responses.

The daily temperature records were obtained from the weather stations nearest to the monitoring units, as provided by the Italian National Meteorological and Climatological Centre for Perugia, the Spanish Meteorological Agency for Jaen, and the National Institute of Meteorology for Zarzis.

2.3. Long-term trends analysis

Analysis of long-term trends in both the cumulative temperatures and the olive reproductive cycle was performed using two approaches. The first was STL, which is a filtering procedure for decomposing seasonal time series into three components: trend, seasonal, and remainder (Cleveland et al., 1990). The trend component is the frequency variation in the data together with non-stationary, long-term changes in the levels. The seasonal component is considered as the variation in the data at or near the seasonal frequency. The remainder component is the remaining variation in the data beyond that in the seasonal and trend components. In the present study, STL was used to distinguish these components in the time-series data.

To assess the trend component that results from the STL decomposing procedure, it is helpful to construct a trend-diagnostic plot, which eliminates distortions in the interpretation of the data. In the elaboration of the trend-diagnostic plots, the trend and remainder data were considered (Cleveland et al., 1990). STL was applied to

Table 1
Main features of the study sites.

Study site	Country	Coordinates	Altitude (m a s l)	Mean annual temperature (°C)	Total annual precipitation (mm)
Perugia	Italy	43°06′ N, 12°23′ E	450	14.2	829
Jaen	Spain	37°48′ N, 03°48′ W	568	17.1	485
Zarzis	Tunisia	33°35′ N, 11°01′ E	17	21.2	170

both the cumulative temperatures and the variables related to the flowering period, according to the yearly periodicity in these data series. STL was not applied to olive fruit production, as these data were annual and were not sufficient to allow statistical analysis.

For the second analysis, once the different components of the dataset had been filtered using the STL decomposing procedure, the trend components were analysed using Mann–Kendall tests, which are non-parametric tests for detecting the presence of monotonic increasing or decreasing trends. In this second approach, we used only the trend component to detect the real trends over time, and to avoid distortion due to seasonality or irregularity in the data. In particular, the trends were evaluated using the Z coefficient estimation for every variable considered. A positive or negative Z-value indicates the presence of an increasing or decreasing trend within a data series, respectively. To estimate the true slope of any existing trend, the Sen's non-parametric method was used (Sirois, 1998).

The statistical software R version 3.0.2 was used for the STL, and the Excel template application MAKESENS Version 1.0 (Salmi et al., 2002) was used for the Mann–Kendall trend analysis.

3. Results

The data derived from the STL are presented in Figs. 1, 2 and 3, for Perugia, Jaen and Zarzis, respectively, as the cumulative temperature, the full flowering dates, and the pollen concentrations during the effective pollination period. Figs. 1, 2 and 3 thus show the trends, the remainder components extracted by STL, and the linear regression trends. To reveal significant trends, these STL data were integrated with Mann–Kendall tests.

The daily mean cumulative temperatures during the spring season in Perugia showed a clear increasing trend. The lowest value was recorded in 1995, with an increasing tendency in successive years towards the maximum values recorded in the last few years (2007, 2009, 2011) (Fig. 1A, Table 2). The Mann–Kendall tests confirmed this behaviour, with a Z-value of 3.19 and significance of $p < 0.01$ (Table 3). For the full flowering dates in Perugia, Fig. 1B shows a clear decreasing trend until 2003, and then no clear trend over the rest of the study period. The pollen emission trend in Perugia (Fig. 1C) suggests the presence of two behaviours within the historical series. An increasing pollen emission period was observed from 1993 to 1999, the year with the maximum pollen concentration, followed by a second lower emission period (2000–2011). Mann–Kendall tests confirmed the first impressions derived from the interpretation of the data shown in Fig. 1, with a large and significant negative Z-value of -3.45 ($p < 0.001$) over the entire period, although with aninitial positive trend ($Z = 2.03$, $p < 0.01$) over the first 7 years of the temporal trend.

The cumulative daily mean temperatures recorded for the Jaen site showed great variability year by year, with values that ranged from 1014 °C to 1263 °C (Table 2). Both the STL plot and the regression line suggest the absence of any trend, with only a weak decreasing tendency and a minimum in 2004 (Fig. 2A). The Mann–Kendall tests confirmed this behaviour, with a non-significant Z-value of -0.18 (Table 3). The full flowering dates for Jaen are shown in Fig. 2B,and these are in agreement with the cumulative temperature pattern, with no clear trend; this was confirmed also by the non-significant data from the Mann–Kendall tests (Z-value = 0.84). Fig. 2C shows a particular phenomenon for the pollen emission. A first increasing trend until 2003 was observed, but this did not continued into the following years of the study. The Mann–Kendall tests were carried out for two periods, i.e. 1993–2003 and 1993–2011, whereby only the first restricted period of 11 years showed a positive and significant Z-value of 4.08 ($p < 0.001$), which confirmed the increasing pollen emission trend up to 2003.

For the Zarzis site, an increasing trend in the cumulative temperature was detected (Fig. 3A). This trend was relatively homogeneous over the first 17 years, until 2009, while the last two years were particular variable. The cumulative temperatures were between 1311 °C and 1876 °C (Table 2). The year 2010 was characterised by an extremely hot spring season, with cumulative temperature value well above the average value of the 19-year period. For this reason the Mann–Kendall tests were carried out considering 2010 as an outlier. The Mann–Kendall tests confirmed an increasing trend in the cumulative temperature, showing a significant Z-value of 4.32 ($p < 0.001$). The flowering dates in Zarzis also showed a notable decreasing trend (Fig. 3B), which was confirmed by the Mann–Kendall tests (Z-value = -4.20; $p < 0.001$). The pollen concentrations recorded in Zarzis (Fig. 3C) showed a slight decreasing trend considering the entire study period (Table 2). As for the Perugia site, one extreme value was observed in the pollen emission trend, with 1999 as the year of maximum pollen concentration in the whole time series. The Mann–Kendall tests showed that from 1993 to 2011 there was a Z-value of -1.83 ($p = 0.1$), confirming the suggested decreasing trend from the STL.

Table 3 also shows the values of the Mann–Kendall tests regarding the annual olive fruit production for each study site. The only significant and positive trend detected was for the Jaen study site, which showed a Z-value of 3.15, with a significance of $p < 0.01$. It is worth noting that in this case, the trend to increasing fruit production can certainly be related to the positive pollen emission trend recorded in the same area over the first 11 years of the study (1993–2003).

4. Discussion

Many studies have confirmed strong relationships between the climate and the life-cycles of bio-organisms (Aguilera et al., 2014a; Bock et al., 2014; Bonofiglio et al., 2009; Menzel et al., 2006; Orlandi et al., 2014a; Ziello et al., 2012). Warming trends and spatial variability in rainfall patterns, which are both expected in the future under different greenhouse emission scenarios, can affect the composition and functioning of natural and managed ecosystems. This could incur serious difficulties in adapting to climate change (Alcamo et al., 2007; Food and Agriculture Organization, 2014; Giorgi and Lionello, 2008; Moriondo et al., 2013).

A comparison of the cumulative temperature trends recorded for the three study areas showed similarities between Perugia and Zarzis, which are located very close in terms of their longitudinal ranges, but are at the north and south latitudinal limits, respectively, of the distribution of olive-producing areas. In both of these areas, significant clear increasing trends in the cumulative spring temperatures were detected, in comparison to the absence of such tendency in the Spanish area of Jaen. Similarities between the northernmost and southernmost sites were observed also in the flowering periods, which represent a probable phenological

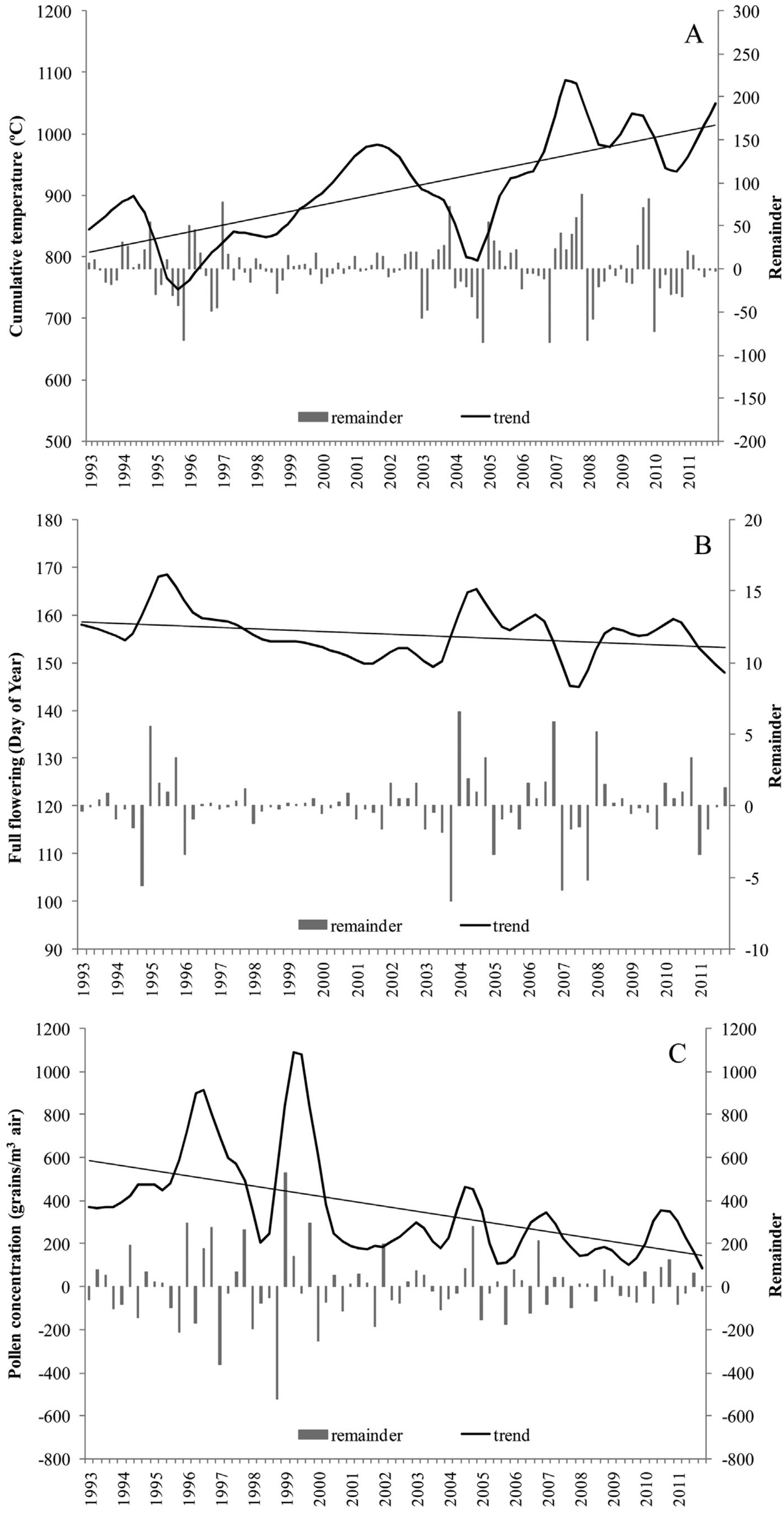

Fig. 1. Perugia study site: trend-diagnostic plots for cumulative temperatures (A), flowering dates (B), and pollen concentrations (C).

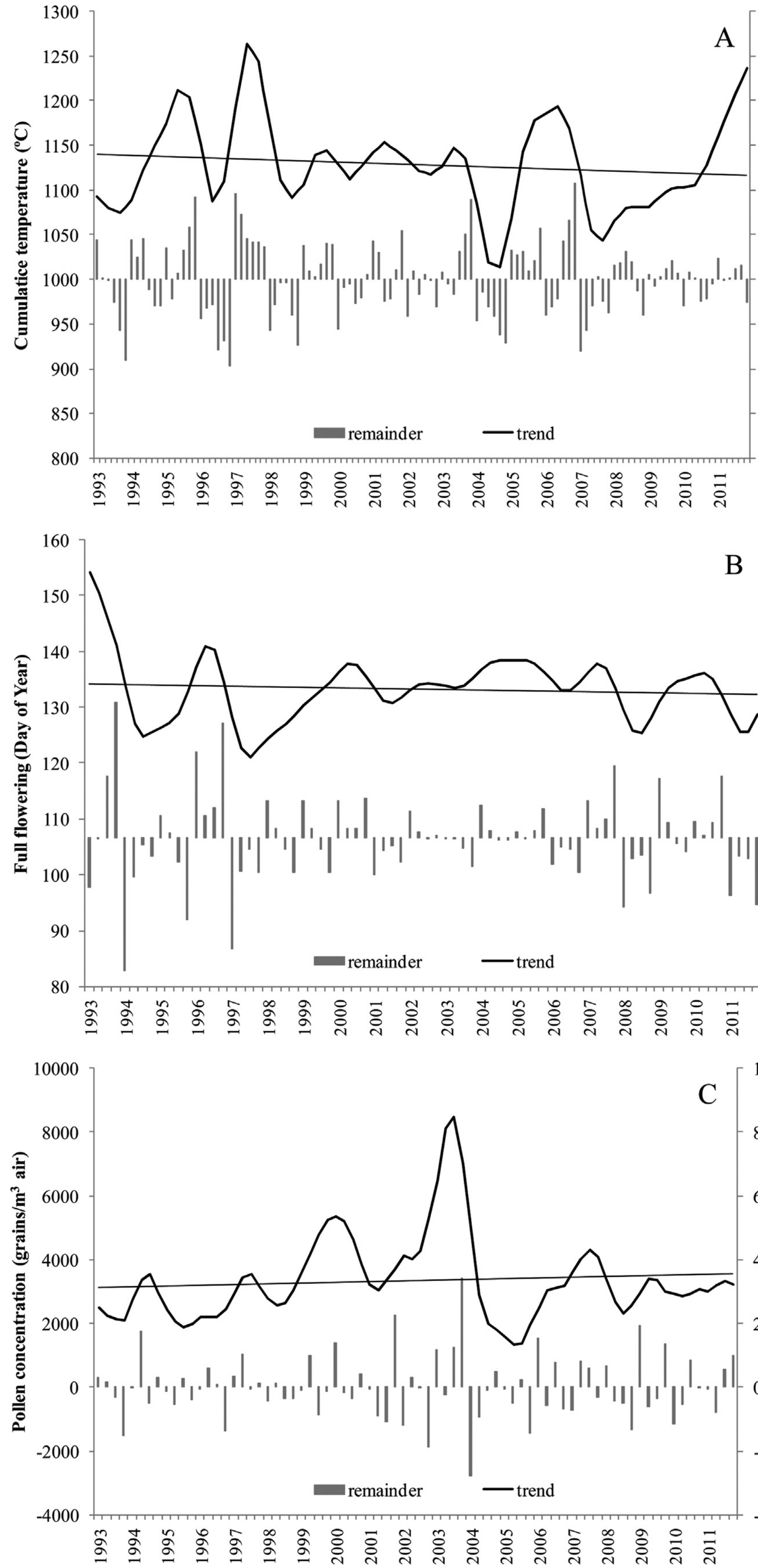

Fig. 2. Jaen study site: trend-diagnostic plots for cumulative temperatures (A), flowering dates (B), and pollen concentrations (C).

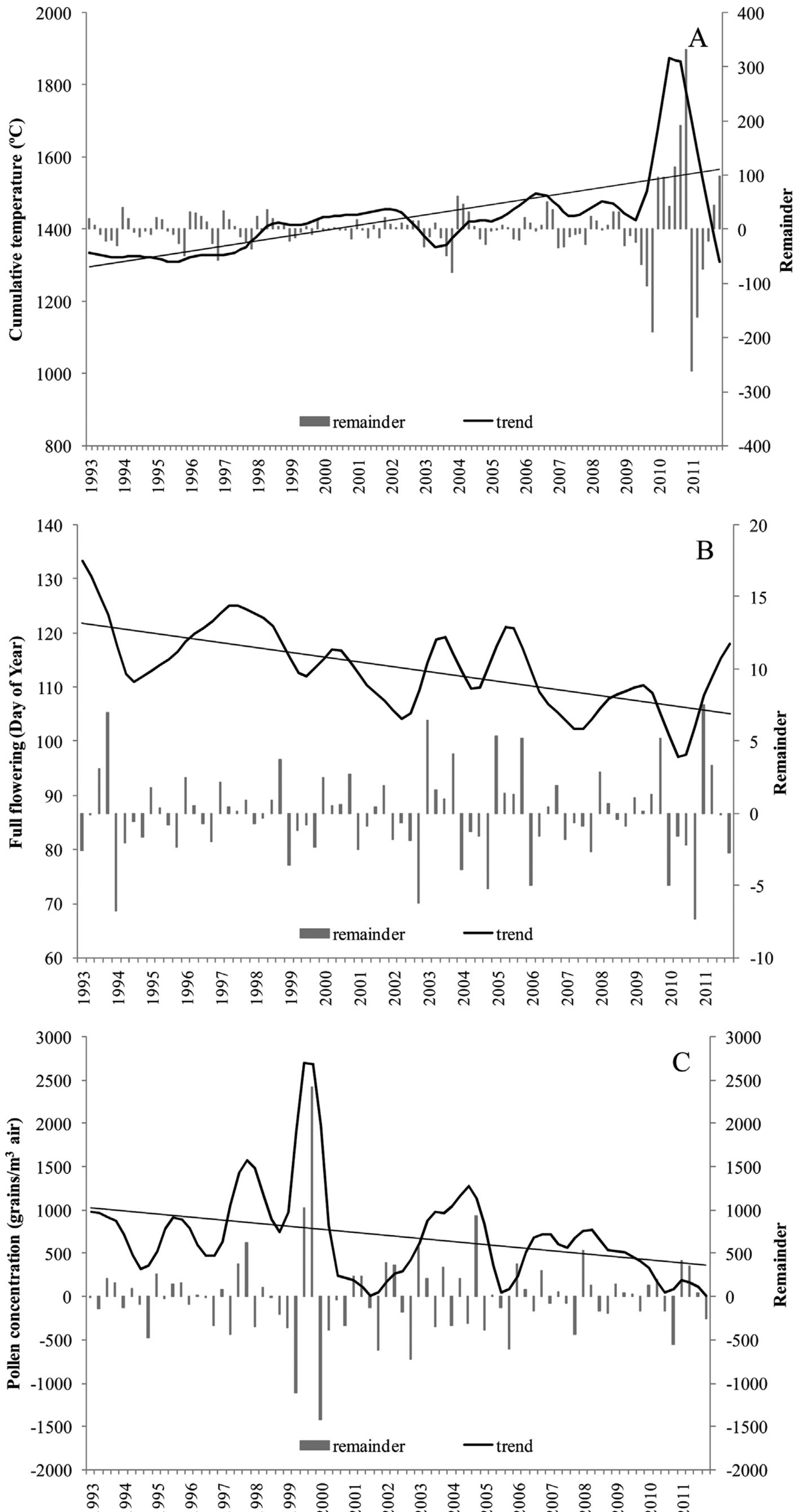

Fig. 3. Zarzis study site: trend-diagnostic plots for cumulative temperatures (A), flowering dates (B), and pollen concentrations (C).

Table 2
Summary of the main features of the seasonal trend decomposition procedure based on Loess smoothing.

Feature	Site	Minimum	Maximum	Mean	SD
Cumulative temperature (°C)	Perugia	746 (1995)	1087 (2007)	911	83
	Jaen	1014 (2004)	1263 (1997)	1129	51
	Zarzis	1311 (1995)	1876 (2010)	1432	113
Flowering date (DOY)	Perugia	145 (2007)	168 (1995)	155	5
	Jaen	121 (1997)	154 (1993)	133	4
	Zarzis	97 (2010)	133 (1993)	114	8
Pollen concentration (grains/m^3)	Perugia	89 (2011)	1093 (1999)	366	233
	Jaen	1327 (2005)	8462 (2003)	3347	1360
	Zarzis	4 (2001)	2703 (1999)	694	542

DOY, day of the year; SD, standard deviation.

response to the weather conditions that occurred during the previous months. Decreasing trends in the full flowering dates of the olive trees located in Perugia and Zarzis were evident, but again, no such trend was seen for Jaen. According to Menzel et al. (2006), the temperature response of the spring phenology is not questionable. They observed that the flowering and fruiting phases are strongly regulated by temperature, and in particular at higher latitudes. Peak pollen emission dates are being recorded earlier, as observed in the Italian and Tunisian areas in the present study, where increasing temperature trends are clearly observed. These data are in agreement with previous studies that have detected earlier mean flowering dates in numerous plant species within European countries (Bock et al., 2014; Bonofiglio et al., 2009; García-Mozo et al., 2009, 2014; Menzel et al., 2006). The warming tendency observed in the present study areas is in agreement with the anticipation of the timing of the olive flowering period, and it therefore appears reasonable that this phenological stage might manifest particular sensitivity to future global climate change.

Some extreme values in the pollen emission trends were observed. The highest pollen concentrations were detected in 1999 for both the Perugia and Zarzis sites, and in 2003 for the Jaen site. These values, which were well above the average value of the 19-year period, can be considered extreme values, but not outliers. One main reason might explain these extreme values in the pollen emission trends. The most favourable microclimatic conditions for both flower and pollen production rates in olive trees are found in years and/or olive growing areas with low temperatures and high precipitation during the months prior to flowering (Aguilera and Ruiz-Valenzuela, 2012). The years with the highest pollen concentrations were those with spring cumulative temperatures values lower or around the average value of the 19-year period. In addition, and according to the historical databases of monthly precipitation, the spring months of these years also showed one of the highest precipitation records in the whole time series. The combination of these meteorological conditions, i.e. low spring cumulative temperatures and high rainfall records, might explain the extreme values detected in the olive pollen trends.

In general, the olive pollen emissions are decreasing, which is a phenomenon that is more evident in the highest and lowest latitudinal study sites. Both of these olive-growing areas showed negative trends considering the entire study period. The noticeable increase in the temperature trends recorded in these areas might be the main reason to explain this. Higher temperatures during the spring months, when the olive flowering takes place, might have a double effect. In the warmest Mediterranean areas, excessive temperatures can be a limiting factor for the metabolic activity of the olive tree, and can negatively influence several reproductive parameters, including flower development, pollen production, pollen-tube growth, and pollen viability (Cuevas et al., 1994; Krueger, 1994). On the other hand, and according to previous studies, increases in temperature can limit the physiological performance of plant species that grow at high latitudes at lower temperatures, including their pollen release (Emberlin et al., 2002; Ziello et al., 2012). Anticipation of the first flowering would be necessary to ensure the success of the pollination and fertilisation processes, with this representing an adaptive phenomenon of the olive-tree phenology to higher spring temperatures.

The decreases in the airborne pollen concentrations observed in the present study can be considered surprising in view of a recent study that reported an increase in the olive pollen emission in southern Spain, the area where we did not otherwise obtain significant trends considering the whole study period (García-Mozo et al., 2014). The increase in the pollen levels detected by García-Mozo et al. (2014) can be partially attributed to the increase in the land surface that is devoted to olive cultivation that has occurred in this area over more recent years. Indeed, this can be considered the main cause of the clear and positive trend detected in the olive fruit production of Jaen, where a yearly increase in the cultivation area till 2003 has been documented (Aguilera, 2012). Moreover, Ziello et al. (2012) observed a tendency towards an increase in

Table 3
Summary of the main features of the Mann–Kendall trends.

Factor	Site (time series)	First year	Last year	*n*	Test *Z*	Sign.	Sen's slope estimate (Q)
Cumulative temperature (°C)	Perugia	1993	2011	19	3.19	**	13.71
	Jaen	1993	2011	19	−0.18	*n.s*	−1.20
	Zarzis	1993	2011	*18*	4.32	***	10.45
Flowering date (DOY)	Perugia	1993	2011	19	−1.58	*n.s*	−0.05
	Perugia	*1993*	*2003*	*11*	*−4.77*	***	*−0.25*
	Jaen	1993	2011	19	0.84	*n.s*	0.05
	Zarzis	1993	2011	19	−4.20	***	−0.20
Pollen concentration (grains/m^3)	Perugia	1993	2011	19	−3.45	***	−3.81
	Jaen	1993	2011	19	1.06	*n.s*	10.30
	Zarzis	1993	2011	19	−1.83	+	−3.78
Olive fruit production (tonnes)	Perugia	1993	2011	19	1.26	*n.s*	718.83
	Jaen	1993	2011	19	3.15	**	101494.50
	Zarzis	1993	2011	19	−0.81	*n.s*	−1187.50

DOY, day of the year; n.s (not significant) $p > 0.1$; +$p \leq 0.1$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

atmospheric pollen in several northern European countries, although decreasing trends were recorded for Spain. Inconsistent results regarding the airborne pollen trends do not allow any firm conclusions here, and therefore further studies are needed.

The use of STL has provided a good approach to study these long-term meteorological and phenological trends. According to García-Mozo et al. (2014), removing both the seasonal and the remainder components, and avoiding therefore the random features linked to the seasonal variability of the Mediterranean climate, the real trends over time can be interpreted. This statistical technique is particularly useful to study natural processes that have a clear seasonal component, such as the olive pollen season.

Considering the findings presented here, the temperature increase might reduce the atmospheric pollen levels, and consequently reduce the human exposure to olive pollen in the Mediterranean area. Moreover, in terms of pollen allergy, public health would also benefit by a shortening of the pollen emission period, as has been suggested by Bock et al. (2014). Nevertheless, from an agronomic point of view, this anticipated flowering and/or the lower pollen emissions will have negative effects on the pollination phenomenon, leading to a decline in the agricultural crop production.

5. Conclusions

The findings herein imply that increasing temperatures result in both anticipated flowering and lower airborne pollen emission for olive trees. This pattern is evident in the northernmost and southernmost sites but not clear in the intermediate latitude of Jaen site, where further analysis is needed. The STL used in this study is a more robust approach to investigate long-term phenological trends. Removing both the seasonal and the remainder components, the real rising trends over time can be interpreted. This is a noteworthy aspect given that Mediterranean species such as the olive tree has a seasonal behaviour.

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