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Trends in airborne pollen and pollen-season-related features of anemophilous species in Jaen (south Spain): A 23-year perspective

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ABSTRACT

Over the last few decades, global warming is prompting phenological changes in numerous plant species across Europe, and a trend towards rising airborne pollen concentrations has been detected. This study, focused on the most frequent pollen types from arboreal and herbaceous species in the airborne spectrum of Jaen (southern Spain), revealed significant changes in airborne pollen intensity and duration of the pollen season over the 23-year study period. Here Cupressaceae, *Olea*, *Pinus*, *Platanus*, *Quercus* as arboreal taxa and *Plantago* as herbaceous taxa were the most important with notable changes of at least three pollen season characteristics. Airborne pollen trends from arboreal taxa with high to very high allergenic potential are rising in line with the local temperature increasing trend, and their pollen seasons tend to end later and last longer. However, both the pollen concentrations and the duration of the pollen season of some herbaceous taxa are declining. The climate conditions projected for south Europe under different greenhouse emissions scenarios could continue to prompt greater pollen release and longer pollen season in tree species, especially those that flowering in winter and early spring, but these warming trends might be adverse for the local development of some herbaceous species and favorable for others sharing the same ecological niche. If similar warming trends accompany long-term climate change, greater exposure times to seasonal allergens may occur with subsequent effects on health.

1. Introduction

Global warming over the last few decades is promoting important and severe impacts on living organisms and ecosystems. According to the Intergovernmental Panel on Climate Change -IPCC- (2014), terrestrial ecosystems are being affected in diverse aspects such as distribution, composition and biodiversity, average crops yields tend to decrease across some regions and marine ecosystem composition is being altered tracking climate trends. The long-term warming trend, including continental warming since the mid-1970s, has been conclusively associated with the predominant global forcing, human-made greenhouse gases, which began to grow substantially early in the 20th century (Hansen et al., 2013; IPCC, 2014). The phenology of many species which grow in temperate climate is principally regulated by the temperature and plants display variations in the timing of life-cycle events (budburst, flowering) as a response to climate change (Frenguelli et al., 2002; Menzel et al., 2006; Aguilera et al., 2015a; Galán et al., 2016; Orlandi et al., 2016). Plant phenology is for this reason one of the preferred indicators of climate change as their recorded dates provide a high-temporal resolution of ongoing changes. Among the different types of phenological datasets that can be provided, airborne pollen is generally the most used (Chuine et al., 1998; Menzel et al., 2006; García-Mozo et al., 2009; Aguilera et al., 2015b).

Airborne pollen monitoring is regarded as an effective tool for studying the reproductive phenology of wind-pollinated plant species, especially as a bio-indicator of their behavior in areas where there are variations in pollen concentrations. Pollen production and dispersion is strongly modulated by a complicated complex of biotic and environmental factors. It depends in fact on the production rate of pollen grains for individual plants which in turn depend on the genotype, age and size of the plant, phenology, regional climatic and edaphic factors, diseases, etc (Branzi and Zanotti, 1992; Walther et al., 2002; Aguilera and Ruiz-Valenzuela, 2012; Scheifinger et al., 2013; García-Mozo et al., 2016). Most of airborne pollen detected at a given area is also influenced by local land uses, vegetation distribution and pollen transport, deposition and re-suspension phenomena (Fernández-Rodríguez et al., 2014; Oteros et al., 2015; Rojo et al., 2016; Maya-Manzano et al., 2017).

Current aerobiological research uses a number of different indicators to describe the pollen season (e.g., start and end dates,

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duration, annual pollen concentration or peak day). Recent changes in these pollen season characteristics were reported concerning an earlier onset (Sparks et al., 2000; Clot, 2003; Orlandi et al., 2010), a longer pollen season (Stach et al., 2007; Makra et al., 2011; De Linares et al., 2017) and a trend towards rising airborne pollen concentrations (Frenguelli et al., 2002; Damialis et al., 2007; Ziello et al., 2012; Fernández-Llamazares et al., 2014; Galán et al., 2016). However, for certain taxa, either no significant trends are observed (Jäger et al., 1991; Spieksma et al., 2003; Emberlin et al., 2007) or, being sensitive to warming, an opposite change in pollen season parameters has been detected (Jato et al., 2009; Alcázar et al., 2011; Bogawski et al., 2014; Cariñanos et al., 2014a).

Airborne pollen grains are widely known for being one of the most important allergy factors in humans (D'Amato, 2011). According to the World Allergy Organization (2013), allergic disorders constitute an important public health problem with high prevalence across Europe, where the 20% of the total population suffers from pollen-induced allergies. Over the past four decades, in parallel with global warming, the sensitization to pollen allergens has increased in many areas, which may result in changes in the prevalence and severity of symptoms in individuals with allergic diseases (Troise et al., 1992; Beggs, 2004; Stach et al., 2007; Reid and Gamble, 2009). In this sense, studies on trends in airborne pollen and pollen-season-related features are of great importance.

This study focused on the analysis and interpretation of long temporal trends in a comprehensive spectrum of airborne pollen data from twelve pollen types belonging to arboreal and herbaceous taxa in Jaen (southern Spain). As climate change, mainly temperature increase, may influence the pollination characteristics of different taxa in a variety of ways, the contributions of any changes in the temperature patterns to changes in trends of airborne allergic pollen and pollen-season-related features over a 23-year period were evaluated.

2. Materials and methods

2.1. Study area

This study was carried out in Jaen (37°48′N, 03°48′W), southern Spain (Fig. 1). This city is located at 573 m a.s.l. The climate profile is continental Mediterranean, with cold winters, hot-dry summers and marked year-on-year variations in weather patterns. Annual average temperature is 17.1 °C and annual average precipitation is 485 mm. The province of Jaen covers a surface area of 13,489 km^2 and has a population density of 47.93 inhabitants per km^2 (Spanish Statistical Office, 2016). Only 1.6% of the territory is urbanized land (Andalusia Regional Government, 2007). The city of Jaen is heavily built up and has several urban and periurban green spaces in which herbaceous (grasses, lawn) and ornamental tree species (Cupressaceae, *Platanus* spp., *Ligustrum* spp., etc), included expontaneous vegetation, prevail. Agriculture is its main economic activity. Crops cover around 49% of the total surface area, mainly olives trees (*Olea europaea* L.), that with more than 585,000 ha throughout the province makes Jaen the most important olive crop area in the world (Bermejo et al., 2011; International Olive Council, 2016). Natural vegetation (49.1% of the territory) mostly comprises Mediterranean woodland, where holm oaks (*Quercus* spp.) and coniferous species (*Pinus* spp.) are predominant (Plan Forestal Andaluz HORIZONTE, 2015). Numerous riverbank plants species (*Populus* spp., *Ulmus* spp. or *Fraxinus* spp.) can be found in riparian ecosystems and surrounding areas.

2.2. Airborne pollen and meteorological data

The study focused on the more frequent and abundant airborne pollen types detected in the pollen spectrum of Jaen (Aguilera and Ruiz-Valenzuela, 2009). A total of twelve pollen types were considered: eight belonging to arboreal taxa (Cupressaceae, *Fraxinus*, *Olea*, *Pinus*, *Platanus*, *Populus*, *Quercus and Ulmus*) and four belonging to herbaceous taxa (Amaranthaceae, *Plantago,* Poaceae and Urticaceae -this last including also species with the *Parietaria* pollen type-). Airborne pollen data were collected continuously over a 23-year period (1994–2016) using a Hirst-type volumetric spore-trap, based on the impaction process (Hirst, 1952). The monitoring station, it placed in the University of Jaen (15 m above ground level), is surrounded by urban green spaces and olive groves. The standard data management procedures were used following the recommendations outlined in the Management and Quality Manual of the Spanish Aerobiological Network (Galán et al., 2007), which complies to the minimum requirements from the European Aerobiology Society (Galán et al., 2014).

The main pollen season of each taxa was considered. The start of the pollen season was defined as the first day on which at least five pollen grains m^{-3} were collected, with the subsequent days at ≥ 5 pollen grains m^{-3} (Aguilera and Ruiz-Valenzuela, 2014). The end of the pollen season was the last day on which five pollen grains m^{-3} were collected, when the subsequent days had concentrations < 5 pollen grains m^{-3}. The most relevant data that were recorded during the main pollen season of each taxa were as follows: the Seasonal Pollen Integral (SPIn), obtained by summing the average daily pollen concentrations over the main pollen season (Galán et al., 2017); the starting date, peak date (the day on which the maximum daily pollen concentration was recorded) and ending date of the pollen season, that were reported as day of the year from 1 January, DOY; and the duration (number of days) of the pollen season.

The meteorological variables considered in the present study were all related to the temperature and arranged as three-monthly (i.e., seasonal) as follows: January, February, March (JFM); and April, May, June (AMJ). These provided the mean maximum temperature (Tmax, °C), the mean minimum temperature (Tmin, °C), the mean temperature (Tmean, °C) and the mean temperature oscillation or range (Tosc, °C). Meteorological data were provided by the University Jaen weather station, which is over 200 m from the trap position.

2.3. Statistical methods

The analyzed data set covered a total of 276 time series from twelve pollen types over the 23-year period. Descriptive analysis was performed first. Mean and standard variations of the SPIn, the starting-peak-ending dates and the duration of the pollen season of each taxa were summarized in a table as average values for the study period as a whole. The allergenic potential of each pollen type was reported as levels or categories from Null (for species reported to be non-allergenic) to Very High (for species reported to be highly allergenic, with very marked effect on population) based on data provided in previous reports and databases (D'Amato et al., 2007; Trigo et al., 2008; Cariñanos et al., 2014b).

Analysis of long-term trends of all the aerobiological and meteorological variables considered in this study during the entire period 1994–2016 was performed using Mann–Kendall test, which is non-parametric test for detecting the presence of monotonic increasing or decreasing trends. 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 nonparametric method was used (Sirois, 1998). For the four tested significance levels the following symbols were used: $^{+}p \leq 0.1$; $^{*}p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$.

Spearman nonparametric correlation analysis was also performed to establish the statistical relationships between the meteorological variables and the aerobiological variables described for each taxa. Correlation coefficient (r) and probability level (p) were calculated.

The STATISTICA 7.0 (StatSoft Inc., USA) software package was used for both the descriptive and correlation analysis, while the Excel template application MAKESENS version 1.0 (Salmi et al., 2002) was used

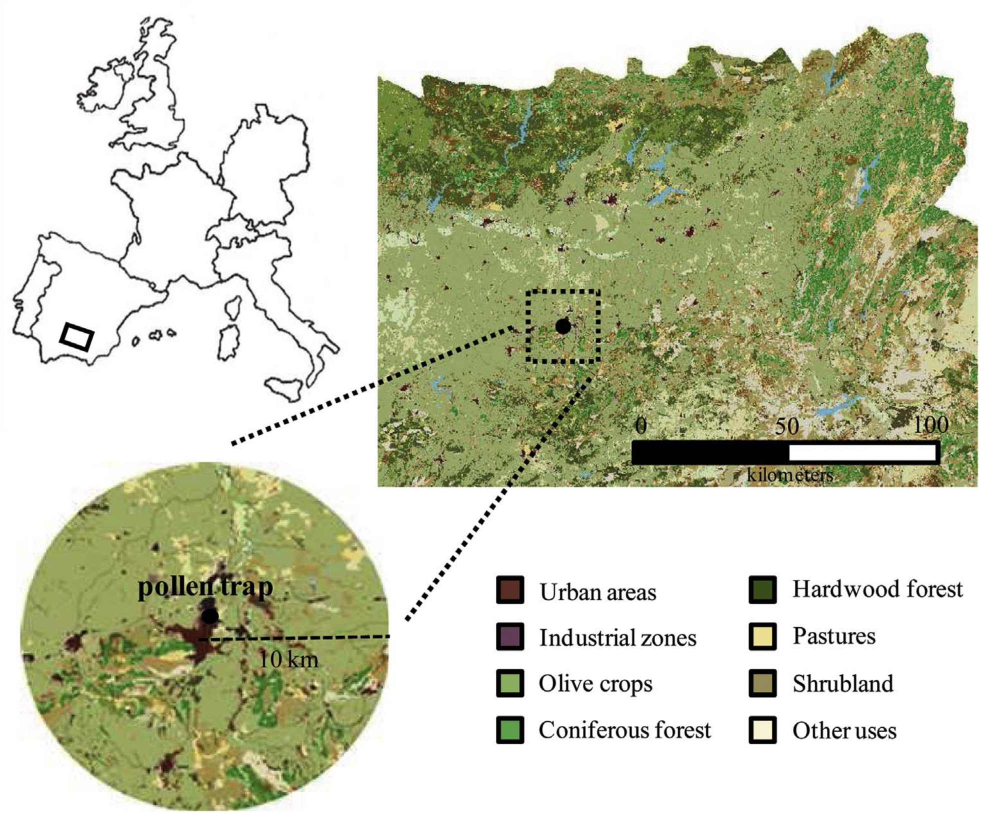

Fig. 1. Location of Jaen city (southern Spain) and position of the pollen trap. Land use map at 2007 (Andalusia Regional Government 'MUCVA project' 2007).

for the Mann–Kendall trend analysis.

3. Results

3.1. Main pollen season

The main pollen season features were reported for each taxa in Table 1 as average values during the whole study period. The standard deviation values were also presented. The highest SPIn was recorded for *Olea* (average SPIn of 53,466 pollen grains*day m^{-3}), followed by Cupressaceae (4314 pollen grains*day m^{-3}) and *Quercus* (4252 pollen grains*day m^{-3}). For herbaceous taxa, the higher SPIns were recorded for Poaceae (2709 pollen*day m^{-3}), Urticaceae (909 pollen grains*day m^{-3}), and *Plantago* (800 pollen grains*day m^{-3}). The start of the pollen season takes place from the first fortnight of January (Cupressaceae, *Fraxinus*, Urticaceae) to mid-April (*Olea*, Amaranthaceae) depending on whether they are winter or spring flowering species. The first pollen peak was reached by winter flowering *Fraxinus* species on the first days of February, while the last pollen peak was reached on the last days of May by Poaceae species. Winter flowering tree species, such as Cupressaceae, *Fraxinus*, *Populus* and *Ulmus*, were the first to finish their pollination period (mid-March). However, those Amaranthaceae, Poaceae and Urticaceae herbaceous species that flowering in late spring or summer-autumn were the last ending the pollen season (mid-July; Amaranthaceae first October). The duration of the main pollination period ranged from 26 days (*Ulmus*) to 184 days (Urticaceae species). It should be noted that Urticaceae, as other herbaceous plants, comprises species flowering in different seasons and these could lengthen the pollen season. Finally, it was found that nine out of the twelve pollen types studied have been described with high to very high allergenic potential.

Table 1

Principal features of the main pollination period of the twelve arboreal and herbaceous taxa (1994–2016). N = 23. SPIn, Seasonal Pollen Integral (pollen*day m^{-3}); Dates are reported as DOY; Jan, January; Feb, February; Mar, March; Apr, April; Jun, June; Jul, July; Oct, October; Duration is reported as number of days. *(D'Amato et al., 2007; Trigo et al., 2008; Cariñanos et al., 2014b).

	SPIn	Start date	Peak date	End date	Duration	Allergenic potential*
Cupressaceae	4314 (± 2173)	10 (± 5); 10 Jan	53 (± 14); 22 Feb	85 (± 11); 25 Mar.	76 (± 16)	Very High
Fraxinus	59 (± 40)	7 (± 4); 7 Jan	38 (± 25); 7 Feb	69 (± 23); 10 Mar	59 (± 25)	Moderate
Olea	53,466 (± 24,890)	111 (± 7); 21 Apr	134 (± 7); 14 May	204 (± 23); 23 Jul	95 (± 20)	Very High
Pinus	1362 (± 794)	68 (± 9); 9 Mar	77 (± 9); 18 Mar	122 (± 27); 2 May	55 (± 26)	Moderate
Platanus	2655 (± 1813)	72 (± 7); 13 Mar	81 (± 6); 22 Mar	99 (± 9); 9 Apr	28 (± 6)	Very High
Populus	381 (± 221)	50 (± 11); 19 Feb	67 (± 13); 8 Mar	85 (± 10); 26 Mar	36 (± 13)	High
Quercus	4252 (± 2352)	86 (± 10); 27 Mar	109 (± 14); 19 Apr	159 (± 12); 8 Jun	73 (± 17)	Moderate
Ulmus	112 (± 70)	41 (± 9); 10 Feb	49 (± 8); 18 Feb	66 (± 10); 7 Mar	26 (± 10)	High
Amaranthaceae	565 (± 157)	107 (± 9); 17 Apr	133 (± 10); 13 May	279 (± 12); 6 Oct	172 (± 15)	High
Plantago	800 (± 524)	88 (± 9); 29 Mar	115 (± 10); 25 Apr	158 (± 16); 7 Jun	71 (± 23)	High
Poaceae	2709 (± 1233)	92 (± 20); 2 Apr	141 (± 9); 21 May	191 (± 12); 10 Jul	99 (± 26)	Very High
Urticaceae	909 (± 439)	9 (± 7); 9 Jan	85 (± 15); 26 Mar	195 (± 15); 14 Jul	184 (± 20)	Very High

Table 2A

Mann–Kendall test for the trend analysis of the main pollen season features from arboreal taxa during the period 1994–2016. N = 23. SPIn, Seasonal Pollen Integral (pollen*day m^{-3}). n.s (not significant) $p > 0.1$; $+p \leq 0.1$; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$.

	Test Z	Sign.	Sen's slope estimate (Q)
Aerobiological features			
SPIn			
Cupressaceae	2.80	**	209.42
Fraxinus	2.88	**	3.43
Olea	2.63	**	1464.99
Pinus	1.86	+	50.06
Platanus	4.07	***	208.67
Populus	0.06	n.s	0.33
Quercus	1.69	+	86.62
Ulmus	1.92	+	4.58
Start Date			
Cupressaceae	−1.86	+	−0.60
Fraxinus	−1.55	n.s	−0.30
Olea	1.27	n.s	0.31
Pinus	1.03	n.s	0.44
Platanus	1.17	n.s	0.36
Populus	1.64	n.s	0.57
Quercus	0.08	n.s	0.00
Ulmus	−0.48	n.s	−0.17
Peak Date			
Cupressaceae	1.01	n.s	0.52
Fraxinus	−0.63	n.s	−0.90
Olea	0.66	n.s	0.18
Pinus	1.49	n.s	0.40
Platanus	0.77	n.s	0.17
Populus	0.03	n.s	0.00
Quercus	2.70	**	1.30
Ulmus	1.42	n.s	0.33
End Date			
Cupressaceae	2.65	**	1.00
Fraxinus	0.63	n.s	0.50
Olea	2.06	*	1.50
Pinus	4.97	***	3.57
Platanus	2.65	**	0.75
Populus	1.91	+	0.45
Quercus	2.33	*	0.95
Ulmus	0.64	n.s	0.20
Duration			
Cupressaceae	3.36	***	1.84
Fraxinus	2.35	*	2.21
Olea	2.26	*	1.23
Pinus	4.18	***	3.23
Platanus	2.60	**	0.50
Populus	−0.13	n.s	−0.07
Quercus	1.72	+	1.00
Ulmus	1.69	+	0.67

Table 2B

Mann–Kendall test for the trend analysis of the main pollen season features from herbaceous taxa during the period 1994–2016. N = 23. SPIn, Seasonal Pollen Integral (pollen*day m^{-3}). n.s (not significant) $p > 0.1$; $+p \leq 0.1$; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$.

	Test Z	Sign.	Sen's slope estimate (Q)
Aerobiological features			
SPIn			
Amaranthaceae	0.45	n.s	2.10
Plantago	−2.23	*	−43.50
Poaceae	1.27	n.s	62.62
Urticaceae	−1.32	n.s	−21.67
Start Date			
Amaranthaceae	1.80	+	0.50
Plantago	2.49	*	0.57
Poaceae	−0.90	n.s	−0.58
Urticaceae	0.03	n.s	0.00
Peak Date			
Amaranthaceae	−0.24	n.s	−0.08
Plantago	1.32	n.s	0.42
Poaceae	−1.01	n.s	−0.37
Urticaceae	2.85	**	0.91
End Date			
Amaranthaceae	−0.34	n.s	−0.18
Plantago	−1.69	+	−0.73
Poaceae	−0.19	n.s	−0.06
Urticaceae	−1.48	n.s	−0.61
Duration			
Amaranthaceae	−2.03	*	−1.07
Plantago	−2.22	*	−1.43
Poaceae	0.53	n.s	0.37
Urticaceae	−1.85	+	−1.00

3.2. Temporal trends

3.2.1. Airborne pollen and pollen-season-related features

Results derived from the Mann–Kendall test regarding the analysis of temporal trends of the main pollen season features for each taxa over the 23-year period are provided in Tables 2A and 2B. A positive Z-value indicates the presence of an increasing trend within a data series, while a negative Z-value indicates the presence of a decreasing trend. Start and peak dates of the main pollen season were the variables with lower number of significant trends (three and two respectively). Starting date of the pollen season of Cupressaceae showed a significant decreasing trend (Table 2A), while Amaranthaceae and *Plantago* start dates showed significant increasing trends (Table 2B). Regarding the peak pollination date, only *Quercus* and Urticaceae showed significant increasing trends.

SPIn, ending date and duration of the pollen season were the aerobiological features that reached higher number of statistically significant trends. A significant increase in the SPIn was clearly observed for seven arboreal taxa (Cupressaceae, *Fraxinus*, *Olea*, *Pinus*, *Platanus*, *Quercus* and *Ulmus*) (Fig. 2). The trend was more significant ($p \leq 0.01$) in ornamental tree species –e.g. Cupressaceae (SPIn from a minimum value of 488 pollen grains*day m^{-3} in 1995 to a maximum value of 8637 pollen grains*day m^{-3} reached in 2009), *Fraxinus* (SPIn from 8 pollen grains*day m^{-3} in 1998 to 223 pollen grains*day m^{-3} in 2015) and *Platanus* (SPIn from 250 pollen grains*day m^{-3} in 1995 to 6671 pollen grains*day m^{-3} in 2014)- and crops (*Olea*, SPIn from 23,766 pollen grains*day m^{-3} in 1995 to 117, 791 pollen grains*day m^{-3} reached in 2013). No trend was discerned for *Populus*. For the herbaceous taxa, only *Plantago* showed a statistically significant trend, with decreasing tendency (SPIn from 2345 pollen grains*day m^{-3} in 1996 to 92 pollen grains*day m^{-3} in 2007).

Trends observed in the ending pollination date suggest the presence of two behaviors within the pollen types studied. All the arboreal taxa showed increasing trends, and six of them were statistically significant (Cupressaceae, *Olea*, *Pinus*, *Platanus*, *Populus* and *Quercus*). However, herbaceous taxa showed decreasing trends, being statistically significant only in *Plantago*. The same pattern can be generalized regarding the duration of the pollen season (Fig. 3). Analyses showed that seven arboreal taxa significantly increased this feature, of which Cupressaceae (Duration from 40 days in 1995 to 104 days recorded in 2014) and *Pinus* (Duration from 13 days in 1996 to 114 days in 2016) can be highlighted. In general, herbaceous taxa showed decreasing trends, of which Amaranthaceae (Duration from 202 days in 1995 to 150 days recorded in 2008), *Plantago* (Duration from 119 days in 1997 to 15 days in 2007) and Urticaceae (Duration from 221 days in 1998 to 145 days in 2010) were statistically significant. No clear trend was discerned for Poaceae pollen type.

Once the temporal trends were analyzed, changes during the last years of the data series (2007–2016 *versus* 1994–2006) for the aerobiological variables that showed the highest number of significant trends (SPIn and duration of the pollen season) were evaluated in detail by using Mann-Whitney test. A positive or negative z-value indicates the presence of an increase or decrease between data series, respectively. The proportional change or effect size was also estimated. For five taxa (Cupressaceae, *Fraxinus*, *Olea*, *Platanus* and *Ulmus*), the average SPIn value reached during the last decade increased significantly regarding the previous years (Mann-Whitney test, $p \leq 0.05$),

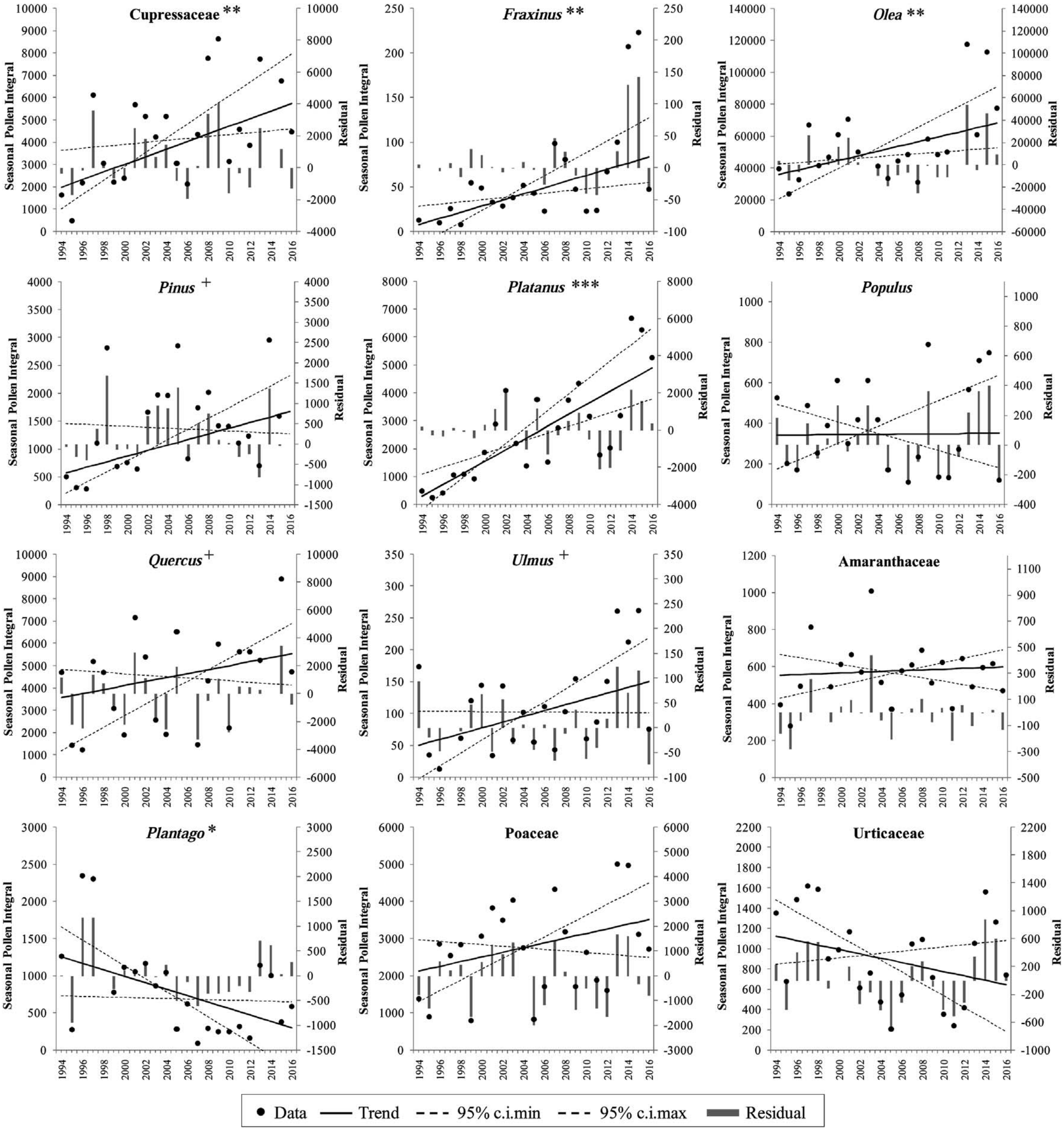

Fig. 2. Trend-diagnostic plots for Seasonal Pollen Integral (pollen*day m^{-3}) of the twelve main pollen types (1994–2016). c.i.min, the lower limit of the confidence interval; c.i.max, the upper limit of the confidence interval; $p > 0.1$; $+p \leq 0.1$; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$.

while only one taxa (*Plantago*) decreased significantly (Fig. 4). These changes correspond to an increase (decrease) that ranges from 34% (e.g. *Olea*) to 83% (e.g. *Platanus*). Comparing study periods, significant changes in the duration of the pollen season were observed for a total of eight taxa; increasing values for six arboreal taxa (Cupressaceae, *Fraxinus*, *Olea*, *Pinus*, *Platanus* and *Quercus*) and decreasing values for two herbaceous taxa (Amaranthaceae and *Plantago*). These changes correspond to an increase (decrease) that reaches more than three weeks in some taxa such as Cupressaceae, *Pinus* and *Plantago*.

3.2.2. Meteorological variables

The three-monthly temperatures recorded during the study period showed a clear and generalized increasing tendency (Table 3). The proportional annual increase detected for the Tmax_JFM was 0.07 °C/year, being this change higher regarding the Tmax_AMJ, with a significant increase of 0.18 °C/year. The exception was Tmin_JFM, whose trend decreased 0.06 °C/year. However, this parameter significantly increased −0.06 °C/year-in the successive trimester. The mean temperature increased significantly during the study period, being statistically significant only for Tmean_AMJ. Finally, the mean temperature oscillation or range showed a significant increasing tendency for both three-monthly periods.

3.3. Correlations between airborne pollen and temperature

In an attempt to identify the possible causes of increases or decreases detected in trends of aerobiological data, correlation analyses between these and trends of temperature were tested. Significant correlations were observed for several taxa (Tables 4A and 4B). Mean maximum temperature was the meteorological variable that showed the highest number of significant correlations with aerobiological data, followed by mean temperature oscillation. In general, these variables correlated significantly and positively with SPIn, ending date and duration of the pollen season in arboreal taxa, while both parameters correlated negatively with herbaceous taxa. Similarly occurred respect to the mean temperature values, although with a considerably lower number of significant correlations. Mean minimum temperature correlated significantly and negatively only with some herbaceous taxa.

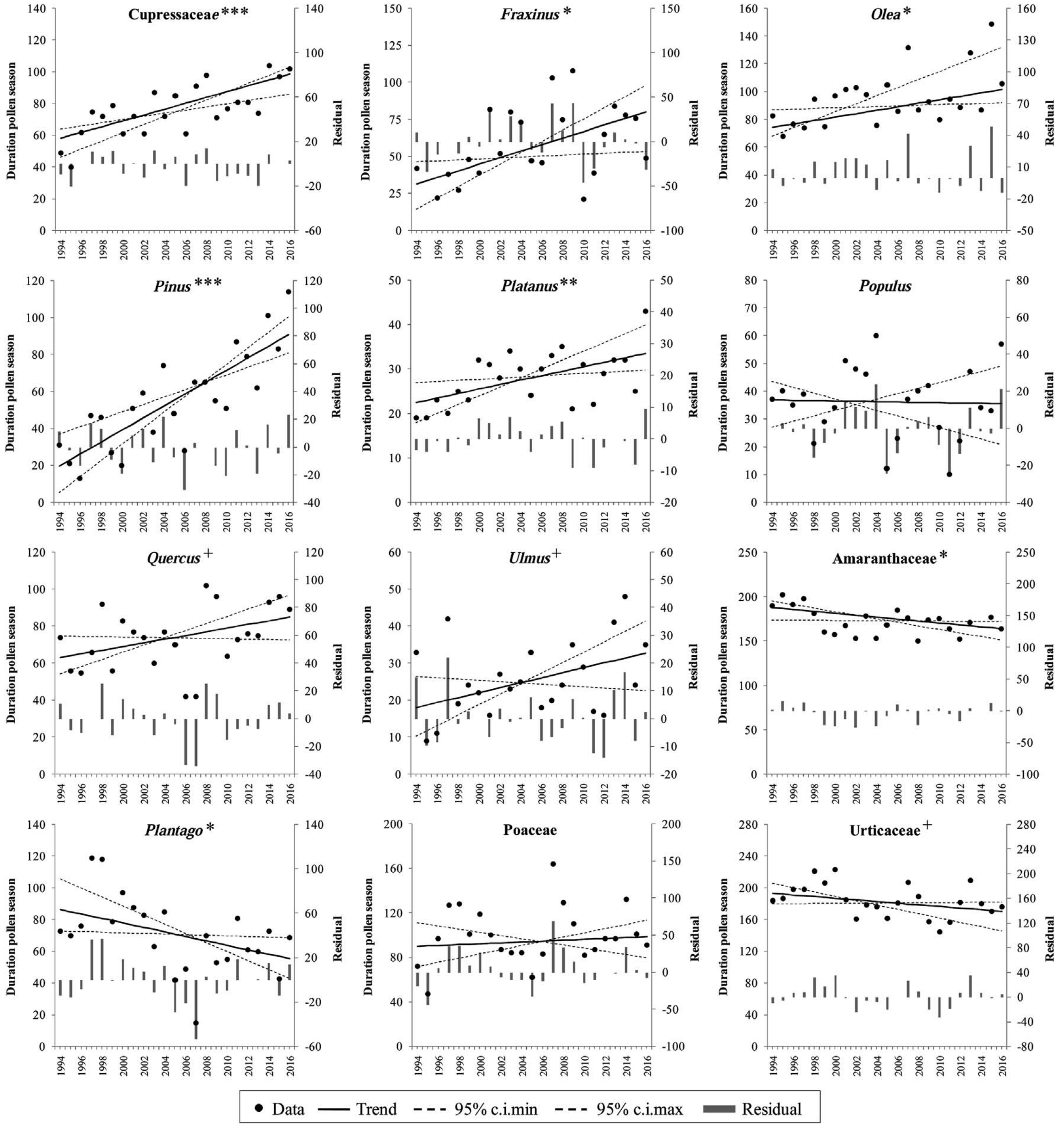

Fig. 3. Trend-diagnostic plots for duration of the pollen season (number of days) of the twelve main pollen types (1994–2016). c.i.min, the lower limit of the confidence interval; c.i.max, the upper limit of the confidence interval; $p > 0.1$; $+p \le 0.1$; $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$.

High temperatures during the first months of the year had a positive effect on SPIn of all the arboreal taxa with the exception of *Populus*, where not significant correlation was detected. This effect was negative in relation to airborne pollen from herbaceous taxa, particularly on SPIn of *Plantago*. Both the ending date and duration of the main pollen season of arboreal taxa were positively influenced by increasing temperatures, mainly during the second trimester of the year (AMJ). The inverse effect was observed with respect the herbaceous taxa.

4. Discussion

The present study, focused on the most frequent pollen types from arboreal and herbaceous plants species in the airborne spectrum of Jaen (southern Spain), revealed significant changes in pollen intensity and duration of the pollen season over the study period, while no clear pattern was observed for both the starting and peak pollination dates.

Increasing airborne pollen trends were clearly detected for arboreal taxa. The most significant changes emerge in ornamental tree species commonly used in urban green zones (Cupressaceae, *Fraxinus* and *Platanus*) as well as for olive trees (*Olea*), the main crop growing around the sampling station. Likewise, *Pinus*, *Quercus* and *Ulmus* taxa showed positive airborne pollen trends in the study area, while no clear trend was discerned for *Populus*. Rising trends in airborne pollen from tree species have been detected in other Mediterranean-climate regions. Total annual pollen concentrations for Cupressaceae, *Fraxinus*, *Olea*, *Pinus*, *Platanus* and *Quercus* showed increasing trends in different study areas through the Iberian Peninsula (Ribeiro et al., 2008; Tormo-Molina et al., 2010; Alcázar et al., 2011; Fernández-Llamazares et al., 2014; Galán et al., 2016; De Linares et al., 2017). Likewise, increasing trends in the annual pollen atmospheric abundance were observed for several woody plants in similar bioclimatic regions (Frenguelli et al., 2002, *Pinus*; Tedeschini et al., 2006, *Platanus*; Damialis et al., 2007, Cupressaceae, *Pinus*, *Platanus* and *Quercus*). In central Europe, the pollen concentrations for most of the arboreal pollen types have been increasing, as has been reported for numerous research teams (Jäger et al., 1996, *Corylus*, *Pinus* and *Ulmus*; Clot, 2003, Cupressaceae and *Alnus*; Makra et al., 2011, *Populus* and *Taxus*/Cupressaceae). Also in colder north Europe areas, positive trends in airborne pollen have been

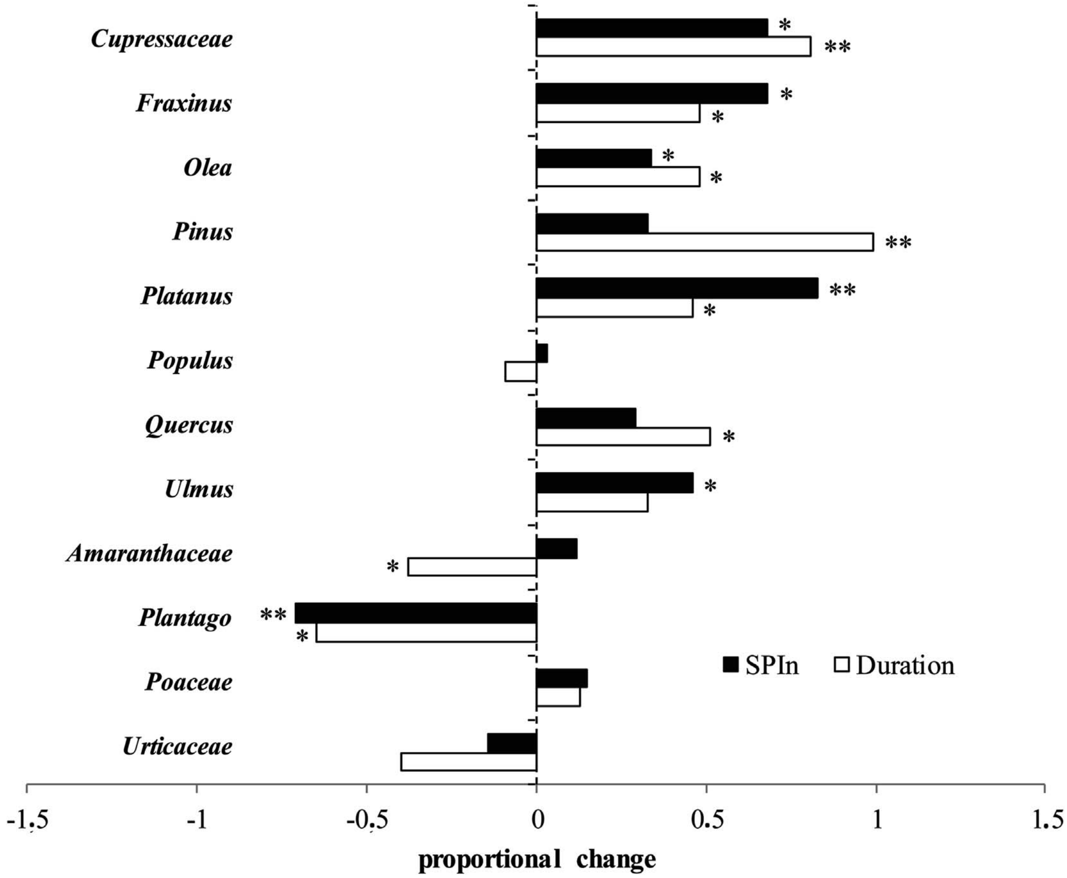

Fig. 4. Proportional change for both Seasonal Pollen Integral and duration of the pollen season for the twelve taxa during the last decade (2007–2016 *vs* 1994–2006). Mann-Whitney test revealed significant variation between periods for a total of nine taxa. A positive or negative value indicates the presence of a proportional increase or decrease between data series, respectively; *p ≤ 0.05; **p ≤ 0.01.

Table 3
Mann–Kendall test for the trend analysis for the three-monthly meteorological parameters recorded during the period 1994–2016. N = 23. Tmax, mean maximum temperature (°C); Tmin, mean minimum temperature (°C); Tmean, mean temperature (°C); Tosc, mean temperature oscillation or range (°C); JFM, January-February-March; AMJ, April-May-June. n.s (not significant) p > 0.1; +p ≤ 0.1; *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001.

	Test Z	Sign.	Sen's slope estimate (Q)
Meteorological variables			
Tmax_JFM	2.03	*	0.07
Tmax_AMJ	3.12	**	0.18
Tmin_JFM	−1.93	+	−0.06
Tmin_AMJ	1.72	+	0.06
Tmean_JFM	0.79	n.s	0.04
Tmean_AMJ	2.85	**	0.12
Tosc_JFM	2.80	**	0.13
Tosc_AMJ	2.43	*	0.12

observed for several tree taxa (Yli-Panula et al., 2009, *Betula*; Lind et al., 2016, *Alnus*, *Corylus* and *Quercus*).

For herbaceous taxa, airborne pollen concentrations decreased over the study period for both *Plantago* and Urticaceae, remained stable for Amaranthaceae and showed a slight but not significant increase for Poaceae. Changes in airborne pollen trends from several herbaceous taxa have been previously found in different ways. In general, negative trends have been reported for *Plantago* (Tormo-Molina et al., 2010; Galán et al., 2016) and Amaranthaceae (Cariñanos et al., 2014a; Galán et al., 2016), so as in *Artemisia* (Cariñanos et al., 2013; Bogawski et al., 2014) and *Rumex* (Makra et al., 2011; Galán et al., 2016). A moderately increasing trend in the annual totals of daily concentrations of Urticaceae pollen has been detected in central Europe (Makra et al., 2011; Spieksma et al., 2003). However, and according to the results herein, negative trends have been found for this pollen type in similar climatic environments (Recio et al., 2009). Reported findings for Poaceae, by contrast, differ considerably and no clear pattern can be observed. Negative trends were detected in north Spain (Latorre and Belmonte, 2004; Jato et al., 2009), becoming positive but not significant in the southern Spanish areas (Galán et al., 2016) and no change -increasing or decreasing trend-was discerned by Ziello et al. (2012) in Europe as a whole. A clear pattern could not be extracted from the data of this study.

Flowering advance (start and/or peak of the pollination season) has been detected in central and southern Europe for a number of arboreal taxa such as *Betula* (Emberlin et al., 2002; Frei and Gassner, 2008), *Alnus* (Jäger et al., 1996), *Corylus* (Jäger et al., 1996; Sparks et al., 2000), *Fraxinus* (Clot, 2003), *Ulmus* (Jäger et al., 1996), Cupressaceae (Clot, 2003), *Platanus* (Clot, 2003), *Pinus* (Frenguelli et al., 2002; De Linares et al., 2017), *Olea* (Orlandi et al., 2010; Aguilera et al., 2015b) and *Quercus* (García-Mozo et al., 2006). In this case of study, no systematic tendency towards an advance in the start or peak of the pollen season has been detected (with the exception of Cupressaceae starting date). However, the pollen season tends to end later and last longer for most of the deciduous and the evergreen arboreal taxa (Cupressaceae, *Fraxinus*, *Olea*, *Pinus*, *Platanus*, *Populus*, *Quercus* and *Ulmus*).

Trends observed in pollen-season-related attributes from herbaceous taxa suggest the presence of different behaviors across Europe. Pollen season tends to start earlier and be longer in central and north Europe, as has been reported for *Plantago* (Makra et al., 2011; Bogawski

Table 4A

Spearman's correlation coefficients between pollen season features from arboreal taxa and meteorological variables during the period 1994–2016. SPIn, Seasonal Pollen Integral (pollen*day m^{-3}); Tmax, mean maximum temperature (°C); Tmin, mean minimum temperature (°C); Tmean, mean temperature (°C); Tosc, mean temperature oscillation or range (°C); Significant probability results are indicated in bold letter. *Significant at 95%; **Significant at 99%.

	January-March				April-June			
	Tmax	Tmin	Tmean	Tosc	Tmax	Tmin	Tmean	Tosc
SPIn								
Cupressaceae	**0.502***	0.106	0.388	0.320	0.232	−0.091	0.134	0.352
Fraxinus	0.353	−0.222	−0.071	**0.478***	0.280	0.187	0.282	0.231
Olea	**0.423***	0.189	0.194	0.227	0.112	0.163	0.145	0.071
Pinus	**0.420***	0.049	0.185	0.251	0.403	0.021	**0.489***	0.149
Platanus	**0.526****	−0.201	0.058	**0.554****	**0.529****	0.209	**0.494***	**0.535****
Populus	0.027	−0.089	0.029	0.060	0.082	0.171	0.144	0.029
Quercus	**0.420***	−0.119	0.220	0.256	**0.456***	0.209	0.311	0.382
Ulmus	0.333	−0.393	−0.003	**0.513***	0.299	0.100	0.258	0.312
End date								
Cupressaceae	0.184	−0.310	−0.172	**0.424***	**0.455***	0.136	0.413	**0.434***
Fraxinus	0.033	−0.059	−0.060	0.044	0.019	−0.217	−0.032	0.194
Olea	0.138	−0.301	−0.276	0.250	0.074	0.254	0.179	−0.011
Pinus	0.408	−0.327	−0.159	**0.508***	**0.551****	0.299	**0.510***	**0.528****
Platanus	0.011	−0.370	−0.300	0.193	**0.508***	0.308	**0.471***	0.214
Populus	−0.048	−0.019	−0.300	−0.025	0.085	0.258	0.177	0.079
Quercus	**0.563****	−0.204	0.129	**0.600****	**0.427***	0.002	0.297	**0.486***
Ulmus	−0.013	−0.359	−0.325	−0.054	0.359	0.173	0.287	0.092
Duration								
Cupressaceae	0.221	−0.219	−0.116	0.416	**0.427***	0.225	0.397	0.400
Fraxinus	0.150	−0.079	−0.129	0.099	0.151	0.097	0.181	0.202
Olea	0.276	−0.152	−0.046	0.267	0.099	0.167	0.164	0.072
Pinus	**0.559****	−0.064	0.154	**0.463***	**0.460***	0.127	0.365	**0.499***
Platanus	0.213	0.088	0.003	0.181	−0.011	−0.106	−0.036	0.017
Populus	0.070	0.412	0.304	−0.246	−0.294	−0.310	−0.310	−0.122
Quercus	**0.668****	0.083	**0.478***	**0.456***	0.285	−0.107	0.171	**0.425***
Ulmus	0.059	−0.076	0.063	0.189	0.092	−0.184	0.047	0.224

et al., 2014), Urticaceae (Makra et al., 2011; Clot, 2003; Bogawski et al., 2014) or *Artemisia* (Clot, 2003; Stach et al., 2007; Lind et al., 2016). On the contrary, later start, earlier end and shorter pollen seasons have been observed for Amaranthaceae, *Plantago* and Urticacea in Jaen, results in line with those previously reported by different authors throughout Spain (Recio et al., 2009; Tormo-Molina et al., 2010; Cariñanos et al., 2014a). The behavior of Poaceae is even more complex. While in some regions Poaceae pollen season ends later and last longer (Makra et al., 2011), in others similar bioclimatic regions it starts later and last shorter (Jato et al., 2009; Tormo-Molina et al., 2010) and also no tendency is discerned (Clot, 2003). Our findings regarding Poaceae did not show any consistent increasing or decreasing trend over the period of study.

Phenology is probably the simplest process in which to track changes in the ecology and behavior of plant species in response to climate change. The physiological behavior of temperate-zone species is regulated by different bio-climatic parameters, where temperature is a factor that has a particularly important role (Menzel et al., 2006). Climate signal controlling spring phenology is fairly well understood and most of the flowering and fruiting phenophases correlate with temperatures in the preceding months (Walther et al., 2002). Flowering, inflorescence maturation and pollen release are some of the processes that show strong responses to temperature (Emberlin et al., 2002; García-Mozo et al., 2006; Damialis et al., 2007; Orlandi et al., 2010; Ziello et al., 2012; Aguilera and Ruiz-Valenzuela, 2014; Aguilera et al., 2015a).

Table 4B

Spearman's correlation coefficients between pollen season features from herbaceous taxa and meteorological variables during the period 1994–2016. SPIn, Seasonal Pollen Integral (pollen*day m^{-3}); Tmax, mean maximum temperature (°C); Tmin, mean minimum temperature (°C); Tmean, mean temperature (°C); Tosc, mean temperature oscillation or range (°C); Significant probability results are indicated in bold letter. *Significant at 95%; **Significant at 99%.

	January-March				April-June			
	Tmax	Tmin	Tmean	Tosc	Tmax	Tmin	Tmean	Tosc
SPIn								
Amaranthaceae	0.110	0.215	0.257	0.008	−0.059	−0.119	−0.120	−0.080
Plantago	−0.358	0.359	0.095	**−0.539****	**−0.556****	−0.197	**−0.478***	**−0.515***
Poaceae	0.174	0.367	0.215	−0.127	−0.204	−0.213	−0.205	−0.126
Urticaceae	−0.140	0.397	0.316	−0.41	−0.400	−0.375	−0.407	−0.266
End date								
Amaranthaceae	**−0.532****	−0.020	−0.295	**−0.439***	−0.056	0.024	0.042	−0.079
Plantago	0.188	0.403	0.390	0.112	**−0.428***	−0.162	−0.415	−0.408
Poaceae	0.027	0.227	0.234	−0.144	−0.407	**−0.461***	**−0.480***	−0.330
Urticaceae	−0.113	0.134	0.121	−0.195	**−0.454***	−0.368	**−0.498***	**−0.420***
Duration								
Amaranthaceae	**−0.537****	0.147	−0.112	**−0.586****	−0.127	0.030	−0.021	−0.141
Plantago	0.043	0.331	0.389	−0.207	**−0.478***	−0.261	**−0.500***	**−0.452***
Poaceae	0.365	0.283	**0.454***	0.092	−0.146	−0.260	−0.204	−0.115
Urticaceae	−0.249	0.305	0.152	−0.407	**−0.660****	**−0.424***	**−0.630****	**−0.578****

Mean maximum temperature was the weather parameter that showed the highest number of significant correlations with aerobiological data, followed by mean temperature oscillation. A notable increasing trend for winter and spring temperatures has been detected over the study period, as well as in the diurnal temperature ranges as a consequence of maximum temperatures are increasing at higher rate than minimum temperatures. This pattern could partly explain the changes detected in pollen concentrations and pollen-season-related features. Our findings indicate that increasing temperatures during the first months of the year were positively linked to pollen intensity, ending date and duration of the main pollen season for arboreal taxa. Nevertheless, the inverse effect was observed with respect the herbaceous taxa.

Warming temperatures contribute to a phenological advance and greater pollen concentrations for tree species that flowering in winter and early spring across Europe (Sparks et al., 2000; Emberlin et al., 2002; Clot, 2003; Frei and Gassner, 2008; Yli-Panula et al., 2009; Ziello et al., 2012; Lind et al., 2016; De Linares et al., 2017), but few studies focused on the analysis of other important phenological attributes such as the ending date and the length of the pollination season have reported significant trends. Here Cupressaceae, *Olea*, *Pinus*, *Platanus*, *Quercus* as arboreal taxa and *Plantago* as herbaceous taxa were the most important with notable changes of at least three pollen season characteristics. Increasing temperatures in Jaen are having a double effect. Pollen season of tree species, especially those that flowering in winter and early spring, is clearly more intense and longer in line with the local temperature increasing trend. However, higher spring temperatures seem to be a limiting factor for the biological development of some herbaceous species that are less tolerant than others to excessive temperatures and water stress. According to several authors, Amaranthaceae family is better placed to resist high temperatures and drought than other herb species (Li et al., 2005; Gehrig, 2006; Cariñanos et al., 2014a). On the contrary, studies carried out in similar biogeographical areas note that temperature negatively affects the airborne pollen concentrations of *Plantago* and Urticaceae (Alcázar et al., 2009; Recio et al., 2009; Tormo-Molina et al., 2010). In this study, the decline detected in the airborne pollen concentrations of *Plantago* and Urticaceae was more marked than that for other species sharing the same ecological niche, such as Amaranthaceae, whose airborne pollen concentrations remained stable even if a decline in the duration of the pollen season was observed, and Poaceae, whose pollen trends showed a slight but not significant increase. This may be attributable in part not only to the adverse effect of the increasing trend temperatures but also to the fact that their presence and abundance could decrease in favor of other more resistant herbaceous species.

Although local airborne pollen is obviously governed by the plant response to climate, there is other important driver that is being considered as a descriptive variable in recent aerobiological studies: land use and land cover (Foley et al., 2005; García-Mozo et al., 2016; Rojo et al., 2016; Maya-Manzano et al., 2017). Given the link between pollen spectrum and plants abundance and distribution, one indirect consequence of land cover changes is cause fluctuations in airborne pollen concentrations (Oteros et al., 2015). In fact, it would be logical to think that the observed increase in airborne pollen from arboreal taxa could be explained by a greater pool of pollen producers in the area. The possibility that this might have happened for certain species cannot be excluded. The increase in *Olea* pollen levels detected in Jaen can be partly attributed to the increase in the land surface that is devoted to olive cultivation that has occurred in this area over more recent decades (Aguilera and Ruiz-Valenzuela, 2014). In many areas, the natural vegetation has been almost completely replaced by non-irrigated olive groves. These results are in agreement with those reported by García-Mozo et al. (2016) that studied land-use changes provoked by human activities and found a significant rise in *Olea* pollen concentrations as a consequence of a growing surface occupied by olive crops. However, changes in abundance or habitat composition of local *Pinus* and *Quercus* forests as well as urban green spaces (e.g. Cupressaceae and *Platanus*) have not been observed. Thus, the factor most likely to be responsible for the detected changes in pollen concentrations and pollen-season-related features of these taxa is the rise in air temperature, as has been discussed in previous reports (Walther et al., 2002; Menzel et al., 2006; Damialis et al., 2007).

5. Conclusions

Changes in the pollen spectrum of Jaen have been detected during the last years. Airborne pollen trends from woody species with high to very high allergenic potential are rising in line with the local temperature increasing trend. However, pollen levels from herbaceous taxa, particularly *Plantago*, are declining. Earlier tree species seem to be more sensitive to temperature and they better indicated changes in temperature. In this way, we propose Cupressaceae, *Pinus*, *Platanus*, *Quercus* and *Plantago* pollen types as the best bio-indicators to detect local climate change. Moreover, pollen season of most of the arboreal taxa here studied tends to end later and last longer. In consequence, greater exposure times to seasonal allergens may occur in the next years.

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