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ORIGINAL PAPER

# Pollen season trends in winter flowering trees in South Spain

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**Abstract** The present work has studied the trends in pollen seasons of winter flowering trees (*Alnus, Cupressaceae, Fraxinus, Populus* and *Ulmus*) in Córdoba, Granada and Málaga (Andalusia, Spain) over the years 1994–2017. The influence of meteorological parameters on the seasonal airborne pollen has been also analyzed. Pollen concentrations were recorded using Hirst-type volumetric spore traps, following the standardized methodology of the Spanish Aerobiology Network and the European Aerobiology Society. The nonparametric Mann–Kendall test and the nonparametric Sen's method have been used to study linear trends for pollen season timing and intensity, and for temperature and rainfall. Significance was determined using the *F*-test. Spearman analyses were applied to test for correlations between pollen season parameters and weather-related factors before and over the pollen season. The results obtained suggest that flowering has delayed over recent years, especially for trees with a bloom closer to spring (poplar and elm). Earlier flowering species are more influenced by the meteorological parameters before the flowering. However, species blooming later are more influenced by the meteorological parameters during the pollen season. Meteorological parameters affect more the interior cities than the coastal city.

**Keywords** Winter flowering trees · Pollen season · Climate effects · Meteorological factors · Aerobiology

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## 1 Introduction

During the last few years, the impact of climate change on ecosystems has prompted growing research into the effect of climate on plant phenology. Numerous studies have focused on analyzing possible trends and modeling the response of plants to the climate (Walther 2010; Ziello et al. 2012; Bogawski et al. 2014; Heap et al. 2014; Galán et al. 2016).

A number of authors have confirmed a generalized advance in flowering (Gordo and Sanz 2010; Anderson et al. 2012; Bellard et al. 2012; Cook et al. 2012; Franks et al. 2014) as well as greater flowering intensity (Ziello et al. 2012). In southern Europe, this generalized advance in flowering has been reported, especially in woody species blooming in early spring (García-Mozo et al. 2010a, b; Fernández-Llamazares et al. 2014), some of them with clear trends on flowering intensity (Galán et al. 2016; Recio et al. 2018). However, contrary tendencies have been observed in some species of winter flowering (Mercuri et al. 2013).

Several studies have highlighted the importance of temperature patterns for the tree's phenological development (Emberlin et al. 2002, 2007; Mutke et al. 2003; Ariano et al. 2010; García-Mozo et al. 2011). In south Spain, researches have also highlighted the important contribution of rainfall to plant phenology, and various papers have paid special attention to changes in precipitation and water availability as a major driver of climate change in the Mediterranean area (Peñuelas et al. 2004; Tormo-Molina et al. 2010; García-Mozo et al. 2010b). Climate change has had a particularly marked effect on southern Spain, increasing temperatures and reducing rainfall (IPCC 2014). Rainfall has also become increasingly torrential in recent years (Priego et al. 2017; Rodríguez-Solà et al. 2017).

Airborne pollen monitoring is regarded as an effective tool for studying the reproductive phenology of anemophilous plant, especially as a bioindicator of their behavior in areas, where there are important variations in flowering (Fernández-Llamazares et al. 2014).

The presence of airborne pollen in the atmosphere is directly affected by weather conditions, not only by daily changes, but also by seasonal climatic trends (Mercuri et al. 2016). On the other hand, some authors also attribute these trends to changes in other components of climate change, i.e., the NAO index or an increase in anthropogenic $CO_2$ emissions (Rogers et al. 2006; Levetin and Van de Water 2008; Galán et al. 2016) and other human activities (Cariñanos and Casares-Porcel 2011; Oteros et al. 2013; Velasco-Jiménez et al. 2013; Mercuri et al. 2016).

Longer pollen seasons with higher concentrations of airborne pollen, due to variations in climate, may also affect the prevalence and severity of allergic diseases. Indeed, there is evidence that climate change will influence aeroallergens by altering the amounts, the allergenicity and the pollen season, as well as the distribution and other attributes of pollen-releasing plants (Ariano et al. 2010). Recent studies highlight the links between global climate change and respiratory allergies, showing that allergic disease is becoming increasingly prevalent, affecting the quality of life of many millions of individuals all over the world (D'Amato et al., 2016; Bousquet et al. 2017).

During winter months, main airborne pollen types detected in Andalusian cities are, in order of importance, Cupressaceae, *Populus*, *Ulmus*, *Fraxinus* and *Alnus* (Trigo et al. 2008; Martínez-Bracero et al. 2015). Cupressaceae pollen is considered highly allergenic and is the main cause of winter pollinosis in the population (Di Felice et al. 2001; Charpin et al. 2005; Díaz de la Guardia et al. 2006a, b); the other pollen types are not very important from the point of view of allergies, although they have been described by the literature as allergens (Lorenzoni-Chiesura et al. 2000; Cariñanos and Casares-Porcel 2011).

The main goal of this paper was to investigate variations in pollen seasons of the principal winters flowering trees in Andalusia (Cupressaceae, *Populus*, *Ulmus*, *Fraxinus* and *Alnus*) and charting trends over the last 24 years (1994–2017). Another objective has been to analyze how the meteorological parameters have influenced the seasonal airborne pollen.

## 2 Materials and Methods

### 2.1 Study area

Airborne pollen was recorded in three cities in the southern Spanish region of Andalusia: Cordoba, Granada and Malaga (Fig. 1). Some geographical

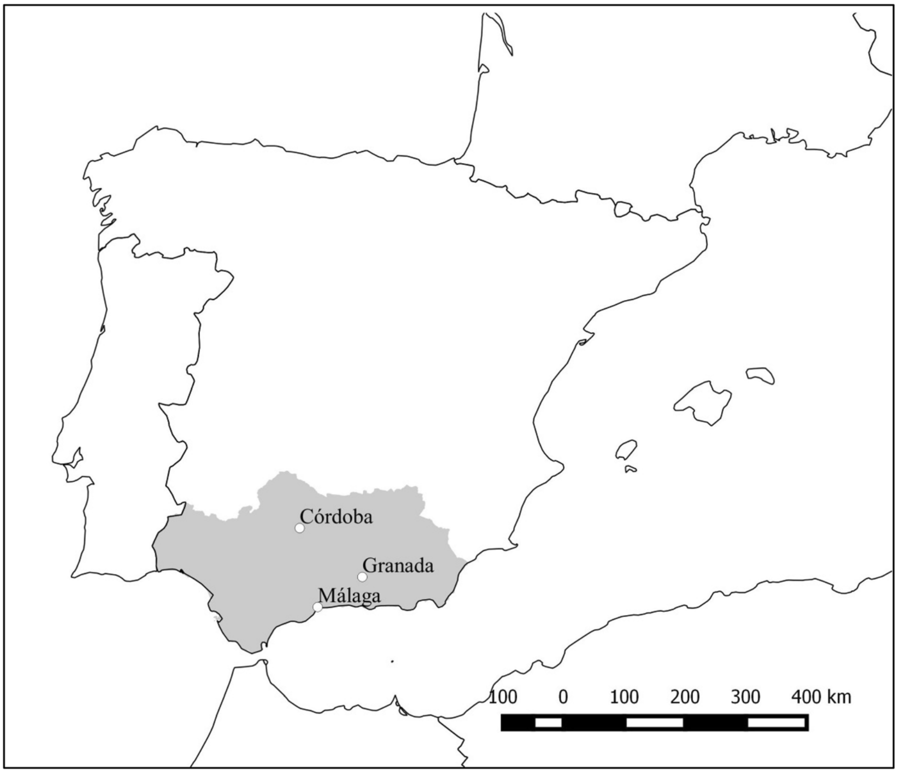


**Fig. 1** Location of the study cities in south Spain

**Table 1** Geographical and meteorological characteristics of the study cities

| City | | | | | | Meteorological stations | |
|---|---|---|---|---|---|---|---|
| Coordinate | Altitude (m) | *T* (°C) | TM (°C) | Tm (°C) | *R* (mm) | Coordinate | Altitude (m) |
| Cordoba | | | | | | | |
| 37° 50′ N, 4° 45′ W | 122.2 | 18.2 | 25.1 | 11.4 | 605 | 37° 50′ 56″ N, 4° 50′ 48″ W | 90 |
| Granada | | | | | | | |
| 37° 11′ N, 3° 35′ W | 689.1 | 15.4 | 23 | 7.8 | 365 | 37° 11′ 23″ N, 3° 47′ 22″ W | 567 |
| Malaga | | | | | | | |
| 36° 47′ N, 4° 19′ W | 9.7 | 18.5 | 23.3 | 13.7 | 534 | 36° 39′ 58″ N, 4° 28′ 56″ W | 5 |

*T* (mean annual average temperature), TM (mean annual maximum temperature), Tm (mean annual minimum temperature), *R* (total annual rainfall). Meteorological data from 1981–2010. AEMET (state weather agency). Geographical characteristics of the meteorological stations

and meteorological information on these sampling sites is provided in Table 1.

Andalusia has a Mediterranean climate. Malaga is a coastal city, with mild temperatures reflecting a strong maritime influence. Cordoba is an inland city located in the valley of the Guadalquivir River, with mild winters and very hot summers. Granada is also an inland city, but it is located next to Sierra Nevada, so the winters are colder than that in Cordoba (Agencia Estatal de Meteorología 2010).

## 2.2 Meteorological parameters

Meteorological parameters during pollen season in winter flowering trees have been considered in the present study, over 1994–2017. In the same way, meteorological parameters of the 3 months before flowering, over 1993–2016, have been taken into account, since some studies indicate their influence on the pollen season (Recio et al. 2018; Cook et al. 2012; Tormo-Molina et al. 2010; Emberlin et al. 2002, 2007).

Mean daily temperature (TM = maximum temperature, Tm = minimum temperature, *T* = mean temperature) and accumulative daily rainfall (*R*) data were obtained from the regional weather station network run by the Spanish Meteorological Agency (AEMet). Table 1 shows the geographical characteristics of each meteorological station, located in the respective airports of each city.

### 2.3 Airborne pollen

Daily mean pollen concentrations corresponding to five principal arboreal pollen types flowering at winter (Trigo et al. 2008; Martínez-Bracero et al. 2015) were utilized in this survey: *Alnus*, Cupressaceae, *Fraxinus*, *Populus* and *Ulmus*.

These pollen concentrations were recorded over a 24-year period (1994–2017) using Hirst-type volumetric spore traps (Hirst 1952), following the standardized methodology of the Spanish Aerobiology Network (REA) (Galán et al. 2007) and in compliance with the minimum requirements set out by the European Aerobiology Society (EAS) (Galán et al. 2014).

Table 2 shows the species included in each pollen type present in the studied cities as well as mean and standard deviation (SD) of annual pollen integral (APIn) in each city. All *Fraxinus* species are considered as anemophilous except *F. ornus* (Dommee et al. 1999), so it can be considered that this specie has low contribution to airborne pollen concentration.

Different methods were tested for the calculation of the pollen season, and the one that best suited reality was used in each case. This fact did not affect change in the results because the same method has been used for the same pollen type to calculate the pollen season every year. The pollen season start (PSS) and pollen season end (PSE) were taken as the day on which specific daily pollen concentrations (pollen grains/m$^3$) were reached, as a function of intensity and timing flowering:

- Cupressaceae: Start $> 30$; End $< 30$.
- *Alnus* and *Ulmus*: Start = first winter day with pollen grains/m$^3$; End = last spring day with pollen grains/m$^3$.
- *Fraxinus* and *Populus*: Start = 1 pollen grains/m$^3$ + 5 days with 1 or more pollen grains/m$^3$; End = 1 pollen grains/m$^3$ + 5 days with counts below this level.

Cupressaceae pollen type remains in the air over a long period of the year, even out of season. For this reason, to avoid very low concentrations out season, sometimes due to re-suspension, we have chosen a minimum concentration to determinate the pollen season. Although in other studies, a level of 50 pollen grains has been proposed for this pollen type (Velasco-Jiménez et al. 2013), we have considered a lower level of just 30 (Mesa et al. 2003) to equate conditions in the 3 study cities. For *Fraxinus* and *Populus* pollen types, the methodology proposed by Velasco-Jiménez et al. (2013) has been followed because they have a short pollen season and are very well delimited. In these cases, the start date was defined as the first day on which a daily pollen concentration of at least 1 pollen grain/m$^3$ was recorded, followed by 5 days with 1 or more pollen grains/m$^3$, and the end of pollen season was defined as the last day on which a daily concentration of at least 1 pollen grain/m$^3$ was recorded, followed by 5 days with concentrations below this level. Finally, *Alnus* and *Ulmus* pollen types have low concentrations in the study cities, even with no pollen days during the pollen season. For this reason, it has been necessary to choose a new method for the calculation of the pollen season, according to the characteristics of their pollen seasons. The start of pollen season has been considered the first winter day when pollen was detected and the end of pollen season the last spring day with pollen.

The main pollen season (MPS) refers to the number of days for pollen season. The annual pollen integral (APIn) was defined as the annual sum of daily values (measured in pollen grains/m$^3$). The peak day (PD) refers to the day of the year in which the maximum daily pollen concentration (MDC) was reached.

**Table 2** Species of the selected pollen types present in the study cities

| Pollen types | Species | | | | | |
|---|---|---|---|---|---|---|
| | Cordoba | | Granada | | Malaga | |
| *Alnus* | *A. glutinosa* (L.) Gaertner | | *A. glutinosa* (L.) Gaertner | | *A. glutinosa* (L.) Gaertner | |
| | Mean: 66 | SD: 31.822 | Mean: 21 | SD: 17.575 | Mean: 35 | SD: 20.797 |
| Cupressaceae | *Cupressus sempervirens* L | | *Cupressus lusitanica* Miller | | *Cupressus lusitanica* Miller | |
| | *Hesperocyparis arizonica (Greene) Bartel* | | *C. sempervirens* L | | *C. sempervirens* L | |
| | *H. glabra (Sudw.) Bartel* | | *Hesperocyparis. arizonica (Greene) Bartel* | | *Hesperocyparis arizonica (Greene) Bartel* | |
| | *H. macrocarpa (Hartw. ex Gordon) Bartel* | | *H. macrocarpa (Hartw. ex Gordon) Bartel* | | *H. macrocarpa (Hartw. ex Gordon) Bartel* | |
| | Mean: 7070 | SD: 3805.2 | Mean: 17,975 | SD: 8318 | Mean: 5411 | SD: 3374.9 |
| *Fraxinus* | *F. angustifolia* Vahl | | *F. angustifolia* Vahl | | *F. angustifolia* Vahl | |
| | *F. excelsior* L | | *F. ornus* L | | | |
| | *F. ornus* L | | | | | |
| | Mean: 298 | SD: 233.29 | Mean: 121 | SD: 63.863 | Mean: 85 | SD: 34.468 |
| *Populus* | *P. x canadensis* Moench | | *P. alba* bolleana (Lauche) & Otto | | *P. x canadensis* Moench | |
| | *P. alba* bolleana (Lauche) & Otto | | *P. alba* L | | *P. alba* L | |
| | *P. alba* L | | *P. caroliniana* Hort. ex McMinn & Maino | | | |
| | *P. caroliniana* Hort. ex McMinn & Maino | | *P. nigra* L | | | |
| | *P. nigra* L | | *P. simonii* Carrieré | | | |
| | *P. simonii* Carrieré | | *P. tremula* L | | | |
| | *P. x canescens* (Aiton) Sm | | | | | |
| | Mean: 1075 | SD: 662.5 | Mean: 1148 | SD: 580.94 | Mean: 122 | SD: 45.504 |
| *Ulmus* | *U. americana* L | | *U. glabra* Hudson | | *U. minor* Miller | |
| | *U. glabra* Hudson | | *U. minor* Miller | | | |
| | *U. minor* Miller | | | | | |
| | *U. pumila* L | | | | | |
| | Mean: 220 | SD: 154.98 | Mean: 262 | SD: 179.16 | Mean: 23 | SD: 14.67 |

Mean and standard deviation (SD) of pollen in each city during the study period

### 2.4 Statistical analysis

The nonparametric Mann–Kendall test for testing the presence of the monotonic increasing or decreasing trends and the nonparametric Sen's method for estimating the slope of a linear trend have been used to study annual linear trends for main pollen season timing and intensity, and also for temperature and rainfall. Significance was determined using the *F*-test.

On the other hand, Spearman analyses were applied to test for possible correlations between pollen parameters and climatic-related factors before and over the main pollen season.

## 3 Results

### 3.1 Meteorological parameters trends during the study years

The temperature during the autumn (3 months before pollen winter season) is increasing during the last 23 years with significant values in Granada for minimum (+ 0.094 °C/year) and average temperature (+ 0.064 °C/year). During the main pollen season, from December to March, decreasing temperature trend has been observed, reaching significant values in the cities of Cordoba and Granada for maximum temperature (− 0.052 °C/year in Córdoba and

− 0.091 °C/year in Granada) and average temperature (− 0.083 °C/year in Córdoba and − 0.065 °C in Granada) (Table 3).

### 3.2 Pollen seasons during the study years

According to Fig. 2, during the study period (1994–2017), main pollen seasons generally extended from December to March in the studied cities. The first flowering tree was *Fraxinus*, whose pollen grains were detected since the beginning of December; it is followed by *Alnus*, detecting pollen in late December, Cupressaceae at the beginning of the year, and *Ulmus* and *Populus* pollen was not detected until February. In general, the more abundant pollen types in all cities have been Cupressaceae and *Populus*. The other pollen types have presented low concentrations, with a daily average concentration of less than 15 pollen grains/m$^3$ of air, even not exceeding 3 grains of pollen daily/m$^3$ of air in the case of *Alnus*.

### 3.3 Trends in main pollen season during the study years

Slope, $R^2$ and significance ($p$) values for the temporality and intensity of the pollination (PSS, PSE, APIn, PD, MCD) in each city are summarized in Table 4. Pollen season start tends to be delayed for *Alnus* in Cordoba and Malaga, *Populus* in Malaga and *Ulmus* in Granada, while it tends to be advanced for Cupressaceae in Granada and *Fraxinus* in Córdoba. Pollen season end tends to be delayed for *Alnus*, Cupressaceae and *Ulmus* in Granada and *Populus* in Cordoba and Granada, while it tends to be advanced for *Alnus* in Malaga. Annual pollen integral is increasing for *Alnus*, Cupressaceae and *Fraxinus* in Granada and *Populus* and *Ulmus* in Cordoba, while it is decreasing for Cupressaceae in Malaga and *Ulmus* in Granada. Maximum daily pollen concentration is increasing for *Alnus* in Granada, Cupressaceae and *Ulmus* in Cordoba and Granada and *Populus* in Cordoba, while it is decreasing for Cupressaceae in Malaga. Neither result was statistically significant for date of peak day.

### 3.4 Correlation between the pollen season start (PSS) or annual pollen integral (APIn) and Climatic parameters

Results of Spearman correlation analyses between PSS and APIn of pollen types studied and the climatic parameters (TM, Tm, T and R) before and during main pollen season in each city over the study period are shown in Table 5. As general results, and in spite of not obtaining significant values in the majority of the cases, it has been observed that these climatic parameters affect more the interior cities (Cordoba and Granada) than the coastal city (Malaga). It is observed that higher rainfall and temperatures prior to flowering cause a delay in the PSS and an increase in the APIn. Similarly, higher temperatures during the pollen season cause greater delay in the PSS and an increase in the APIn.

**Table 3** Slope values, $R^2$ and significance ($p$) for the meteorological parameters (Maximum temperature—TM, minimum temperature—Tm, average temperature—*T*, rain—*R*) during main pollen season (December–March) and before (September–November) in each city

| | Before MPS | | | | During MPS | | | |
|---|---|---|---|---|---|---|---|---|
| | TM | Tm | *T* | *R* | TM | Tm | *T* | *R* |
| *Cordoba* | | | | | | | | |
| Slope | 0.040 | 0.017 | 0.003 | − 0.393 | − 0.052 | − 0.056 | − 0.083 | − 1.867 |
| $R^2$ | 0.062 | 0.015 | 0.001 | 0.001 | 0.157 | 0.070 | 0.348 | 0.005 |
| *p* | 0.242 | 0.568 | 0.916 | 0.886 | **0.055**$^+$ | 0.213 | **0.002**$^{**}$ | 0.746 |
| *Granada* | | | | | | | | |
| Slope | 0.066 | 0.094 | 0.064 | 1.008 | − 0.091 | − 0.005 | − 0.065 | − 0.179 |
| $R^2$ | 0.117 | 0.207 | 0.126 | 0.012 | 0.223 | 0.001 | 0.175 | 0.000 |
| *p* | 0.102 | **0.026**$^*$ | **0.089**$^+$ | 0.608 | **0.020**$^*$ | 0.904 | **0.042**$^*$ | 0.966 |
| *Malaga* | | | | | | | | |
| Slope | 0.047 | − 0.023 | 0.000 | 0.971 | − 0.007 | − 0.038 | − 0.028 | − 0.733 |
| $R^2$ | 0.069 | 0.017 | 0.000 | 0.003 | 0.006 | 0.070 | 0.074 | 0.001 |
| *p* | 0.214 | 0.544 | 0.996 | 0.811 | 0.728 | 0.212 | 0.199 | 0.862 |

Significant values are highlighted in bold

$^{**}$Correlation is significant at the 0.01 level; $^*$correlation is significant at the 0.05 level; $^+$correlation is significant at the 0.1 level

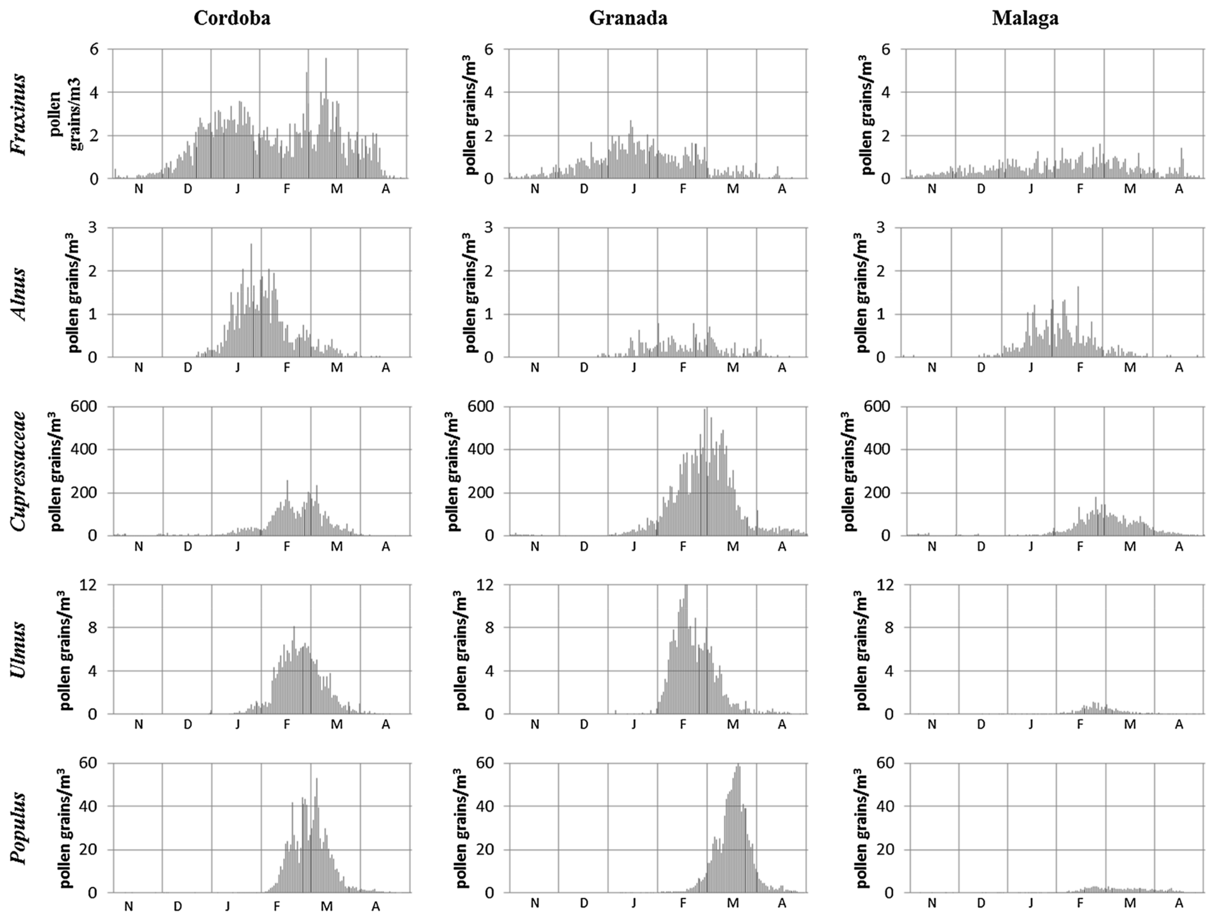


**Fig. 2** Average daily pollen concentration of each pollen types in each city during the study years

## 4 Discussion

This study focused on the most frequent winter pollen types in the atmosphere of south Spain. Different pollen season characteristics (PSS, PSE, APIn and MCD) were analyzed as indicators of timing flowering and intensity in these anemophilous plants in areas surrounding the sampling station. In this sense, foreground the higher pollen concentration of Cupressaceae was detected in Granada, since several cypress species are widely used as ornamental in this city (Díaz de la Guardia et al. 2006a, b; Velasco-Jiménez et al. 2014). In the same way, pollen concentrations of *Alnus*, *Populus* and *Ulmus* pollen types, typical riverside species, are similar in Cordoba and Granada, both cities crossed by rivers. Nevertheless, pollen concentrations of these species are lower in Malaga because they are worse represented in this city (Velasco-Jiménez et al. 2014). In addition, it is a coastal city and suffers from the influence of wind direction, which usually has a southeast component (from the sea) and therefore, the pollen concentration detected is much lower.

The present study examined data over the same 24-year period, and generally speaking, PSS and PSE have delayed over recent years, although the delay is more evident for trees with a bloom closer to spring (*Populus* sp. and *Ulmus* sp.). This result is different from other studies in central Europe (Clot 2003; Bogawski et al. 2014), with a predominantly Euro-Siberian temperate climate. In other studies carried out in southern Spain (García-Mozo et al. 2010a, b; Tormo-Molina et al. 2010), it is about other species blooming later in spring (*Quercus* sp. and *Platanus* × *hispanica Mill. ex Münchh.*), even sometimes with no significant results for Cupressaceae pollen type.

**Table 4** Slope, $R^2$ and significance ($p$) values for the seasonality and intensity of the pollination (pollen season start—PSS, pollen season end—PSE, annual pollen integral—APIn, maximum daily pollen concentration—MCD) of pollen types studied in each city

| | Cordoba | | | | Granada | | | | Malaga | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PSS | PSE | APIn | MCD | PSS | PSE | APIn | MCD | PSS | PSE | APIn | MCD |
| *Fraxinus* | | | | | | | | | | | | |
| Slope | − 1.345 | | | | | | 3.466 | | | | | |
| $R^2$ | 0.222 | | | | | | 0.147 | | | | | |
| $p$ | $0.020^{*}$ | | | | | | $0.064^{+}$ | | | | | |
| *Alnus* | | | | | | | | | | | | |
| Slope | 0.897 | | | | | 2.971 | 2.334 | 0.440 | 1.859 | − 1.248 | | |
| $R^2$ | 0.210 | | | | | 0.160 | 0.215 | 0.215 | 0.276 | 0.165 | | |
| $p$ | $0.024^{*}$ | | | | | $0.053^{+}$ | $0.022^{*}$ | $0.023^{*}$ | $0.008^{**}$ | $0.049^{*}$ | | |
| *Cupressaceae* | | | | | | | | | | | | |
| Slope | | | | 80.409 | − 8.527 | 3.690 | 1445.442 | 103.451 | | | − 391.670 | − 33.442 |
| $R^2$ | | | | 0.229 | 0.491 | 0.817 | 0.579 | 0.381 | | | 0.163 | 0.205 |
| $p$ | | | | $0.018^{*}$ | $0.000^{***}$ | $0.000^{***}$ | $0.000^{***}$ | $0.001^{**}$ | | | $0.050^{+}$ | $0.026^{*}$ |
| *Populus* | | | | | | | | | | | | |
| Slope | | 0.870 | 56.413 | 11.527 | | 0.981 | | | 0.443 | | | |
| $R^2$ | | 0.266 | 0.363 | 0.295 | | 0.391 | | | 0.121 | | | |
| $p$ | | $0.001^{**}$ | $0.002^{**}$ | $0.006^{**}$ | | $0.001^{**}$ | | | $0.095^{+}$ | | | |
| *Ulmus* | | | | | | | | | | | | |
| Slope | | | 9.705 | 1.291 | 0.749 | 0.588 | − 10.953 | − 1.461 | | | | |
| $R^2$ | | | 0.196 | 0.209 | 0.294 | 0.166 | 0.187 | 0.194 | | | | |
| $p$ | | | $0.030^{*}$ | $0.023^{*}$ | $0.006^{**}$ | $0.048^{*}$ | $0.035^{*}$ | $0.031^{*}$ | | | | |

$^{***}$Correlation is significant at the 0.001 level; $^{**}$correlation is significant at the 0.01 level; $^{*}$correlation is significant at the 0.05 level; $^{+}$correlation is significant at the 0.1 level

**Table 5** Spearman correlations analysis between pollen season characteristics (pollen season start—PSS, annual pollen integral—APIn), of pollen types studied and the meteorological parameters (maximum temperature—TM, minimum temperature—Tm, average temperature—T, rain—R) before and during main pollen season

| | Before MPS | | | | | | During MPS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cordoba | | Granada | | Malaga | | Cordoba | | Granada | | Malaga | |
| | PSS | APIn | PSS | APIn | PSS | APIn | PSS | APIn | PSS | APIn | PSS | APIn |
| *Fraxinus* | | | | | | | | | | | | |
| TM | | | | | | | $(+)^{+}$ | | | | | |
| Tm | | | | | $(+)^{*}$ | | | | | | | |
| *T* | | | | | | | $(+)^{*}$ | $(+)^{**}$ | | | | |
| *R* | | | | | | | | | | | | |
| *Alnus* | | | | | | | | | | | | |
| TM | | | | | | | | | | | | |
| Tm | $(+)^{*}$ | | $(+)^{***}$ | | $(+)^{*}$ | | | $(+)^{*}$ | | | | |
| *T* | | | $(+)^{*}$ | | $(+)^{*}$ | | | $(+)^{***}$ | | | | |
| *R* | $(+)^{*}$ | | $(+)^{*}$ | | | | | | | | | |
| *Cupressaceae* | | | | | | | | | | | | |
| TM | | | | | | | | | | | | |
| Tm | | | | | | | | | | | | |
| *T* | | | | | | | | | | | | |
| *R* | | | $(+)^{+}$ | | | | | | | | | |
| *Populus* | | | | | | | | | | | | |
| TM | | | | $(+)^{+}$ | | $(+)^{+}$ | | | $(+)^{**}$ | | | |
| Tm | | | $(+)^{*}$ | | | | $(+)^{**}$ | | | | | |
| *T* | $(+)^{**}$ | $(+)^{+}$ | | | | | $(+)^{*}$ | | $(+)^{**}$ | | | |
| *R* | $(+)^{*}$ | | | | | | | | | | | |
| *Ulmus* | | | | | | | | | | | | |
| TM | | | | | | | | | | | | |
| Tm | | $(+)^{**}$ | | | | | $(+)^{*}$ | | | | | |
| *T* | | $(+)^{**}$ | | | | | $(+)^{*}$ | | | | | |
| *R* | $(+)^{*}$ | $(+)^{+}$ | | | | | | | | | | |

$^{***}$Correlation is significant at the 0,001 level; $^{**}$correlation is significant at the 0.01 level; $^{*}$correlation is significant at the 0.05 level; $^{+}$correlation is significant at the 0.1 level

However, we have observed that over last years, there is a trend to advance the beginning of pollination of some anemophilous taxa with winter flowering in Granada (Cupressaceae) and Cordoba (*Fraxinus*) because temperature during previous months (autumn) tends to increase, especially in Granada.

The APIn, the annual sum of daily airborne pollen concentration, can provide information on the distribution and flowering intensity of wind-pollinated plants (Galán et al. 2016). For this parameter, different results have been obtained, depending on the city in question, and no clear trends, probably due to the management on these ornamental trees, with periodic pruning, which alter the formation of flowers and, therefore, pollen production (Cariñanos and Casares-Porcel 2011).

We also think that the increase in temperature in months before flowering (whose trend has been significant and positive in Granada) favors the formation and differentiation of sexual reproductive buds, which implies a higher number of flowers and therefore more pollen. This fact, together with a slight decrease in the rainfall during the pollen season, could favor this increase in the APIn. This reality has been observed in the case of *Populus* and *Ulmus* pollen types in Córdoba and in *Fraxinus*, *Alnus* and Cupressaceae pollen types in Granada in which as previously mentioned, the last is widely used as an ornamental species.

However, a decrease was observed in the case of *Ulmus* pollen type in Granada, probably due to the effects of Dutch elm disease (González-Ruiz 1998), but not really in Córdoba, probably because the damage of this pest has been less here or because the trees are already recovering. The APIn for Cupressaceae pollen type has decreased in the city of Malaga, a result that coincides with that obtained by Galán et al. (2016) for this city.

About the influence of meteorological conditions during this period of years, it has been observed that they affect more the interior cities (Cordoba and Granada) than the coastal city (Malaga). This could be due to the fact that the sea exerts a mitigating effect on the climate, so that the meteorological changes have not been appreciated too much in this city. It has been also observed that a higher temperature before flowering causes a delay in the start of the pollen season. This result coincides with other studies carried out with winter flowering species in Italy, where this delay in the pollen season was already observed due to higher temperatures in autumn (Mercuri et al. 2013, 2016). An explanation of this could be that these trees need a cold blow to break the dormancy of their buds (Perry 1971) and if the temperatures are not low enough, this break of dormancy is delayed. On the other hand, a higher precipitation prior to flowering is also causing a delay in the PSS. This could be due to the fact that on rainy days, the temperatures in winter are less cold and this would be delaying the dormancy, as previously were mentioned.

On the other hand, in the interior cities, an effect of the altitude has also been observed, so in the city of Granada, a greater effect of the climate was appreciated.

Finally, it has been observed that these trends could not be solely due to climate or to any specific component of climate change, and they could be dictated more by local changes due to human activity. For example, the adoption of gardening practices such as pruning before flowering can reduce flowering intensity, leading to lower airborne pollen concentrations than in other cities. In the same way, an increase in the number of individuals planted in parks and gardens steps up the pollen concentration in the air (Cariñanos and Casares-Porcel 2011; Velasco-Jiménez et al. 2014).

## 5 Conclusions

Pollen concentration of each city is a reflection of the ornamental and natural flora present in each one of them.

Generally, more clear trends have been observed in inland cities than in coastal one, where the sea exerts a mitigating effect on the climate. An effect of the altitude has also been observed, so at higher altitude, better trends have been observed.

A delay on flowering during the study period, especially for trees with a bloom closer to spring (poplar and elm), has been observed.

An increase in the temperature and precipitation in the months before flowering has been able to cause the increase in the pollen concentrations in many of the studied trees. However, this could also be the cause of the delay in the pollen season due to the fact that these trees need a cold blow to break the latency.

The trends observed could be also dictated by local changes due to human activity.

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