



# Impact of land cover changes and climate on the main airborne pollen types in Southern Spain



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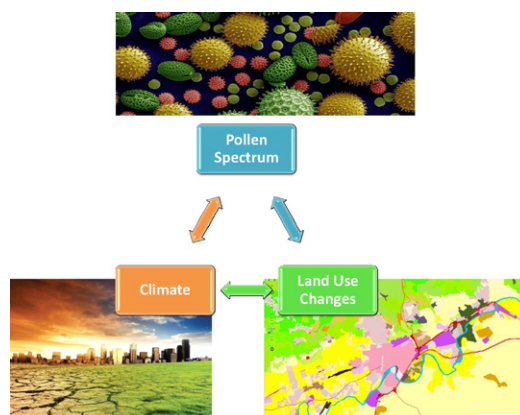
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## HIGHLIGHTS

- Usually airborne pollen changes are attributed only to climate and land cover changes are not taking into account.
- Pollen trends extracted by STL were compared with main changes on land use and climate.
- Changes in land uses and land cover may explain pollen spectrum variations through the years.
- Different increasing or decreasing trends depending on pollen taxa reflecting land cover and/or climate fluctuations

## GRAPHICAL ABSTRACT



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## ABSTRACT

Airborne pollen concentrations strongly correlate with flowering intensity of wind-pollinated species growing at and around monitoring sites. The pollen spectrum, and the variations in its composition and concentrations, is influenced by climatic features and by available nutritional resources but it is also determined by land use and its changes. The first factor influence is well known on aerobiological researches but the impact of land cover changes has been scarcely studied until now.

This paper reports on a study carried out in Southern Spain (Córdoba city) examining airborne pollen trends over a 15-year period and it explores the possible links both to changes in land use and to climate variations. The Seasonal-Trend Decomposition procedure based on Loess (STL) which decomposes long-term data series into smaller seasonal component patterns was applied. Trends were compared with recorded changes in land use at varying distances from the city in order to determine their possible influence on pollen-count variations. The influence of climate-related factors was determined by means of non-parametric correlation analysis.

The STL method proved highly effective for extracting trend components from pollen time series, because their features vary widely and can change quickly in a short term. Results revealed mixed trends depending on the taxa and reflecting fluctuations in land cover and/or climate. A significant rising trend in *Olea* pollen counts was observed, attributable both to the increasing olive-growing area but also to changes in temperature and rainfall. Poaceae pollen concentrations also increased, due largely to an expansion of heterogeneous agricultural areas

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and to an increase in pollen season length positively influenced by rainfall and temperature. By contrast, the significant declining trend observed for pollen from ruderal taxa, such as *Amaranthaceae*, *Rumex*, *Plantago* and *Urticaceae*, may be linked to changes in urban planning strategies with a higher building pressure.

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## 1. Introduction

Changes in land use and land cover are major components of global dynamic, directly prompting alterations in habitat composition, biodiversity and the functioning of the ecosystem (Foley et al., 2005; Turner et al., 2007). The impacts and consequences of such changes directly affect processes such as land degradation and biodiversity loss that modify environmental conditions (Figuerola and Sánchez-Cordero, 2008; Sánchez-Cuervo et al., 2012). Since airborne pollen detected at a given location correlate directly with local land uses, one indirect consequence of changes in the landscape is the alteration of airborne pollen concentrations (Oteros et al., 2015). Moreover pollen grains preserved in soil sediment provide a record of past vegetation and they are an important source of information about climate and land cover during the Quaternary Period (Davis, 2000; Seppä and Bennett, 2003).

Most of airborne pollen is emitted by wind-pollinated plants, and it is strongly modulated by their phenology and flowering intensity. Both the timing and the intensity of the pollen season obviously vary among taxa and regions, due to differences in vegetation, climate, biogeography and land use (Scheffinger et al., 2013). Although some aerobiological studies include land use as a descriptive variable (e.g. Haberle et al., 2014; Rojo et al., 2015) there has been no specific analysis of the influence of land-use changes on variations in airborne pollen counts, which are usually attributed to weather-related factors.

The present study was carried out in Córdoba, a medium-sized city in Andalusia (southern Spain) belonging to the Mediterranean region, which has a lower degree of landscape persistence and a higher anthropization rate than the temperate region, and is therefore highly vulnerable to the impact of land cover changes on natural habitats and

on the plant species growing in them (Martínez-Fernández et al., 2015). Plant physiology and phenology are also influenced by a number of biological factors, including pests, soil-related factors and age (Walther et al., 2002). Topography is responsible for micro-climate and micro-ecological conditions, and it is also a major factor driving phenology (Oteros et al., 2013a). However, the single factor most affecting phenology is the prevailing weather during the growing season, and more specifically temperature and water availability (Schwartz, 2013). Plant phenology is modulated by climate, and closely governed by air temperature for both herbaceous and arboreal species and water availability in the case of herbaceous plants, particularly in the Mediterranean Basin. Over recent years, southern Europe has witnessed an increase both in temperature and in rainfall intensity, especially in the Mediterranean climate area (IPCC, 2013). These changes are influencing the distribution areas of anemophilous species (Hamaoui-Laguel et al., 2015), and have a twofold effect on affecting pollen emission, influencing both pollen-season timing and pollination intensity (Ziello et al., 2012; Menzel et al., 2006; García-Mozo et al., 2010).

In wind-pollinated taxa airborne pollen concentrations are higher than in entomophilous ones and they are widely regarded as reliable indicators of flowering intensity and floral phenology (Menzel and Sparks, 2006). Although pollen production per flower is genetically determined in each species (Tormo et al., 1996; Prieto-Baena et al., 2003), atmospheric pollen concentration are obviously governed by the plant response to climate variables, but also by local land uses which determine the number of individuals of each species in a given area. Relatively few studies have focused on the impact of landscape management on airborne pollen, and these mainly address crop or ornamental species (Cariñanos and Casares-Porcel, 2011; Oteros et al., 2013b; Haberle et al., 2014).

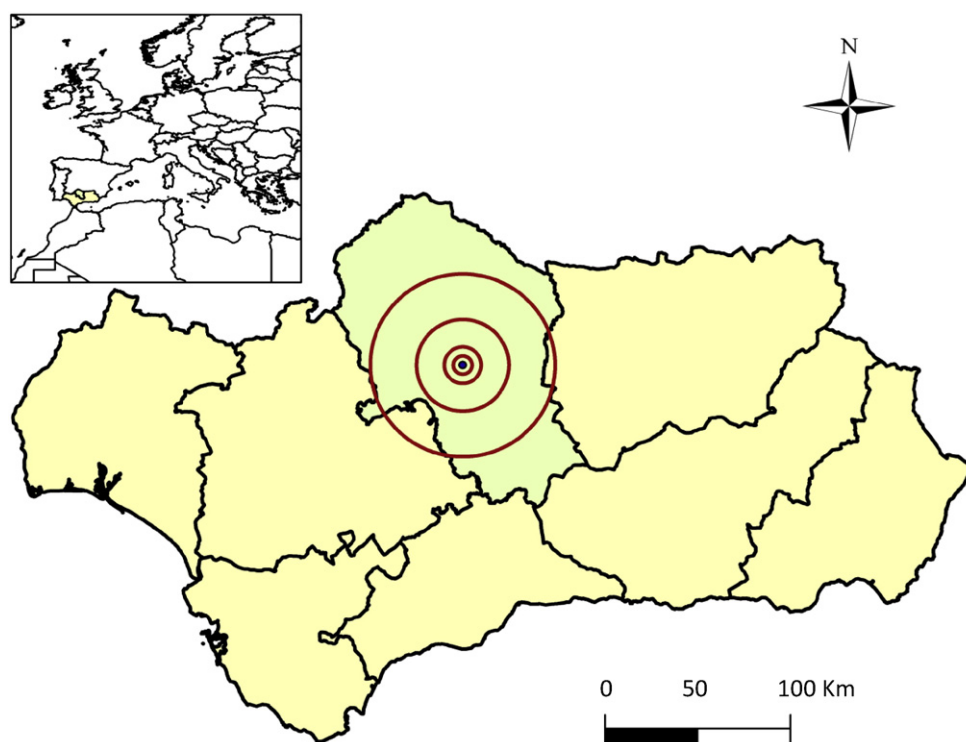


Fig. 1. Location of Córdoba city and range of land use analysis (outlined at 5 km, 10 km, 25 km and 50 km around pollen-trap location).

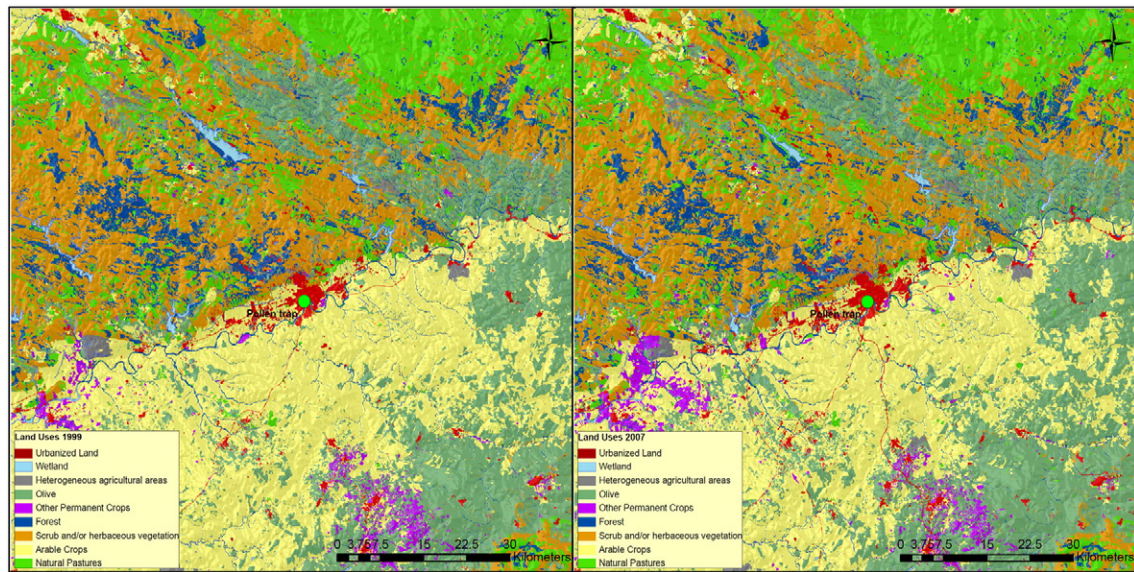


Fig. 2. Land use maps around Córdoba city at 1999 and 2007.

Research into pollen-concentration variations has traditionally focused on changes in weather patterns. The present study examined the potential joint influence of climate-related variables and changes in land use on fluctuations in airborne pollen concentrations in the city of Córdoba, southern Spain. Investigation of the role played by biogeography in regional and urban variations in pollen composition can potentially provide insights into how pollen production and dispersal may respond to changes in climate and urban and peri-urban land use. The influence of these variables and their implications for other fields such as allergy, ecology and agronomy, are also discussed.

## 2. Material and methods

### 2.1. Study area

Airborne pollen data for the period 1996–2010 were analyzed in the southern Spanish city of Córdoba (37°53'0"N 4°46'0"W), located at 120 m.a.s.l. (Fig. 1). The city has a Mediterranean climate with some continental features, characterized by marked year-on-year variations in weather patterns, with alternating wet and dry periods. Annual mean temperature is 17.8 °C and annual average rainfall is 621 mm. The city covers a surface area of 290.23 km<sup>2</sup>, and has 329,249

inhabitants, giving a population density of 1134.44 inhab./km<sup>2</sup>. It is remarkable that it is a historic city which receives around one million of tourists each year. The central urban area is heavily built up, though buildings do not exceed 30 m in height. Córdoba has several urban parks in which grasses and ornamental tree species (*Cupressaceae*, *Platanus*, *Ulmus*, *Ligustrum*, *Citrus*, *Acer*) predominate. Along the River Guadalquivir, which flows to the south of the city, vegetation comprises natural riverbank plants (*Populus*, *Alnus*, *Salix*, *Ulmus*), and ornamentals. Crops devote to olives (*Olea*), sunflowers (*Helianthus*) and cereals (cultivated *Poaceae*) are grown on the outskirts of the city (Velasco-Jiménez et al., 2014). Natural vegetation in the Sierra Morena Mountains to the north comprises mainly Mediterranean forest, in which oak species predominate.

### 2.2. Pollen data

Analysis of airborne pollen records over a 15-year period enabled variations in pollen concentrations to be charted and set against changes in land use and in weather patterns.

Airborne pollen was recorded using a Hirst-type volumetric spore trap (Hirst, 1952) placed on the roof of the Educational Sciences Faculty, at 15 m above ground level. Pollen data regarding the average daily

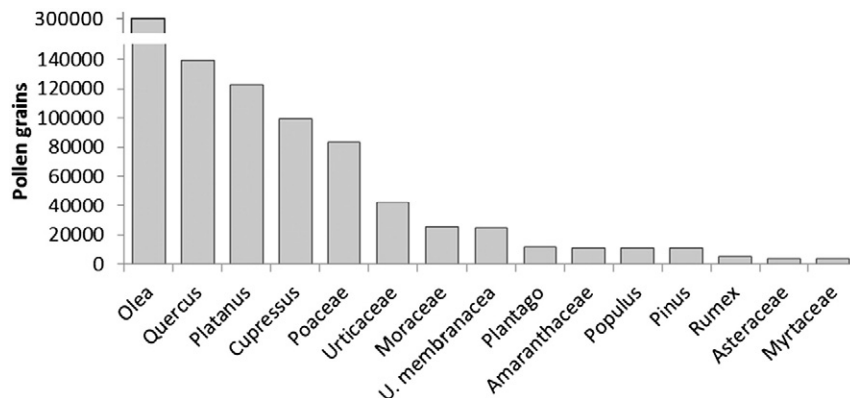


Fig. 3. Sum of daily concentrations (pollen grains/m<sup>3</sup>) of the main pollen types recorded in Córdoba city during the period (1996–2010).

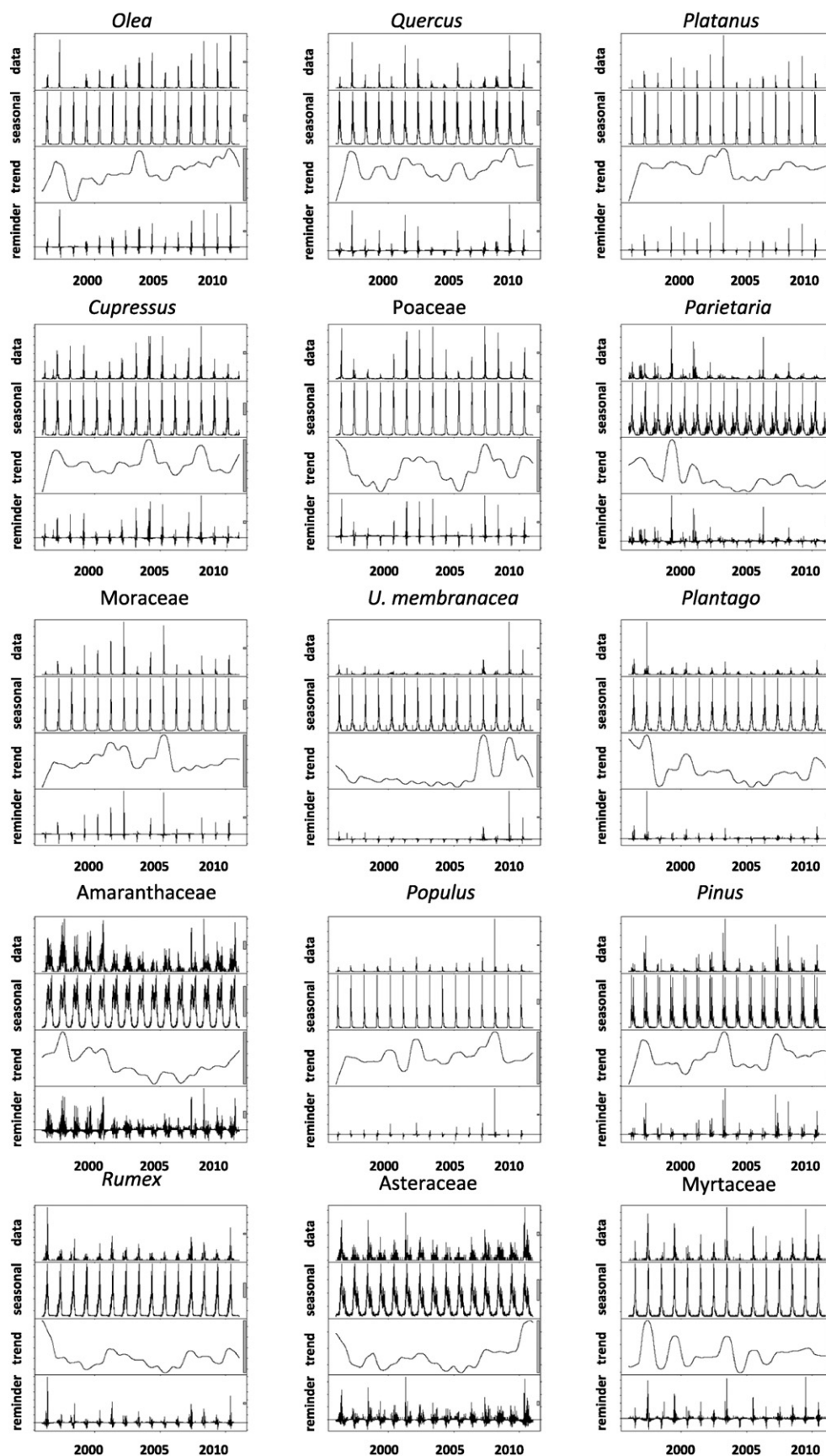


Fig. 4. Seasonal decomposition by Loess of daily airborne pollen data recorded during the study period (1996–2010) from the analyzed pollen types. Graphs show pollen data series, seasonal component, trend component and remainder component.

pollen concentration were obtained using a standard protocol published by the Spanish Aerobiology Network (REA), in accordance with the minimum recommendations of the European Aerobiology Society (Galán et al., 2007, 2014). Annual Pollen Index (API), which is the annual sum of the daily pollen concentrations monitored in the atmosphere for each pollen type, was also analyzed. Records for the study period 1996–2010 were examined for the following 15 pollen types: *Olea*, *Quercus*, *Platanus*, Cupressaceae, Poaceae, *Parietaria*, *Urtica membranacea*, *Morus*, *Plantago*, Amaranthaceae, *Populus*, *Pinus*, *Rumex*, Asteraceae and Myrtaceae. These taxa are regarded as key contributors to the local pollen spectrum because of their abundance, their allergenicity or their ecological/agricultural value.

### 2.3. Land use analysis

Changes in land use and land cover around the city were analyzed for different radius levels from the trap: 5000, 10,000, 25,000, and 50,000 m (Fig. 1). The geographical information were obtained from the results of the MUCVA project (1999; 2007) funded by the Andalusia Regional Government (Hurtado, 2013). MUCVA project was developed in base to the Corine European Land Cover project, but with information only for Andalusia region. Land uses categories were determined in accordance with data provided by the European CORINE (Coordination of Information on the Environment) Land Cover project (Heymann et al., 1994; Büttner et al., 2004, 2011). The available Andalusia land use information has a high detailed level due to the specific development taking into account the special features and the environmental data bases of the area. MUCVA provides GIS data in vectorial format with a spatial resolution of 1:25,000 (González-Fernández et al., 1997; Moreira-Madueño, 2007). These data enabled analysis of changes in land use recorded between 1999 and 2007 that are showed in Fig. 2.

### 2.4. Statistical analysis and meteorological data

The trend component was extracted from pollen time series using the Seasonal-Trend Decomposition procedure based on Loess (STL), a statistical technique which decomposes long-term data series into smaller seasonal component patterns (Verbesselt et al., 2010; Pomati et al., 2012; García-Mozo et al., 2014).

Airborne pollen trends can only be charted on the basis of daily data ranges. Time series for daily pollen counts were decomposed by STL into three components: seasonal, trend and remainder. A linear regression analysis was performed on the trend component in order to detect changes in daily pollen production over the long term. Deseasonalization

of variables enabled a better correlation for determining the actual influence of external variables on pollen counts.

The influence of weather-related factors on pollen concentrations was established by means of a Spearman correlation test, as was the impact of changes in land use around the city, with a view to obtaining an overview of the factors shaping airborne pollen concentrations over the long term.

Data for the following weather variables were analyzed: annual mean temperature (Mean T°), maximum temperature (Max T°), minimum temperature (Min T°) and rainfall (Rf), and quarterly data for the same variables (January–March; April–June; July–September). Correlations between weather-related variables and API were examined by non-parametric Spearman correlation tests, using SPSS Statistics® 20 software. Weather data were provided by the Cordoba weather station belonging to the Spanish Meteorological Agency (AEMET).

## 3. Results and discussion

The total sum of daily pollen counts for each pollen type over the period 1996–2010, is shown in Fig. 3. Although dependent on specific conditions, the pollen concentrations recorded at a specific site are known to represent emission sources up to 100 km away, thus providing a good indication of flowering phenology and intensity for the whole urban and peri-urban area (Fornaciari et al., 2000; Oteros et al., 2015).

By far the highest API was recorded for *Olea* pollen, followed by *Quercus*. Both pollens are from tree species located outside the city, olive groves to the south and *Quercus* in the Sierra Morena forest to the north of the city. The third and fourth largest PIs were recorded for *Platanus* and Cupressaceae, respectively; both are abundant in urban green areas. Among herbaceous taxa, high pollen counts were observed for Poaceae, which recorded the fifth highest API. Fairly high counts were also observed for the Urticaceae family, which includes species with the *Parietaria* pollen type as well as *Urtica membranacea* species which has a different pollen type.

Results regarding pollen-count trends over the study period, obtained by Seasonal-Trend decomposition by Loess (STL) analysis of daily local airborne pollen concentrations, are provided in Fig. 4, which shows pollen series, seasonal components, trend components and the remainder component. Different species displayed different trends. The main statistics resulting from STL linear trend component analysis for the fifteen main pollen types recorded in Córdoba between 1996 and 2010 are shown in Table 1. The statistics used were: Daily Change (DC) coefficient, defined as the difference between average daily pollen

**Table 1**

Linear trend analysis of trend components of the fifteen main pollen types recorded in Córdoba city during the period 1996–2010. The three last columns show daily change (average difference on daily amount of pollen detected between the start and the end of time series), daily corrected change (the average difference on daily amount of pollen detected between the start and the end of time series, with the assumption of airborne pollen of each species is mainly present during 2 months), annual change (average difference on annual pollen counts between the start and the end of time series).

|                       | R <sup>2</sup> | Slope     | p     | Daily change<br>(Pollen grains) | Daily corrected change<br>(Pollen grains) | Annual change<br>(Pollen grains) |
|-----------------------|----------------|-----------|-------|---------------------------------|-------------------------------------------|----------------------------------|
| Amaranthaceae         | 0.33           | −0.000367 | 0.000 | −2.01                           | −12                                       | −734                             |
| Asteraceae            | 0.12           | 0.000078  | 0.000 | 0.43                            | 3                                         | 157                              |
| Cupressaceae          | 0.00           | 0.000284  | 0.001 | 1.55                            | 9                                         | 567                              |
| <i>Morus</i>          | 0.00           | 0.000078  | 0.009 | 0.43                            | 3                                         | 157                              |
| Myrtaceae             | 0.00           | −0.000018 | 0.000 | −0.10                           | −1                                        | −35                              |
| <i>Olea</i>           | 0.42           | 0.009600  | 0.000 | 52.56                           | 320                                       | 19,184                           |
| <i>Pinus</i>          | 0.06           | 0.000174  | 0.000 | 0.95                            | 6                                         | 348                              |
| <i>Plantago</i>       | 0.21           | −0.000356 | 0.000 | −1.95                           | −12                                       | −712                             |
| <i>Platanus</i>       | 0.00           | 0.000027  | 0.790 | 0.15                            | 1                                         | 54                               |
| Poaceae               | 0.03           | 0.000779  | 0.000 | 4.27                            | 26                                        | 1558                             |
| <i>Populus</i>        | 0.11           | 0.000229  | 0.000 | 1.25                            | 8                                         | 458                              |
| <i>Quercus</i>        | 0.08           | 0.002653  | 0.000 | 14.53                           | 88                                        | 5302                             |
| <i>Rumex</i>          | 0.03           | −0.000050 | 0.000 | −0.27                           | −2                                        | −100                             |
| <i>U. membranacea</i> | 0.28           | 0.001517  | 0.000 | 8.30                            | 51                                        | 3031                             |
| <i>Parietaria</i>     | 0.38           | −0.002078 | 0.000 | −11.38                          | −69                                       | −4152                            |

counts during the latter years of the data series and those recorded during earlier years; Daily Corrected Change (DCC), defined as the DC coefficient assuming that the main airborne pollen season for all studied pollen types is on average two months; and finally, the Yearly Change (YC) defined as differences in the average API between earlier and later years of the data series. The STL method proved highly effective for extracting trend components from ecological time series, because environmental features vary widely and can change quickly in the short term. It is well known the advantages of Loess method when we are modeling complex time series with variable trend values. But Loess method is also very sensitive to outliers' presence (Cleveland, 1979). Loess method is appropriate for focusing pollen production because this is a continuous process along the time with low prevalence of outliers respecting to the huge amount of data. It has been already proved to be an effective technique for analyzing changes in daily pollen production over the long term (García-Mozo et al., 2014; Aguilera et al., 2015).

Landscape changes taking place in the area surrounding the city over the study period are shown in Table 2. In Table 2a it is possible to observe the changes on land use and land cover expressed in total surfaces and percentages, and in Table 2b the description of the land use categories analyzed is indicated. The data show a clear increase is apparent in the urbanized land area at the expense of forest areas, natural pastures or natural wetlands. Cropland has become considerably more heterogeneous: a greater area is now devoted to olives, whereas the area given over to arable crops (mostly cereals and sunflowers) has diminished.

Results of the correlation analysis performed to detect the possible influence of weather variables on flowering intensity as expressed by the PI are shown in Table 3. Significant correlations were observed for several taxa. A clear positive correlation was recorded between rainfall during the months prior to flowering and pollen concentrations for *Olea*, and more particularly for herbaceous taxa such as Poaceae, *Plantago*, *Rumex* and *Asteraceae*. Temperature displayed a less marked, though there is still a significant negative correlation with *Olea* and *Parietaria* pollen concentrations. It should be noted that the earliest and latest years of the study were the wettest in their respective North Atlantic Oscillation (NAO)-linked micro-climatic cycles; these cycles repeat, though with irregular periodicity, in the Iberian Mediterranean region (Barnston and Livezey, 1987; Chen and van den Dool, 2003).

Analysis of pollen trends in conjunction with weather variations and changes in land use yielded various striking results. A significant rising trend in *Olea* pollen concentrations was observed. This pollen type includes pollen from both cultivated and natural olives, although the presence of these last ones is so scarce, so our results could be attributable both to the increasing area given over to olive-growing in recent years but also to changes in temperature and rainfall prior to olive flowering. By contrast, the significant declining trend observed for airborne pollen from ruderal species and other taxa associated with marked anthropogenic activity, such as *Amaranthaceae*, *Rumex*, *Plantago* and *Urticaceae* (except *U. membranacea*), may be linked to recent changes in urban planning strategies, involving an increase in the surface area of urbanized land and a reduction of urban wastelands in the last years of the study. Poaceae pollen concentrations displayed a rising trend favored by increased rainfall prior to the flowering season which influenced on the increase of the number of days with high grass pollen counts and therefore the extension of the pollen-season length.

*U. membranacea* is a nitrophilous species, and the positive trend in pollen concentrations may be linked to the expansion both of heterogeneous agricultural areas and of olive groves on the outskirts of the city. Rising trends observed for pollen concentrations of ornamental species such as *Platanus*, *Cupressaceae*, *Myrtus* or *Morus* are clearly linked to an increase in the amount of urbanized land in the vicinity of the pollen trap.

The ecological impact both of human activity and of recent climate change has been widely documented (Laliberté and Tylanakis, 2012;

**Table 2**

a. Changes in land uses around pollen trap location. Range indicates the radius of circular surface analyzed around pollen trap. Source: Data of the Corine Land Cover project for Andalucía Region (<http://www.juntadeandalucia.es/medioambiente>). b Description of the land use categories analyzed. Source: Corine Land Cover Nomenclature European Commission 1993.

| Land use                                                                                  | Range<br>(Km) | 1999<br>Surface<br>(ha) | 2007<br>Surface<br>(ha) | Change                |                   |
|-------------------------------------------------------------------------------------------|---------------|-------------------------|-------------------------|-----------------------|-------------------|
|                                                                                           |               |                         |                         | Surface<br>(ha)       | Percentage<br>(%) |
| Urbanized land                                                                            | 5             | 3043                    | 3402                    | 358                   | 11.8              |
|                                                                                           | 10            | 5059                    | 5957                    | 897                   | 17.7              |
|                                                                                           | 25            | 7610                    | 9461                    | 1851                  | 24.3              |
|                                                                                           | 50            | 14,085                  | 18,751                  | 4666                  | 33.1              |
| Wetlands                                                                                  | 5             | 349                     | 367                     | 18                    | 5.2               |
|                                                                                           | 10            | 1146                    | 1166                    | 21                    | 1.8               |
|                                                                                           | 25            | 7312                    | 7479                    | 168                   | 2.3               |
|                                                                                           | 50            | 22,892                  | 22,354                  | − 538                 | − 2.4             |
| Arable crops                                                                              | 5             | 2917                    | 1767                    | − 1150                | − 39.4            |
|                                                                                           | 10            | 13,859                  | 8947                    | − 4912                | − 35.4            |
|                                                                                           | 25            | 79,395                  | 49,412                  | − 29,983              | − 37.8            |
|                                                                                           | 50            | 239,486                 | 156,901                 | − 82,586              | − 34.5            |
| Forest                                                                                    | 5             | 102                     | 53                      | − 50                  | − 48.7            |
|                                                                                           | 10            | 1822                    | 1684                    | − 138                 | − 7.6             |
|                                                                                           | 25            | 12,175                  | 11,707                  | − 469                 | − 3.9             |
|                                                                                           | 50            | 42,267                  | 40,519                  | − 1749                | − 4.1             |
| Heterogeneous<br>agricultural areas                                                       | 5             | 369                     | 1224                    | 856                   | 232.2             |
|                                                                                           | 10            | 1906                    | 6401                    | 4495                  | 235.8             |
|                                                                                           | 25            | 15,430                  | 39,682                  | 24,252                | 157.2             |
|                                                                                           | 50            | 36,595                  | 90,297                  | 53,702                | 146.7             |
| Natural pastures                                                                          | 5             | 707                     | 635                     | − 73                  | − 10.2            |
|                                                                                           | 10            | 3215                    | 3124                    | − 91                  | − 2.8             |
|                                                                                           | 25            | 24,778                  | 24,019                  | − 759                 | − 3.1             |
|                                                                                           | 50            | 112,292                 | 112,931                 | 639                   | 0.6               |
| Olive groves                                                                              | 5             | 137                     | 155                     | 18                    | 13.0              |
|                                                                                           | 10            | 734                     | 891                     | 157                   | 21.4              |
|                                                                                           | 25            | 12,898                  | 16,917                  | 4019                  | 31.2              |
|                                                                                           | 50            | 174,630                 | 194,960                 | 20,330                | 11.6              |
| Other permanent crops                                                                     | 5             | 55                      | 39                      | − 16                  | − 29.3            |
|                                                                                           | 10            | 590                     | 129                     | − 461                 | − 78.1            |
|                                                                                           | 25            | 731                     | 905                     | 174                   | 23.8              |
|                                                                                           | 50            | 11,618                  | 15,828                  | 4210                  | 36.2              |
| Scrub and/or herbaceous<br>vegetation associations                                        | 5             | 172                     | 211                     | 39                    | 22.5              |
|                                                                                           | 10            | 3080                    | 3112                    | 33                    | 1.1               |
|                                                                                           | 25            | 35,990                  | 36,739                  | 748                   | 2.1               |
|                                                                                           | 50            | 131,432                 | 132,757                 | 1325                  | 1.0               |
| Original variable MUCVA 25                                                                |               |                         |                         | Clustered variable    |                   |
| Road Infrastructures                                                                      |               |                         |                         | Urbanized land        |                   |
| Urbanizations                                                                             |               |                         |                         |                       |                   |
| Urban areas                                                                               |               |                         |                         |                       |                   |
| Industrial and commercial areas                                                           |               |                         |                         |                       |                   |
| Continental wetlands and water surfaces                                                   |               |                         |                         | Wetland               |                   |
| Annual crops associated with permanent crops                                              |               |                         |                         | Heterogeneous         |                   |
| Complex cultivation patterns                                                              |               |                         |                         | agricultural areas    |                   |
| Land principally occupied by agriculture, with<br>significant areas of natural vegetation |               |                         |                         |                       |                   |
| Agro-forestry areas                                                                       |               |                         |                         |                       |                   |
| Unirrigated olive groves                                                                  |               |                         |                         | Olive                 |                   |
| Irrigated olive groves                                                                    |               |                         |                         |                       |                   |
| Vineyards                                                                                 |               |                         |                         | Other permanent crops |                   |
| Fruit trees and berry plantations                                                         |               |                         |                         |                       |                   |
| Broad-leaved forest                                                                       |               |                         |                         | Forest                |                   |
| Coniferous forest                                                                         |               |                         |                         |                       |                   |
| Mixed forest                                                                              |               |                         |                         |                       |                   |
| Moors and heathland                                                                       |               |                         |                         | Scrub and/or          |                   |
| Sclerophyllous vegetation                                                                 |               |                         |                         | herbaceous vegetation |                   |
| Transitional woodland-shrub                                                               |               |                         |                         | associations          |                   |
| Unirrigated arable crop                                                                   |               |                         |                         | Arable crops          |                   |
| Irrigated arable crop                                                                     |               |                         |                         |                       |                   |
| Natural pastures                                                                          |               |                         |                         | Natural pastures      |                   |
| Pasture with woodland (Dehesa)                                                            |               |                         |                         |                       |                   |

Walther et al., 2002). There is considerable concern that the functioning of ecosystems will be affected by human-induced changes in biodiversity, of which land-use change is the one of the most important drivers. However, changes in biodiversity may be only one of many pathways

**Table 3**

Results from the Spearman Correlation analysis performed between meteorological and Pollen Index data during 1996–2010. Significant probability results are indicated in bold letter.

| Pollen type        | Annual data   |                |              |               | January–March |               |              |               | April–June |        |        |       | July–September |               |                |               |
|--------------------|---------------|----------------|--------------|---------------|---------------|---------------|--------------|---------------|------------|--------|--------|-------|----------------|---------------|----------------|---------------|
|                    | Mean T°       | Max T°         | Min T°       | Rf            | Mean T°       | Max T°        | Min T°       | Rf            | Mean T°    | Max T° | Min T° | Rf    | Mean T°        | Max T°        | Min T°         | Rf            |
| <i>Olea</i>        | <b>.504*</b>  | .029           | <b>.543*</b> | <b>.582*</b>  | -.221         | .157          | -.043        | <b>.529*</b>  | .093       | .146   | .182   | -.193 | .250           | .429          | .407           | .179          |
| <i>Quercus</i>     | .271          | .061           | 0.000        | .182          | .325          | .146          | .221         | .054          | .168       | -.221  | .168   | -.154 | -.307          | -.111         | -.214          | -.086         |
| <i>Platanus</i>    | -.007         | -.043          | -.029        | .014          | .529*         | -.021         | .250         | -.132         | -.104      | -.154  | -.175  | -.071 | -.011          | -.004         | -.114          | .096          |
| Cupressaceae       | <b>-.461*</b> | -.079          | -.361        | -.354         | .411          | -.068         | .136         | -.350         | -.175      | .054   | -.204  | .289  | -.296          | -.189         | -.279          | .018          |
| Poaceae            | .043          | -.404          | .439         | <b>.614**</b> | -.246         | .364          | .289         | <b>.514*</b>  | -.229      | -.157  | -.229  | .286  | -.218          | -.114         | -.104          | .325          |
| <i>Parietaria</i>  | -.368         | -.375          | -.025        | .136          | .432          | .075          | .343         | -.146         | -.029      | -.096  | -.025  | .314  | <b>-.639*</b>  | <b>-.582*</b> | <b>-.736**</b> | .511          |
| <i>Morus</i>       | -.132         | -.104          | -.350        | -.075         | .182          | -.021         | .007         | -.175         | .054       | -.407  | -.100  | -.082 | -.089          | -.368         | -.243          | <b>-.518*</b> |
| <i>Urtica</i>      | .057          | .007           | .071         | .182          | .079          | .150          | .214         | .054          | -.332      | -.179  | -.318  | .396  | -.057          | .236          | .132           | .207          |
| <i>membranacea</i> |               |                |              |               |               |               |              |               |            |        |        |       |                |               |                |               |
| <i>Plantago</i>    | -.171         | <b>-.525*</b>  | .286         | <b>.568*</b>  | .175          | .136          | .193         | .250          | -.189      | .046   | -.114  | .271  | -.271          | -.386         | -.421          | .321          |
| Amaranthaceae      | -.214         | -.432          | .046         | .261          | .389          | .193          | .250         | .007          | -.132      | -.061  | -.121  | .189  | -.436          | -.336         | <b>-.518*</b>  | .282          |
| <i>Populus</i>     | -.086         | .282           | -.307        | -.264         | .400          | -.418         | .093         | <b>-.557*</b> | -.125      | .082   | -.186  | .414  | .104           | -.057         | .007           | .143          |
| <i>Pinus</i>       | .232          | -.225          | .343         | .329          | .164          | .354          | .364         | .350          | -.261      | .021   | -.189  | .075  | -.150          | .193          | .011           | .175          |
| <i>Rumex</i>       | -.064         | <b>-.668**</b> | .436         | <b>.661**</b> | -.093         | <b>.675**</b> | <b>.518*</b> | <b>.611*</b>  | -.386      | -.304  | -.393  | .357  | -.432          | -.207         | -.311          | .271          |
| Asteraceae         | -.050         | -.357          | .234         | <b>.483*</b>  | -.052         | .441          | .366         | .374          | -.345      | -.356  | -.422  | .349  | -.232          | .025          | -.068          | .241          |
| Myrtaceae          | .275          | .193           | .086         | .139          | .089          | -.279         | -.221        | .007          | .411       | .386   | .486   | -.339 | .025           | .107          | .032           | .114          |

\* Significant at 95%.

\*\* Significant at 99%.

via which land use alters ecosystem functioning (Laliberté and Tylianakis, 2012). Its importance relative to other characteristics remains unclear, particularly with regard to the impact of changing land-use on plant phenology and in particular, on flowering intensity, due to the paucity of research on this issue (Haberle et al., 2014). Changing land use may well influence both the severity and timing of the airborne pollen season in wind-pollinated species. Moreover, atmospheric pollen analysis could be a good complement to modern sediment pollen samples as invaluable research tools improving investigation of the relationship between pollen production and the environmental parameters such as vegetation, land-use, and climate that the pollen proxy represents (Davis et al., 2013).

The expansion of urbanized areas in Mediterranean countries has prompted a sharp increase in the incidence of pollen allergies, particularly in densely-populated cities. In seeking to meet the esthetic and recreational needs of inhabitants and visitors, the management of urban green areas often fails to take into account the allergenicity of the ornamental plants introduced (Cariñanos and Casares-Porcel, 2011; Velasco-Jiménez et al., 2014). Moreover, the increase in certain kinds of croplands and the abandoning of others due to specific economic policies also influences plant biodiversity and pollen emission (García-Mozo, 2011). Changes in land use on urban boundaries may also have an impact on pollen source areas. The source area for pollen in a more built up area or closed forests is quite different from an open area. It is also important to take into account not only fluctuations in crop areas but also increased use of agricultural inputs (e.g. fertilizers, irrigation) and harvest pressure, which drive changes in plant phenology (García-Mozo, 2011).

Possible triggers of the changes recorded over the study period include the increase in pollen from highly-allergenic taxa such as *Olea*, Cupressaceae and Poaceae, considered the principal cause of pollinosis in southern Europe (D'Amato et al., 2007). Research into airborne pollen trends has hitherto focused mainly on the influence of climate change. Overall warming is clearly influencing phenology, especially flowering time (i.e. Menzel et al., 2006), and a number of studies highlight possible links between the increase in airborne pollen concentrations and both climate change and the increased atmospheric CO<sub>2</sub> (Ziello et al., 2012). However, pollen trends should be examined not only in terms of the potential impact of climate change but also taking into account the effect of changes in land use. Finally it would be necessary to remind the limitations of remote sensed datasets and to point out that those data coupled with direct observation allows recent changes in vegetation to be better investigated (Pérez-Hoyos et al., 2012; Woodbridge et al., 2014).

The present study may serve as a pilot study in this respect, in that it examines both factors with a view to showing how the effect of climate

on plant phenological response can be strengthened or mitigated by the impact of human activity on plant distribution through changes in land use. This interaction is likely to affect public health, agriculture and even the functioning of the ecosystem. Moreover, in order to extend our understanding of land-cover change further back in time, different proxies for vegetation, such as airborne pollen would be a valuable tool for a better interpretation of sedimentary pollen data.

#### 4. Conclusions

Results obtained from the Seasonal-Trend Decomposition analysis revealed mixed trends of Annual Pollen Indexes depending on taxa.

Pollen spectrum variations, traditionally attributed to climate features, may be also influenced by land use and by changes in land cover.

Some allergenic pollen types, as *Olea* or Poaceae recorded significant increases reflecting fluctuations in land cover and climate.

Different behavior was observed for other species including ruderal species, as those included in the Amaranthaceae, *Rumex*, *Plantago* and Urticaceae taxa, their airborne pollen decrease could be related to the reduction of their land cover surfaces around in the city by a high building pressure.

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