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

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HIGHLIGHTS

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

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ABSTRACT

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

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

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

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

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

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

1. Introduction

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

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

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

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

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

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

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

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

2. Material & methods

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

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

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

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