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

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ABSTRACT

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

1. Introduction

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

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

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

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

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

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

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

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

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

2. Materials and methods

2.1. Study area

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

2.2. Phenological and meteorological data

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

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

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

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

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

2.3. Long-term trends analysis

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

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