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Spatiotemporal analysis of olive flowering using geostatistical techniques

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HIGHLIGHTS

- A geostatistical analysis of olive flowering was performed.
- The results of geostatistical models were shown in olive tree phenological maps.
- We compared flowering intensity in the maps with airborne pollen counts.
- We used back trajectory models to determine remote sources of olive pollen.

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ABSTRACT

Analysis of flowering patterns in the olive (*Olea europaea* L.) are of considerable agricultural and ecological interest, and also provide valuable information for allergy-sufferers, enabling identification of the major sources of airborne pollen at any given moment by interpreting the aerobiological data recorded in pollen traps. The present spatiotemporal analysis of olive flowering in central Spain combined geostatistical techniques with the application of a Geographic Information Systems, and compared results for flowering intensity with airborne pollen records. The results were used to obtain continuous phenological maps which determined the pattern of the succession of the olive flowering.

The results show also that, although the highest airborne olive-pollen counts were recorded during the greatest flowering intensity of the groves closest to the pollen trap, the counts recorded at the start of the pollen season were not linked to local olive groves, which had not yet begin to flower. To detect the remote sources of olive pollen several episodes of pollen recorded before the local flowering season were analysed using a HYSPLIT trajectory model and the findings showed that western, southern and southwestern winds transported pollen grains into the study area from earlier-flowering groves located outside the territory.

1. Introduction

Flowering phenology is influenced by environmental changes (Menzel et al., 2006; Sparks et al., 2000) and by differences in geographical gradients, e.g. latitude, longitude, elevation, slope and topographical orientation (Dai et al., 2014; Pellerin et al., 2012). A number of papers have highlighted the influence of geographical factors such as elevation on olive flowering patterns (Oteros et al., 2013; Rojo and Pérez-Badia, 2014), noting in particular a correlation between flowering onset date and elevation gradient: flowering can thus be regarded as a continuous environmental variable which can be modelled spatially as a function of geographical aspects such as elevation.

The use of geostatistical techniques in conjunction with Geographic Information Systems (GIS) enables the spatial analysis of environmental variables whose distribution in the study area is continuous (Oliver and Webster, 2014). Kriging is an interpolation procedure widely used to analyse the spatial behaviour for a given variable in many of the natural sciences, including geology (Mendes and Ribeiro, 2010; Pérez-Rodríguez et al., 2007), zoology (Lin et al., 2011), botany (Fortin et al., 1989), ecology (Robertson, 1987), and climatology (Bajat et al., 2013). Over the last few years, a number of papers have addressed the use of geostatistical techniques coupled with GIS in phenological and aerobiological researches (e.g. Alba et al., 2006; Schröder et al., 2006).

Analysis of the phenology of wind-pollinated plants is a valuable tool for interpreting aerobiological findings (Hidalgo et al., 2003), and numerous studies have reported relationships between the temporal succession of phenological phases and airborne pollen count data derived from pollen-trap records (Fornaciari et al., 2000; Tormo et al., 2011). Moreover, knowledge of local variations in phenology patterns

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Table 1
Geographical characteristics of the sampling sites.

N	Site	Code	X UTM	Y UTM	Elevation (m a.s.l.)	Studied years
1	La Puebla de Montalbán	1LPue	382,943	4,411,251	440	2010–2013
2	Toledo	2To	415,808	4,412,711	470	2010–2013
3	Algodor	3Alg	423,119	4,416,329	482	2013
4	Burujón	4Buru	387,437	4,414,795	496	2013
5	Recas	5Rec	421,121	4,432,562	560	2013
6	Olías del Rey	6Oli	414,984	4,422,076	590	2010–2013
7	San Martín de Montalbán	7SMar	381,562	4,394,399	658	2013
8	Nambroca	8Nam	419,846	4,405,134	680	2013
9	Burguillos	9Bu	415,895	4,405,941	686	2010–2013
10	Mazarambroz	10Maz	409,643	4,393,526	730	2010–2013
11	Gálvez	11Gal	393,215	4,393,622	735	2013
12	Mascaraque	12Mas	429,795	4,391,837	748	2010–2013
13	Cuerva	13Cuer	402,970	4,392,225	760	2013
14	Manzaneque	14Manz	431,628	4,384,802	789	2013
15	Navahermosa	15Nava	370,089	4,388,000	790	2013
16	Los Yébenes	16LYeb	427,653	4,383,483	875	2010–2013

is of value for identifying the major sources of airborne pollen (Estrella et al., 2006; León et al., 2012). Research into spatiotemporal aspects of flowering phenology has to date been sparse, and few published studies have addressed this issue (García-Mozo et al., 2006).

The pollen-release patterns in a local scale are largely governed by climate-related factors, and temperature and relative humidity are among the most important meteorological variables (García-Mozo et al., 2014; Hernández-Ceballos et al., 2011). However, when pollen grains are as small as those from the olive tree (Nilsson, 1988), certain amounts of pollen may be transported from very long distances (Fernández-Rodríguez et al., 2014). The identification of pollen sources at great distances required to apply atmospheric transport models that take into account the movement of air masses at a mesoscale level.

There has been considerable research into olive phenology and aerobiology, since this is a major cash crop throughout the Mediterranean region, which accounts for 98% of the world's olive groves. Spain is the

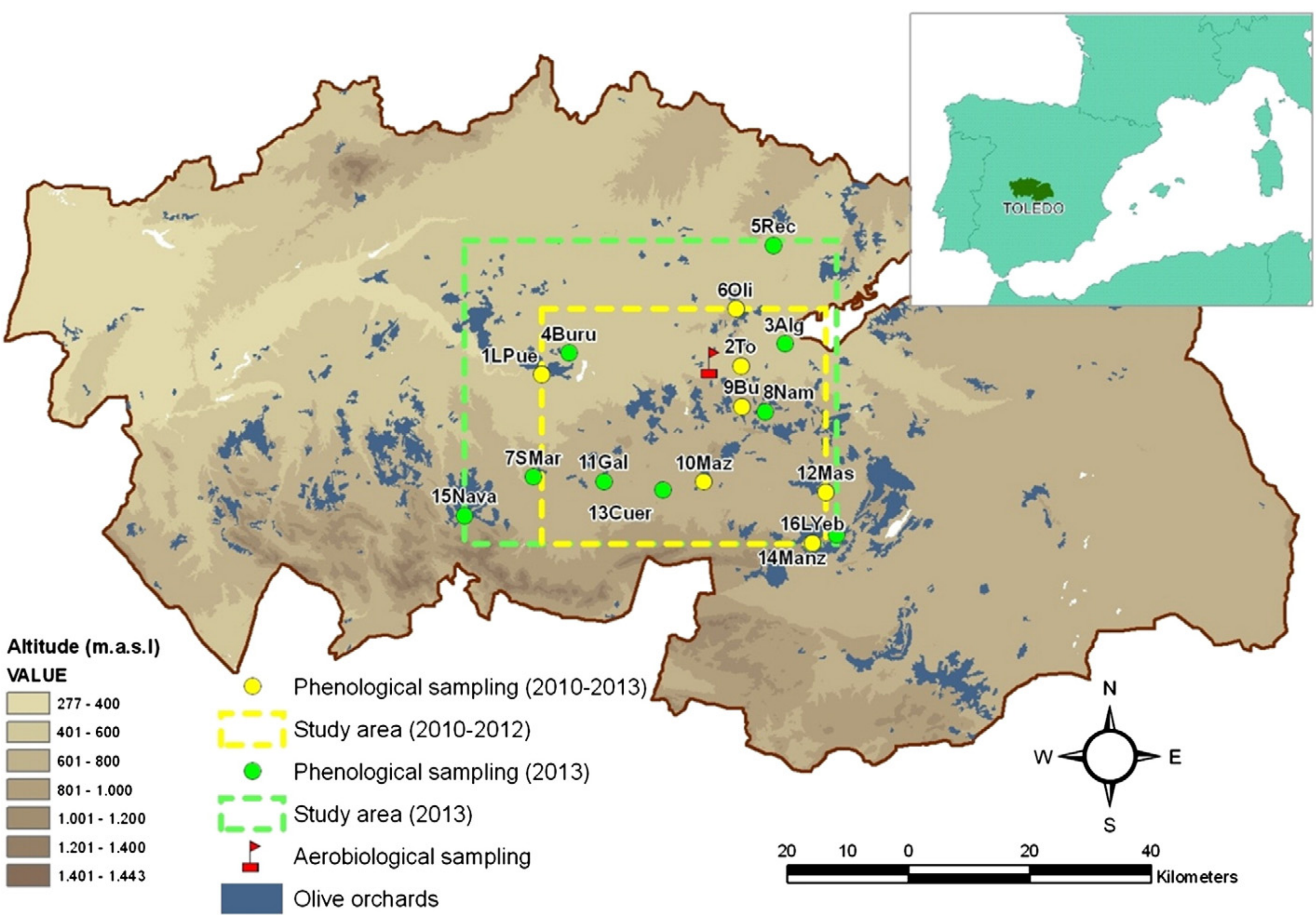

Fig. 1. Location of sampling sites and study area. Olive-crop map produced by the Corine Land Cover 2006 project © National Geographic Institute of Spain.