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Concentric Ring Method for generating pollen maps. *Quercus* as case study

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Mapping pollen concentrations is of great interest to study the health impact and ecological implications or for forestry or agronomical purposes. A deep knowledge about factors affecting airborne pollen is essential for predicting and understanding its dynamics. The present work sought to predict annual *Quercus* pollen over the Castilla and León region (Central and Northern Spain). Also to understand the relationship between airborne pollen and landscape. Records of *Quercus* and *Quercus pyrenaica* pollen types were collected at 13 monitoring sites over a period of 8 years. They were analyzed together with land use data applying the Concentric Ring Method (CRM), a technique that we developed to study the relationship between airborne particle concentrations and emission sources in the region.
The maximum correlation between the *Quercus* pollen and forms of vegetation was determined by shrubland and "dehesa" areas. For the specific *Qi pyrenaica* model (*Q. pyrenaica* pollen and *Q. pyrenaica* forest distribution), the maximum influence of emission sources on airborne pollen was observed at 14 km from the pollen trap location with some positive correlations up to a distance of 43 km. Apart from meteorological behavior, the local features of the region can explain pollen dispersion patterns. The method that we develop here proved to be a powerful tool for multi-source pollen mapping based on land use.

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1. Introduction

Many plant species release airborne pollen grains into the atmosphere as a mechanism of genetic transmission during sexual reproduction. Pollen dispersion and transport in the atmosphere are directly linked to meteorological factors, mainly temperature, solar radiation, precipitation and wind, but also to plant physiology involving other environmental factors such as soil type or the pathogenic response (Sofiev et al., 2013a,b). Airborne pollen concentrations depend on both local flora and atmospheric transport. The study of airborne pollen transport provides information on pollen concentration variations for the purpose of accurate forecasting (Damialis et al., 2007; Prank et al., 2013).

Aerobiological studies have shown that pollen grains can be transported over long distances up to 1000 km and at different atmospheric heights (Giostra et al., 1991; Hernández-Ceballos et al., 2015; Mandrioli et al., 1984; Schueler and Schlünzen, 2006; Sofiev et al., 2006; Tampieri et al., 1977). Pollen grains have been observed in both the atmospheric boundary and free troposphere layers (Noh et al., 2013). Therefore, the study of the transport of organic and inorganic particles is based on daily mean analysis.

This pollen dispersion or transport is directly related to the forest conformation and the distance from the sampling station (Pauling et al., 2012; Skjøth et al., 2008; Sofiev et al., 2013a,b). Although the study of pollen dispersion and transport also involves the distribution of plant producers and their changes in space and time, very few studies have focused on the sources of airborne pollen emission (Garcia-Mozo et al., 2016; Haberle et al., 2014; Rojo and Perez-Badia, 2015). The production of pollen maps from this information is especially interesting for the general public, especially for species with impacts on human health, for gene flow, species distribution, for species used as ecological indicators or for species with forestry or agronomical interest (Aguilera et al., 2015; Orlandi et al., 2013).

Although anemophilous species account for the minority of vascular plants, they have a huge number of individuals in arboreal, shrubs and herbaceous taxa (that is most Gymnosperms, or some Angiosperms families, e.g. *Poaceae*, *Oleaceae*, *Fagaceae*, etc.). They occupy large land areas in different ecosystems all over the northern hemisphere. The potential vegetation in the Iberian Peninsula is mainly formed by plant communities where the dominant taxa are *Quercus* genus, including deciduous, evergreen and marcescent species (Rivas-Martínez et al., 2011a, 2011b).

The *Quercus* genus in the Castilla and Leon region comprises 9 tree species and many hybrid taxa commonly known as oaks and holm oaks (cork-oaks, gall-oaks, etc.). These species are distributed throughout the region, the most abundant being *Q. pyrenaica* Willd. and *Q. rotundifolia* Lam. Both species belong to plant communities considered natural and seminatural habitats in the Habitats Directive (Council Directive 92/43/CEE) on the conservation of natural habitats and wild fauna and flora. All are anemophilous trees or shrubs producing high quantities of pollen grains dispersed through the air (Galán et al., 2016). The abundance of these species and their environmental impact emphasize the need for *Quercus* airborne pollen studies. *Quercus* pollen is considered moderately allergenic (Darrow et al., 2012; Prados et al., 1995; Ross et al., 1996), but it cross-reacts with allergens from other species (Fernández-González et al., 2010; Weber, 2007), thereby exacerbating the allergic response currently increasing in some patients due to climate change and the interaction with other aerosols (D'Amato et al., 2014; D'Amato et al., 2015).

This study relies on the assumption that can be generated accurate pollen maps from experimental models by knowing the specific sources of pollen emission. We used the "concentric ring method" (CRM) devised by Oteros et al. (2015) to determine the relationship between olive pollen and the distance from the emission source (Oteros et al., 2015). The main aim of the study was to adapt the CRM using only land use information to produce accurate pollen maps of *Quercus* in the region of Castilla and León.

2. Material and methods

2.1. Study area

The study was performed in Castilla and León, and inland region located in the central-northwestern part of the Iberian Peninsula (Fig. 1a). The region covers an area of 94,222 km^2, almost a fifth of the national territory, making it the largest region in Spain. The northern areas of the region are part of the Euro-Siberian biogeographical region, whereas the remaining territory belongs to the Mediterranean region (Rivas-Martínez et al., 2014).

The whole region consists of a central plateau around 750 m·a.s.l. although some mountains are higher than 2000 m. It is enclosed by

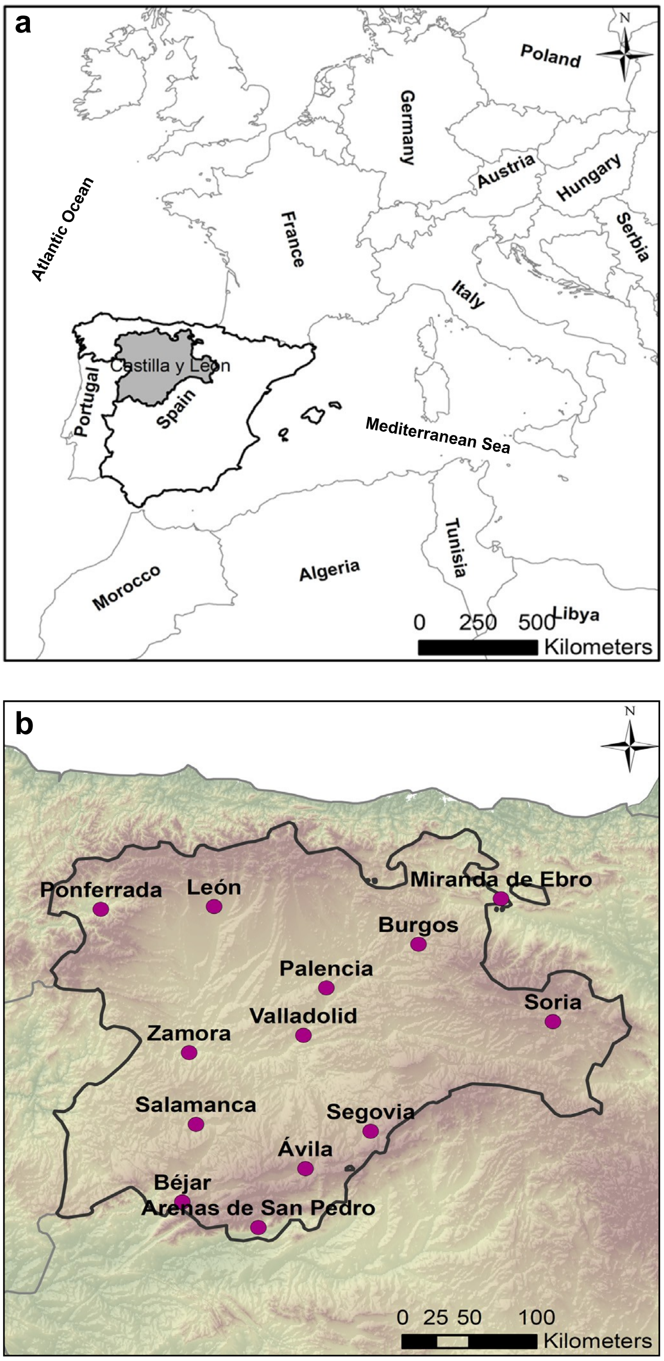

Fig. 1. Castilla and León location. a. Castilla and León position in the northwestern Iberian Peninsula. b. Aerobiological monitoring sites of the Castilla and León Pollen Network.

mountain chains to the North (the Cantabrian Range, with Torrecerredo as the highest altitude 2648 m), the Galician Range (Teleno 2188 m) to the Norhwest, to the East (the Iberian Range, Moncayo 2313 m) and to the South (Central Range, Almanzor 2592 m).

This special orographic condition gives Castilla and León specific climatic features protecting the whole region from the impact of foreign atmospheric events and maritime influences. The mountain ranges act as a barrier to maritime influences, giving most of the region a continental climate with long cold winters and hot summers. The mean annual temperature in Castilla and León is about 11 °C with a strong gradient from the north and east to the south and west. The average mean temperature is 5 °C during winter months and 20 °C in summer. Mean maximum and minimum temperatures are about 8.5 and − 0.5 °C respectively in winter and about 27 and 7.5 °C in summer. January is the coldest month in the year (3 °C average) and august is the month with the highest values (with records higher than 20 °C).

About precipitation is concerned, the area under study is limited by 1000 mm isohyets to the North, 500 mm to the West and 800 mm to the East and South according to annual records, although on the higher mountain peaks rainfall can reach 2000 mm. The average annual rainfall is between 450 mm and 1600 mm. Winter is the rainiest season of the year and most of the region suffers periods of drought in summer (García-Fernández, 1986; Font-Tullot, 2000).

Castilla and León is characterized by wide bioclimatic diversity with 80% of the region having a Mediterranean macrobioclimate. In the northernmost areas and highlands of the main mountain ranges the macrobioclimate is temperate with no summer drought (Rivas-Martínez et al., 2011b). This biogeographic and bioclimatic diversity determines a great variety of vegetation types. Formations dominated by *Quercus* occupy more than 75% of the territory, developing in both acidic and basic substrates and absent in cacuminal areas of high mountains. The deciduous trees acidophilus *Q. orocantabrica* Rivas-Mart., Penas, Díaz & LLamas, *Q. petraea* (Matt). Liebl. and *Q. robur* L., and also marcescent *Q. pyrenaica* Willd. occupy montane territories between 650 and 1700 m·a.s.l. depending on exposure and other factors. Formations characterized by the evergreen species *Q. rotundifolia* Lam, *Q. suber* L. and *Q. coccifera* L. in addition to marcescent *Q. pyrenaica* Willd., *Q. faginea* Cav. and *Q. pauciradiata* Penas, Llamas, Pérez-Morales, Acedo are typical of the Mediterranean areas ranging approximately between 150 and 1600 m·a.s.l. (del Río, 2005).

Castilla and León has an active bio-monitoring network, Registro Aerobiológico de Castilla y Leon (RACYL), focused on pollen sampling with 13 monitoring stations located all over the region (Fig. 1b).

2.2. Data sources

The present study used two data sources: land use information and aerobiological data.

Aerobiological data were provided by RACYL from 13 monitoring stations with a density of 1 trap for every 7250 km^2 (Fig. 1b). Data were collected following the Spanish Aerobiology Network (REA) standardized methodology and the minimum recommendations of the European Aeroallergen Society (Galán et al., 2007; Galán et al., 2014). Data are subjected to the quality control program of REA (Oteros et al., 2013). Aerobiological data consist in daily airborne pollen concentrations (pollen grains/m^3 air) of *Quercus* sp. (*Quercus pyrenaica* pollen were also differentiated during 2013–2014). *Quercus* pollen is identified at genus level because it is stenopalynous and the pollen from several species share certain features under optical microscope making unable the identification at more specific level. But it is also possible to identify the *Q. pyrenaica* pollen kind, including the pollen of *Q. pyrenaica* at specie level plus all its hybrids and other marcescent arboreal species of *Quercus* genus. Aerobiological monitoring covers 8 years from 2007 to 2014 (2007 is missing in Arenas de San Pedro and 2007–2009 are missing in Béjar). The pollen index (PI), defined as the sum of the annual average daily pollen concentrations, was calculated to characterize the aerobiological features of each sampling point.

General land use data were obtained from the European CORINE (Coordination of Information of the Environment) Land Cover project (CLC) (Heymann et al., 1994). CLC is a land coverage map for the whole EU territory at a scale of 1:100,000, a minimum mapping unit (MMU) of 25 ha and a minimum width of linear elements of 100 m. CLC information is available from 2006. Analyzed land use types were Shrub areas, Dehesa (Pasture with woodland), Mixed forest and Broad-leaved forest (Fig. 2a). These forms of vegetation cover most of the *Quercus* sp. predominant at the studied area. Each form of vegetation has different features taking into account *Quercus* species conformation and abundance, structure of vegetation, anthropogenic management of landscapes and pollen emission pattern.

Specific land use data on well-conformed forests of *Q. pyrenaica* and *Q. rotundifolia* (Fig. 2b) from the Spanish Environment Ministry (Ministerio de Medio Ambiente) were also used (Rivas-Martínez and Penas, 2003). The *Q. pyrenaica* layer corresponds to most of the montane *Quercus* forest linked to all deciduous broad-leaved *Quercus* species like *Q. robur* or *Q. petraea*, whereas the *Q. rotundifolia* layer is linked to all evergreen *Quercus* species like *Q. ilex* or *Q. faginea*. As can be seen, the CLC broad-leaved layer is well related to *Q. pyrenaica* forests, whereas *Q. rotundiafolia* forests are represented in different CLC layers characterized by different structures.

2.3. Data analysis

CRM was applied to calculate the relationship between emission source surfaces and airborne pollen, namely land use information on *Quercus* distribution and *Quercus* airborne pollen. Two different models were developed: 1, a general model taking into account *Quercus* pollen (2007–2014) and 2, a specific model taking into account *Q. pyrenaica* pollen (2013–2014).

CRM is a well-described method based on the fact that the extension of the emission surface around a point is correlated with the total number of airborne particles at that point (Oteros et al., 2015). To calculate the relationship between land use and PI, the land use surface is calculated on several concentric rings with a known area in the surroundings of different places with defined aerobiological features. Land use is then analyzed by correlating the relationship between the emission surface on each ring and airborne pollen. The main CRM steps are the calculation of:

1. The pollen index (PI).
2. Multiple concentric buffers around each sampling point. Each consecutive buffer has a difference in the diameter of 1000 m.
3. The actual emission surface (AES) on each ring ("ring" is the space between two consecutive buffers).
4. Pearson's correlation between AES and PI for each ring.
5. The mathematical relationship between correlations and the distance of each tested ring.
6. The theoretical influence (TI) parameter of each ring, from step 5.
7. The influence index (II) parameter of each ring. By relating TI and the total surface of each ring.
8. The specific influence index (SII) parameter of each ring, from the relationship between steps 3 and 7.
9. The emission index (EI) parameter.
10. The actual influence index (AAI) parameter of each ring. This parameter means the amount of pollen that each ring contributes to the monitoring location applying the formula: $AAI_p = II_p * AES_p * EI$; where p is the ring number.

2.3.1. General model

In this model, CRM was applied to *Quercus* pollen collected during the period 2007–2014 and land use information from CLC. CRM was first conceived to study airborne particles with just one kind of emission

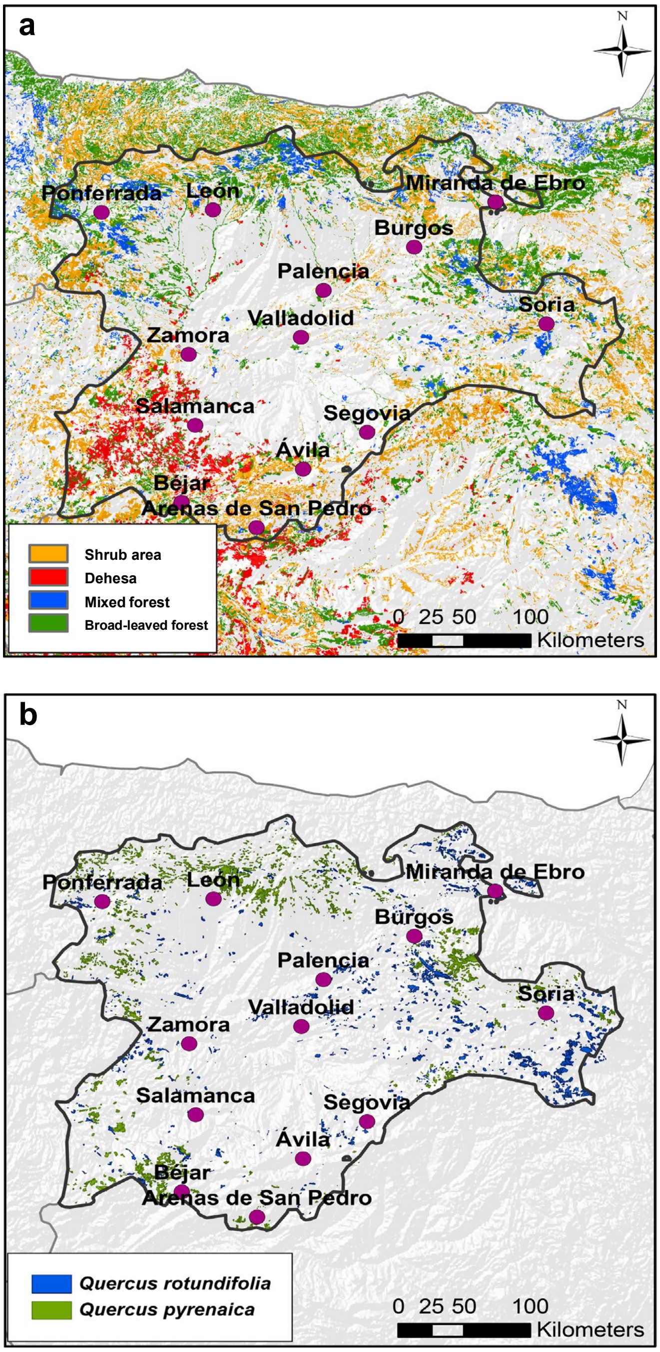

Fig. 2. Distribution of vegetation forms through Castilla and León. a. Forms of vegetation related to *Quercus* sp. in the surroundings of Castilla and León from Corine land cover. b. Well-conformed forests of *Quercus* species in Castilla and León, from the Spanish Environment Ministry.

source in the surroundings, and does not differentiate the contribution of each form of vegetation in particulate matter from multiple sources. *Quercus* pollen is emitted by several species in different landscapes featuring different emission patterns. After forecasting the PI by applying the CRM four times, one to each potential emission source (Shrub, Dehesa, Mixed forest and Broad-leaved forest), we used an ensemble of results to obtain a more realistic prediction. The ensemble of different models in climatology and atmospheric sciences is usually the average of the individual model forecasts (e.g. Sofiev et al., 2015). We selected the optimal ensemble model by calculating Pearson's correlation between observed and expected values and the root mean square error (RMSE), we selected the smallest RMSE:

$$RMSE = \sqrt{\frac{\sum(Observed - Expected)^2}{n}}$$

2.3.2. Specific model

In this model, CRM was applied to *Q. pyrenaica* pollen collected during the period 2013–2014 and land use information on *Q. pyrenaica* forests in the region. Final models were validated by full cross validation (each case was validated with an external model developed with the other 12 cases).

2.3.3. Validation

Both models (general and specific) were validated by full cross validation. The method of full cross validation used is the leave-one-out cross-validation (LOOCV) method. In the LOOCV validation, a model is performed excluding each case (if we have a total of 13 locations, 13 models are developed being trained with 12 locations each one and validated with the 13th). Both validation parameters (R^2 and RMSE) were calculated from the cross validation residuals (difference between observed value and expected value by a model trained excluding the validation location).

2.3.4. Mapping

Each model was applied to the whole surface of Castilla and León and represented as a pollen map. The models generated by the CRM were applied by an iterative process to each pixel of 1 km^2 resolution through a region of 94,222 km^2, that is generating multiple buffer-ring shaped areas with a tightness of 1000 m at each one of the 94,222 pixels. The number of rings (1 km tightness each) depends on the distance of observed influence of the emission source on airborne pollen, calculated in step 6 for mapping:

1. The surface covered by the emission source, termed emission surface of the pixel (ESP) is calculated for each pixel.
2. The theoretical ESP contribution of pollen to each of its surrounding rings is assigned applying a new function termed actual influence index of the pixel (API). For each ring $_p$ in surrounding of each pixel: $API = II_p * ESP * EI$.
3. The pollen maps are generated by summing all the overlapping API values across the whole surface.

3. Results

3.1. General model

Fig. 3 shows the *Quercus* average PI and its confidence limits at each monitoring site. Béjar has the highest uncertainty, influenced by the lack of information for 2007–2009.

By applying the CRM, the *Quercus* pollen concentrations shown in Fig. 3 were related to land use using an ensemble of the different models produced by different forms of vegetation (Shrub, Dehesa, Mixed forest and Broad-leaved forest). Fig. 4 shows the validation of each model by calculating the RMSE and the correlation between observed and expected values for each land use and all possible combinations of ensemble models. The models for Mixed forest (M) and Broad-leaved forest (BL) cannot be taken into account in the study. The Mixed forest model has low correlation coefficient and a high RMSE, while the Broad-leaved forest has low correlation coefficient meaning the model does not reflect the actual state. On the other hand, Dehesa (D) and Shrub (S) models show high correlation coefficients and low RMSE. The ensemble of Dehesa and Shrub models shows the best validation features and was selected as the General Model.

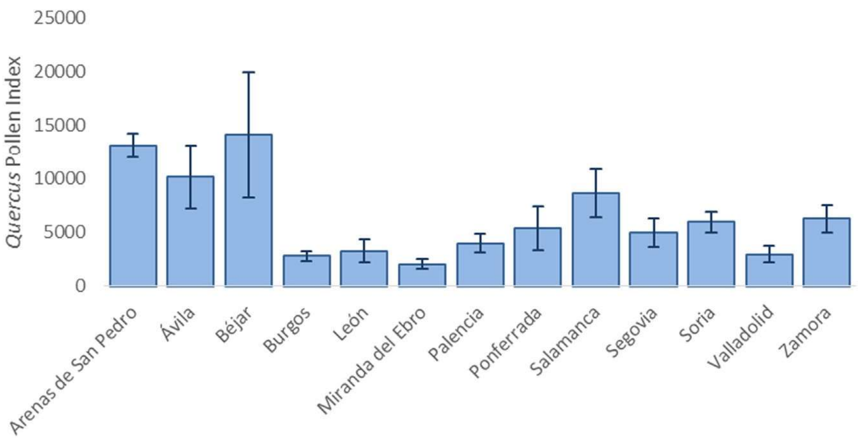

Fig. 3. *Quercus* pollen index at each monitoring site in the Castilla and León region (2007–2014). Vertical bars are the confidence intervals (95%).

The General Model is conformed by the ensemble of models developed with Dehesa and Shrub information. The validation was performed by full cross validation and the parameters showed the Model's high robustness and accuracy: $r = 0.95$; $r^2 = 0.90$ and RMSE = 2559. The General Model forecast of the *Quercus* PI is shown in Fig. 5. The areas on the edge of the region show higher PI than the interior plateau. This is because the vegetal formations containing *Quercus* sp. are located in the mountain ranges and their borders. Southwestern Castilla and León shows the highest PI predictions as some *Quercus* species in this area have been managed by anthropic activity, favoring long extensions of Dehesa landscape.

3.2. Specific model

Fig. 6 shows the *Q. pyrenaica* PI at each monitoring site during 2013–2014. *Q. pyrenaica* pollen includes different species of *Quercus* well-represented in the Castilla and León area. The distribution of these species in the region is well-known, so the CRM applied to *Q. pyrenaica* should give a more accurate result than the General Model. However, the typical biennial flowering pattern of these species has a major impact on PI, so a monitoring period longer two years would increase CRM accuracy (García-Mozo et al., 2008).

Fig. 7 shows the correlations between *Q. pyrenaica* PI and the total emission surface inside 1 km rings at different distances from each monitoring site. As can be seen, the area of influence includes the first 43 km while maximum influence is observed at 14 km: 25% of *Q. pyrenaica* PI comes from the first 9 km, 50% from the first 17 km and 75% from the first 26 km. The graph shows a major city effect as these species are related to well-conformed forests and not usually found in cities.

The validation of the Specific Model was performed by full cross validation and the parameters showed the Model's high robustness and accuracy of: $r = 0.84$; $r^2 = 0.71$ and RMSE = 1774. The Specific Model forecast of *Q. pyrenaica* PI in Fig. 8 shows three areas with high concentrations of *Q. pyrenaica* pollen.

4. Discussion

This manuscript describes the mapping of annual airborne pollen concentrations in the Castilla and León region, central-northwestern Spain, an area of 94,222 km^2 with a resolution of 1 km^2. The concentric

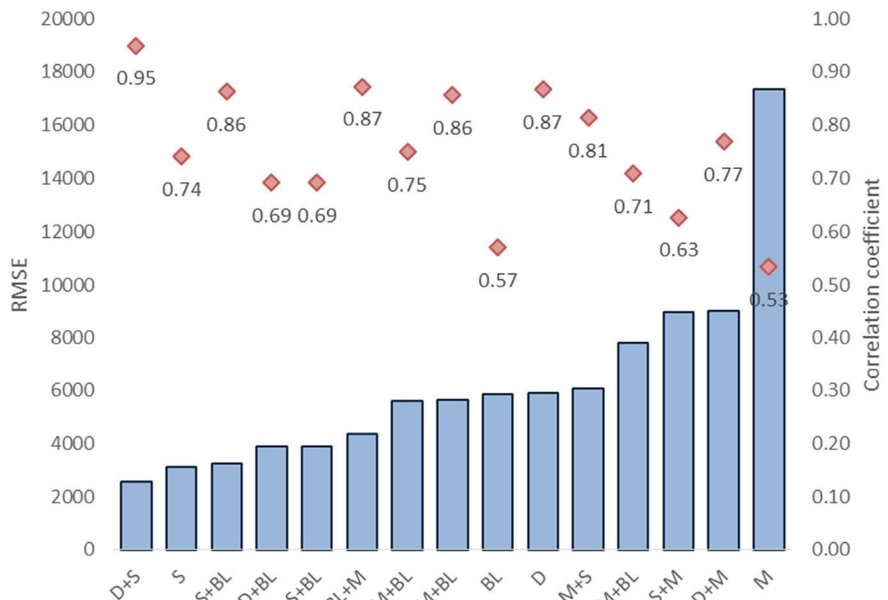

Fig. 4. Validation features of the General Model. Root Means Square Error (RMSE) "represented by bars" and correlation coefficient "represented by diamons". Land use abbreviations: Mixed forest (M), Broad-leaved forest (BL), Dehesa (D), Shrub (S).

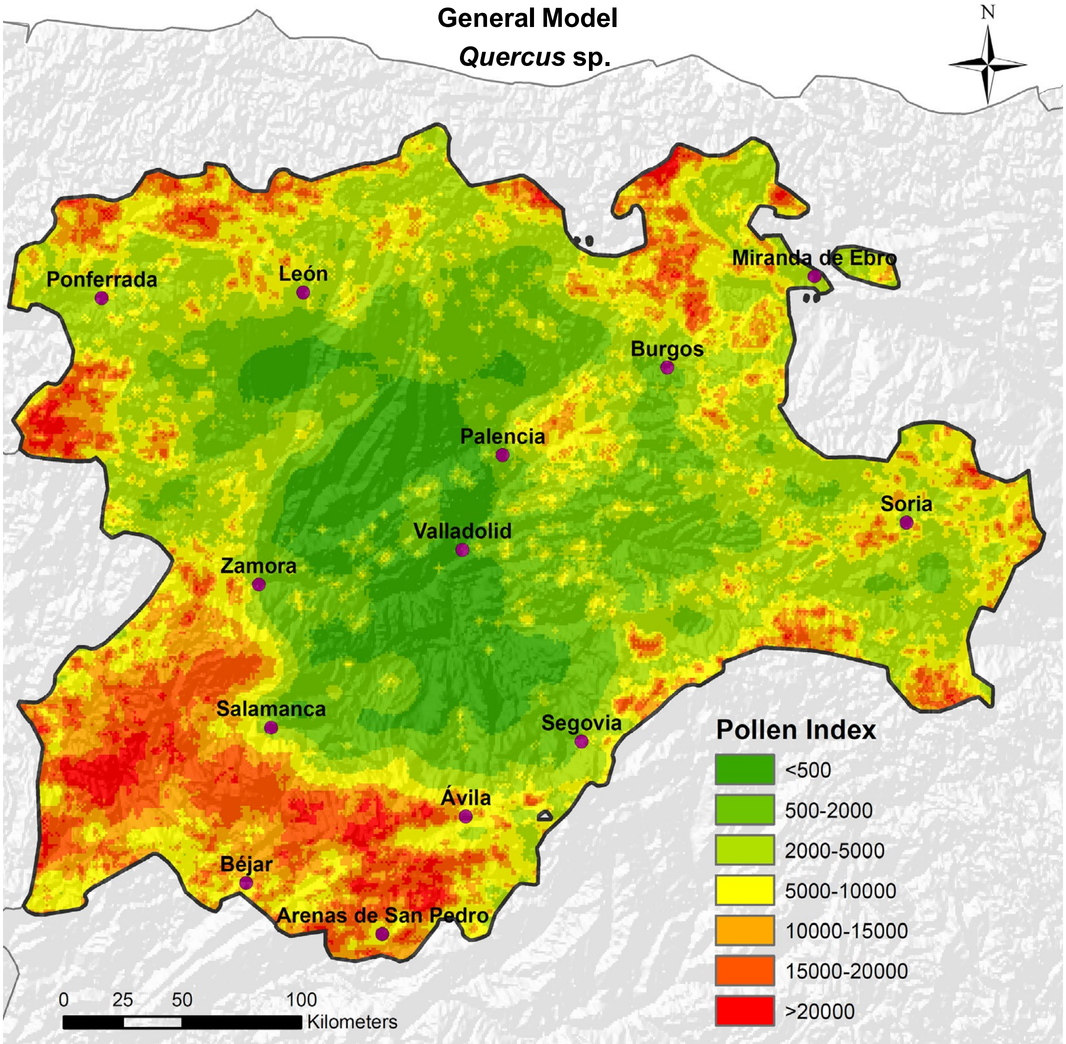

Fig. 5. *Quercus* pollen index forecast by applying the concentric ring method to the Castilla and León region.

ring method (CRM) was used to build the predictions at unmonitored places. This method was developed to study the relationship between airborne pollen concentrations in one place and the extension of emission sources in the surroundings (Oteros et al., 2015). The present study implemented the model to analyze the dynamics of a given pollen type (*Quercus)* in a large area. The final objective will be to fit this modeling to estimate the airborne pollen level in under-monitored areas and thereby improve forecasting maps of aeroallergens. In addition, pollen concentrations are useful for agronomical predictions of anemophilous species and to gauge the impact of climate change on phenology and pollen production, and the effect of gene flow in anemophilous vegetation and genetically modified plants.

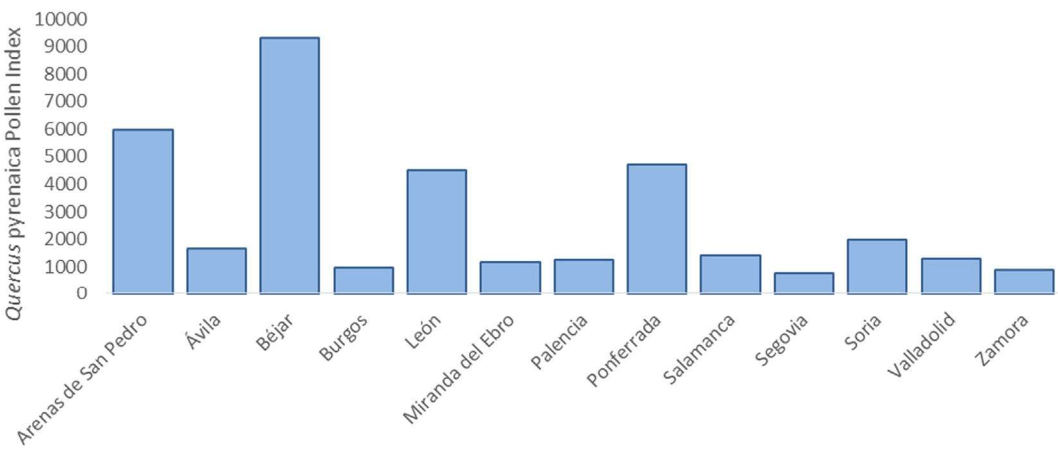

Fig. 6. *Q. pyrenaica* pollen index at each monitoring site in the Castilla and León region (2013–2014).

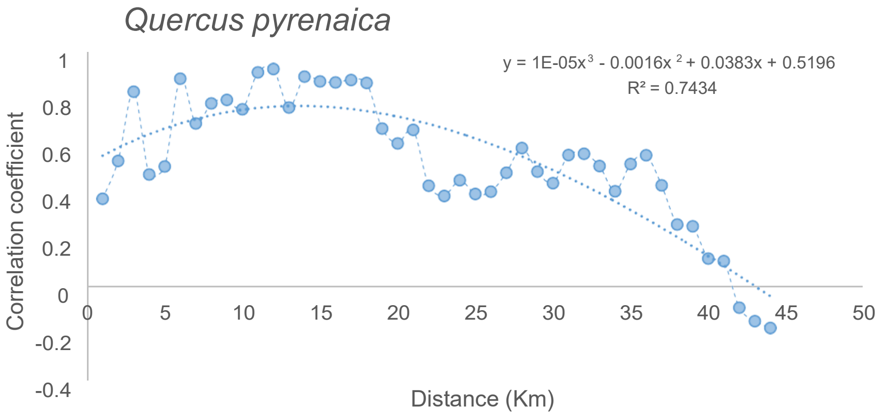

Fig. 7. Correlations between *Q. pyrenaica* pollen index and the total emission surface inside 1 km rings at different distances from each monitoring site in the Castilla and León region.

The genus *Quercus* is one of the most important components of potential vegetation in Iberian forests, together with the "dehesa" landscape, the most emblematic naturalized anthropic ecosystem of the country. This gives the *Quercus* genus a significant ecological and economic importance (García-Mozo et al., 2007). Individuals of the different species of the *Quercus* genus produce large amounts of pollen during the spring, and are the major contributors to the biological exposome for most of the Iberian population (Gómez-Casero et al., 2007). This makes the *Quercus* pollen clinically important because of frequent cross-reactions among major allergens and with other species (Weber, 2007).

The reason why we used more than 1 year for defining pollen index is that pollen production can undergo weather-related or genetic interannual variations (Hicks, 2001), that could distort the relationship between airborne pollen and land use information. This is particularly true for *Quercus* due to it is well-documented biennial flowering pattern

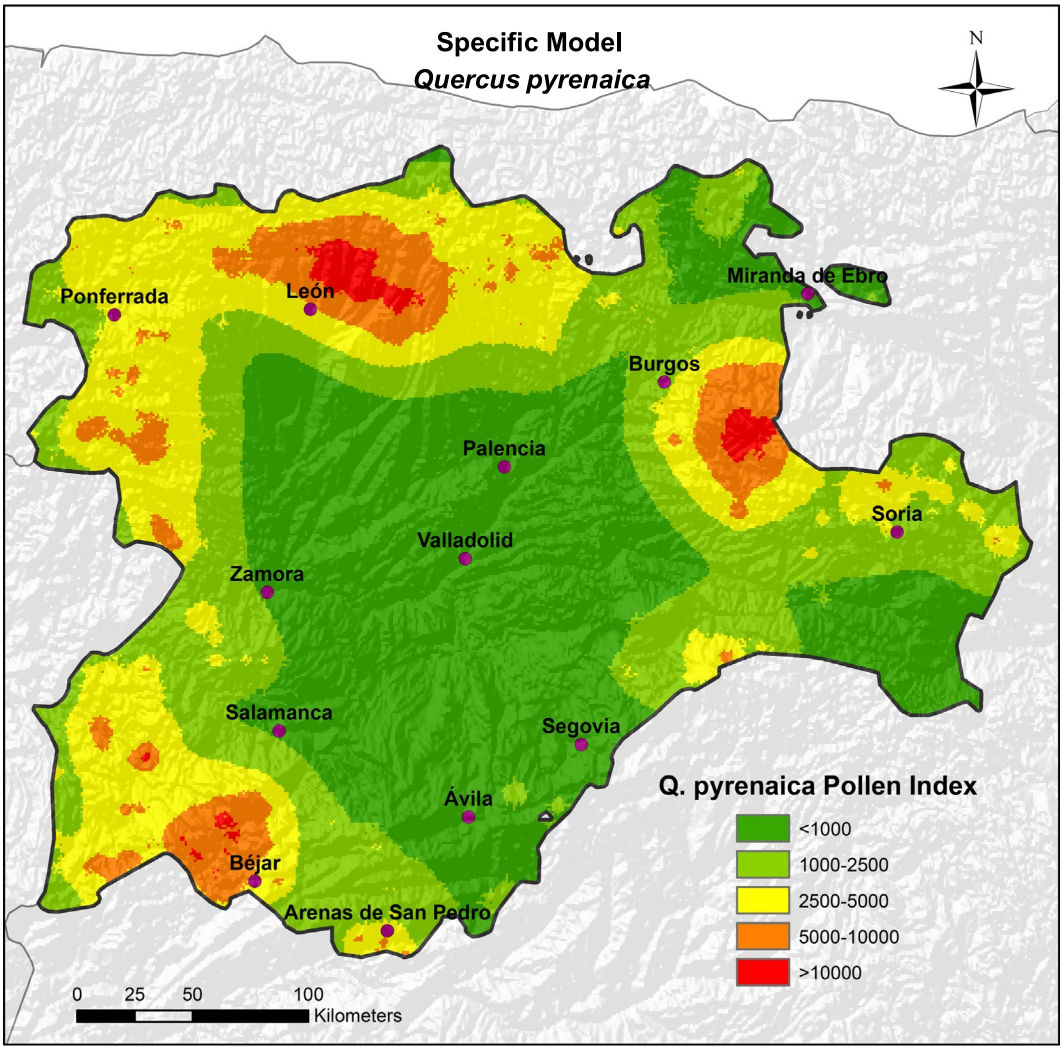

Fig. 8. *Q. pyrenaica* pollen index forecasted by applying the concentric ring method to the Castilla and León region.

(García-Mozo et al., 2008). Long term trends in pollen records could also have a critical effect (Spieksma et al., 2003; Kasprzyk et al., 2014; Galán et al., 2016).

The CRM should be interpreted as the averaged behavior of a particle in the studied area by extracting the dispersion pattern of the same particle at several sampling points. The use of different study years homogenizes the dynamics of the atmospheric circulation patterns. Likewise, the CRM can only be applied to explain annual pollen index and not to study the source of daily pollen concentrations. To perform daily or even hourly pollen concentrations from land use information will require of wind dispersion simulations and phenology of source areas (Oteros et al., 2015).

We applied the CRM to *Quercus* pollen to generate a general model for the genus and a specific model for *Q. pyrenaica* pollen. As *Quercus* pollen is emitted by different forms of vegetation with unknown contributions to the pollen spectrum, we used an ensemble of models for the different land uses in the general model. We observed low correlation between Quercus pollen and the forms of vegetation Broad-leaved and Mixed forests. This may be due to the lack of realistic calibration data for *Quercus* pollen as these forms of vegetation are not the main sources for this type of pollen. Individually, we observed the greatest correlation between *Quercus* and shrub. We also observed a maximum correlation with the ensemble model of shrubland and "dehesa", probably because those forms of vegetation are the main contributors to the *Quercus* pollen spectrum. "Dehesa" areas are especially widespread in the southern part of Castilla and León, whereas *Quercus* shrublands are especially abundant in the south and northwestern areas, coinciding with the highest records for *Quercus* airborne pollen.

The specific model for *Q. pyrenaica* showed the maximum influence of land use on airborne pollen at a distance of 14 km with positive correlations up to a distance of 43 km. It is noteworthy that the nearest surrounding area is not the most correlated point. This is apparently in contrast with the knowledge of most pollen is deposited in the immediate area surrounding the trap (Hofmann et al., 2014). We also observed that the nearest areas have, in proportion, the highest contribution to the pollen load. That is the same area of emission surface close to the trap contributes much more to the pollen index that the same area of emission surface at longer distances. But this is not contradictory with the fact that most of the pollen is coming from long distances, explained by the dramatic increase in the surface of potential emission sources at longer distances (Oteros et al., 2015). One point supporting our findings is that pollen traps use to be located at 10–20 m evading deposition effect from all close sources and trapping only pollen suspended by wind forces (Mandrioli et al., 1998a). Our model explains the averaged features of a study area, but has to be assumed that for each individual location there are differences in pollen sources contribution. An extreme case of the prevalence of long distance transport vs short distances transport is in places with lack of potential sources in the surroundings. This effect was already observed in the airborne particles content by Charles Darwin in the middle XIX century (Darwin, 1846). This was also observed by Izquierdo et al. (2011) in Tenerife (Canary Islands, Atlantic Ocean) where it was estimated that around 89–97% of annual *Olea* pollen concentrations originated from extra-regional sources located in the Iberian Peninsula (Southern Europe) and Morocco (Northern Africa) (Izquierdo et al., 2011).

The results obtained from the specific *Q. pyrenaica* model tested in the present work disagree with those observed in the previous application of the CRM for *Olea* pollen (Oteros et al., 2015). In that case, the maximum influence of land use on olive pollen in Southern Spain was at a distance of 37 km and positive correlations were observed up to 200 km from the pollen source. In addition, Rojo et al. (2016) observed that the maximum influence of land use on olive pollen in an extensive area of the Western Mediterranean Basin is at a distance of 42 km and with positive correlations up to 200 km from the pollen source (Rojo et al., 2016). These differences could be due to pollen transport variations. On the one hand, the atmospheric dispersion of pollen depends on its aerodynamic features such as size, shape and density (Mandrioli, 1998b; Okubo and Levin, 1989; Prentice, 1985), which determine the settling velocities of pollen generally varying from 1 to 30 cm/s (Aylor, 2002). Differences between the aerodynamic features of *Olea* and *Quercus* pollen can partially explain these results.

On the other hand, wind is the main driving force in Aerobiology, and windy conditions can have an impact on the amount of pollen recorded at a given site (Damialis et al., 2005). Although pollen size and settling velocity are important parameters for pollen deposition, classical wind tunnel experiments have shown that sedimentation is negligible at wind speeds lower than 2 m/s (Gregory, 1973). However, wind speeds below 2 m/s are rare, so differences in atmospheric conditions between the study areas should be taken into account. The topographical conditions of Castilla and León make the atmospheric features of the region very special. The whole region is surrounded by high mountain ranges which can act as walls for the transport of foreign pollen. It is proved that pronounced mountain ranges can act as a barrier for pollen transport (Izquierdo et al., 2016). In this sense, CRM shows a specific pattern for pollen dispersion in the region. Rojo et al. (2016) showed that the topography of the study area can have a major impact on pollen dispersion (Rojo et al., 2016). They found marked differences with respect to the dispersal patterns associated with the altitudinal gradient indicating that areas at higher altitude receive greater amounts of olive pollen from nearby pollen sources with respect to lower areas. The model has to be interpreted as the averaged behavior of airborne pollen at the study area, so the homogeneity of the study area will have strong effect on the features of the model.

The poorer performance of the validation parameters in the *Quercus* model than in previous works based on *Olea* pollen can be related to the wide variability in *Quercus* pollen deposition (Oteros et al., 2015; Rojo et al., 2016). Di-Giovanni et al. (1995) suggest that size variations among pollen grains from the same plant or from different plants in the population and the different moisture content of the grains may explain the varying settling velocities of a simple pollen type (Di-Giovanni et al., 1995). The *Quercus* pollen grain is highly polymorphic, so its averaged dispersion by a static model will include a greater error than for other less variable particles. Another factor making *Quercus* less favorable to land use explanation is that information on emission sources is not as accurate as it is for olive pollen. Olive pollen emission sources are well described and easier to identify by geostatistical methods, while the quantification of *Quercus* sources is hampered by their heterogeneous emission pattern.

In conclusion, the CRM model proposed in this manuscript proved to be a powerful tool for pollen index mapping based on land use information and forms of vegetation. The multisource pollen type *Quercus* can be mapped from the ensemble of different land use models. CRM allows us to understand better what are the potential sources of pollen. So climate change impact on Pollen Index at a simple place can be interpreted according to the sources. This method is also useful for understand the health impact of pollen sources on populated areas and extrapolate pollen information from monitoring locations. In this sense, Pollen index maps also serve to gauge the impact of climate change on vegetation changes and health.

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