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Impact of Plane Tree Abundance on Temporal and Spatial Variations in Pollen Concentration

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Abstract: Many ornamental species growing in cities have considerable allergenic potential and pose a risk to allergy sufferers. Such species include members of the genus *Platanus*, or London plane tree, which is increasingly prevalent in a number of southern European cities. Analysis of airborne pollen concentrations enables biological air quality to be assessed, and also provides information on the local distribution of vegetation. The aim of this study was to analyze trends in annual *Platanus* pollen concentrations in central Spain and to determine the extent to which they are linked to the presence of this species in urban green spaces. The results point to a correlation between the growing number of plane trees and an increase both in the annual pollen index and in the number of days on which allergy sufferers are at risk. Analysis suggests that variations in the diversity and abundance of allergenic ornamental species in urban green spaces may account for the trends observed in the dynamics and behavior of airborne pollen from these species. The results obtained in studies of this kind should be reflected in urban green-space management plans, in order to decrease the allergenic load and thus both reduce exposure to allergenic pollen and improve air quality in these spaces.

Keywords: urban green spaces; land uses; trends; pollen; allergy; urban planning

1. Introduction

Urban green spaces promote the quality of life of local residents thanks to the well-being associated with having a place to relax, socialize and undertake sporting activities [1–3]. However, urban green spaces also pose a number of public–health problems, including increased exposure to allergenic pollen from certain ornamental species [4–6].

The quality of urban green spaces depends on both intrinsic factors (design, accessibility, biodiversity and infrastructure) and external factors linked to the area in which they are located [7]. Due to the complex physiology and ecological functioning of plant species, efforts to select ornamental species offering certain social and economic advantages (increased shade, rapid growth) may lead to undesirable side-effects for local allergy-sufferers, including increased aeroallergen production [8]. Thus, key questions remain in urban design and planning with regard to how to invest in green urban infrastructure in ways which incorporate the large body of scientific understanding [9], particularly given the need to prioritize public health [10].

Airborne pollen records provide valuable information on biological air quality, and on the distribution of local vegetation [11]. The identification of pollen sources and the quantification of their contribution to overall pollen concentrations are tools enabling a more efficient design of urban parks and gardens in terms of the choice of species [11–15]. Moreover, pollen records provide information on the nature and magnitude of variations occurring as a result of changes in flora and vegetation [12,16].

Urban aerobiological research is now incorporating new tools linked to 3D simulation, mapping and urban planning for the study of pollen exposure [17–19]. Furthermore, it has been suggested that aerobiological data should be borne in mind in the design and construction of buildings, since the spatial configuration of the urban fabric directly influences the airborne dispersal of bioaerosols [20].

Prediction models are currently being developed for ornamental species, with a view to assessing the allergy risk in urban green spaces [21], and recent research has focused on evaluating the risk posed by urban green spaces as a function of the presence and abundance of certain species [14,22,23].

A leading contributor to the risk associated with allergenic ornamental species is the prevalence of monospecific tree stands. Increasing the diversity of species growing in cities would help not only to lower the number of allergenic species, but also to reduce the amount of pollen generated by monospecific stands [24]. In many Mediterranean cities, urban green spaces are characterized by the overabundance of a limited number of species, including poplars (*Populus* spp.), willows (*Salix* spp.), elms (*Ulmus* spp.), cypresses (*Cupressus* spp.) and plane trees (*Platanus* spp.) [25]. During the main pollen season, these species simultaneously release large amounts of pollen into the atmosphere; as a result, pollen from ornamental species is among the most prevalent in the pollen spectrum in Mediterranean cities [26–29].

There are a number of reasons for choosing the London plane tree (*Platanus* spp.) as an ornamental species in cities: rapid growth, resistance to drought and a wide crown providing shade, these being criteria of interest in terms of urban tree planning and management [8]. This species has a considerable impact in large Mediterranean cities [30]. In Spain, for example, plane trees are planted extensively in the green spaces, streets and avenues of both Madrid and Barcelona [25,31]. At a local level, the abundance of plane trees, together with their marked allergenicity, requires an assessment of the environmental health risk and an improvement in the planning and design of urban green spaces [32]. Airborne *Platanus* pollen concentrations in cities, and thus the exposure of local residents to their allergenic pollen, vary both in time and in space. It is therefore essential to analyze spatial-temporal patterns and identify the causes of variations when constructing models to predict pollen concentrations [33].

A number of studies report that increased pollen production by allergenic species in cities is prompted by rising temperatures as a result of climate change and increased urban pollution, including higher atmospheric CO_2 concentrations [34–38]. However, it is hard to evaluate the impact of environmental factors on pollen production in ornamental species such as the plane tree, since the effect of anthropic management needs to be clearly distinguished. Water availability plays a major role in the reproductive development of ornamental flora in cities, and irrigation patterns and other management practices such as pruning may also influence pollen production and release by ornamental species [31,39,40].

For all these reasons, this study sought to analyze the dynamics and behavior of airborne *Platanus* pollen and to chart possible correlations with the presence and abundance of plane trees in a number of cities in central Spain. The primary aims were: to determine the causes of observed variations in pollen concentrations over the period 2003–2019; and to test the hypothesis that changes in urban land use, and especially the increased planting of plane trees in urban green spaces in certain Mediterranean cities, are a key contributor to increased exposure of *Platanus* pollen allergy-sufferers.

2. Materials and Methods

2.1. Study Area

The Spanish region of Castilla–La Mancha is located in the center of the Iberian Peninsula. With an area of 79,409 km^2, it accounts for 15.7% of Spain's territory and is the country's third largest region. The climate is Mediterranean with a continental influence, characterized by extreme temperatures due to the alternation of hot summers and cold winters. Drought is common during the summer months [41].

The following cities in the region of Castilla–La Mancha were studied: Albacete, Ciudad Real, Cuenca, Guadalajara, Talavera de la Reina and Toledo (Figure 1).

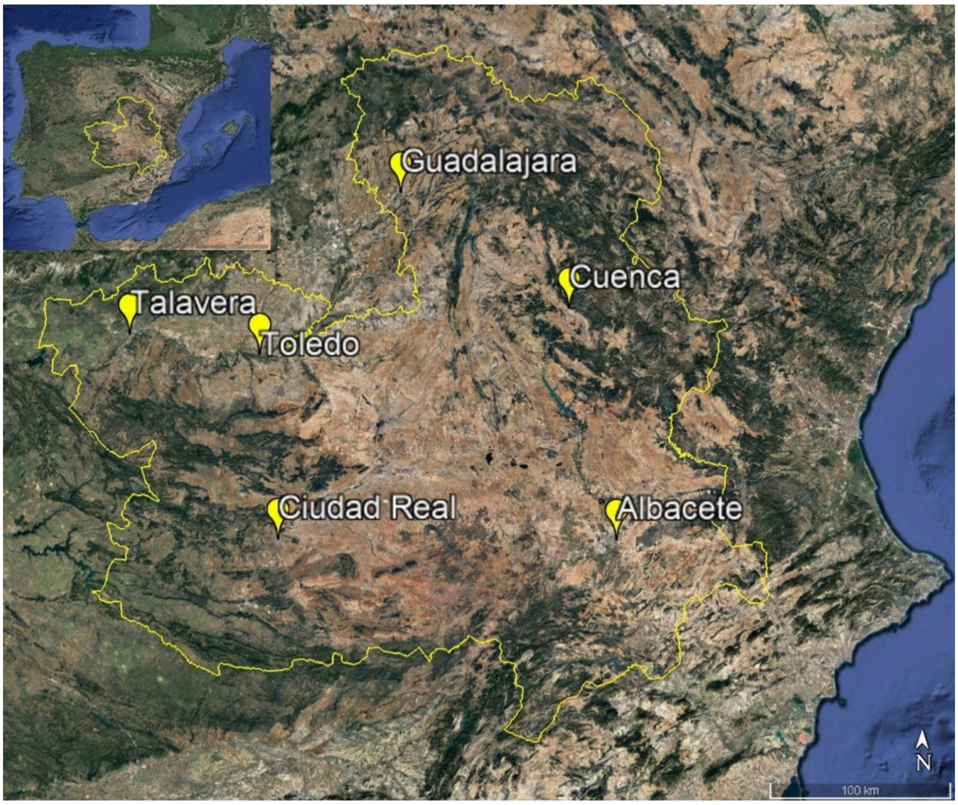

Figure 1. Location of the studied cities (source: GoogleEarth©).

2.2. *Aerobiological Data*

Airborne *Platanus* pollen was collected daily at sampling stations located in each study city (Table 1), using a Hirst-type volumetric sampler with an air flow of 10 L/min [42]. Sampling and pollen counting were performed in accordance with the Minimum Recommendations proposed by the International Association for Aerobiology [43]. Identification and quantification of the airborne pollen types was carried out using optical microscopy (x 400 magnification) and 10% of slide was examined.

Table 1. Characteristics of aerobiological study stations. m.a.s.l.: meters above sea level.

City	Sampling Period	Coordinates	Altitude (m.a.s.l.)
Albacete	2008–2019	38° 58′ N; 1° 51′ W	686
Ciudad Real	2008–2013	38° 59′ N; 3° 55′W	628
Cuenca	2010–2019	40° 4′ N; 2° 07′ W	999
Guadalajara	2008–2019	40° 37′ N; 3° 10′ W	685
Talavera	2009–2013	39° 57′ N; 4° 50′ W	371
Toledo	2003–2019	39° 51′ N; 4° 02′ W	559

The aerobiological data set used comprised daily *Platanus* pollen concentrations expressed as the daily average number of pollen grains per cubic meter of air (grains/m^3). All days on which daily pollen concentrations exceeded 50 grains/m^3 were classified as allergen risk days [44]. Average daily concentrations over the year were added together to give the annual pollen integral [45].

2.3. Inventory of Individuals and Tree Cover

Vegetation analysis included counting individual trees and estimating the crown cover of *Platanus orientalis* L. var. *acerifolia* Dryand. (the only species of the genus *Platanus* present in the study cities) in circular plots of 25 m radius. For larger parks, one plot was sampled per hectare, sample plots being randomly distributed over the total surface area of the park. Parks smaller than one hectare were inventoried in their entirety.

In order to determine the contribution of trees lining streets and avenues, all plane trees in the cities of Toledo and Cuenca were georeferenced in 2019 by exhaustive routes throughout the cities. Toledo was selected as representative of cities where plane trees are widely planted in streets and avenues, whereas Cuenca represented those where planes were less common outside urban green spaces.

The current number of plane trees of Toledo in 2019 was compared with the number recorded on orthophotos in previous years (2003, 2006, 2009, 2012 and 2015) (in these orthophotos, it was easy to recognize visually if the trees were or not in comparison with the georeferenced trees in 2019). Given that the number of trees influences pollen concentrations over subsequent years, correlations were sought between variations in average annual total *Platanus* pollen concentrations over the following 5 years and variations in the number of plane trees observed in the orthophotos. This comparison was made only in Toledo, since the city's pollen database spanned the entire study period (2003–2019).

2.4. Statistical Analysis

Pollen data were subjected to temporal analysis (trends in time series) and spatial analysis (comparison between cities). Trends in pollen-season parameters were studied for those cities with a historical database going back more than 8 years (Albacete, Cuenca, Guadalajara and Toledo). Calculation of pollen-season parameters and trend analysis were performed with the AeRobiology software package [46] using linear regression to detect significant trend patterns. Year-on-year variations in airborne pollen concentrations in Toledo were additionally analyzed in conjunction with variations in the city's plane tree population over the study period; a robust correlation test (Winsorized correlation) was used for this purpose, since classical statistics could not be applied due to the paucity of available data.

For spatial analysis purposes, plane tree distribution and cover with respect to the sampler were compared for all study cities. In order to examine the relationship between spatial distribution and airborne pollen concentrations, plane tree cover in the area surrounding the sampler was analyzed using the concentric ring method [47–49]: taking the sampler as the point of reference, percentage plane tree cover was calculated for concentric rings at 500-meter intervals. Results were plotted on a ring chart using R Software [50].

3. Results

The long-term temporal analysis of pollen load and pollen risk of *Platanus* pollen was carried out using a linear regression analysis of the pollen time-series (Figures 2 and 3). Analysis of total annual *Platanus* concentrations (annual pollen integral) revealed a significant positive trend in Albacete, Cuenca and Toledo (Figure 2). The greatest slope was shown in Toledo, the longest historical time-series (slope = 301). This means that in general terms, every year an increase of 300 pollen grains/m^3 is revealed in the annual pollen amounts in Toledo.

A significant positive trend was also observed for number of allergenic risk days (over 50 pollen grains/m^3) in Albacete, Cuenca, Guadalajara and Toledo (Figure 3). In the last studied year (2019), the number of allergenic risk days was the maximum observed for the entire study period in each station. Therefore, the *Platanus* pollen risk in Castilla–La Mancha is becoming higher, with regard to the number of risk days. In addition, during the year 2019, the risk threshold (50 pollen grains/m^3) was exceeded on more than 15 days in Guadalajara and Toledo, and did not exceed eight days in

Cuenca, although the slope of the trends was very similar for all pollen stations ranging from 0.6 to 1.1 in number of risk days per year (Figure 3).

Tests to determine the relationship between increased plane tree populations and rising total annual *Platanus* pollen concentrations in Toledo over the period 2003–2019 (Figure 4) revealed a significant positive correlation between the two variables ($\rho_w = 0.92$, $p < 0.05$), as well as a statistically-significant increasing trend fitting an exponential function (Figure 4). Therefore, a clear significant relationship has been demonstrated between the rise of the pollen load and the increase of plane trees in the city of Toledo during the last 15 years.

Comparisons of total trees of the species *Platanus orientalis* var. *acerifolia* both in urban green spaces at all study sites and in the streets and avenues of Cuenca and Toledo, together with total annual pollen concentrations, are shown in Figure 5. Higher pollen concentrations, and larger plane tree populations, were recorded in Toledo than in Cuenca. Specifically, a mean annual pollen integral of 5407 pollen grains/m^3 was related to 5168 individual plane trees in the city of Toledo. However, a considerable reduction of mean annual pollen integral was found in Cuenca (588 pollen grains/m^3), and this city is characterized by a total of 1044 individual plane trees accounted for in the year 2019 (current situation).

Spatial analysis of plane tree abundance (%) inside the green urban spaces revealed that the cities with the highest plant cover of plane tree species in the vicinity of the sampler were Ciudad Real and Talavera de la Reina (Figure 6). Both were the cities with the greatest annual pollen amounts, with mean values of 7192 and 17,711 pollen grains/m^3, respectively. Moreover, in the vicinities of these cities the plant cover of plane tree species is higher than in the rest of pollen stations, and most of the concentric rings (1000, 1500, 2000 m around the pollen trap) are covered by plane trees, with this being the reason for the higher pollen load (Figure 6).

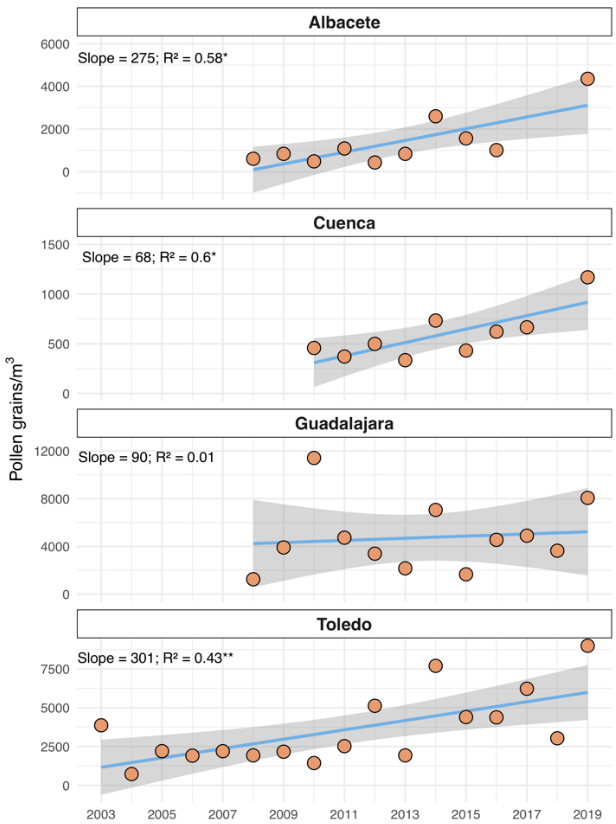

Figure 2. Trends of the annual pollen integral of *Platanus* pollen. Levels of significance: * $p < 0.05$, ** $p < 0.01$. Blue line represents the regression line and grey zone corresponds to 95% confidence interval.

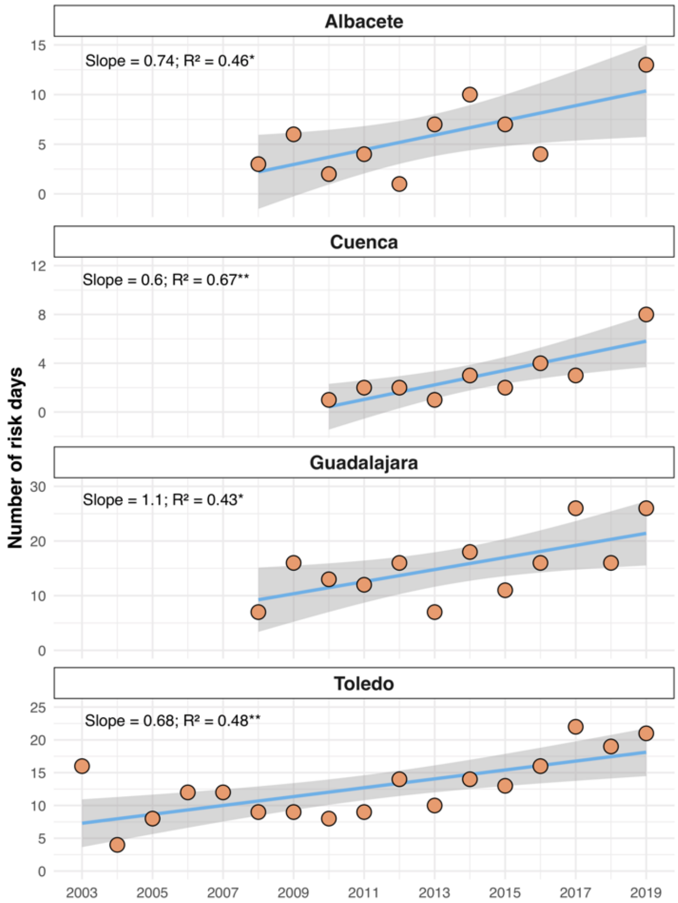

Figure 3. Trends of number of risk days of *Platanus* pollen (>50 pollen grains/m^3). Levels of significance: * $p < 0.05$, ** $p < 0.01$. Blue line represents the regression line and grey zone corresponds to 95% confidence interval.

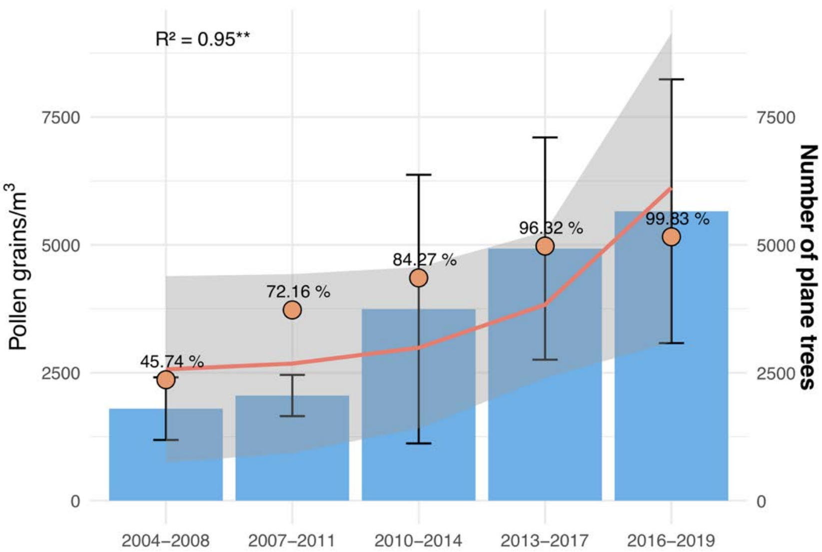

Figure 4. Mean and standard deviation of the annual pollen integral of *Platanus* (bars) and number of plane trees (points). Values above points represent the percentage of trees in respect to the total number of trees in 2019. Orange line represents the exponential function fitted to pollen amounts and grey area corresponds to 95% confidence interval. Whiskers are standard deviation of mean *Platanus* pollen. Levels of significance: ** $p < 0.01$.

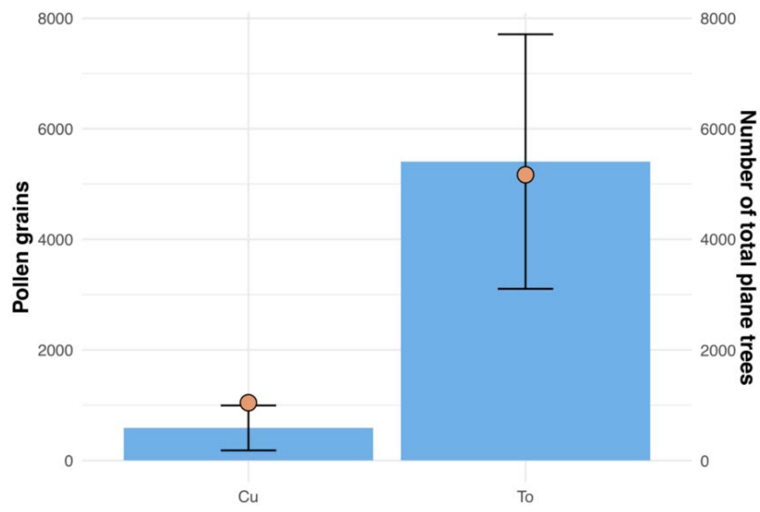

Figure 5. Annual total pollen (bars) and number of total plane trees (points) in the cities of Cuenca (Cu) and Toledo (To). Whiskers are standard deviation of mean annual pollen integral.

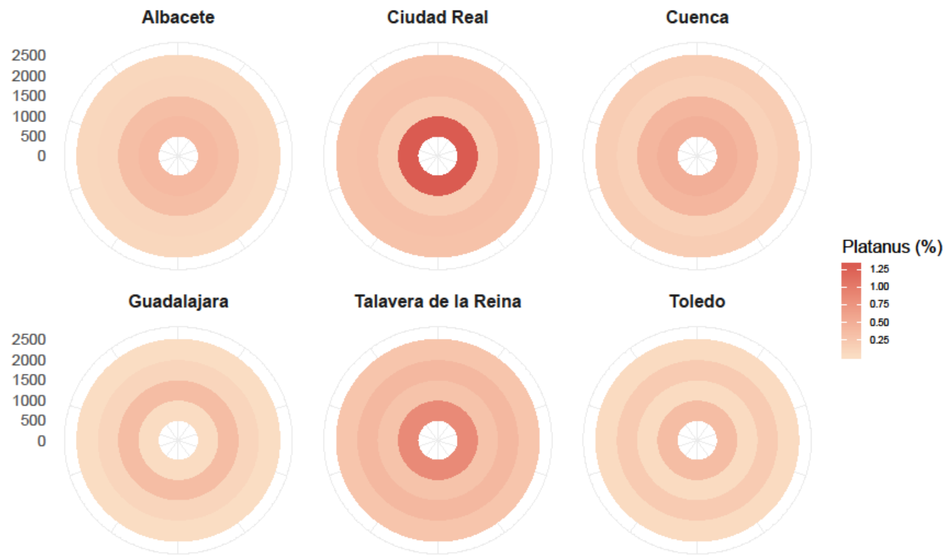

Figure 6. Concentric rings showing the percentage of the surface of *Platanus* in the main urban green zones for the studied cities.

4. Discussion

Pollen release and dispersal patterns are influenced by biotic and abiotic factors, which have been the subject of extensive aerobiological research. However, given the ornamental character of the plane tree, pollen release patterns are determined to a large extent by anthropic factors, which were assessed in this study. Trends observed in the dynamics and behavior of ornamental species such as the plane tree are linked to local changes attributable mainly to the action of man, as shown here, and to a lesser extent to environmental factors [34,36,37].

Time-series analysis confirmed a clear trend towards rising annual *Platanus* pollen concentrations, as well as a progressive increase in the number of allergenic risk days in the study cities, all located in the center of the Iberian Peninsula. Research in other Spanish cities has revealed a similar increase in plane tree pollen concentrations: studies in Jaén (southern Spain) report a clearly significant rising trend over the period 1994–2016 [51]. Indeed, a significant increase in total annual *Platanus* pollen concentrations has been noted for all Andalusian cities with the exception of Seville [52]. Data for Badajoz confirm a significant year-on-year increase in *Platanus* pollen levels in April, the peak pollination month [53].

Elsewhere in Europe, research has highlighted a significant positive trend in the annual pollen index for *Platanus* pollen [36]. To date, however, there has been no direct measurement of urban plane tree populations as a potential anthropic cause of increased airborne pollen concentrations. The present study indicates a direct correlation between rising annual *Platanus* pollen levels and increasing plane tree populations in urban areas of the Mediterranean region.

These findings highlight a clear link between the increased planting of plane trees and overall increased exposure to pollen from ornamental flora in cities [54]. In Toledo (Figure 4), for example, plane tree populations increased by 20% between 2003 and 2019, while annual *Platanus* pollen concentrations doubled over the same period.

Moreover, data for Albacete, Cuenca, Toledo and Guadalajara showed a significant positive trend in the number of allergenic risk days for local residents allergic to *Platanus* pollen; this finding has unquestionable implications in the field of public health in urban areas [55]. In most central Spanish cities, the number of risk days for residents sensitized to aeroallergens is rising.

With regard to the spatial distribution of pollen exposure, the presence and abundance of ornamental species is largely governed by urban development plans—which determine the size and number of urban green spaces—and more directly by the species selected when designing urban parks and gardens [8]. The results obtained here indicate that plane tree cover is not always greater in the immediate vicinity of the pollen sampler: although this was the case in Ciudad Real and Talavera, where plane stands are very old, it was not so in the other cities, where plane plantations are more recent. There is evidence that other factors may influence the relationship between pollen release and the abundance of cover in the vicinity of the sampler, including the size and maturity of individual trees, and the impact of environmental factors (e.g., wind) on pollen release and dispersal patterns [12,32]. Furthermore, although long–range transport of *Platanus* pollen is not very probable [56], potential long-range pollen transport between cities would be interesting to analyze in future studies [57].

Due to the local provenance of plane tree pollen (as distinct from pollen generated by vegetation growing outside cities), dispersal takes place over shorter distances [58,59]. This is especially relevant in the case of large urban areas containing monospecific stands of an allergenic ornamental species, which pose an enormous risk to allergic citizens making use of these green spaces [23]. Major influential factors therefore include not only the number of individual trees constituting major sources of pollen, but also the distribution of these trees within cities. Here, however, the results for Toledo and Cuenca showed a direct positive correlation between the total number of plane trees and total annual *Platanus* pollen concentrations, regardless of distribution. Similar findings have been reported by other authors [14].

Pollen types from species abundant in urban environments, such as ornamental species, may exhibit vertical distribution profiles different from those of species growing mainly outside urban areas [58]. Research shows that pollen is deposited within a few hours of its release, and that more than 88% of pollen is deposited within a range of less than 3 km from its source [56], with the highest deposition being recorded in the first few hundred meters from the point of release [60,61].

By analyzing pollen concentrations for allergenic species frequently planted in urban green spaces in Mediterranean cities, such as the plane tree, we can estimate the allergy risk posed by the green spaces themselves; this is of particular importance for the quality of life of allergy sufferers in urban areas [19]. Aerobiological research aimed at identifying the sources of airborne pollen concentrations and quantifying their contribution to overall pollen levels enables specific recommendations to be made regarding the most suitable ornamental species, and is thus an essential step in ensuring a more efficient design of urban parks and gardens [8,11,62].

5. Conclusions

This study revealed a rising trend both in total annual *Platanus* pollen concentrations and in the number of risk days for allergy sufferers over recent years. This increase was linked to the number and percentage cover of plane trees growing in urban green spaces.

The findings confirm, once again, that essential changes in land use in urban areas, and equally-essential planning decisions made regarding the choice of ornamental species for green spaces have unfortunately led—at least in Spain—to an increase both in plane tree pollen concentrations and in the number of risk days for people sensitive to this pollen type.

The results derived from aerobiological research of this kind should be taken into account in management plans for urban green spaces, contributing to reduce the exposure of people sensitive to pollen produced by ornamental species. The findings should be borne in mind when applying nature-based solutions in existing green areas, and when deciding on future municipal development plans in areas of urban expansion.

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