Science of the Total Environment 737 (2020) 139722

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Assessing pollination disservices of urban street-trees: The case of London-plane tree (*Platanus* x *hispanica* Mill. ex Münchh)

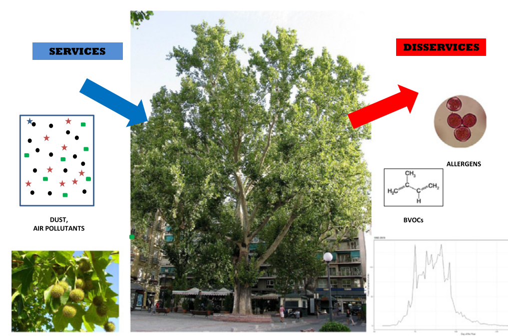
Paloma Cariñanos [a,b,*], Soledad Ruiz-Peñuela [a], Ana M. Valle [c], Consuelo Díaz de la Guardia [a]

[a] *Department of Botany, University of Granada, Spain*
[b] *Andalusian Institute for Earth System Research, IISTA-CEAMA, University of Granada, Spain*
[c] *Pharmacy Service, Hospital Virgen de las Nieves, Granada, Spain*

HIGHLIGHTS

- London plane is one of the most used tree in world's urban forests.
- Emission of allergens by plane tree is affected by meteorological factors and pollutants.
- Minimum winter temperature is the most influential variable in Seasonal Pollen Index.
- The value of the seasonal pollen peak is influenced by the presence of NOx and O_3.
- London plane's disservices should be considered when being selected as an urban tree.

GRAPHICAL ABSTRACT



London Plane tree in the city of Granada.

ARTICLE INFO

Article history:
Received 5 February 2020
Received in revised form 23 May 2020
Accepted 24 May 2020
Available online 30 May 2020

Editor: Elena Paoletti

Keywords:
Green infrastructure
Allergens
Ecosystem disservices
London plane tree
Pollination
Urban ecosystem services

ABSTRACT

Platanusx hispanica (London plane) is a tree species widely used in urban areas due to the diversity of ecosystem services it provides. However, its functions also have some negative effects or associated disservices, such as the emission of Biogenic Volatile Organic Compounds (BVOCs) and allergens. This work aims to analyze the effect that urban environmental conditions and air pollutants have on pollen emissions of plane tree. The study has been carried out in Granada, in the southeast of the Iberian Peninsula, a city with a Mediterranean climate and one of the most polluted in Spain. Granada is also one of the Mediterranean cities in which the increase in the percentage of the population affected by allergy to Platanus pollen in recent decades has been most significant. The 1992–2019 *Platanus* pollen data series has been considered to establish the main aerobiological parameters, trends and correlations with meteorological variables and particulate and gaseous atmospheric pollutants, both before and during the flowering period. The average Seasonal Pollen Integral (SPIn) of about 2700 pollen grains has shown a significant increase throughout the series. This increase in allergen emissions could be related to the increase in crown volume associated with tree growth, but also to other environmental factors. Precipitation and minimum temperatures of the winter prior to flowering were the parameters that have shown the most influence with SPIn, while O_3 and NO_x are the pollutants that have the most effect on the peak value. Due to the good adaptation that London plane has to changing climatic conditions in urban environments, its hegemonic presence as an element of Urban Green infrastructure must be reviewed so that the net balance of ecosystem services is not diminished by the disservices.

* Corresponding author at: Department of Botany, Andalusian Institute for Earth System Research, IISTA-CEAMA, University of Granada, E-18071 Granada, Spain.
E-mail address: palomacg@ugr.es (P. Cariñanos).

https://doi.org/10.1016/j.scitotenv.2020.139722

1. Introduction

Platanus x hispanica Mill. Ex Münchh (sycamore, London plane, shadow plane, London plane tree, or hybrid plane), also known as *Platanus* x *acerifolia*, is a hybrid of *Platanus occidentalis* L. and *Platanus orientalis* L. (Castroviejo et al., 1990; Cennamo and Cafasso, 2002). It is a species widely used as an urban tree due to the large number of ecosystem services it provides. In addition to being fast growing and having a good tolerance to urban microclimate conditions, it is quite resistant to soil compaction and air pollution (Hull, 2009). As a result, it is a very popular street tree both in Europe and elsewhere of the world (Pauleit et al., 2002; McBride, 2017). The London plane tree's pollution tolerance is due to its ability to accumulate pollutants in its cortex (Willis and Petrokofsky, 2017), and most importantly because of its high capacity to capture Particulate Matter (PM) due to the morphological characteristics of its leaves (Popek et al., 2013; Baldachini et al., 2017), in which the superficial hairs have shown efficiency in the retention of ferromagnetic particles (McIntosh et al., 2007). Notable features of the London plane tree are its phenotypic plasticity, with resistance to frost and drought and moderate wind regimes, which has allowed it to be part of urban forests in cities of distinct climatic typology (Pauleit et al., 2002; Hull, 2009). As a prominent species in the Urban Green Infrastructure (UGI), it also helps regulate the urban microclimate due to its large shade provisioning cup and support biodiversity (Fernández-Sarría et al., 2013; Georgi and Zafiriadis, 2006; Yang et al., 2015; Endreny, 2018). These are some of the reasons why the London plane tree is such a popular urban tree in cities such as New York, Sydney, and London. These cities contain over 100,000 plane tree specimens which makes it the most featured species among the world's urban forests (McBride, 2017). Its presence can be further increased through Nature Based Solutions (NBS), where the planting of plane tree specimens is indicated as one of the main measures of strengthening urban resilience against the effects of climate change (Willis and Petrokofsky, 2017).

On the other hand, there are also references of negative effects or disservices associated with the presence of London plane trees in cities (Salmond et al., 2016; Cariñanos et al., 2017). Among them, the susceptibility to pests and diseases such as the deadly canker stain caused by the fungus *Ceratocystis platani*, or anthracnose that can recurrently affect individuals after rainy springs (Tubby and Pérez-Sierra, 2015). The high amount of organic debris derived from the annual foliage renewal (Jin et al., 2014), or the high maintenance costs necessary to maintain the shape of the canopy (Ferrini, 2006) are other associated disservices. However, the impact that Biogenic Volatile Organic Compounds (BVOCs) and allergens have on air quality is perhaps the most significant negative effect the London plane tree has on urban communities. In relation to BVOCs, the London plane tree is indicated as one of the main species of urban trees emitting monoterpenes and sesquiterpenes (Curtis et al., 2014), participating in the formation of atmospheric ozone (Xiaoshan et al., 2000). Regarding the emission of allergens, the involvement of *Platanus* pollen grains as a causative agent of respiratory symptoms is widely referenced (Varela et al., 1997; Valero et al., 1999; Alcázar et al., 2004; Iglesias et al., 2007; Nowak et al., 2012; Willis and Petrokofsky, 2017). This allergenic capacity is given both by the presence of *Pla a* 1–3 allergens in their pollen grains (Fernández-González et al., 2010; Alcázar et al., 2015), and by the large amounts of pollen that are emitted during the flowering period due to the London plane tree's effective wind pollination strategy. The estimated pollen production of 3.3×10^6 pollen grains per inflorescence (Maya-Manzano et al., 2017a) is one of the highest of the woody anemophilous species (Damialis et al., 2011). If we add to this that the flowering period can extend for >4 weeks, it is understood that the London plane has an Allergenic Potential Value of 24 (VPA), one of the highest in the database of parameters for the calculation of the Index of Allergenicity of Urban Green Zones (I_{UGZA}), registered in the Safe Creative platform, N° IPR-684 (Cariñanos et al., 2014, 2017, 2019a). It should be also noted that the threshold of symptomatic responses in people sensitized to this pollen type is only 50 grains of pollen/m^3 of air (Alcázar et al., 2004; Nowak et al., 2012). Therefore, it is clear why the *Platanus* pollen has been identified as the main cause of pollen allergies in urban environments, with incidence ratios >60% of the affected population in cities such as Madrid (Varela et al., 1997; Subiza et al., 1998). Cross-allergenicity has also been reported with other species of the same genus and with other plant species (Miralles et al., 2002; Pazouki et al., 2008). The increase in cross-allergies that can occur between pollen panallergens and fruits such as apples, bananas, kiwis, melons, peaches, and vegetables has also been reported (Miralles et al., 2002; Cariñanos et al., 2019b).

Another aspect that has been studied recently is the impact that the current and future effects of climate change, exacerbated in urban environments, have upon the species that make up the urban vegetation (Ordoñez and Duinker, 2014; Esperon-Rodriguez et al., 2019). Some studies highlight how the phenology of urban trees is already being affected as a result of changes in local environmental conditions, such as the increase in minimum temperatures and the change in the rainfall pattern (Menzel and Fabian, 1999; Galán et al., 2001; Menzel et al., 2006; Nanninga et al., 2017). In this sense, the changes that have taken place have been in both the phenological phenomena (Luo et al., 2006; Neil and Wu, 2006) and in the advancement and intensity of the flowering (Lu et al., 2006), as well as in the amount of pollen emitted (Ziello et al., 2012). The proven linkage of the reproductive biology of the London plane tree with the climatic parameters of the environment in which they grow can alter current phenological and reproductive dynamics predictable (Díaz de la Guardia et al., 1999; Alcázar et al., 2004; Iglesias et al., 2007; Sabariego-Ruiz et al., 2008; Makra et al., 2014; Alcázar et al., 2015). In addition to the effects of meteorological parameters in urban settings, the impact that air pollutants have on pollen emissions must also be considered (Sénéchal et al., 2015; Oduber et al., 2019). Given certain concentrations of air pollutants, pollen grains can undergo physical-chemical changes on the surface, increasing the fragility of the exine (Duhoux, 1982), modifying the total protein and allergen content (Bist et al., 2004), changing reproductive functions (in particular viability and/or germination (Iannotti et al., 2000)), and altering the allergenic potential which results in an allergic response of greater intensity in sensitive patients (Sedghy et al., 2018). All these effects may be most notable in regions where the greatest impact of climate change is expected, such as the Mediterranean basin, which has been classified as one of the most vulnerable regions to climate change in the world due to the projected temperature increase of >2 °C and a marked decrease in precipitation (Giorgi and Lionello, 2008). The response to this change could in turn affect the key role that the plane tree has in the green infrastructure (GI) of many cities, tilting the net balance of ecosystem services towards disservices – particularly those services that have an impact on public health. Therefore, given that the presence of the London plane in many cities is expected to grow as part of the GI to combat the effects of climate change, and given the strong impact that *Platanus* allergens have on public health, this work aims to estimate the dynamics and response that the allergens can have against changing weather variables in polluted urban environments. This will allow for a greater understanding of its reproductive behaviour in urban scenarios which are undergoing changes in climate. The study will be carried out in an area where very pronounced climatic alterations are expected to take place, such as medium-sized Mediterranean cities (IPCC, 2007).

2. Material and methods

2.1. Study area

The city of Granada was selected as the study area to assess the disservices of the plane tree (Andalusia, Spain). It is located in the southeast of the Iberian Peninsula (37° 10′ 27″ N; 3° 35′ 55″ W; 680 m a.s.l), in the northwest of the Mediterranean. According to data from the

National Institute of Statistics, the city has a surface area of 21 km^2 and a population of 232,208 inhabitants (INE, 2019).

In terms of biogeography, the city is in the Mediterranean Basin, more specifically in the Baetic Province (Costa-Pérez and Valle-Tendero, 2004). The area has an Oceanic Pluviestational bioclimate with a lower Mesomediterranean thermotype and a lower dry ombrotype, characterized by hot, dry summers and cold winters (Costa-Pérez and Valle-Tendero, 2004). The average temperature is 15 °C and the mean precipitation is 439 mm for the 1981–2019 series (AEMET, 2017).

The urban forests of the city are made up of a wide number of species of different genera, including *Platanus*, *Ulmus*, *Acer*, *Cupressus*, *Citrus*, and *Populus* (Cariñanos et al., 2016a). These species are distributed in 363 green infrastructure elements catalogued in the city, totalling 1060×10^3 m^2 of total green area, and an average of 5 m^2 of green area per inhabitant (Cariñanos et al., 2016a). Approximately 40,000 trees are in the city, with an estimated average of 19 trees/ha and 170 trees per approximately 1000 inhabitants.

Regarding allergenic indicators in the city, the most recent data from the Allergy Service of the Clinic Hospital San Cecilio indicates that 30% of the population of Granada is diagnosed with a pollen allergy, a figure that according to specialists has doubled in the last two decades. The pollen types with the greatest impact on the population are *Olea* (80% of the total affected), Grasses (54% of the total) and *Cupressus* (50% of the total). The percentage of the population affected by allergy to *Platanus* pollen is 26,2%, but it is worth noting that this number has increased significantly in recent years; since in 1990 the incidence rate was only 0,4% (Vegetation and Pollen Allergy in Granada, 2005; De Linares-Fernández, 2007).

2.2. *Platanus x hispanica* inventory

The last tree census available from the Parks and Garden Service of the City Council is from 2008, in which 4592 specimens of *Platanus* x *hispanica* were counted in the city of Granada (https://www.granada.org/inet/warboles.nsf/xtod/D563002478832861C1256E35007B9CF9; Cariñanos et al., 2016a). Given that important urban changes have taken place in the city over the last decade, and that in the census there is no other information available for the interpretation of the results (age and size of the trees), an on-site inventory of the specimens of *P.* x *hispanica* trees present in both public and private areas was carried out. To do this, the city was divided into 4 zones, grouping the main neighbourhoods and districts of the city – Zone 1: Center-East; Zone 2: North; Zone 3: West; Zone 4: South. Within these zones the number and location of the trees were recorded. The number of trees in private areas was determined from the outside and only those trees visible from the public areas were counted.

In addition to the number of *P.* x *hispanica* trees, data were also collected to calculate the age of the specimens, since we started from the assumption that mature trees produce substantially more pollen than younger trees (Matthias et al., 2012). To estimate tree age, some data on the annual potential increase in diameter at breast height (DBH) for *Platanus* x *hispanica* in the climatic conditions of Granada (Ripoll Morales et al., 2009) were used. For this calculation, a growth rate of 2,6 cm per year of the species was considered (Peper et al., 2001; Ripoll Morales et al., 2009; Shoda et al., 2020). Taking into account that our study covers a period of 27 years, the age classes indicated in Table 1 have been established.

The green infrastructure typology of which the censored specimens were a part of, according to the established categories (Branquinho et al., 2015; Salbitano et al., 2016), was also registered during the visits.

2.3. Airborne pollen data

Daily airborne pollen counts were provided by the Aerobiological Monitoring Unit, located in the Faculty of Science, University of Granada (37° 10′ 50″ N, 3° 36′ 31″ W, Fig. 1). Pollen sampling was carried out by means of a Hirst-type suction volumetric sampler, in accordance with the standardised methodology of the Spanish Aerobiology Network (REA) procedure (Galán et al., 2007). The results are expressed in pollen grains/m^3 of air/day. For our purposes, the daily data from the series between 01/1992 to 05/2019 was used.

Table 1
Tree classes established for this work based on Diameter Breast height (DBH). The classes have been established taking into account a rate of 2.6 cm of annual increase for the climate of Granada (Ripoll Morales et al., 2009).

Class	
I	Young trees (<25 years old) DBH <50 cm
II	Mature trees (between 25 and 50 years old) DBH between 50 and 100 cm
III	Old trees (more than 50 years old) DBH > 100 cm

From this daily pollen series, different phenological and aerobiological parameters of interest were determined: Pollen-Season Start Day: the day of the year where 1 pollen grain/m^3 of air is registered for at least 5 consecutive days (García-Mozo et al., 2006); Pollen-Season End Day: the day of the year were 1 pollen grain/m^3 of air is registered, followed by 5 consecutive days without any pollen count (Algarra et al., 2019); Length of the Pollen-Season: the period of time (days) between the start and end day of the season; Pollen Peak: the maximum amount of daily pollen recorded within the pollen season; Pre-Peak Period: the period of time (days) between the start day and the pollen-peak day; and Seasonal Pollen Integral (SPIn): the seasonal sum of daily pollen values (Galán et al., 2017).

2.4. Meteorological data

Daily Meteorological parameters including the maximum, minimum, and average daily temperature (°C), the total daily precipitation (mm), the relative humidity (%), the insolation (tenth of hour), the total daily radiation (W/m^2), the wind speed (m/s), and the wind direction for the 1992–2019 period were supplied by the State Agency of Meteorology (AEMET) from the closest Meteorological Weather Station (Base Aerea Armilla, 37° 8′ 14″ N, 3° 37′ 53″ W).

From these variables, other parameters were studied. Both cumulative (Ac) and average (Av) values from the previous autumn (6 months before the start of the pollen season, PA), the previous winter (3 months before the start of the pollen season, PW) and the main pollen season (MPS), were calculated in order to understand their influence on the aerobiological variables.

2.5. Air pollution data

In order to explore the possible relationships between airborne pollen and atmospheric pollutants, data about the main air pollutants were requested from the Network of Environmental Data of Andalusia (REDIAM) the General Directorate of Prevention and Environmental Quality of the Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development of the Junta de Andalucía. Data included gases (CO, NO_2, NO, NO_X, O_3, SO_2) and particulate matter ($PM_{2.5}$, PM_{10}) for the period available (2010–2019), and were recorded in the Station of the Environmental Surveillance Control Network located in the Conferences Centre of Granada (37° 10′ 03″ N, 03° 35′ 56″ W, Fig. 1).

Similar to what was done with the meteorological variables, new monthly and seasonal variables for statistical purposes were created using the data provided – i.e. the average data of the values during 1, 2, or 3 months before pollen season start (1 M, 2 M, 3 M) and seasons prior (previous autumn PA, previous winter PW), as well as during the Main Pollen Season (MPS).

2.6. Statistical analysis

Average annual data (aerobiological, phenological, meteorological, and atmospheric pollutants) were fitted to simple linear regression

Fig. 1. Location of study area.

models, and slopes of regression equations and determination coefficients (R^2) were examined in order to determine possible trends throughout the study period.

A Shapiro-Wilk Test for normality was carried out to contrast the normality of the data and select the appropriate correlation test. Afterwards, either Spearman's or Pearson's correlation between aerobiological data and environmental data (meteorological and pollution) were tested in order to find significant relationships between variables.

The variables that previously correlated with the SPIn and Peak Value were adjusted to Generalized Linear Models (GLM) using the Poisson distribution and the logarithmic link function. Various models were created and the most appropriate one was chosen according to the Akaike Information Criterion (AIC), so that the variables that performed best were selected, and therefore were the ones that had the greatest influence on these parameters. All the statistical analyses were carried out using R software (R Core Team, 2019).

3. Results

The census of London plane specimens in the city of Granada resulted in a total of 5655 individuals of *P.* x *hispanica*, representing a density of 2.7 trees/ha, although this value was not uniform throughout the entire city. The densest populations were in the northern zone and in the central zone of the Genil river where they are mainly in road alignments, sidewalks, and parks (Table 2, Fig. 2). The Center-East area of the city contained the highest percentage of Class III trees (trees over 50 years old), while the North area contained the highest percentage of Class I trees (trees under 25 years old). Most of the trees in the city were Class II, that is, mature trees between the ages of 25 and 50 years old. If we consider that the populations located within a radius of 2 km around the pollen sampler are the ones that most influence the pollen levels collected, then these concentrations come mainly from the populations located to the east, south, and southwest of the sampler. These populations have an average of between 20 and 40 trees, although there are also populations that exceed one hundred individuals in full reproductive maturity (Table 2).

Table 2
Percentage of trees of each class in each of the areas of Granada established in this study. Trees in the different areas: 1163 in Center-Eastern zone; 2568 in Northern zone; 864 in West; 1339 in Southern zone.

Zone	Class I	Class II	Class III
Center-East	3.78	64.75	31.47
North	72.28	25.66	2.06
West	41.09	58.91	0
South	48.02	48.99	2.99

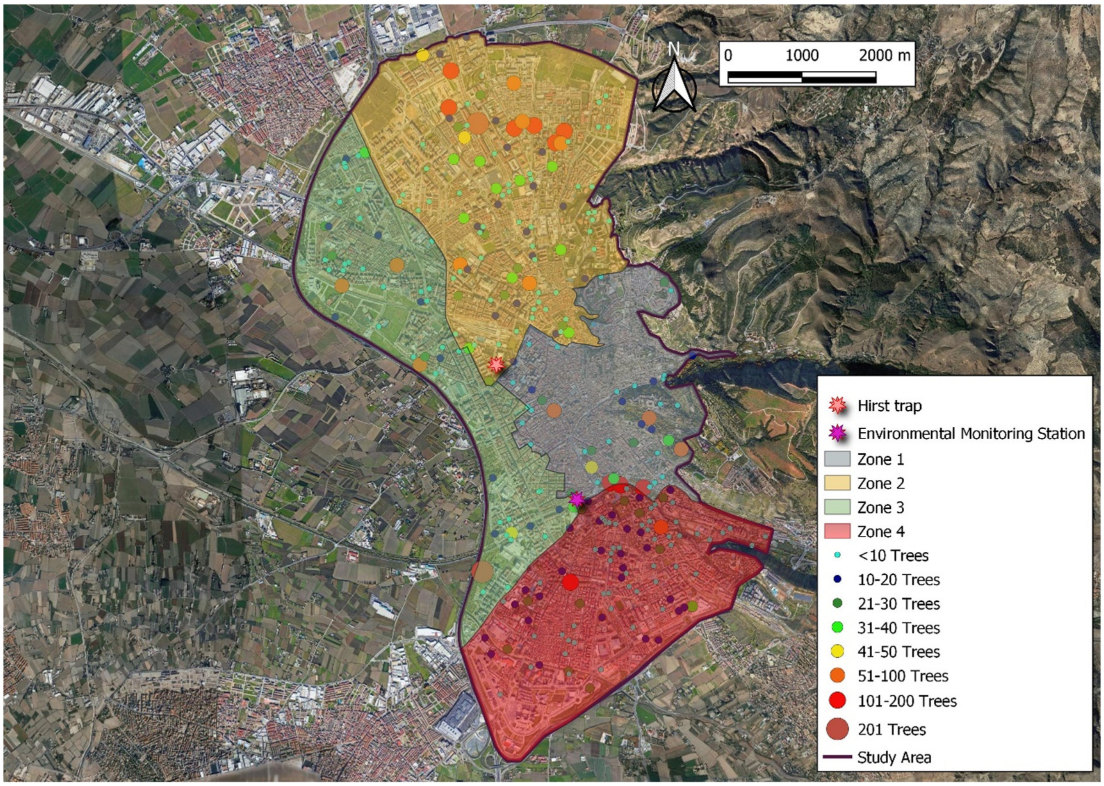


Fig. 2. Distribution map of *P.* x *hispanica* in the city of Granada (Spain).

As for the aerobiology of this taxa, the pollen begins to be detected in the atmosphere of the city at the end of February and the beginning of March, peaking generally in the middle of March, after which the concentrations decrease between the end of March and April (Fig. 3). The pollen season start date takes place from the beginning to the end of March, and the pollen season end date takes place from mid-April to the end of May. This has generated flowering periods of an average duration of 44 days, but with oscillations ranging from 27 days in 2004 to

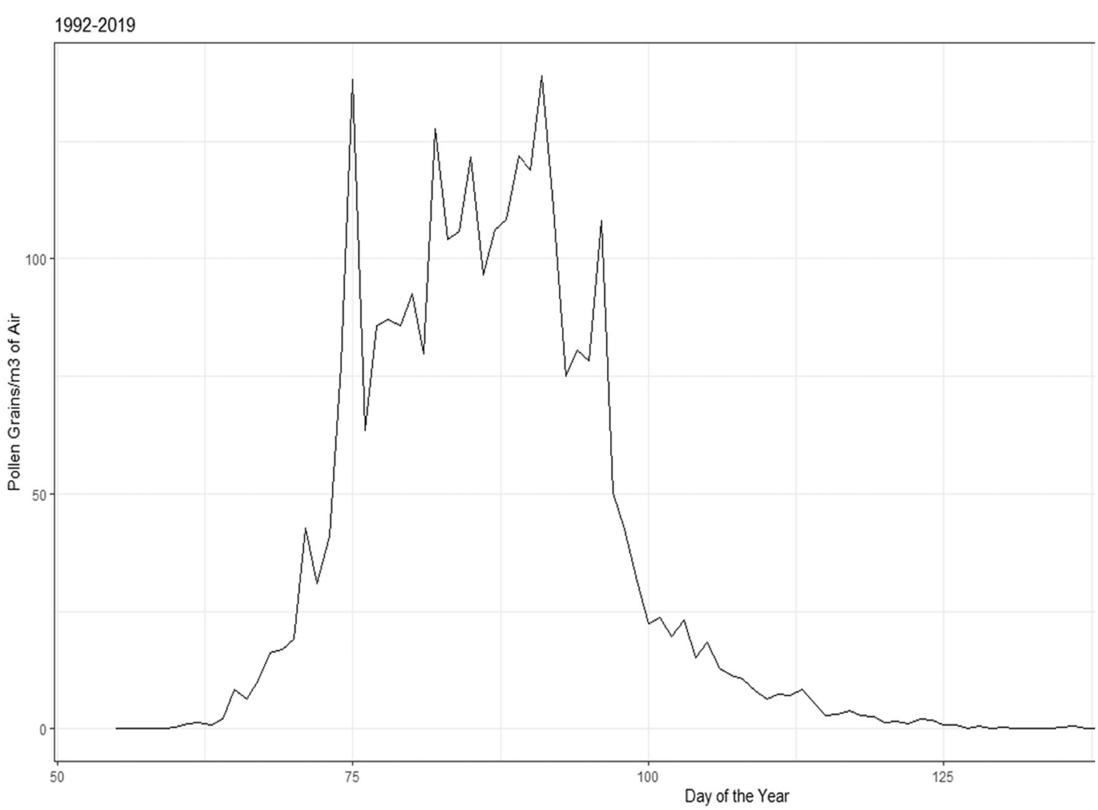


Fig. 3. Mean daily pollen concentrations from 1992 to 2019 in the city of Granada.

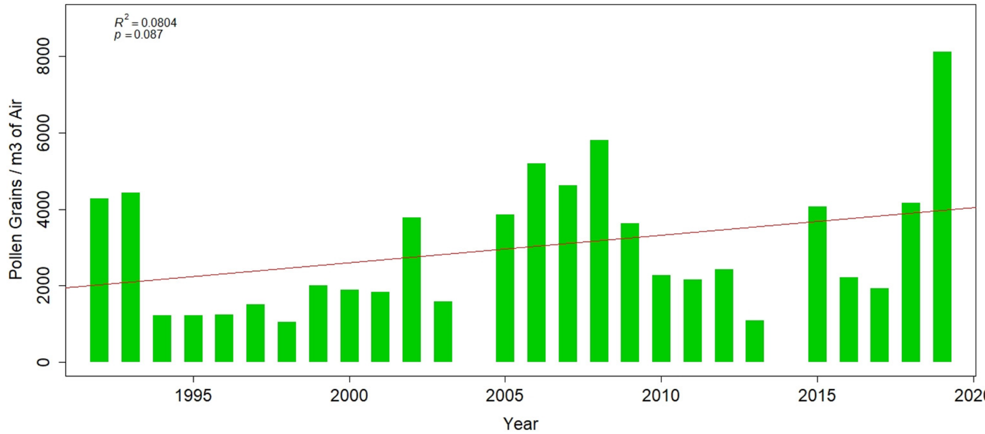


Fig. 4. *P. x hispanica* Seasonal Pollen Integral (SPIn) (Pollen grains/season) from 1992 to 2019. The years 2004 and 2014 have been removed from the series due to the sensor malfunction.

74 days in 2017 (Supplementary Table 1). The time elapsed between the beginning of flowering and the peak date has also been highly variable: just 2 days in some years (2003, 2010), up to 22 days in 2004. With an average peak value of 486 pollen grains throughout of the series, this data had a minimum of 128 pollen grains in 1994 and a maximum of 1534 pollen grains in 2004. The Average Seasonal Pollen Integral (AvSPIn) throughout the series resulted in a value of 2708 pollen grains, with a coefficient of variability between years (the difference between the maximum and the minimum value divided by the average value) of 190%. The two extremes of this average are 1998 which had a SPIn value of 1058, and 2019 which had 8114 pollen grains.

Adjustments to the simple linear regression of the main aerobiological parameters resulted in a significant trend towards the delay at the beginning of flowering throughout the series (+0.3979 days/year, p-value = 0.029; $R^2 = 0.136$) and a significant delay at the end of the season (+0.7833 days/year; p-value = 0.0023; $R^2 = 0.28$). However, these trends did not generate a significant increase in the length of the season (0.407 days/year; p-value = 0.12; $R^2 = 0.0571$) (Supplementary Figs. 1–3). As for the Seasonal Pollen Integral (SPIn), although it has shown a tendency to increase by 72 pollen grains/year, this trend was not significant (p-value = 0.087; $R^2 = 0.0804$) (Fig. 4).

3.1. Relationship between aerobiological and meteorological data

The linear regression adjustment of the meteorological data for the 1992–2019 period showed significant linear trends (p-value < 0.05) in the case of the annual average humidity (p-value = 0.042; $R^2 = 0.122$), the annual average pressure (p-value = 0.017; $R^2 = 0.175$), and the annual average maximum temperature (p-value = 0.0067; $R^2 = 0.229$) (data not shown). It is also worth noting that, although not significant, the annual average minimum temperatures (p-value = 0.77; $R^2 = -0.0363$), annual average temperature (p-value = 0.55; $R^2 = -0.0247$) and total annual precipitation (p-value = 0.46; $R^2 = -0.0174$) for the entire period considered showed a negative trend (Supplementary Figs. 4 and 5), that is, towards a progressive decrease.

Spearman's non-parametric correlation analysis between aerobiological variables and meteorological variables (Table 3) resulted in significant correlations ($p < 0.05$) between SPIn and the accumulated precipitation during the winter prior to the pollen season (AcPrec_PW), the minimum temperature (average and cumulative) from the previous winter (AvTmin_PW, AcTmin_PW) to the pollen season, and the wind speed during the main pollen season (WS_MPS). In the case of the pollen peak value, the correlation between the temperatures during the winter prior to the flowering season was significant (AvTmin_PW, AcTmin_PW, AvT_PW) (Table 3).

For the parameters start date, end date, and length of MPS, different correlations with the meteorological variables were presented (Supplementary Table 2). In summary, the beginning of the pollen season showed a significant negative-sign relationship between the relative humidity and the temperature during February (1 month before the pollen season). Also, there was a positive relationship between global radiation and the temperature prior to the pollen season. Regarding the end date, negative correlations were obtained with the humidity prior to the MPS. On the other hand, the duration of the flowering period was related to the maximum temperature immediately prior to flowering (Supplementary Table 2).

The variables that best correlated with both SPIn and the Pollen Peak were adjusted to Generalized Linear Models (GLM) by using the Poisson distribution and the logarithmic link function. In the case of SPIn (Table 4), the model that performed best according to the Akaike Information Criterion (AIC), and once the lack of multicollinearity was verified using the Variance Inflation Factor (VIF > 5), included the Average minimum Temperature (AvTmin_PW) and precipitation accumulated during the previous winter (AcPrec_PW), and the wind speed during

Table 3
Spearman's Correlations significant results between the SPIn and Peak value with meteorological variables. **AcPre_PW**: Accumulated Precipitation during Previous Winter; **AvTmin**: Average Minimum Temperature during Previous Winter; **AcTim_PW**: Accumulated Minimum Temperature during Previous Winter; **AvT_PW**: Average Temperature during Previous Winter; **WS_MPS**: Win Speed during Main Pollen Season.

Aerobiological variable	Meteorological variable	Correlation coefficient (rho)
Seasonal Pollen Index	AcPre_PW	−0.4038462*
	AvTmin_PW	−0.4175487*
	AcTmin_PW	−0.4069231*
	AvT_PW	−0.3962335*
	WS_ MPS	0.4595099*
Peak value	AvTmin_PW	−0.4029417*
	AcTmin_PW	−0.3962393*
	AvT_PW	−0.3982883*

* p < 0.05.

Table 4
Results, Coefficients and significance levels of the GLM between SPIn and Meteorological Data. **AcPre_PW**: Accumulated Precipitation during Previous Winter; **AvTmin**: Average Minimum Temperature during Previous Winter; **WS_MPS**: Wind Speed during Main Pollen Season.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	Signif. ***
AvTmin_PW	−0.0629568	0.0045382	−13.87	<2e−16	***
WS_ MPS	0.0896658	0.0037640	23.82	<2e−16	***
AcPrec_PW	−0.0015994	0.0000748	−21.38	<2e−16	***

AIC: 10507; Null Deviance: 14647; Residual Deviance: 10325; D^2: 29.51.
*** <0.001.

Table 5
Results, Coefficients and SPIn significance levels of the GLM between Pollen Peak Value and Meteorological Data. **AvTmin**: Average Minimum Temperature during Previous Winter; **AvT_PW**: Average Temperature during Previous Winter.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	Signif. ***
AvTmin_PW	−0.21016	0.01206	4.061	0.000049	***
AvT_PW	0.07548	0.01859	4.061	<2e−16	***

AIC: 6405.9; Null Deviance: 6982.9; Residual Deviance: 6197.8; D^2: 11.24.
*** <0.001.

the pollen season (WS_MPS) ($p < 0.001$). With these parameters, a 29.51% of the variability of the variable (deviance) is explained by the model. It is interesting to note that the average minimum temperature of the previous winter (AvTmin_PW) has a negative sign. The variables selected by the GLM to explain the value of the pollen peak included those with which it had a significant correlation (Table 3). Once the lack of multicollinearity of the variables (VIF > 5) was verified and according to the AIC, the model obtained explained a variance of 11.24% (deviance) with the average minimum temperature of the previous winter (AvTmin_PW), and the average temperature of the winter prior to the pollen season (AvT_PW) (Table 5).

3.2. Relationship between aerobiological and air pollution data

Spearman's correlations between aerobiological variables and pollution data showed a highly significant correlation ($p < 0.01$) between the peak value and O_3 concentrations two months before the pollen season, and a significant correlation ($p < 0.05$) with NO_2 prior to the flowering, in both cases with a negative sign. The relationship between SPIn and PM_{10} content (PM_{10}_MPS1) in the first month of the pollen season was also significant ($p < 0.05$) (Table 6).

For the rest of the aerobiological variables, different correlations were presented to highlight the relationship between the length of the MPS and CO, NO_2, NOx, and SO_2, both before and during the flowering period. The Peak Day was correlated with both PM_{10} and $PM_{2.5}$, before and during the MPS (Supplementary Table 3).

Since PM_{10} was the only variable with which a significant correlation was obtained for SPIn, several GLM models were tested to analyze the possible influence of other variables, achieving the best results in the models that included the PM_{10} concentrations of the first month of the pollen season (PM_{10}_MPS1) as an independent variable (Estimate = 0.062148; z-value = 44.45; Pr(>|z|) = <2e−16; Signif. = ***) which can explain up to 22.27% of the variance (D^2).

Regarding the results of the GLM modelling for the pollen peak and the contaminants, according to the AIC, the models that included the NO and O_3 variables were the most adjusted ($D^2 = 53.33$). The best model obtained was the one that incorporated data from both pollutants (NO and O_3) before the flowering season (Table 7).

4. Discussion

P. x hispanica is one of the most abundant plant species in the green infrastructure of the city of Granada (Cariñanos et al., 2016a). The 5655 inventoried specimens in this work represent 14.5% of the total trees in the city. As such, it is the most prominent species (Cariñanos et al., 2016a). Unlike other urban trees, the plane tree is present in all kinds of green infrastructure elements (road alignments, sidewalks, roundabouts, squares, parks, public and home gardens, and historical gardens) which denotes its versatility and great adaptability to urban environmental conditions (Valero et al., 1999; Gabarra et al., 2002; Nowak et al., 2012; Alcázar et al., 2015; Willis and Petrokofsky, 2017). However, its distribution throughout the city is not uniform, with the most numerous populations being found in road alignments in the northern district and along sidewalks and squares of the downtown district of the city. The specimens found in the latter section are the oldest in the city of Granada, where they provide the greatest coverage and are commonly used as shade trees. Therefore, these populations contribute most to the pollen concentrations detected in the pollen sampler, both because they are located within a radius of 500 m, and thus have the greatest influence on the pollen concentrations recorded at the monitoring site (Maya-Manzano et al., 2017a,b), and because of their age and crown volume, producing significantly more pollen than younger trees (Matthias et al., 2012; Bogawski et al., 2019).

The period in which pollen is present in the atmosphere of Granada usually begins during the month of March and ends between the end of April and the beginning of May. The trend analysis throughout the study period has shown a delay of the start and end date. The delay is greatest for the end date which might result in a longer flowering period. This trend towards increasingly later flowering periods has been observed in other areas of the region on the same species, but with different bioclimatic features (Alcázar et al., 2011). Furthermore, *Platanus* pollen usually is recorded in the atmosphere at an average of 47 days per year. This data positions Granada as one of the Spanish cities with the greatest number of days in which this specific pollen is present in the aerobiological records, only behind Madrid in which the number of trees of this species exceeds 125,000 specimens (Alcázar et al., 2011; Borrajo Millán et al., 2018).

The seasonal peak is recorded after a few days (an average of 10 days after flowering begins). This dynamic of rapid and intense flowering coincides with studies carried out in other locations (Alcázar et al., 2004; Iglesias et al., 2007; Nowak et al., 2012; Alcázar et al., 2015), which may indicate that although the release of pollen can be advanced or delayed according to the weather conditions of each year (Tedeschini et al., 2006), once flowering begins, the pattern of the curve is quite similar. The average value of the pollen peak has also presented strong oscillations throughout the series, representing only 6.8% of the total pollen count recorded in the 2017 season, up to 36.9% of the total pollen count in the 2019 season. With an average value of 480 pollen grains throughout the series, this peak value exceeds the threshold of 50 pollen grains/day required to develop allergic symptoms several times (Varela et al., 1997; Nowak et al., 2012), and also exceeds the 150 grains of pollen/day considered as a high risk value (Alcázar et al., 2004). The maximum daily pollen concentrations recorded in Granada are also among the highest in Andalusia which itself is among the highest in Spain (Díaz de la Guardia et al., 1999; Alcázar et al., 2011).

With regard to Seasonal Integral Pollen (SPIn), trends towards higher amounts of atmospheric pollen were observed throughout the series. Bearing in mind that the number of plane trees in the city of

Table 6
Spearman's correlations between Aerobiological Variables and Atmospheric pollution (2010–2019). SPIn: Seasonal Pollen Integral; **PM_{10}_MPS1**: PM_{10} concentration the first month of the Main Pollen Season; **NO_3M**: NO concentrations three months prior to flowering; **O_3_2M**: O_3 concentrations two months prior to flowering.

Aerobiological variable	Pollutant	Correlation coefficient (rho)
Seasonal Pollen Index	PM_{10} _MPS1	0.7380952*
Peak value	NO_3M	−0.716666*
	O_3_2M	−0.7815402**

** p < 0.01.
* p < 0.05.

Table 7
General Linear Model (GLM). Peak Value as Dependent Variable. **O_3_2M**: O_3 concentrations two months prior to flowering. **NO_3M**: NO concentrations three months prior to flowering.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	Signif. ***
O_3_2M	−0.130177	0.005956	−21.86	<2e−16	***
NO_3M	−0.069459	0.003322	−20.91	<2e−16	***

AIC: 1443.4; Null Deviance: 2928.5; Residual Deviance: 1366.8; D^2: 53.33.
*** <0.001.

Granada over the last two decades has marginally increased by 1000 specimens, mostly in new peripheral neighbourhoods, the rise in pollen concentrations may be due to several causes. In principle, the growth of the trees over the study time, 27 years, could be considered enough time for the specimens to reach their optimum maturity, and therefore, their maximum pollen emission capacity (Bogawski et al., 2019). While for many years the trees have been pruned frequently and intensively, dramatically decreasing the amount of pollen emitted, the new concepts of pruning may be favouring the production of flowers and the amount of pollen/tree (Bedker et al., 1995; Ferrini, 2006). Another potential cause could be due to the changing weather during the flowering period, with a clear continuous decline of precipitation in March (Paredes et al., 2006). This would allow for the amount of pollen released to remain airborne longer, since they are not washed away by the rain (Jones and Harrison, 2004). A third cause that would explain this increase in annual pollen concentrations would be in line with the trends observed in numerous European locations, where a greater intensity of flowering is detected as a result of anthropogenic CO_2 emissions and increased temperatures (D'Amato et al., 2010; Ziello et al., 2012).

Related to the effect of the meteorological parameters, the temperature prior to the flowering period showed to be one of the most influential factors on the Seasonal Pollen Integral (SPIn). Previous studies had already highlighted that temperature is the weather parameter with the greatest influence on the *Platanus* pollen season (Tedeschini et al., 2006; Iglesias et al., 2007; Sánchez-Reyes et al., 2009; Maya-Manzano et al., 2017a). The accumulated minimum and average temperature values in the period prior to flowering have also been indicated as some of the most influential parameters on the vegetative period of deciduous species with similar behaviour to that of the shadow plane, such as *Fraxinus* (Kubik-Komar et al., 2018), *Alnus* (Piotrowska-Weryszko, 2013), *Betula*, *Populus* (Pletser et al., 2015), and the deciduous *Quercus* species close to the study area (García-Mozo et al., 2011). In urban environments, the influence of the minimum temperature on flowering is even more evident due to urban microclimate conditions (Li et al., 2019). In the case of the city of Granada, the temperature threshold needed to break the dormancy of the buds of *P.* x *hispanica* is of 2.5 °C to be accumulated from February 10th (Alcázar et al., 2011). Therefore, the increase of the minimum winter temperatures of 1.1 °C every 30 years (which is the projected increase for the Mediterranean region) (De Castro et al., 2005; Giorgi and Lionello, 2008), can negatively affect the reproductive development of this species. This has been indicated by the negative correlation shown between the minimum winter temperature prior to flowering and SPIn, indicative of the inverse relationship between both variables. The correlation with winter precipitation prior to flowering has also been shown to be negative. Again, climate projections for the region also estimate a significant reduction in rainfall, especially in the summer-autumn seasons (Giorgi and Lionello, 2008), which will affect the amount of water accumulated during the vegetative phase. As a result, the phenological and aerobiological monitoring of *P.* x *hispanica* in the city of Granada can become an important source of environmental information due to its dependence on these changing environmental conditions (Mimet et al., 2009).

During flowering, the variable that relates to the amount of atmospheric pollen is the wind speed due to a double effect, since it favours the release from anthers and transports the pollen through the atmosphere (Grundström et al., 2017; Recio et al., 2018). The predominant wind direction throughout the study period was south, in which the highest number of high-speed gusts were reached, as well as the northwest. The relationship between wind speed and pollen is positive since these winds would transport pollen emitted by the populations located in the northern part of the city, as well as those found in the downtown district, which contain the most mature trees with the highest pollen emission. Subsequently, they would be at a lesser distance from the one established as adequate for the transport of pollen from *Platanus* in the urban area, which is approximately 2550 m (Bricchi et al., 2000).

Most of the pollutants in the city's atmosphere have shown a downward trend since 2010, although not significantly. However, 2017 has been described as having the worst air quality of the entire historical data series (European Environmental Agency, 2017; Ceballos, 2018). This reduction may be related to the implementation of international air quality policies (Council Directive 96/6/EC Air Quality Framework Directive 96/62/EC), national air quality policies (National Air Quality Plan 2017–2019_Plan Aire II), and local air quality policies (Casquero-Vera et al., 2016). Despite this, O_3 has shown a slight tendency to increase its levels in the atmosphere, exceeding the target values for the protection of the vegetation of 120 micrograms/m^3 several times (Report of the Evaluation of Air Quality in Spain, 2018, 2019). The atmospheric ozone values of the city are not only at the level of Madrid and Barcelona (with a population 20 times higher), but also far from the values contained in Royal Decree 1796/2003, which denotes the amount of ozone in ambient air which would be harmful to the health of vegetation and people (Environmental Profile of Spain, 2006). As a secondary pollutant, ozone appears in the atmosphere as a consequence of reactions initiated by nitrogen oxides (NOx) and volatile organic compounds (VOCs), in particular hydrocarbons, in the presence of visible radiation (Velázquez de Castro González and Jiménez Arcas, 2007). This situation frequently occurs in Granada. It must be stated that both the NO_x and O_3 variables have been included in the GLM model and show a significant correlation with the value of the pollen peak both before and during flowering. However, we must also consider Biogenic Volatile Organic Compounds (BVOCs) emissions, especially isoprene, produced by the London plane tree, since the plane tree produces the highest amount of BVOCs among all of the most prominent urban tree species (Chaparro and Terradas, 2009; Steinbrecher et al., 2009). The negative sign that the correlation has shown may be indicative of the reducing effects on growth and productivity that both pollutants exert on plants (Ziello et al., 2012; WHO, 2013; Oduber et al., 2019).

For the SPIn, the correlation with the concentrations of PM_{10} once flowering began was significant. A correlation between daily pollen levels and daily PM_{10} concentrations had already been observed in a previous study by Cariñanos et al. (1999) in the city of Córdoba (Spain). Although several studies link the presence of PM in the atmosphere with the direct emission of anthropogenic sources and with the intrusion of Saharan dust, the origin of these particles may also be found in the rupture of pollen grains. An increase in the total suspended particulate matter (PM) mass during the pollen season has been observed in some areas (Laakso et al., 2003; Manninen et al., 2014), and the presence of these particles can be explained by both the abundant biological load at certain times, such as the agglomeration that can occur between smaller particles (Laakso et al., 2003). The period in which the plane tree blooms in Granada coincides with that of other anemophilous species which are abundant in the city and in its peri-urban environment, such as *Quercus*, *Pinus*, *Acer* and *Populus*, and significant pollen levels of Cupressaceae are still registered (Díaz de la Guardia et al., 2003; Cariñanos et al., 2016b). Atmospheric interactions between the plane tree and these other anemophilous species could cause a mechanical breakdown and the formation of PM which have a size of 10 μm or even smaller. It has also been observed how the pollen of *Platanus* become swollen after being exposed to some pollutants (Lu et al., 2006; Sénéchal et al., 2015), which leads to a breakdown in unequal size fragments. Studies in which the allergenic load has been analyzed in fractions of submicron size have revealed that the *Pla a* 3 allergen is more abundant in particulate material of size >7 μm (Zhou et al., 2019), and that *Pla a 2* is more abundant in the fraction of size range 2.1–1.1 μm (De Linares-Fernández, 2007), which could explain the adjusted results obtained in the GLM between SPIn and both types of PM. It has also been observed that under conditions on ambient humidity above 50%, plane tree pollen grains can release the allergens in the pollen wall (Suárez-Cervera et al., 2005). This breakdown of pollen grains into submicron fragments may also cause symptoms of severe asthma that occur in the population sensitized to *Platanus* pollen up to 15 days after flowering ends, when pollen concentrations are <200 grains of pollen/day (Varela et al., 1997). In Granada, the percentage of the population who are allergic to *Platanus* pollen has increased 25% in 30 years. Therefore, rethinking and reconsideration of the role of plane tree as an element of urban green infrastructure is necessary in order to shift the net balance of Ecosystem Services to the side of benefits and to minimize the disservices associated with their presence.

5. Conclusions

The results obtained in this study highlight that, apart from the key role that London plane has as a provider of ecosystem services in urban green infrastructure, allergen pollen emissions during the reproductive phase are a significant disservice. This has been confirmed by the rapid increase in the percentage of people sensitive to its allergens which has been experienced in recent decades in cities like Granada. This increase in the incidence percentage could be related to the trend towards higher allergen emissions that has been detected throughout the series. Among the causes that justify this increase may be the intrinsic growth of trees in the three decades considered, as well as the new concepts of pruning and management, which can lead to a greater production of pollen per tree. The effect that both meteorological parameters and air pollutants have on the phenology and aerobiology of *Platanus* x *hispanica* have been also analyzed. One of the most influential factors in pollen emissions is the temperature prior to the flowering period, and the alterations for this parameter foreseen in the different climate change scenarios projected for the Mediterranean region could have a direct effect on the reproductive phase. The correlations obtained between seasonal pollen levels and some air pollutants also highlight the possible involvement of *Platanus* pollen in worsening urban air quality, as it may contribute to an increase in PM during the flowering period, in addition to the direct effect that these pollutants can have on the growth and productivity of trees in urban environments. These results also highlight the need to rethink the hegemonic role that the London plane tree plays today in the Green Infrastructure of many cities, especially given the challenge of climate change that cities face, where the reinforcement of green elements is indicated as one of the more effective measures. An adequate selection of species as well as an expanded knowledge of possible associated disservices that they entail would prevent the net balance of benefits from being minimized.

CRediT authorship contribution statement

Paloma Cariñanos: Conceptualization, Formal analysis, Writing - original draft.**Soledad Ruiz-Peñuela:**Formal analysis, Writing - review & editing.**Ana M. Valle:**Formal analysis, Writing - review & editing. **Consuelo Díaz de la Guardia:**Investigation, Writing - review & editing.

Declaration of competing interest

Paloma Cariñanos, as corresponding author and on behalf of the co-authors, declares that she has not have any conflicts of interest.

Acknowledgements

The authors thank REDIAM and AEMET for the data provided. Paloma Cariñanos also thanks the Spanish Ministry of Economy and Competitiveness (MINECO) for support through project BIOCLOUD RTI2018-101154-A-100, and the University of Granada, Programa Operativo FEDER Andalucia 2014–2020 through project INPARK B-RNM-474-UGR18.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.139722.

References

Alcázar, P., Cariñanos, P., De Castro, C., Guerra, F., Moreno, C., Dominguez-Vilches, E., Galán, C., 2004. Airborne plane-tree (*Platanus hispanica*) pollen distribution in the city of Cordoba, South-western Spain, and possible implications on pollen allergy. J Invest Allergol Clin Immunol 14 (3), 238–243.

Alcázar, P., García-Mozo, H., Trigo, M.M., Ruiz, L., González-Minero, F.J., Hidalgo, P., Díaz de la Guardia, C., Galán, C., 2011. Platanus pollen season in Andalusia (southern Spain): trends and modelling. J. Environ. Monit. 13, 2502.

Alcázar, P., Galán, C., Torres, C., Dominguez-Vilches, E., 2015. Detection of airborne allergen (Pla a 1) in relation to Platanus pollen in Cordoba, South Spain. Annals of Agricultural and Environmental Medicine 22, 96–101.

Algarra, J.A., Cariñanos, P., Herrero, J., Delgado-Capel, M., Ramos-Lorente, M.M., de la Guardia, C.D., 2019. Tracking Montane Mediterranean grasslands: analysis of the effects of snow with other related hydro-meteorological variables and land-use change on pollen emissions. Sci. Total Environ. 649, 889–901.

Agencia Estatal de Meteorología. Informe Anual 2016. Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente. Gobierno de España. 2017.

Baldachini, C., Castanheiro, A., Maghakyan, N., Sgrigna, G., Verhelst, J., Alonso, R., Amorim, J.H., Bellan, P., Dunisijevic Bojovic, D., Breuste, J., Bühler, O., Cantar, I., Cariñanos, P., CArriero, G., Churkina, G., Dinca, L., Esposito, R., Gawronski, S.W., Kern, M., Le Thiec, D., Moretti, M., Ningal, T., Rantzoudi, E.C., Sinjur, I., Stojanova, B., Calfapietra, C., Samson, R., 2017. How does the amount and composition of PM deposited on Platanus acerifolia leaves change across different cities in Europe? Environ. Sci. Technol. 57, 1147–1156.

Bedker, P.J., O'Brien, J.G.O., Mielke, M.M., 1995. How to Prune Trees. NA-FR-01-95. USDA Forest Service. Northeastern Area State and Private Forestry (28 pp.).

Bist, A., Pandit, T., Bhatuagar, A.K., Sing, A.B., 2004. Variability in protein content of pollen of Castor Bean (Ricinus communis) before and after exposure to the air pollutants SO2 and NO2. Grana 43 (2), 94–100.

Bogawski, P., Grewling, L., Dziób, K., Sobieraj, K., Dale, M., Dylawerska, B., Pupkowski, D., Nalej, A., Nowak, M., Szymanska, A., Kostecki, L., Nowak, M.M., Jackowiak, B., 2019. Lidar-derived tree crown parameters: are they new variables explaining local birch (Betula sp.) pollen concentrations? Forest 10, 1154.

Borrajo Millán, J.M., Rastrollo, Gonzalo A., Nowak, D.J., 2018. Valor del Bosque Urbano de Madrid. Subdirección General de Conservación de Zonas Verdes y Arbolado Urbano del Ayuntamiento de Madrid.

Branquinho, C., Cvejic, R., Eler, P., Gonzales, P., Haase, D., Hansen, R., Kabish, N., Rall, L., Niemela, J., Pauleit, S., et al., 2015. A Typology of Urban Green Spaces, Ecosystem Services, Provisioning Services and Demands; Report D3.1. Green Surge Project, Copenhagen, Denmark.

Bricchi, E., Frenguelli, G., Mincigrucci, G., 2000. Experimental results about *Platanus* pollen deposition. Aerobiologia 16, 347–352.

Cariñanos, P., Galán, C., Alcázar, P., Dominguez, E., 1999. Diurnal variation of biological and non-biological particles in the atmosphere of Córdoba, Spain. Aerobiologia 15, 177–182.

Cariñanos, P., Casares-Porcel, M., Quesada-Rubio, J.M., 2014. Estimating the allergenic potential of urban green spaces: a case study in Granada, Spain. Landsc. Urban Plan. 123, 134–144.

Cariñanos, P., Adinolfi, C., Díaz de la Guardia, C., De Linares, C., Casares-Porcel, M., 2016a. Characterization of allergen emission sources in urban areas. J. Environ. Qual. 45, 244–252.

Cariñanos, P., Casares-Porcel, M., de la Guardia, A.V.D., de la Cruz-Márquez, R., de la Guardia, C.D., 2016b. Charting trends in the evolution of the La Alhambra forest (Granada, Spain) through analysis of pollen emission dynamics over time. Clim. Chang. 135 (3–4), 453–466.

Cariñanos, P., Calaza-Martínez, P., O'Brien, L., Calfapietra, C., 2017. The cost of greening: disservices of urban trees. The Urban Forest. Springer, Cham, pp. 79–87.

Cariñanos, P., Grilo, F., Pinho, P., Casares-Porcel, M., Branquinho, C., Acil, N., Andreucci, M.B., Anjos, A., Bianco, P.M., Brini, S., Calaza-Martínez, P., Calvo, E., Carrari, E., Castro, J., Chiesura, A., Correia, O., Gonçalves, A., Gonçalves, P., Mexia, T., Mirabile, M., Paoletti, E., Santos-Reis, M., Semenzato, P., Vilhar, U., 2019a. Estimation of the allergenic potential of urban trees and urban parks: towards the healthy design of urban green spaces of the future. Int. J. Environ. Res. Public Health 16. https://doi.org/10.3390/ijerph16081357.

Cariñanos, P., Delgado-Capel, M., Madariaga-Marín, M.F., 2019b. Considerations on the allergy-risks related to the consumption of fruits from urban trees in Mediterranean cities. Urban Forestry and Urban Greening 45, 126303.

Casquero-Vera, J.A., Titos, G., Alados-Arboledas, L., 2016. Diagnóstico de la Calidad del Aire del área metropolitan de Granada. Agenda 21. Ayuntamiento de Granada.

Castroviejo, S., Aedo, C., Cirujano, S., Laínz, M., Montserrat, P., Morales, R., Muñoz Garmendia, F., Navarro, C., Paiva, J., Soriano, C. (Eds.), 1990. Flora Ibérica 2. Real Jardín Botánico, CSIC, Madrid.

Ceballos MA. 2018. La calidad del aire en el Estado español durante 2017. Ecologistas en Acción (Ed.). (Madrid).

Cennamo, P., Cafasso, D., 2002. Molecular markers as a tool for the identification of hybrid plane trees. Delpinoa 44, 89–94.

Chaparro, L., Terradas, J., 2009. Report on Ecological Services of Urban Forest in Barcelona. Barcelona City Council, Barcelona, Spain: Department of Environment (96 pp.).

Costa-Pérez, J.C., Valle-Tendero, F., 2004. Modelos de restauración forestal: datos botánicos aplicados a la gestión del medio ambiente andaluz. Manual de Restauración Forestal. Consejeria de Medio Ambiente, Junta de Andalucía, Sevilla.

Curtis, A.J., Helmig, D., Baroch, C., Daly, R., Davis, S., 2014. Biogenic volatile organic compound emissions from nine tree species used in an urban tree-planting program. Atmos. Environ. 95, 634–643.

D'Amato, G., Cecchi, L., D'Amato, M., Liccardi, G., 2010. Urban air pollution and climate change as environmental risk factors of respiratory allergy: an update. J Invest Allergol Clin Immunol 20 (2), 95–102.

Damialis, A., Fotiou, C., Halley, J.M., Vokou, D., 2011. Effects of environmental factors on pollen production in anemophilous woody species. Trees, Structure and Function 25, 253–264.

De Castro, M., Martín-Vide, J., Alonso, S., 2005. The climate of Spain: past, present and scenarios for the 21st century. In: MMA (Ed.), Evaluación preliminary de los impactos en España por efecto del cambio climático. Ministerio de Medio Ambiente, Madrid, Spain, pp. 1–65.

De Linares-Fernández, C., 2007. Análisis del polen alergógeno en la atmósfera de Granada: Evolución de las concentraciones polínicas, actividad alergénica e incidencia en la población atópica. (Tesis Doctoral). Universidad de Granada, Granada.

Díaz de la Guardia, C., Sabariego, S., Alba, F., Ruiz, L., García-Mozo, H., Toro Gil, F.J., Valencia, R., Rodriguez Rajo, F.J., Guárdia, A., Cervigón, P., 1999. Aeropalynological study of the genus *Platanus* L. in the Iberian Peninsula. Polen 10, 89–97.

Díaz de la Guardia, C., Alba, F., Nieto-Lugilde, D., Sabariego, S., 2003. Diez años de control aerobiológico en la atmósfera de la ciudad de Granada. Calendario polínico (1992–2001). Polen 13, 251–260.

Duhoux, E., 1982. Mechanism of exine rupture in hydrated taxoid type of pollen. Grana 21, 1–7.

Endreny, T.A., 2018. Strategically growing the urban forest will improve our world. Nat. Commun. 9, 1160.

Environmental Profile of Spain, 2006. An Indicator-based Report. Ministerio de Medio Ambiente, Gobierno de España.

Esperon-Rodrigez, M., Power, S.A., Tjoelker, M.G., Beaumont, L.J., Burley, H., Caballero-Rodriguez, D., Rymer, P.D., 2019. Assessing the vulnerability of Australian urban forests to climate extremes. Plants, People, Planet 1, 387–397.

European Environment Agency, 2017. Air quality e-reporting (AQ e-reporting) — European Environment Agency [WWW document]. URL. https://www.eea.europa.eu/data-and-maps/data/aqereporting-8#tab-figures-produced accessed 12.5.19.

Fernández-González, D., González-Parrado, Z., Vega-Maray, A.M., Valencia Barrera, R.M., Camazón-Izquierdo, B., De Nuntis, P., Mandrioli, P., 2010. Platanus pollen allergen a 1: quantification in the atmosphere and influence on a sensitizing population. Clin. Exp. Allergy 40 (1), 1701–1708.

Fernández-Sarría, A., Martínez, L., Velázquez-Martí, B., Sajdak, M., Estornell, J., Recio, J.A., 2013. Different methodologies for calculating crown volumes of Platanus hispánica tres using terrestrial laser scanner and a comparison with classical dendrometric measurements. Computer and Electronics in Agriculture 90, 176–185.

Ferrini, F., 2006. Pollarding and its Effects on the Physiology: A Look to Mature and Senescent Tree Management in Italy. 1er Colloque Européen sur les Trognes. pp. 1–8.

Gabarra, E., Belmonte, J., Canela, M., 2002. Aerobiological behaviour of *Platanus* L. pollen in Catalonia (north-east Spain). Aerobiologia 18 (3–4), 185–193.

Galán, C., García-Mozo, H., Cariñanos, P., Alcázar, P., Domínguez-Vilches, E., 2001. The role of temperature in the onset of the Olea europaea L. pollen season in southwestern Spain. Int. J. Biometeorol. 45 (1), 8–12.

Galán, C., Cariñanos, P., Alcázar, P., Dominguez, E., 2007. Quality and Management Manual of the Spanish Aerobiology Network (REA). Servicio de Publicaciones de la Universidad de Córdoba.

Galán, C., Ariatti, A., Bonini, M., Clot, B., Crouzy, B., Dahl, A., Fernández-González, D., Frenguelli, G., Gehrig, R., Isard, S., Levetin, S., Li, D.W., Mandrioli, P., Rogers, C.A., Thibaudon, M., Sauliene, I., Skjoth, C., Smith, M., Sofiev, M., 2017. Recommended terminology for aerobiological studies. Aerobiologia 33, 293–295.

García-Mozo, H., Galán, C., Jato, V., Belmonte, J., De La Guardia, C.D., Fernández, D., Gutiérrez, M., Aira, M.J., Roure, J.M., Ruiz, L., Trigo, M.M., Domínguez-Vilches, E., 2006. *Quercus* pollen season dynamics in the Iberian Peninsula: response to meteorological parameters and possible consequences of climate change. Annals of Agricultural and Environmental Medicine 13 (2), 209.

García-Mozo, H., Mestre, A., Galán, C., 2011. Climate change in Spain. Phenological trends in southern areas. In: Kheradmand, H., Blanco, J.A. (Eds.), Climate Change. Socioeconomic Effects. InTech Open.

Georgi, N.J., Zafiriadis, K., 2006. The impact of park trees on microclimate in urban areas. Urban Ecosyst. 9, 195–209.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. Glob. Planet. Chang. 63, 90–104.

Grundström, M., Dahl, A., Ou, T., Pleijel, H., 2017. The relationship between birch pollen, air pollution and weather types and their effects on antihistamine purchase in two Swedish cities. Aerobiologia 33, 457–471.

Hull, R., 2009. A short guide to the London plane. Islington, London. http://www.treetree.co.uk/treetree_downloads/the_London_Plane.pdf.

Iannotti, O., Mincigrucci, G., Bricchi, E., Frenguelli, G., 2000. Pollen viability as a bioindicator of air quality. Aerobiologia 16, 361–365.

Iglesias, I., Rodriguez-Rajo, F.J., Méndez, J., 2007. Behaviour of Platanus hispánica pollen, an important spring aeroallergen in northwestern Spain. J Invest Allergol Clin Immunol 17 (3), 145–156.

Informe de la Evaluación de la calidad del aire en España 2018, 2019. Subdirección General de Calidad del Aire y Medio Ambiente Industrial. Ministerio para la Transición Ecológica, Gobierno de España.

Instituto Nacional de Estadística (INE), National Instituto of Statistics (NIS), 2019. Estadística territorial del Municipio de Granada (Retrieved on 18/12/2019).

IPCC, 2007. In: Parry, M.L., Canziani, J.P., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of WG II to the Fourth Assessment Report of the Intergovernmental Panel of Climate Change 2007. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Jin, S., Guo, J., Wheeler, S., Kan, L., Che, S., 2014. Evaluation of impacts of trees on PM2.5 dispersion in urban streets. Atmos. Environ. 99, 277–287.

Jones, A.M., Harrison, R.M., 2003. The effects of meteorological factors on atmospheric bioaerosol concentrations: a review. Sci. Total Environ. 326, 151–180.

Kubik-Komar, A., Piotrowska-Weryszko, K., Weryszko-Chmielewska, E., Kaszewski, B.M., 2018. Analysis of Fraxinus pollen seasons and forecast models based on meteorological factors. Annals of Agricultural and Environmental Medicine 25, 285–291.

Laakso, L., Hussein, T., Aamio, P., Komppula, M., Hiltunen, V., Viisonen, Y., Kulmala, M., 2003. Diurnal and annual characteristics of particle mass and number concentrations in urban, rural and Arctic environments in Finland. Atmos. Environ. 37, 2629–2641.

Li, D., Stucky, B.J., Deck, J., Baiser, B., Guralnik, R.P., 2019. The effect of urbanization on plant phenology depends on regional temperature. Nature Ecology and Evolution 3, 1661–1667.

Lu, P., Yu, Q., Liu, J., Lee, X., 2006. Advance of tree-flowering dates in response to urban climate change. Agric. For. Meteorol. 138, 120–131.

Luo, Z., Su, O.J., Ge, Q., Xu, W., Zheng, J., 2006. Phenological responses of plants to climate change in an urban environment. Ecol. Res. https://doi.org/10.1007/s11284-006-0044-6.

Makra, L., Csépe, Z., Matyasovszky, I., Déak, A.J., Sümeghy, Z., Tusnády, G., 2014. The effects of the current and past meteorological elements influencing the current pollen concentrations for different taxa. Bot. Stud. 55, 43.

Manninen, H.E., Bäck, J., Sihto-Nissilä, S.L., Huffman, J.A., Pessi, A.M., Hiltunen, V., Aalto, P.P., Hidalgo, P.J., Hari, P., Saarto, A., Kulmala, M., Petäjä, T., 2014. Patterns in airborne pollen and other primary biological aerosol particles (PBAP), and theri contribution to aerosol mass and number in a boreal forest. Boreal Environmental Research 19, 383–405.

Matthias, J., Nielsen, A.B., Giesecke, T., 2012. Evaluating the effect of flowering age and forest structure on pollen productivity estimates. Veg. Hist. Archaeobotany 21, 474–484.

Maya-Manzano, J.M., Fernández-Rodriguez, S., Monroy-Colín, A., Silva-Palacios, I., Tormo-Molina, R., Gonzalo-Garijo, A., 2017a. Allergenic pollen of ornamental plane trees in a Mediterranean environment and urban planning as a prevention tool. Urban Forestry and Urban Greening 27, 352–362.

Maya-Manzano, J.M., Tormo-Molina, R., Fernández-Rodriguez, S., Silva-Palacios, I., Gonzalo-Garijo, A., 2017b. Distribution of ornamental urban trees and their influence on airborne pollen in the SW of Iberian Peninsula. Landsc. Urban Plan. 157, 434–446.

McBride, J., 2017. The world's urban forests. History, composition, design, function and management. Future City. vol. 8. Springer, Cham. Switzerland.

McIntosh, G., Gómez-Pacard, M., Osete, M.L., 2007. The magnetic of particles deposite don Platanus x hispánica leaves in Madrid, Spain, and their temporal and spatial variations. Sci. Total Environ. 382, 135–146.

Menzel, A., Fabian, P., 1999. Growing season extended in Europe. Nature 397 (6721), 659.

Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., ... Chmielewski, F.M., 2006. European phenological response to climate change matches the warming pattern. Glob. Chang. Biol. 12 (10), 1969–1976.

Mimet, A., Pellisier, V., Quénol, H., Aguejdad, R., Dubreuil, V., Rozé, F., 2009. Urbanization induces early flowering. Evidence from Platanus acerifolia and Prunus cerasus. Int. J. Biometeorol. 53, 287–298.

Miralles, J.C., Caravaca, F., Guillen, F., Lombardero, M., Negro, J.M., 2002. Cross-reactivity between Platanus pollen and vegetables. Allergy: European. J. Allergy Clin. Immunol. 57 (2), 146–149.

Nanninga, C., Buyarski, C.R., Pretorius, A.M., Montgomery, R.A., 2017. Increased exposure to chilling advances the time to budburst in North American tree species. Tree Physiol. 37 (12), 1727–1738.

Neil, K., Wu, J., 2006. Effects of urbanization on plant flowering phenology: a review. Urban Ecosyst. 9, 243–257.

Nowak, M., Szymanska, A., Grewling, L., 2012. Allergic risk zones of plane tree pollen (Platanus sp.) in Poznan. Postepy Dermatologii I Alergologii 3, 156–160.

Oduber, F., Calvi, A.I., Blanco-Alegre, C., Castro, A., Vega-Maray, A.M., Valencia-Barrera, R.M., Fernández-González, D., Fraile, R., 2019. Links between recent trends in airborne pollen concentrations, meteorological parameters and air pollutants. Agric. For. Meteorol. 264, 16–26.

Council Directive 96/6/EC of 27 September 1996 on ambient air quality assessment and management. Off. J. Eur. Communities.

Ordoñez, C., Duinker, P.N., 2014. Assessing the vulnerability of urban forests to climate change. Environ. Rev. 22 (3), 311–321.

Paredes, D., García-Herrera, R., Franco-Trigo, I., 2006. Understanding precipitation changes in Iberian early spring weather typing and storm-tracking approaches. Journal of Hidrometeorology 7, 101–113.

Pauleit, S., Jones, N., Garcia-Martin, G., Garcia-Valdecantos, J.L., Rivière, L.M., Vidal-Beaudet, L., Bodson, M., Randrup, T.B., 2002. Tree establishment practice in towns and cities–results from a European survey. Urban For. Urban Green. 1 (2), 83–96.

Pazouki, N., Sankian, M., Nejadsattari, T., Khavari-Najad, R.A., Varasteh, A.R., 2008. Oriental plane pollen allergy: identification of allergens and cross-reactivity between relevant species. Allergy Asthma Proceedings 29 (6), 622–628.

Peper, P., McPherson, G., Mori, S.M., 2001. Equations for predicting diameter, height, crown width and leaf area of San Joaquin Valley Street Trees. J. Arboric. 27, 306–317.

Piotrowska-Weryszko, K., 2013. The effect of the meteorological factor son the Alnus pollen season in Lublin (Poland). Grana 52 (3), 221–228.
Pletser, A., Caffara, A., Kelleher, C.T., Donelly, A., 2015. Chilling temperature and photoperiod influence the timing of bud burst in juvenile *Betula pubescens* and Populus tremula. Ann. For. Sci. 72, 941–953.
Popek, R., Gawronska, H., Wrochna, M., Gawronski, S.W., Saebo, A., 2013. Particulate matter on foliage of 13 woody species: deposition on surfaces and phytostabilisation in waxes: a 3-year study. International Journal of Phytoremediation 15 (3), 245–256.
R Core Team, 2016. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austriahttps://www.R-project.org/.
Recio, M., Picornell, A., Trigo, M.M., Gharbi, D., García-Sánchez, J., Cabezudo, B., 2018. Intensity and temporality of airborne *Quercus* pollen in the southwest Mediterranean area: correlation with meteorological and phenoclimatic variables, trends and possible adaptation to climate change. Agric. For. Meteorol. 250, 308–318.
Ripoll Morales, M.A., Navarro Reyes, F.B., Jiménez Morales, M.N., Montosa Salas, J.M., Gallego Teruel, E., Terrón López, L., De Simón Navarrete, E., 2009. Cultivos forestales para la producción de madera de calidad en la Vega de Granada: crecimiento inicial y comportamiento forestall de Juglans regia L., Celtis australis L., Platanus hispanica Münch y *Prunus avium* L. 5° Congreso Forestal Español Abstract Book. Sociedad Española de Ciencias Forestales. Junta de Castilla Y León, pp. 1–13.
Sabariego-Ruiz, S., Gutiérrez-Bustillo, A.M., Cervigón-Morales, P., Cuesta, P., 2008. Forecasting airborne Platanus pollen in Madrid region. Grana 47, 234–240.
Salbitano, F., Borelli, S., Conigliaro, M., Chen, Y., 2016. Guidelines on Urban and Periurban Forestry. FAO Forestry Papers N° 178. Food and Agriculture Organization of the United Nations, Rome, Italy.
Salmond, J.A., Tadaki, M., Vardoulakis, S., Arbuthnott, K., Coutts, A., Demuzere, M., Dirks, K.N., Heaviside, C., Lim, S., Macintyre, H., McInnes, R.N., Wheeler, B.W., 2016. Health and climate related ecosystem services provided by street trees in the urban environment. Environ. Health 15, 36.
Sanchez-reyes, E., Rodriguez de la Cruz, D., Sanchís-Merino, M.E., Sánchez-Sánchez, J., 2009. First results of *Platanus* pollen airborne content in the middle west of the Iberian Peninsula. Aerobiologia 25, 209–215.
Sedghy, F., Varasteh, A.R., Saukian, M., Moghadam, M., 2018. Interaction between air pollutants and pollen grains: the role on the rising trend in allergy. Reports on Biochemistry and Molecular Biology 6 (2), 219–224.
Sénéchal, H., Visez, N., Charpin, D., Shahali, Y., Peltre, G., Bioley, J.P., Lhuisier, F., Coudere, R., Yamada, O., Malrat-Domenge, A., Phan-Thi, N., Poncet, P., Sutra, J.P., 2015. A review of the effects of major atmospheric pollutants on pollen grains, pollen content and allergenicity. Tranfus Apher Sci 1–29.
Shoda, T., Imonishi, J., Shibata, S., 2020. Growth characteristics and growth equations of the diameter at breast height using tree ring measurement of street trees in Kyoto, Japan. Urban Forestry and Urban Greening 126627.
Steinbrecher, R., Smiatek, G., Köble, R., Seufert, G., Theloke, J., Hauff, K., Ciccioli, P., Vautard, R., Curci, G., 2009. Intra- and inter-annual variability of VOC emissions from natural and seminatural vegetation in Europe and neighbouring countries. Atmos. Environ. 43, 1380–1391.
Suárez-Cervera, A., Asturias, J., Vega-Maray, A.M., Castells, T., López-Iglesias, C., Ibarrola, I., Arilla, M.C., Gabarayena, N., Seoane-Camba, J.A., 2005. The role of allergenic proteins Pla a 1 and Pla a 2 in the germination of Platanus acerifolia pollen grains. Sex. Plant Reprod. 18, 101–112.
Subiza, J., Jerez, M., Gavilan, M.J., Varela, S., Rodriguez, R., Nargenes, M.J., et al., 1998. Cuales son los polenes que producen polinosis epidémica en el medio urbano de Madrid? Revista Española de Alergologia e Inmunología Clínica 13 (2), 107–119.
Tedeschini, E., Rodriguez-Rajo, F.J., Caramiello, R., Jato, V., Frenguelli, G., 2006. The influence of climate changes in Platanus spp. pollination in Spain and Italy. Grana 45, 222–229.
Tubby, K.V., Pérez-Sierra, A., 2015. Pests and pathogen threats to plane (*Platanus*) in Britain. Arboricultural Journal 37 (2), 85–98.
Valero, A.L., Rosell, E., Amat, P., Sancho, J., Roig, J., Piulats, J., Malet, A., 1999. Hipersensibilidad a polen de *Platanus acerifolia*: detección de las fracciones alergénicas. Alergol Inmunol Clin 14 (Suppl. 4), S220–S226.
Varela, S., Subiza, J., Subiza, J.L., Rodriguez, R., García, B., Jerez, M., Jiménez, J.A., Panzani, R., 1997. Platanus pollen as an important cause of polinosis. J. Allergy Clin. Immunol. 100, 748–754.
Vegetación Ornamental y Polinosis en Granada. Caracterización y propuestas desde la Agenda 21 local, 2005. Hernández del Águila R. (Coord.). Delegación de Salud de Medio Ambiente, Salud y Consumo del Ayuntamiento de Granada. Agenda 21 Local.
Velázquez de Castro González, F., Jiménez Arcas, S., 2007. La contaminación por ozono troposférico. El caso de Motril (Granada). Observatorio Medioambiental 10, 265–280.
Willis, K.J., Petrokofsky, G., 2017. The natural capital of city trees. Science 356 (6336), 374–376.
World Health Organization, 2013. Review of Evidence on Health Aspects of Air Pollution–REVIHAAP Project: Final Technical Report. WHO European Centre for Environment and Health, Bonn.
Xiaoshan, Z., Yujing, M., Wenzhi, S., Yahui, Z., 2000. Seasonal variations of isoprene emission from deciduous trees. Atmos. Environ. 34, 3027–3032.
Yang, J., Chang, Y., Ya, P., 2015. Ranking the suitability of common urban tree species for controlling $PM_{2.5}$ pollutants. Atmospheric Pollution Research 6, 267–277.
Zhou, S., Zhao, H., Peng, J., Hang, Q., Xiao, K., Shang, Y., Lu, S., Zhang, W., Wu, M., Li, S., Yu, S., Wang, W., Wang, Q., 2019. Size distribution of Platanus acerifolia allergen 3 (Pla a3) in Shanghai ambient sized-resolved particles and its allergenic effects. Atmos. Environ. 198, 324–334.
Ziello, C., Sparks, T.H., Estrella, N., Belomonte, J., Bergman, K.C., Bucher, E., Briguetti, M.A., Damialis, A., Detandt, M., Galán, C., Gehrig, R., Grewling, L., Gutierrez-Bustillo, A.M., Hallsdóttir, M., Kokhan-Biel, M.C., De Linares, C., Myszkowska, D., Páldy, A., Sánchez, A., Smith, M., Thibaudon, M., Trovaglini, A., Valencia-Barrera, R., Vokan, D., Wachter, R., de Werger, L., Menzel, A., 2012. Changes to airborne pollen counts across Europe. PlosOne 7, e34076.