remote sensing

MDPI

Article

Producing Urban Aerobiological Risk Map for Cupressaceae Family in the SW Iberian Peninsula from LiDAR Technology

Raúl Pecero-Casimiro [1], Santiago Fernández-Rodríguez [2], Rafael Tormo-Molina [1], Inmaculada Silva-Palacios [3], Ángela Gonzalo-Garijo [4], Alejandro Monroy-Colín [1], Juan Francisco Coloma [2] and José María Maya-Manzano [5,6,*]

1. Department of Plant Biology, Ecology and Earth Sciences, Faculty of Science, University of Extremadura, Avda. Elvas s/n, 06071 Badajoz, Spain; raulpc@unex.es (R.P.-C.); ratormo@unex.es (R.T.-M.); bioamc@outlook.com (A.M.-C.)
2. Department of Construction, School of Technology, University of Extremadura, Avda. de la Universidad s/n, 10003 Cáceres, Spain; santiferro@unex.es (S.F.-R.); jfcoloma@unex.es (J.F.C.)
3. Department of Applied Physics, Engineering Agricultural School, University of Extremadura, Avda. Adolfo Suárez s/n, 06007 Badajoz, Spain; insilva@unex.es
4. Department of Allergology, University Hospital of Badajoz, Avda. Elvas s/n, 06080 Badajoz, Spain; magonzalog@gmail.com
5. School of Chemical and Pharmaceutical Sciences, Technological University Dublin, D08 X622 Dublin, Ireland
6. Center of Allergy & Environment (ZAUM), Technische Universität München/Helmholtz Center, Biedersteiner Str 29, 80802 Munich, Germany

* Correspondence: jmmaya@unex.es

Received: 24 March 2020; Accepted: 12 May 2020; Published: 14 May 2020

Abstract: Given the rise in the global population and the consequently high levels of pollution, urban green areas, such as those that include plants in the Cupressaceae family, are suitable to reduce the pollution levels, improving the air quality. However, some species with ornamental value are also very allergenic species whose planting should be regulated and their pollen production reduced by suitable pruning. The Aerobiological Index to create Risk maps for Ornamental Trees (AIROT), in its previous version, already included parameters that other indexes did not consider, such as the width of the streets, the height of buildings and the geographical characteristics of cities. It can be considered by working with LiDAR (Light Detection and Ranging) data from five urban areas, which were used to create the DEM and DSM (digital elevation and surface models) needed to create one of the parameters. Pollen production is proposed as a parameter (α) based on characteristics and uses in the forms of hedges or trees that will be incorporated into the index. It will allow the comparison of different species for the evaluation of the pruning effect when aerobiological risks are established. The maps for some species of Cupressaceae (*Cupressus arizonica, Cupressus macrocarpa, Cupressus sempervirens, Cupressocyparis leylandii* and *Platycladus orientalis*) generated in a GIS (geographic information system) from the study of several functions of Kriging, have been used in cities to identify aerobiological risks in areas of tourist and gastronomic interest. Thus, allergy patients can make decisions about the places to visit depending on the levels of risk near those areas. The AIROT index provides valuable information for allergy patients, tourists, urban planning councillors and restaurant owners in order to structure the vegetation, as well as planning tourism according to the surrounding environmental risks and reducing the aerobiological risk of certain areas.

Keywords: AIROT; allergy; Cupressaceae; green infrastructure; risk maps; pollen production; urban ecology

1. Introduction

The global population and consequently the air pollution are increasing [1], negatively affecting to air quality, especially in densely populated areas [2]. Urban forests and green spaces in cities are indispensable for urban sustainability [3] due to their role in mitigating polluting particles [4] and reducing temperatures in urban areas [5]. In addition, these spaces satisfy other important immaterial and non-consumptive human needs, such as fostering positive feelings and helping urban communities articulate their commonly shared values [6,7]. Despite the benefits of urban green spaces, ornamental plants can produce some negative effects on ecosystems, such as problems related to invasive plants [8] and the emission of biogenic volatile organic compounds involved in ozone formation, which can increase smog problems [9]. Moreover, the pollen emission from allergenic plants during the pollination period affects human health, increasing the incidence of respiratory allergies, allergic rhinitis and asthma [10,11].

The family Cupressaceae has great value as ornamental plants, having the ability to capture particle matter, since trees with smaller leaves and more complex shoot structures have been shown to capture larger amounts of pollutants than broadleaved trees [12–14]. However, Charpin et al. [15] indicated that Cupressaceae pollen is the main cause of winter allergic respiratory diseases in central Asian, North American and eastern Mediterranean countries, and it is amongst the major sources of airborne allergens in the Mediterranean region [16]. Furthermore, in the last decades, cypress pollinosis has increased, mainly due to the increasing use of cypress in the form of hedges in private gardens [17] and the interaction of pollen with atmospheric pollutants that come from industrialization and urbanization [18–20]. To try to reduce the problems caused by cypresses, there is a need to carry out information campaigns aimed at the public and local authorities on the importance of cypress pruning [21], suitable planning in the selection of species to achieve healthy urban forests [22] and adequate maintenance of green areas to reduce allergenicity [23].

The examination of Cupressaceae in Extremadura (SW Spain) in the present study is considered another milestone in order to assess new elements of the green infrastructure after our previous study with *Platanus* sp. [24]. This is a genus that has specific patterns in its pollination, since it occurred at a specific time for a short duration (and in an explosive way) [25]. However, the periods of pollination in the studied Cupressaceae species (*C. sempervirens, C. arizonica, C. macrocarpa, Cupressocyparis leylandii* and *Platycladus orientalis*) range from October to April and May [15], although in our work we report a longer period until June for *C. Leylandii*. It prompts allergic symptoms over a longer interval, since newly released pollen is added to already existing airborne concentrations [23]. In addition, the size and use given to each specimen are not the same for these species, which causes pollen production to vary. This indicates that it is not the same when a specimen is used in the form of a hedge, with pruning, and measuring up to 2 m, while another is a specimen with normal growth and development without pruning. This makes it very important to predict their pollen production and possible aerobiological risks within cities.

The mapping of aerobiological sources serves as a reference for decision making in urban planning [24]. Despite having gaps in this understanding, in the field of construction it is starting to be used to study pollen exposure in the designs of new construction [26]. This is because city buildings influence pollen dispersal [27], being able to produce high concentrations of particles in some places [28].

LiDAR (light detection and ranging) has been useful for mapping possible biological risks in cities, considering slopes and geographical characteristics, the influence of buildings and other barriers within cities and their effect on pollen dispersion [24]. In addition, this technology is increasingly used in urban planning and land use [29] and for the study of the height and density of tree canopies [30]. On the other hand, Kriging is an interpolation method used as a geostatistical tool to create risk maps in different fields of research, such as in the chemical prediction of soil composition [31], in phenology [32], for the creation of aerobiological risk maps [24] or more recently to locate critical points of atmospheric pollutant concentrations in urban and peripheral areas [33]. The combination of these tools, together with the use of indexes in aerobiology, specifically AIROT [24], will allow for the creation of a new risk map that will help to provide information on the most harmful places for allergy patients. In addition, this approach can serve to provide basic information for the creation of healthy itineraries in cities [34].

The aims of this work were to put into practice the aerobiological index AIROT with species within the Cupressaceae family. We must consider that there are differences in the use of each species (hedge, bush or tree) and therefore, in the size that they present. These differences, in addition to other characteristics for each species, mean that the production of pollen for each species will not be the same and therefore, neither will be the risk of exposure. To solve this problem, it is proposed to introduce a parameter that will consider the pollen production of each species and its contribution to the Cupressaceae airborne pollen spectrum. If the calculations were made without taking into account the pollen production of each species and specimen, it would not be possible to observe how much each specimen contributes to the value of the index. Furthermore, the representation of risk maps in different months is necessary since not all species pollinate at the same time. Therefore, the phenology of this production will be known, which will allow comparing of the potential aerobiological risk of sources for different species. In short, a parameter that will take into account the use and size of the specimen and in which the pollen production for each species is incorporated. Considering the AIROT index values and the geolocation of these ornamental plants, we propose to create risk maps for the Cupressaceae species in the southwest of the Iberian Peninsula.

2. Material and Methods

2.1. Sampling Site

The cities studied; Badajoz (BA), Cáceres (CC), Don Benito (DB), Plasencia (PL) and Zafra (ZA), are located in the SW Iberian Peninsula (Table 1). Extremadura region is an extensive territory (41,635 km^2), with 1,070,586 inhabitants [35] and two provinces, Cáceres and Badajoz. The climate is continental Mediterranean, with an average annual temperature of 17.1 °C, and annual rainfall of 447 mm [36]. Agriculture is predominately (that which occupies most of the surface of the region) irrigated and dry farming. As for the surface occupied by natural species, most of it belongs to *Quercus rotundifolia*, *Quercus suber*, *Quercus pyrenaica*, *Castanea sativa*, *Pinus pinea*, *Pinus pinaster*, *Eucalyptus camaldulensis* and *Eucalyptus globulus*.

Table 1. Location of the cities studied.

City	Coordinates	m.a.s.l
Badajoz (BA)	38°53′N, 6°58′W	184
Cáceres (CC)	39°48′N, 6°20′W	459
Don Benito (DB)	38°58′N, 5°50′W	253
Plasencia (PL)	43°10′N, 2°25′W	253
Zafra (ZA)	38°25′N, 6°25′W	508

The studied species (*Cupressus arizonica*, *Cupressus macrocarpa*, *Cupresus sempervirens*, *Cupressocyparis leylandii* and *Platycladus orientalis*) of the Cupressaceae family are widely used in the different cities of the region in parks, public and private gardens and in the villas of the urbanizations of the cities. One of the most common forms of use is in the form of hedges, mainly for *P. orientalis* and *C. arizonica*. *C. sempervirens* are also widely used in cemeteries. Cáceres was the city in which the largest number of specimens have been located (3930), followed by Zafra (1742), Badajoz (1227), Don Benito (822) and Plasencia (732), whose urban areas in km^2 are 13.6, 3.5, 15.4, 4.3 and 4.8, respectively.

2.2. Species of Cupressaceae Famzily Studied, Characteristics and Their Uses

The Cupressaceae family includes about 160 species with a common pollen type [37], but different pollination periods (Table 2). The studied species in this work, cultivated in the locations as ornamentals, are:

-*Cupressus sempervirens*: It is a perennial tree native to the eastern areas bathed by the Mediterranean, also known as common cypress. This tree has a height between 25–30 m with pollination from February to March. The average studied heights in this case are between 15–20 m. It is usually cultivated as a tree and sometimes as hedge.

-*Cupressus arizonica*: Originally from the South of the United States and the North of Mexico. This tree has a height of 20 m (in this case between 10–15 m), although this can be used as a hedge as well. Pollination is from January to March. In the cities studied, this species is used both as a tree and hedge.

-*Cupressus macrocarpa*: It is also known as Monterrey Cypress. This tree can have a height of between 25–30 m (between 15–20 m in Zafra). The pollination occurs in February and March; it is originally from North America and used as a tree.

-*Cupressocyparis leylandii*: It is a natural bigeneric hybrid between *Cupressus macrocarpa* and *Chamaecyparis nootkatensis*. This ornamental plant reaches a size between 20 and 25 m high, although its main use is in the form of hedges, considering the cities studied. The pollination is at the end of the spring (May and June), according to the results obtained by the authors in a phenological follow-up study, although it is necessary to make a more concrete study since it can vary depending on the latitude and in general their pollen production is very low.

-*Platycladus orientalis (Thuja)*: Originally from China. It is a tree that measures about 8–9 m, although in Spain it is very common as a hedge. Its pollination is in January and February.

Table 2. Pollination periods for all the considered species in this work.

Pollination Month / Species	Jan	Feb	Mar	Apr	May	Jun
C. sempervirens		■	■			
C. arizonica	■	■	■			
C. macrocarpa		■	■			
C. leylandii					■	■
P. orientalis	■	■				

2.3. LiDAR Data

LiDAR data were used to create the DEM (digital elevation model) and DMS (digital surface model) necessary to perform visibility analysis (used in AIROT as potential dispersibility). With this aim, groups of LiDAR images of 2 km × 2 km were obtained for each urban area (dated in 2010, being the only database available up to date for this region) with a LiDAR point density cloud of 0.5 points/m^3, downloaded from the website of the National Geographic Institute [38] in LAS (LASer) files, a file format designed to archive LiDAR point cloud data. LiDAR technology is very useful in the construction of these digital models, to consider the buildings, trees and other possible obstacles or barriers in creation of DSM with high precision and excellent resolution, and especially characterization of the shape of each building [39].

2.4. Adaptation of the Risk Index AIROT for Cupressaceae Family

The Aerobiological Index of Risk for Ornamental Trees (AIROT) was firstly proposed to establish comparisons in the risk for pollen exposure coming from plane trees [24]. In this study, the AIROT index is developed for some selected species of the Cupressaceae family for which some adaptation of the index itself has been made considering the physical and biological features of each ornamental plant, as well as the phenology of the species and its pollen production. In addition, physical aspects of the city were considered, such as the places where the trees appeared, the forms of the streets, elevation and slopes obtained from the LiDAR (because they determine the potential dispersion for pollen grains) and other biological characteristics (the degree of maturity and number of specimens) of each sampling point. These parameters and the characteristics of the urban street design are proposed by the new Equation (1) to give value to the aerobiological risk of the different areas of the city. This AIROT value does not indicate the pollen concentration of the place or of each source, although it considers the pollen production of the specimens, but rather shows the exposure risk in each point taking into account the parameters indicated. After being represented on the maps, the aerobiological risk of each zone is shown, but not the pollen concentration.

$$AIROT = \sum_{i=1}^{n} \frac{PD_i \cdot \ (N_i \cdot \alpha_i) \cdot M_i \cdot Sh_i \cdot H_i}{\mathrm{ST}} \tag{1}$$

where,

PD_i = potential Dispersibility (0, 10);
N_i = number of specimens by distance (specimens/ha) (from 0 to 10);
α_i = pollen production according to the species and use (0.001, 0.01, 0.05, 0.1, 1);
M_i = maturity degree for each specimen (1, 5, 10);
Sh_i = incidence and presence of high buildings, narrow streets and squares (1, 2, 4, 6, 8, 10);
H_i = height above sea level (1, 2);
S_T = total surface of the city in km^2;
i = each street considered.

This index was normalized considering values between 1 (maximum risk in red) and 0 (minimum risk in green) [24]. The maximum values will be reached in sampling points where there are a high number of adult specimens, in large parks or avenues with large areas, and that are directly exposed to Cupressaceae pollen. The minimum values will be found in places without the presence of Cupressaceae and in narrow streets. However, it is not considered a null category, because the authors consider that a minimum presence of pollen can be caused by the existence in streets close to those studied or by resuspension process. The parameters taken into account for the index calculation are detailed in the following sections.

2.4.1. Potential Dispersibility (PD)

This factor is a theoretical indicator of potential pollen dispersion and transport from one place to another and establishes the extent to which a nominated feature may be seen from a specified location [40]. This parameter was obtained using commercial GIS software and doing a visibility analysis using the "View Shed" tool, where you must enter a height value as z coordinate (m) that indicates the elevation of each transmitter point (ornamental sources). This analysis takes into account buildings, trees and any other obstacles around the selected Cupressaceae specimens that may act as possible barriers to pollen dispersal and that have been obtained by the DSM created from the point cloud LiDAR.

The height from which the trees can be considered as mature and therefore to produce pollen depends on each species. Heights of 5 m have been established for plane trees [24] and from 5 to 20 m for the birch [41]. However, the height of the plants to be observed in this work, varies between 1 and 25 m, because it is the height range in which is contained at least 95% of the plants sampled.

Consequently, to make the visibility analysis, the coordinate z was replaced in each case by the values of height in meters at which species begin to mature. This value was not the same for all species, since not all reach maturity with the same height as indicated in Table 3. The values that were considering following the maturation sizes of each species according to Talhouk et al. [42], are: *C. arizonica*: 5 m; *C. Macrocarpa*: 10 m; *C. Sempervirens*: 10 m; *C. Leylandii*: 5 m and *P. Orientalis*: 3 m. This height value is a general value per species and was only used to make the visibility analysis using GIS. Then, for the calculation of parameters M and α the values used to specify each category also correspond to that height for each species. Each one of the pollination months of the Cupressaceae species were taken into account independently because different species pollinate each month. Nonetheless, the scores given to PD are in absolute terms, as exposed (10) or not exposed (0) areas. The average scores were not considered either [24].

Table 3. Height at which the studied species begin to mature and height when they reach the maturity [42] and values of the "M" parameter of our index according to the heights.

	Height (m)		Values "M" (Expressed in Meters Height for Specimens)		
Species	**Spread at Maturity**	**Maturity**	**Young (1)**	**Adults (5)**	**Mature (10)**
C. sempervirens	10–15	15–23	<10	10–15	>15
C. arizonica	5–8	8–15	<5	5–8	>8
C. macrocarpa	10–15	15–23	<10	10–15	>15
C. leylandii	5–8	8–15	<5	5–8	>8
P. orientalis	3–5	5–8	<3	3–5	>5

2.4.2. Number of Specimens by Surface (specimens/ha) (N)

The presence of vegetation sources is an important factor that influences the pollen load in an area [43]. We calculated the density of specimens in each street for each of the species (specimens/ha), and these were given normalized values from 0 to 10 [24]. For the normalization of the values, the maximum value (400.75 specimens/ha) and the minimum value (0.02 specimens/ha) were taken into account, which were given the normalized values of 10 and 1, respectively, 0 represents the streets in which there are no pollen sources. Then, the proportionality constant was obtained, which in this case is approximately 40. In this work all city specimens have been considered and geolocated.

2.4.3. Pollen Production according to the Species and Use (α)

This is a relevant performance in the AIROT index, considering the species chosen with different pollen production [44]. The α parameter is a theoretical-numerical parameter that will allow the calculation of the AIROT index [24] by comparing different species which have different pollen production. Its value will be between 0.001 and 1, being calculated considering the pollen production for each species. The species with the highest pollen production will be assigned the value of 1, and 0.001 for the species with the lowest production. The inclusion of this parameter in the AIROT index adds great value to the index due to the pollen production, being this relevant for the risk of exposure when we talk about different species. This approach is very important, since to a large extent, the potential risk of the source will depend on the concentration of pollen generated. This parameter was not previously included because *Platanus* sp. had similar pollen production.

C. macrocarpa is the one with the highest pollen production [23,44], being assigned a value of 1. The value 0.001 will be assigned to specimens in the form of hedges, as some authors consider the effect pruning to reduce pollen production [43], this phenomenon being observed for Cupressaceae [45]. Other researchers have argued that pollen production can be eliminated in some types of Cupressaceae, such as the *Thuja*, when it is regularly pruned [44]. However, some authors, years later, studied Cupressaceae for its allergenic effect [23,46]. The authors of this work consider that species used as hedges continue to produce pollen, even if it is at a very low quantity. The species *C. arizonica* and *C. sempervirens* were assigned a value of 0.1 and 0.05, respectively, considering as a reference the study by Hidalgo et al. [44] in which the species of *C. macrocarpa, C. arizonica* and *C. sempervirens* were compared, taking into account their pollen production and they assigned the values of 1, 0.1 and

0.05, respectively. Furthermore, the work carried out by Damialis et al. [47], in which they argue that *C. sempervirens* produces very similar amounts of pollen at the flower level anywhere influenced by the Mediterranean climate or even in climatically similar areas in the world, was also taken into account.

Last, *Cupressocyparis leylandii* was assigned a value of 0.01 because, according to the authors, the level of pollen production is very low, although further work is needed. Finally, *Platycladus orientalis* was assigned a value equal to that of *C. sempervirens* (0.05) because, according to the authors, its behaviour regarding pollen production is similar. However, this value should be studied in greater detail in the future.

2.4.4. Degree of Maturity for Each Specimen (M)

This parameter has been considered to be essential in assessing the potential to release pollen [43], following the previous work on the plane trees. In this case, there is not much literature discussing the age at which the species of the Cupressaceae family reach maturity. Verdú [48] made estimates for the genera *Cupressus* and *Thuja,* establishing an average age of 7.1 and 13.0 years, respectively, to reach maturity, but it is not easy to calculate the age of maturity of these species. However, other authors used height to predict the growth and maturation of herbaceous plants [49], as well as the amount of biomass [50,51] and production [52,53]. Talhouk et al. [42] described certain heights at which these species begin to mature and the heights that they reach once they are mature (Table 3). Using the data in this table, the values of the "M" parameter (1; 5; 10) for each species were established (Table 3). For hedges, a value of 1 was given because although they may be old enough to have a higher score within this parameter, pruning is controlling their pollen production.

2.4.5. Incidence and Presence of High Buildings and the Size of Streets (Sh)

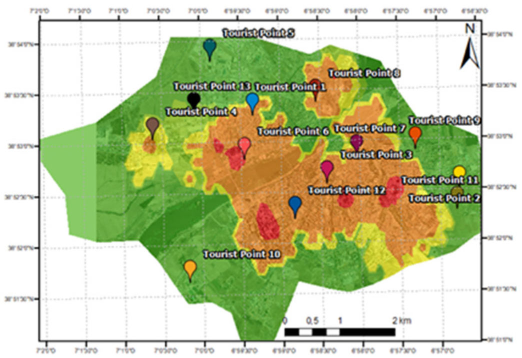
This parameter has the same values as in the case of plane trees [24], since the sampled cities are the same. The assigned values were as follows: local residential/office/commercial/industrial street: 1; parkway: 2; boulevard: 4; main street: 6; wide avenue: 8 and parks or public squares: 10. To distinguish between avenues and wide streets, the number of transit lanes was considered as an easy and objective indicator, with 4 or more lanes considered to be avenues. We also considered avenues with parks and those with greater widths (4 traffic lanes plus parking and sidewalks) to fall within the category of parks or public squares. The width of the streets, as well as the height of buildings, constitute a physical barrier that hinders the dispersion of pollen grains [28]. In narrower streets, the pollen grains will have less dispersion than in avenues or squares, so these values are assigned to it. The value of this parameter is specific to each specimen since the value corresponds to the street in which it is planted. This means that when different species are considered in different months, this parameter has different mean values for each month because the specimens considered are not the same, so neither are these values.

2.4.6. Height above Sea Level (H)

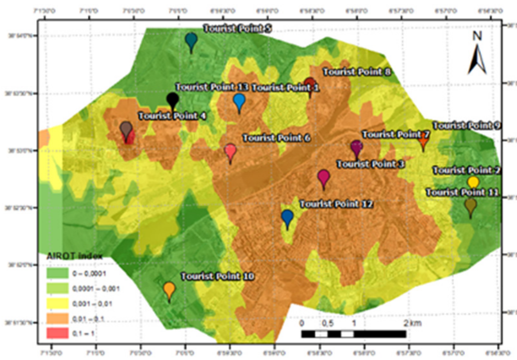
As already mentioned in our previous work [24] and according to Scheifinger et al. [54], at a local or regional scale, changes in phenological time series can be induced by micro-meteorological conditions in mountainous areas (20–40 days every 1000 m of elevation). The authors grouped the sampled locations into those of height >1500 m or height <1500 m above sea level. This is consistent with the findings of Sharma et al. [55], who estimated an average production of pollen cone per tree of $42.44 \pm 8.32 \times 10^3$ at lower altitudes and $28.1 \pm 0.89 \times 10^3$ at higher altitudes. We proposed to use the same two categories previously mentioned in Scheifinger et al. [54], using values of 1 for higher altitudes (sampling points within the city >1500 m.a.s.l) and 2 for lower altitudes (places within the city <1500 m.a.s.l). This parameter can be useful to distinguish the behaviour of phenology and pollen production in places where there are emission sources are both under and over 1500 m height, and it also makes possible the use of AIROT index for different places and the subsequent comparison between them, including different countries and different bioclimatic regions.

2.5. Kriging and Risk Maps

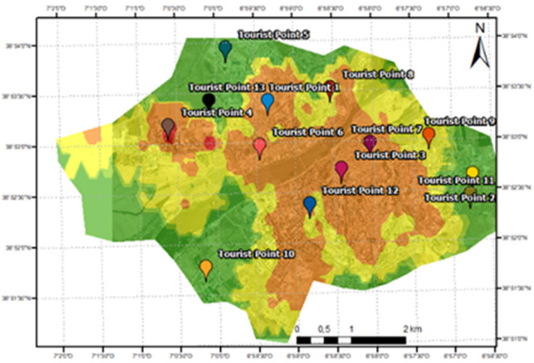
Kriging technique is performed by means of complex mathematical algorithms and equations in order to obtain values in places where there were no sampling points. To obtain these values, the technique uses semivariogram calculations in which the nearby points are taken into account and around 40 of the closest values were used to estimate the scores in areas close to the studied specimens and commercial GIS software was used for this. Five different functions were compared (stable, circular, spherical, exponential and *Gaussian*) (supplementary materials Table S1) and tested until the best aptitude for the points was found, according to the values for the root-mean-square error (RMSE) and Spearman's rank correlation that were obtained by using the R statistical software [56] for the observed values, according to our AIROT calculations against the predicted values by our model for the same points. Then, ordinary Kriging took into account the different points and the z coordinate (AIROT index). Then, points were created for the streets, indicating whether or not they had specimens of Cupressaceae. For each city, maps were made for different months of the year (Figures 1 and 2, Figures S1–S5), corresponding to the months in which the different species under study are pollinated (Table 2). These are January (JAN), February (FEB), March (MAR) and May–June (MAY/JUN). Table 5 shows the specimens considered for each map and city and that were used for Kriging.



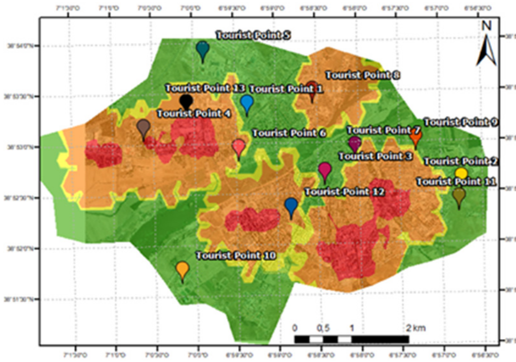
(**a**) Map of Badajoz for January



(**b**) Map of Badajoz for February

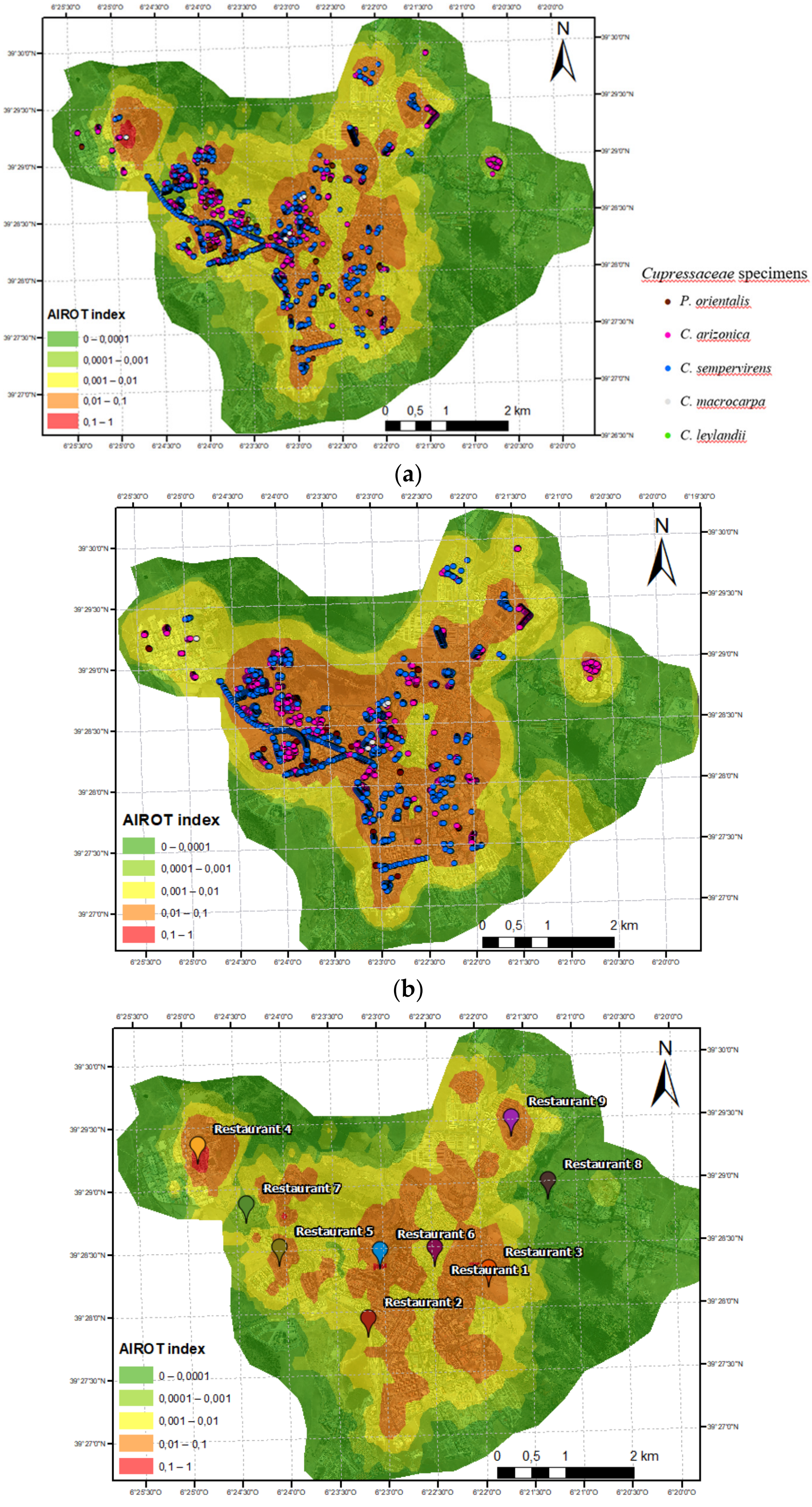


(**c**) Map of Badajoz for March



(**d**) Map of Badajoz for May–June

Figure 1. Tourist risk maps of Badajoz for the months of January (**a**), February (**b**), March (**c**) and May-June (**d**) according to the AIROT index and created using Kriging.



(**c**)

Figure 2. Risk maps of Cáceres for the month of February according to the AIROT index in which are indicated: (**a**) risk map taking into account the parameter α, (**b**) risk map without including the parameter α, and (**c**) restaurants risk map.

2.6. Healthy Maps

Knowing where it is possible to walk within a city is very important for allergic people, because avoiding exposure is a good way to prevent symptoms [57]. A healthy itinerary was established for the city of Badajoz to indicate where one might move around the city while avoiding high-risk areas during the pollination of the plane trees [24].

Cáceres is a place of great tourist importance where, for example, there are some of the best restaurants in Extremadura and also in Spain [58]. In the present study, another example of the use of these healthy itineraries was proposed, and a risk map was obtained following the guidelines established for the previous map created for Badajoz. In this work, simulated restaurants in Cáceres were created, and they were located such that, in times of greater risk, they ccould be avoided by people who are allergic to Cupressaceae. In addition, a tourist risk map was created for Badajoz, where theoretical buildings of tourist interest (cultural buildings, hospitals, schools, etc.) were placed, using as a basis, the risk maps for the Cupressaceae family. In this way, the tourists will have information about the places that are of higher risk due to their exposure to pollen sources.

These are only examples of the many utilities that risk maps have, since as Stephenson and Taylor [59] stated, travelling can increase the chances of the traveller becoming ill. Thus, an important part of the planning for any trip it is to observe the risks that exist in the destination and/or along the itinerary.

3. Results

3.1. Values for the AIROT

Table 4 shows the average values of the parameters used in the AIROT, normalized from 0 to 10 for N, M and Sh, and normalized from 0 to 1 for the parameter α and the value of AIROT. The highest AIROT values for the month of January (JAN) were collected in Plasencia (0.491), followed by Badajoz (0.093), Cáceres (0.022), Zafra (0.014) and Don Benito (0.004). Plasencia has the highest value due to the influence of the parameters N and Sh. Although Plasencia had a low number of specimens (Table 5), they were located very close, as indicated by the value of N, and they are also found in large areas, such as parks and avenues (Sh). Badajoz had the second highest AIROT value, which stood out precisely in the other two parameters: M and α, which had values two and three times higher, respectively, than Cáceres, which is the city in which these parameters reach the second highest score.

For the month of February (FEB), Don Benito (0.159) had the highest value of AIROT due to the breadth of its streets, the density of the trees and the maturity of the specimens. Badajoz (0.052), Plasencia (0.041), Cáceres (0.018) and Zafra (0.014) were the remaining cities and had the lowest values because their specimens were in narrower streets than the other cities. Nevertheless, these cities still presented high values for this parameter. Don Benito also had the highest value for March (MAR) (0.188), followed by Badajoz (0.057), Plasencia (0.041), Cáceres and Zafra, both with a value of 0.019. When we again examined the contributing facts, we found that the breadth of the areas where these specimens were located in Don Benito (9.419) was decisive compared to other cities, as was maturity. In comparison with the two cities that obtained a lower value for MAR, Cáceres stood out for having the lowest α value and the second lowest value of M.

For the months May–June (MAY/JUN), Don Benito again had the highest average value (0.511), with Badajoz (0.510) having practically the same, followed by Zafra (0.353), Plasencia (0.181) and Cáceres (0.041). For MAY/JUN in particular, Don Benito did not have any parameter that was higher than those observed in the other cities, but almost all the values of the parameters were close to the maximum values of the other cities. The rest of the cities, although they had some parameters higher than Don Benito, presented other parameters with very low values. This shows the importance of all the parameters in the index, since maximum values in one parameter do not necessarily give rise to maximum AIROT values, however, medium–high values in all its parameters, it can give rise to maximum values of AIROT.

Table 4. Average values of some parameters (M, N and Sh) used in Index to create Risk maps for Ornamental Trees (AIROT) (normalized values from 0 to 10) and values for the α and AIROT (from 0 to 1).

City	Maps.	Number of Specimens (N)	Maturity of Specimens (M)	Shape of Street (Sh)	Pollen Production (α)	AIROT
JAN	Badajoz	1.288	2.419	6.454	0.032	0.093
	Cáceres	4.856	1.072	6.381	0.009	0.022
	Don Benito	2.537	1.023	9.363	0.002	0.004
	Plasencia	5.362	1.000	8.547	0.001	0.491
	Zafra	4.538	1.003	6.163	0.003	0.014
FEB	Badajoz	1.364	4.157	7.636	0.055	0.052
	Cáceres	4.083	1.921	7.213	0.019	0.018
	Don Benito	3.155	2.806	9.431	0.018	0.159
	Plasencia	4.866	1.654	8.411	0.075	0.041
	Zafra	4.697	2.691	6.650	0.021	0.014
MAR	Badajoz	1.351	4.510	7.743	0.062	0.057
	Cáceres	4.114	1.985	7.195	0.020	0.019
	Don Benito	2.926	3.133	9.419	0.022	0.188
	Plasencia	4.912	1.673	8.572	0.077	0.041
	Zafra	4.284	3.243	6.840	0.028	0.019
MAYJUN	Badajoz	1.315	1.000	8.847	0.010	0.510
	Cáceres	3.325	1.264	4.241	0.002	0.041
	Don Benito	3.077	1.000	8.615	0.004	0.511
	Plasencia	1.000	1.276	10.000	0.006	0.181
	Zafra	2.132	1.000	5.405	0.001	0.353

Table 5. Number of points (specimens) taken for each map and city.

Maps	JAN		FEB				MAR			MAY/JUN
Species City	A*	O*	A*	M*	O*	S*	A*	M*	S*	L*
Badajoz	210	103	210	20	103	691	210	20	691	203
Cáceres	1770	225	1770	7	225	1439	1770	7	1439	489
Don Benito	397	124	397	-	124	288	397	-	288	13
Plasencia	309	20	309	47	20	327	309	47	327	29
Zafra	806	378	806	12	378	340	806	12	340	206

A*: *C. arizonica*/L*: *C. leylandii*/M*: *C. macrocarpa*/O*: *P. orientalis*/S*: *C. Sempervirens*.

3.2. Risk Maps

Table S1 shows the results of the Kriging analysis. For Badajoz and Zafra, the exponential model was the best for the four maps (JAN, FEB, MAR and MAY/JUN). Although the Spearman's rank coefficient was very similar in all functions for MAY/JUN in Badajoz and even 0.001 greater for the stable and Gaussian models, the one with the lowest RMSE was the exponential model. For Cáceres, the exponential model was also the best suited for almost all maps except the FEB map, for which the optimal function was stable. However, for Don Benito, different models were used for each map:

stable (JAN), circular (FEB), exponential (MAR) and Gaussian (MAY/JUN). Plasencia obtained better values for the circular (JAN and MAR), spherical (FEB) and Gaussian (MAY/JUN) models.

Figure 2a,b and Figures S1–S5 show the risk of aerobiological exposure in each city for each of the months in which the species were being pollinated. The highest values of the index were located in places where the species with the highest pollen production (highest α) were found, as seen in Figure 2a, Figures S1B,C, S2C, S4B,C and S5B,C, where the zones of greater risk coincided with specimens of *C. macrocarpa*. There were also high values in places where, in addition to a high α, a large number of specimens, mainly *C. arizonica* (Figures S1A, S2A, S3A, S4A and S5A) and *C. sempervirens* (Figure S3B,C), were clustered, particularly those that were mature.

In the five maps from MAY/JUN, the high values coincided with the maturation of the *C. leylandii* specimens and their use in the form of trees rather than hedges (Figures S2D and S3D) when there was a high number of specimens (Figures S1D and S5D) or when the dispersion zones coincided with large avenues, parks and squares (Figure S4D) due to the lack of obstacles to dispersion in areas where the specimens were mature.

The medium–high values were found in places where many specimens (Figures S1B,C and S5D) coincided or where they had average values for both pollination and maturation (Figures S1A, S3B,C, S4C and S5C). The average risk values on the maps were clustered mainly around high- or medium–high risk areas that were near open places that favour pollen dispersion and the consequent exposure risk (Figure 2a, Figures S1B,C, S2C,D and S3B,C) and where many specimens coincide (Figures S2A,D and S5A,B). Finally, low-risk values occurred when there were a low number of specimens, specimens that were not very mature and those whose α was low due to their use as a hedge (Figures S2A and S3A).

In general, the low- to high-risk areas were located in the centre of the cities, due to their use as ornamental plants in parks and gardens, and on the periphery of urban areas, due to their use as hedges around buildings in new developments and around cemeteries, given the traditional planting of *C. sempervirens* in these places.

On the other hand, Figure 2a represents the aerobiological risk of the city of Cáceres for the month of February calculated from AIROT using the parameter α, while Figure 2b represents the aerobiological risk of the same city and month calculated from AIROT but without using the parameter α. Figure 2a shows red areas (high aerobiological risk) coinciding with C. macrocarpa specimens, while Figure 2b does not represent areas of high risk. Furthermore, the medium–high risk areas (orange) occupy less surface in Figure 2a than in Figure 2b. In addition, Figure 2a shows medium–high risk (orange) in the northern part of the city, which coincides with the existence of C. sempervirens and medium–low risk (olive green) in the eastern zone, where there are hedges of C. arizonica, while Figure 2b shows medium risk in the same northern point and medium–high risk in the eastern zone.

Aerobiological risk maps based on the AIROT index can have many applications, including to locate on these maps those places of tourist interest in order to provide an informative tool to tourists. In this way, tourists will be able to observe which places of interest are in high-risk areas in order to avoid them or prevent possible exposure to their allergens. As an example, the risk maps created for Badajoz were used to create Figure 1, where 12 theoretical places of tourist interest are represented. The species under study pollinate in different months, and for this reason in Figure 1 one can see points of interest that in the JAN map are in areas of high or medium–high risk (tourist points 1 and 3), but in MAY/JUNE, completely lack risk. However, other points that did not show risks in JAN (Tourist Point 9), in FEB, had medium risk. In this way, tourists can decide to visit the city on dates during which the points of interest have the lowest possible aerobiological risk. The second application can be seen in Figure 2c, where theoretical restaurants are represented in Cáceres. In this case, one has the option of choosing a restaurant depending on the area where it is located, considering the aerobiological risk conditions as far as pollen is concerned. This should be taken into account if you want to eat outdoors or to avoid areas of high aerobiological risk while arriving at the restaurant.

4. Discussion

Green spaces in cities are indispensable for people´s lives, with numerous benefits, but their proper planning and their positioning within cities are also important. Therefore, optimal green spaces planning should include not only the benefits but also the problems, such as the risks associated to allergenic pollen exposure. The Cupressaceae family has high allergenic levels in winter [60]. In addition, this family of plants is increasingly used in public spaces and private gardens. For these two reasons, it was the focus of this work. The AIROT index [24] calculates the aerobiological risk of these species, and Kriging was used to create exposure risk maps. We implemented some adaptations in the methodology and changes in the index, since these species have different development in terms of size and ornamental uses (hedges or trees) and therefore, different pollen production.

The PD parameter must be calculated for each city, species and month, since each city has its own constructions and characteristics, and each species has a unique maturation size and timeframe for pollination. This parameter tries to show the places where pollen grains can move from their ornamental sources, in view of the characteristics of the sources and characteristics of the city in the vicinity of those sources (the width of the streets, the height of the buildings and the terrain orography). Wind and other meteorological conditions are not considered, firstly, due to difficulty in capturing these variables continuously in several areas within the city and, secondly, because the aim of this work was to locate the areas where there is risk of exposure to pollen due to the proximity of the sources and the characteristics of the city itself, regardless of the different meteorological variables. It is clear that the direction of the wind influences the dispersion of pollen from one place to another, as it has already been considered in previous studies on the same five cities [34] and their surroundings [43,61]. It is also evident that wind can cause pollen to move to places where it would theoretically otherwise not reach and without sources. Due to the influence of meteorological parameters (including wind) and resuspension phenomena, null risk areas were not considered. The visibility analysis considered the possible changes in the dispersion of the pollen caused by the air currents that occur between the streets and how the barrier effect produced by the buildings. With this tool, we can evaluate whether there are some points that are more exposed than others depending on these effects.

The maturity of the specimens is also a very important characteristic of the sources, one that directly influences the concentration of pollen produced. There are studies in which height was used to predict the growth and maturation of herbaceous plants [49]. Therefore, also based on Table 3 [42], the values of the M parameter (1; 5; 10) were established for each species that are shown in the same table. However, the hedges were omitted from this table, since their heights would always be similar due to pruning, therefore making it difficult to estimate their exact age and degree of maturity. In any case, those data would not be very problematic because, as hedges are continuously pruned, their pollen production is very low. This is why they were assigned as M = 1. The reason for estimating the maturity of the specimens is to be able to make approximate calculations of their pollen production.

The parameter α has been included to address the need for including the pollen production of the studied species, since species with different sizes and uses differ in pollen production [44]. In addition to assigning values of 0.05 to *P. orientalis* and 0.01 to *C. leylandii* (due to the low pollen production of this species, according to phenological studies carried out by the authors in Badajoz), a value of 0.001 was assigned to species used in the form of hedges. This reflects the way that pruning effects on pollination according to the authors of the current work, because there is still slight pollen production in pruned specimens and that is why this casuistry should be included, even with low values. There are researchers that consider pruning to be a tool for reducing pollen production [21]. Therefore, pruning should be taken into account to promote urban sustainability, improving human health and well-being and regulating air quality [62]. In this way, more specific comparisons and measurements of aerobiological risk changes due to pruning are needed for ornamental plants in the future.

Including this parameter in the AIROT index will allow others in the future to create risk maps for cities in which the main species that cause allergy problems are implemented depending on the season of the year. It would be necessary to establish for each of these species an α value that estimates their phenological production. Then, according to the other parameters of the AIROT index, risk maps that serve as informative tools for the population could be created. The pollen production (α) and, therefore the phenology of the plants has not been included in the previous case of the plane trees [24] or in the Urban Green Areas Index (IUGZA) [23]. However, phenology and pollen production are very important factors to consider since the use of plants with high pollen production capacity could increase allergenicity [23]. This pollen production also influences aerobiological risk, and therefore AIROT, as shown in Figure 2a,b. In the first, the high-risk area coincides with specimens of *C. macrocarpa*, the species considered to have the highest pollen production in this and other studies [23,44]. However, for the second figure, the high risk area is located slightly in the western part of the city where there is the greatest accumulation of specimens, regardless of the species and the use in the form of a hedge, shrub or tree. Due to studies of pollen production [44] and observations made by the authors on specimens from cities, it is known that the species have different pollen production and that their pollen production is also reduced due to the effect of pruning [43], so it influences aerobiological risk. After this study, the AIROT will allow for the comparison of aerobiological risks between different cities, as was the case in the previous version, and the consideration of different species that coincide in their pollination period.

Another parameter to highlight is N (density of specimens). This parameter was included in the AIROT equation (1) due to its importance in measuring the aerobiological risk, but in such a way that the total number of specimens in the city was less appropriate than the number of specimens per hectare (ha). There are studies in which the number of specimens per street [63] was examined, but the concentration of trees in a given space is also important. Therefore, it was decided to use the value of specimens per hectare as an objective measurement of the number of specimens throughout the city. The results for MAY/JUN in the present study serve as an example. Don Benito had very few specimens (13), as seen in Table 5. Nevertheless, Don Benito had a value of N of 3.077, while Badajoz, which has the lowest N value (1.315) for MAY/JUN of all of the cities, had 203 specimens (Table 5). This result shows that our treatment of N achieved the result that we pursued and that it could be used to compare any city by area. Thus, it was important and significant to the calculations.

Finally, the height above sea level (H) is another of the parameters that form part of AIROT due to its influence on the pollen production [54,55]. This allows comparisons to be made between cities or areas at altitudes over and under 1500 m.a.s.l. (meters above sea level). However, since the five cities studied in this work have all their sources under 1500 m.a.s.l, this parameter has not been relevant to make comparisons between them, but it may be influential for future studies in the cities with sources located in both height categories. With respect to Kriging analysis, a study of five models (stable, circular, spherical, exponential and Gaussian) was made for each map (20 maps) in order to examine the model that best fit. The results were variable, although the exponential model was determined to be optimal the most of times (12 maps), followed by the circular (3 maps), Gaussian (2 maps), stable (2 maps) and finally the spherical model (1 map). This result contrasts with other authors, who found the Gaussian model to be more appropriate [64,65]. By Kriging, the aerobiological urban risk maps were generated. With the creation of these maps in the AIROT and in previous urban planning studies [34,43], we believe that it is necessary to use them as prevention tools to design healthy itineraries [24], maps of tourist places of interest in cities (Figure 1) or gastronomic maps (Figure 2c). With these kinds of maps, mobility through cities will be facilitated for allergic patients. For example, by knowing the places of tourist interest (Figure 1) that are in areas of greater risk, visiting these can be avoided in times of greater aerobiological risk. Furthermore, they could decide where to take precautions, for example with masks. In addition, they help to choose the month in which it would be possible to visit certain places of interest or restaurants (Figure 2c). In the case of Badajoz (Figure 1), if you want to visit the city in winter the most suitable month would be January, since there is a larger area with low levels of risk than in the rest of the cities. This is again justified by the presence of species that are widely used as hedges in our cities such as *C. arizonica* and *P. orientalis* and the absence of pollination of species more used as trees (*C. macrocarpa* or *C. sempervirens*).

In the future, updating risk maps will be needed considering foreseeable changes in the vegetation due to the removal of specimens, the replanting of other specimens and the modifications stemming from the development of some specimens from hedges to bushes or trees and vice versa. Aerobiological samplings can also be established with portable sensors in the different areas of aerobiological risk in cities [66], in order to establish the relationship between AIROT and the pollen concentration of those areas. In this manner the value of this index could also be strengthened. Other interesting possibilities to improve the index would be using LiDAR to model the pollen production within the city [67], or even by using other remote sensing technologies to detect meteorological changes in temperature to increase the accuracy of the risk maps [68]. Finally, further research should be conducted on the pollination of the studied species to know more about the maturity age of the described species.

With the above methodology and the chosen species, reinforcement of the AIROT index has been achieved with the inclusion of pollen production (parameter α) and can be used to make comparisons between species. Moreover, the risk areas were located within the five studied cities for the months in which the pollination of Cupressaceae lasts. New uses and types of risk maps are proposed as informative tools for the population, such as the location of areas of cultural interest and the use in gastronomic culture. In addition, it could be used for the design of new constructions [26] and to advise people in charge of urban planning and green spaces to reduce the concentration of specimens, or use pruning to reduce the emission of pollen. Additionally it could be used, for example, to inform business owners in order to alleviate the allergic symptoms of their clients, avoiding planting species that produce allergenic pollen, such as Cupressaceae.

5. Conclusions

A new parameter, α (pollen production of each species), has been added to the AIROT index. With the inclusion of this parameter, it is possible to use AIROT for estimating the associated risk of exposure to the Cupressaceae pollen from the species studied in this study and also to compare the regular fluctuations in this risk along the year associated to different species within the same pollen type. Creating aerobiological risk maps for the months in which the studied Cupressaceae species pollinate will allow for the population to be informed of the areas where there exists a greater risk of exposure to pollen, thus enabling people to adapt their itineraries to avoid unnecessary exposure to allergens. It was shown that the AIROT index is a useful tool for mapping possible biological risks in cities, even when several species match, due to the addition of the α parameter. The AIROT allows to evaluate the areas where there is a greater aerobiological risk, contemplating each city's characteristics and the physical and the phenological, characteristics of each species. In addition, the creation of risk maps for tourism can be valuable for allergic patients and tourists, but also for urban planning and tourism councillors in order to structure the vegetation and reduce the allergenic potential of certain areas.

Supplementary Materials: The following are available online at http://www.mdpi.com/2072-4292/12/10/1562/s1, Figure S1: risk maps of Badajoz for each month according to the AIROT index. Figure S2: risk maps of Cáceres for each month according to the AIROT index. Figure S3: risk maps of Don Benito for each month according to the AIROT index. Figure S4: risk maps of Plasencia for each month according to the AIROT index. Figure S5: risk maps of Zafra for each month according to the AIROT index. Figure S6: results for the cross-validation test. Table S1: results for the different functions that were tested in the Kriging analysis according to the RMSE and Spearman's rank coefficient.

Author Contributions: Conceptualization, R.P.-C., S.F.-R., R.T.-M., Á.G.-G. and J.M.M.-M.; methodology, R.P.-C., R.T.-M., J.F.C. and J.M.M.-M.; software, R.P.-C., J.F.C. and J.M.M.-M.; validation, R.P.-C. and J.M.M.-M.; formal analysis, R.P.-C., S.F.-R., R.T.-M. and J.M.M.-M.; investigation, R.P.-C., S.F.-R., R.T.-M. and J.M.M.-M.; resources, R.P.-C., S.F.-R., R.T.-M. and J.M.M.-M.; data curation, R.P.-C., A.M.-C. and J.M.M.-M.; writing—original draft preparation, R.P.-C., S.F.-R., R.T.-M., Á.G.-G. and J.M.M.-M.; writing—review and editing, I.S.-P., A.M.-C. and J.F.C.; visualization, R.P.-C., J.M.M.-M.; supervision, S.F.-R., R.T.-M., Á.G.-G., J.M.M.-M.; project administration, S.F.-R., J.M.M.-M.; funding acquisition, S.F.-R.,Á.G.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This work was possible by funds from research projects PRIIB16029 and research group said GR18113 financed by the Regional Government, Junta de Extremadura (Spain). Particularly, the Irish Environmental Protection Agency (EPA, programme 2014–2020, Climate, 2017) funded to J.M.M.M during part of the realization of this paper and National Commission of Science and Technology of Mexico (CONACyT) funds to A.M.C.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hoesly, R.M.; Smith, S.J.; Feng, L.; Klimont, Z.; Janssens-Maenhout, G.; Pitkanen, T.; Seibert, J.J.; Vu, L.; Andres, R.J.; Bolt, R.M.; et al. Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS). *Geosci. Model Dev.* **2018**, *11*, 369–408. [CrossRef]
2. Chan, C.K.; Yao, X. Air pollution in mega cities in China. *Atmos. Environ.* **2008**, *42*, 1–42. [CrossRef]
3. Duinker, P.N.; Ordez, C.; Steenberg, J.W.N.; Miller, K.H.; Toni, S.A.; Nitoslawski, S.A. Trees in canadian cities: Indispensable life form for urban sustainability. *Sustainability* **2015**, *7*, 7379–7396. [CrossRef]
4. Beckett, K.P.; Freer-Smith, P.H.; Taylor, G. Urban woodlands: Their role in reducing the effects of particulate pollution. *Environ. Pollut.* **1998**, *99*, 347–360. [CrossRef]
5. Maimaitiyiming, M.; Ghulam, A.; Tiyip, T.; Pla, F.; Latorre-Carmona, P.; Halik, T.; Sawut, M.; Caetano, M. Effects of green space spatial pattern on land surface temperature: Implications for sustainable urban planning and climate change adaptation. *ISPRS J. Photogramm. Remote Sens.* **2014**, *89*, 59–66. [CrossRef]
6. Chiesura, A. The role of urban parks for the sustainable city. *Landsc. Urban Plan.* **2004**, *68*, 129–138. [CrossRef]
7. Chaphekar, S.B. Botanist in urban environments. *Environ. Int. Soc. Environ. Bot.* **2009**, *15*, 4–6.
8. Mack, R.N.; Simberloff, D.; Lonsdale, W.M.; Evans, H.; Clout, M.; Bazzaz, F.A. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecol. Appl.* **2000**, *10*, 689–710. [CrossRef]
9. Domm, J.; Drew, R.; Greene, A.; Ripley, E.; Smardon, R.; Tordesillas, J. Recommended urban forest mixtures to optimize selected environmental benefits. *Environ. Int. Soc. Environ. Bot.* **2008**, *14*, 7–10.
10. Pawankar, R. Allergic diseases and asthma: A global public health concern and a call to action. *World Allergy Organ. J.* **2014**, *7*, 12. [CrossRef]
11. Bunne, J.; Moberg, H.; Hedman, L.; Andersson, M.; Bjerg, A.; Lundbäck, B.; Rönmark, E. Increase in Allergic Sensitization in Schoolchildren: Two Cohorts Compared 10 Years Apart. *J. Allergy Clin. Immunol. Pract.* **2017**, *5*, 457–463.e1. [CrossRef] [PubMed]
12. Beckett, K.P.; Freer-Smith, P.H.; Taylor, G. The capture of particulate pollution by trees at five contrasting urban sites. *Arboric. J.* **2000**, *24*, 209–230. [CrossRef]
13. Beckett, K.P.; Freer-Smith, P.H.; Taylor, G. Particulate pollution capture by urban trees: Effect of species and windspeed. *Glob. Chang. Biol.* **2000**, *6*, 995–1003. [CrossRef]
14. Freer-Smith, P.H.; Beckett, K.P.; Taylor, G. Deposition velocities to Sorbus aria, Acer campestre, Populus deltoides × trichocarpa 'Beaupré', Pinus nigra and × Cupressocyparis leylandii for coarse, fine and ultra-fine particles in the urban environment. *Environ. Pollut.* **2005**, *133*, 157–167. [CrossRef]
15. Charpin, D.; Pichot, C.; Belmonte, J.; Sutra, J.; Zidkova, J.; Chanez, P.; Shahali, Y.; Sénéchal, H.; Poncet, P. Cypress Pollinosis: From Tree to Clinic. *Clin. Rev. Allergy Immunol.* **2019**, *56*, 174–195. [CrossRef]
16. Hidalgo, P.J.; Galán, C.; Domínguez, E. Male phenology of three species of Cupressus: Correlation with airborne pollen. *Trees Struct. Funct.* **2003**, *17*, 336–344. [CrossRef]
17. Caiaffa, M.F.; Macchia, L.; Strada, S.; Bariletto, G.; Scarpelli, F.; Tursi, A. Airborne Cupressaceae pollen in Southern Italy. *Ann. Allergy* **1993**, *71*, 45–50.
18. Shahali, Y.; Pourpak, Z.; Moin, M.; Zare, A.; Majd, A. Impacts of air pollution exposure on the allergenic properties of Arizona cypress pollens. *J. Phys. Conf. Ser.* **2009**, *151*, 012027. [CrossRef]
19. Wang, Q.; Morita, J.; Nakamura, S.; Wu, D.; Gong, X.; Suzuki, M.; Miwa, M.; Nakajima, D. Field investigation on modification of Japanese cedar pollen allergen in urban air-polluted area. *World Acad. Sci. Eng. Technol.* **2010**, *70*, 624–629.
20. Shahali, Y.; Poncet, P.; Sénéchal, H. Cupressaceae pollinosis and air pollution. *Rev. Fr. D'allergologie* **2013**, *53*, 468–472. [CrossRef]
21. Laaidi, K.; Carli, P.M. Detecting emerging risks in environmental health: The example of cypress pollinosis in Burgundy. *Environ. Risques Et Sante* **2002**, *1*, 217–222.

22. Conway, T.M.; Vander Vecht, J. Growing a diverse urban forest: Species selection decisions by practitioners planting and supplying trees. *Landsc. Urban Plan.* **2015**, *138*, 1–10. [CrossRef]
23. Cariñanos, P.; Casares-Porcel, M.; Quesada-Rubio, J. Estimating the allergenic potential of urban green spaces: A case-study in Granada, Spain. *Landsc. Urban Plan.* **2014**, *123*, 134–144. [CrossRef]
24. Pecero-Casimiro, R.; Fernández-Rodríguez, S.; Tormo-Molina, R.; Monroy-Colín, A.; Silva-Palacios, I.; Cortés-Pérez, J.P.; Gonzalo-Garijo, Á.; Maya-Manzano, J.M. Urban aerobiological risk mapping of ornamental trees using a new index based on LiDAR and Kriging: A case study of plane trees. *Sci. Total Environ.* **2019**, *693*, 133576. [CrossRef]
25. Alcázar, P.; Galán, C.; Torres, C.; Domínguez-Vilches, E. Detection of airborne allergen (Pla a 1) in relation to Platanus pollen in Córdoba, South Spain. *Ann. Agric. Environ. Med.* **2015**, *22*, 96–101. [CrossRef]
26. Fernández-Rodríguez, S.; Cortés-Pérez, J.P.; Muriel, P.P.; Tormo-Molina, R.; Maya-Manzano, J.M. Environmental impact assessment of Pinaceae airborne pollen and green infrastructure using BIM. *Autom. Constr.* **2018**, *96*, 494–507. [CrossRef]
27. Thompson, R.S. Building amplification factors for sources near buildings: A wind-tunnel study. *Atmos. Environ. Part A Gen. Top.* **1993**, *27*, 2313–2325. [CrossRef]
28. Cariñanos, P.; Alcázar, P.; Galán, C.; Domínguez, E. Privet pollen (Ligustrum sp.) as potential cause of pollinosis in the city of Cordoba, south-west Spain. *Allergy Eur. J. Allergy Clin. Immunol.* **2002**, *57*, 92–97. [CrossRef]
29. Farzinmoghadam, M.; Mostafavi, N.; Infield, E.H.; Hoque, S. Developing an automated method for the application of lidar in iumat land-use model: Analysis of land-use changes using building-form parameterization, GIS, and artificial neural networks. *J. Green Build.* **2019**, *14*, 1–30. [CrossRef]
30. Kanja, K.; Karahalil, U.; Çil, B. Modeling stand parameters for Pinus brutia (Ten.) using airborne LiDAR data: A case study in Bergama. *J. Appl. Remote Sens.* **2020**, *14*, 022205. [CrossRef]
31. Ishida, T.; Ando, H. Computer-assisted mapping of paddy-field soils: 1. production of closely spaced data from sparse data relating to soil chemical properties. *Soil Sci. Plant Nutr.* **1994**, *40*, 391–402. [CrossRef]
32. León Ruiz, E.J.; García Mozo, H.; Domínguez Vilches, E.; Galán, C. The use of geostatistics in the study of floral phenology of Vulpia geniculata (L.) Link. *Sci. World J.* **2012**, *2012*, 624247. [CrossRef] [PubMed]
33. Hien, P.D.; Men, N.T.; Tan, P.M.; Hangartner, M. Impact of urban expansion on the air pollution landscape: A case study of Hanoi, Vietnam. *Sci. Total Environ.* **2020**, *702*, 134635. [CrossRef] [PubMed]
34. Maya Manzano, J.M.; Tormo Molina, R.; Fernández Rodríguez, S.; Silva Palacios, I.; Gonzalo Garijo, Á. Distribution of ornamental urban trees and their influence on airborne pollen in the SW of Iberian Peninsula. *Landsc. Urban Plan.* **2017**, *157*, 434–446. [CrossRef]
35. NSI. Population by Cities. National Institute of Statistics, Madrid, Spain. 2018. Available online: https://www.ine.es/ (accessed on 21 December 2019).
36. *AEMET (2018) Valores climatológicos normales: Badajoz Aeropuerto—Agencia Estatal de Meteorología—AEMET*; AEMET: Gobierno de España, Spain, 2019.
37. Charpin, D.; Calleja, M.; Pichot, C.; Penel, V.; Hugues, B.; Poncet, P. Cypress pollen allergy. *Rev. Fr. D'allergologie* **2016**, *56*, 248–250. [CrossRef]
38. IGN. CORINE Land Cover. Instituto Geográfico Nacional del Gobierno de España. 2019. Available online: http://www.ign.es/ign/main/index.do (accessed on 11 November 2019).
39. Gamba, P.; Houshmand, B. Digital surface models and building extraction: A comparison of IFSAR and LIDAR data. *IEEE Trans. Geosci. Remote Sens.* **2000**, *38*, 1959–1968. [CrossRef]
40. Bartie, P.; Reitsma, F.; Kingham, S.; Mills, S. Incorporating vegetation into visual exposure modelling in urban environments. *Int. J. Geogr. Inf. Sci.* **2011**, *25*, 851–868. [CrossRef]
41. Skjøth, C.A.; Ørby, P.V.; Becker, T.; Geels, C.; Schl€unssen, V.; Sigsgaard, T.; Bønløkke, J.H.; Sommer, J.; Søgaard, P.; Hertel, O. Identifying urban sources as cause of elevated grass pollen concentrations using GIS and remote sensing. *Biogeosciences* **2013**, *10*, 541–554. [CrossRef]
42. Talhouk, S.N.; Fabian, M.; Dagher, R. *Landscape Plant Database. Department of Landscape Design & Ecosystem Management*; American University of Beirut: Beirut, Lebanon, 2015; Volume 2019.
43. Maya-Manzano, J.M.; Fernández-Rodríguez, S.; Monroy-Colín, A.; Silva-Palacios, I.; Tormo-Molina, R.; Gonzalo-Garijo, Á. Allergenic pollen of ornamental plane trees in a Mediterranean environment and urban planning as a prevention tool. *Urban For. Urban Green.* **2017**, *27*, 352–362. [CrossRef]

44. Hidalgo, P.J.; Galán, C.; Domínguez, E. Pollen production of the genus cupressus. *Grana* **1999**, *38*, 296–300. [CrossRef]
45. Charpin, D.; Pichot, C.; Calleja, M. Trimming cypress tree hedges and its effects on subsequent pollination. *Ann. Allergy Asthma Immunol.* **2011**, *106*, 259–260. [CrossRef] [PubMed]
46. Rezanejad, F. Air pollution effects on structure, proteins and flavonoids in pollen grains of Thuja orientalis L. (Cupressaceae). *Grana* **2009**, *48*, 205–213. [CrossRef]
47. Damialis, A.; Fotiou, C.; Halley, J.M.; Vokou, D. Effects of environmental factors on pollen production in anemophilous woody species. *Trees Struct. Funct.* **2011**, *25*, 253–264. [CrossRef]
48. Verdú, M. Age at maturity and diversification in woody angiosperms. *Evolution* **2002**, *56*, 1352–1361. [CrossRef]
49. Huang, L.; Koubek, T.; Weiser, M.; Herben, T. Environmental drivers and phylogenetic constraints of growth phenologies across a large set of herbaceous species. *J. Ecol.* **2018**, *106*, 1621–1633. [CrossRef]
50. Freeman, K.W.; Girma, K.; Arnall, D.B.; Mullen, R.W.; Martin, K.L.; Teal, R.K.; Raun, W.R. By-plant prediction of corn forage biomass and nitrogen uptake at various growth stages using remote sensing and plant height. *Agron. J.* **2007**, *99*, 530–536. [CrossRef]
51. Schirrmann, M.; Hamdorf, A.; Garz, A.; Ustyuzhanin, A.; Dammer, K.-H. Estimating wheat biomass by combining image clustering with crop height. *Comput. Electron. Agric.* **2016**, *121*, 374–384. [CrossRef]
52. Hu, P.; Chapman, S.C.; Wang, X.; Potgieter, A.; Duan, T.; Jordan, D.; Guo, Y.; Zheng, B. Estimation of plant height using a high throughput phenotyping platform based on unmanned aerial vehicle and self-calibration: Example for sorghum breeding. *Eur. J. Agron.* **2018**, *95*, 24–32. [CrossRef]
53. Han, X.; Thomasson, J.A.; Bagnall, G.C.; Pugh, N.A.; Horne, D.W.; Rooney, W.L.; Jung, J.; Chang, A.; Malambo, L.; Popescu, S.C.; et al. Measurement and Calibration of Plant-Height from Fixed-Wing UAV Images. *Sensors* **2018**, *18*, 92. [CrossRef]
54. Scheifinger, H.; Menzel, A.; Koch, E.; Peter, E.; Ahas, C. Atmospheric mechanisms governing the spatial and temporal variability of phenological observations in central Europe. *Int. J. Climatol.* **2002**, *22*, 1739–1755. [CrossRef]
55. Sharma, C.M.; Khanduri, V.P.; Ghildiyal, S.K. Reproductive ecology of male and female strobili and mating system in two different populations of Pinus roxburghii. *Sci. World J.* **2012**, *2012*, 271389. [CrossRef] [PubMed]
56. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2013. Available online: http://www.R-project.org (accessed on 16 October 2019).
57. Baxi, S.N.; Phipatanakul, W. The role of allergen exposure and avoidance in asthma. *Adolesc. Med. State Art Rev.* **2010**, *21*, 57–71. [PubMed]
58. El Periódico Extremadura (2019) Atrio, Entre Los Diez Mejores Restaurantes de Alta Cocina. Available online: https://www.elperiodicoextremadura.com/noticias/caceres/atrio-diez-mejores-restaurantes-alta-cocina_1194675.html (accessed on 28 August 2019).
59. Stephenson, P.L.; Taylor, M.V. Traveler's Health Information on the Internet. *J. Consum. Health Internet* **2013**, *17*, 410–418. [CrossRef]
60. Charpin, D.; Calleja, M.; Lahoz, C.; Pichot, C.; Waisel, Y. Allergy to cypress pollen. *Allergy Eur. J. Allergy Clin. Immunol.* **2005**, *60*, 293–301. [CrossRef]
61. Fernández-Rodríguez, S.; Skjøth, C.A.; Tormo-Molina, R.; Brandao, R.; Caeiro, E.; Silva-Palacios, I.; Gonzalo-Garijo Á, Smith, M. Identification of potential sources of airborne Olea pollen in the Southwest Iberian Peninsula. *Int. J. Biometeorol.* **2014**, *58*, 337–348. [CrossRef]
62. Salmond, J.A.; Tadaki, M.; Vardoulakis, S.; Arbuthnott, K.; Coutts, A.; Demuzere, M.; Dirks, K.N.; Heaviside, C.; Lim, S.; MacIntyre, H.; et al. Health and climate related ecosystem services provided by street trees in the urban environment. *Environ. Health: A Glob. Access Sci. Source* **2016**, *15*, S36. [CrossRef]
63. Nowak, M.; Szymanska, A.; Grewling, L. Allergic risk zones of plane tree pollen (Platanus sp.) in Poznan. *Postepy Dermatol. I Alergol.* **2012**, *29*, 156–160.
64. Manzione, R.L.; Castrignanò, A. A geostatistical approach for multi-source data fusion to predict water table depth. *Sci. Total Environ.* **2019**, *696*, 133763. [CrossRef]
65. Oteros, J.; Bergmann, K.C.; Menzel, A.; Damialis, A.; Traidl-Hoffmann, C.; Schmidt-Weber, C.B.; Buters, J. Spatial interpolation of current airborne pollen concentrations where no monitoring exists. *Atmos. Environ.* **2019**, *199*, 435–442. [CrossRef]

66. Werchan, B.; Werchan, M.; Mücke, H.G.; Bergmann, K.C. Spatial distribution of pollen-induced symptoms within a large metropolitan area-Berlin, Germany. *Aerobiologia* **2018**, *34*, 539–556. [CrossRef]
67. Bogawski, P.; Grewling, Ł.; Dzióbl, K.; Sobieraj, K.; Dalc, M.; Dylawerska, B.; Pupkowski, D.; Nalej, A.; Nowak, M.; Szymańska, A.; et al. Lidar-derived tree crown parameters: Are they new variables explaining local birch (Betula sp.) pollen concentrations? *Forests* **2019a**, *10*, 1154. [CrossRef]
68. Bogawski, P.; Grewling, Ł.; Jackowiak, B. Predicting the onset of Betula pendula flowering in Poznań (Poland) using remote sensing thermal data. *Sci. Total Environ.* **2019b**, *658*, 1485–1499. [CrossRef] [PubMed]