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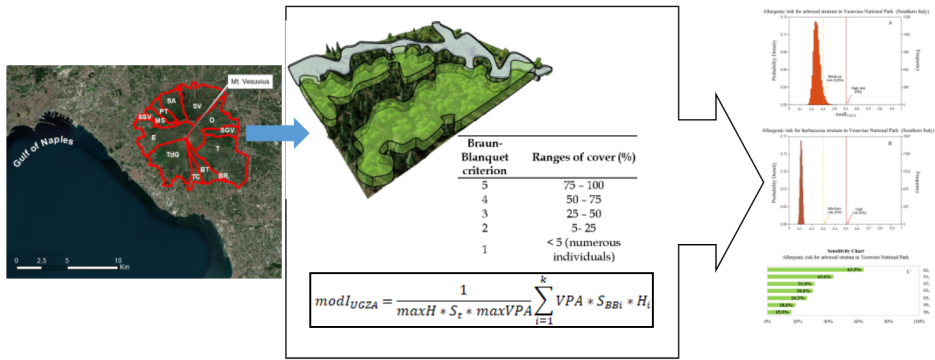
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All authors make substantial contributions to conception and design of the study. AP and DZ provided acquisition of data. RS and CG supervised data acquisition. AP and DZ structured the database and performed the data analysis. All authors jointly interpreted data. DZ and AP wrote the first draft of the manuscript. All authors contributed to the revision of the manuscript and approved the submitted version.



Assessing pollinosis risk in the Vesuvius National Park: a novel approach for Index of Urban Green Zones Allergenicity.

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Abstract

Pollen released by urban flora is the mayor contributor to airborne allergen content, with adverse impact on human health, representing one of the main ecosystems disservices. The Vesuvius National Park (Southern Italy) develops on an area of 8,017 ha, falling within thirteen municipalities, in which 345,000 people live. Pollination events in the park may pose a threat to the health of people damaging their well-being. The objective of this work is to establish the potential allergenic value of the plant species occurring in the Vesuvius National Park, so that the allergenicity of the park can be estimated through version novel approach for Index of Urban Green Zones Allergenicity (modI_{UGZA}). It allows the determination of allergenicity of extended areas, by using sampling area and subsequent estimation of plant covers with Braun-Blanquet scale. Sampling areas have been defined and phytosociological surveys have been conducted to register plant species, relative covers and allergenicity potential. As a weighting factor, the surfaces of the park total area, and municipalities' areas were used. First, we obtained the results by the traditional deterministic approach. The results indicated that an allergic risk cannot be excluded for Ottaviano municipality and the whole park. Subsequently, we developed a quantitative risk assessment model for allergenic risk based on probabilistic model resulting in a more exhaustive risk assessment. There is a 5% probability that in the Vesuvius National Park, the vegetation may rise to an allergenic risk. The municipality-level probabilistic risk outcomes also reveal a certain probability of risk even for eleven municipalities. Sensitivity analysis indicate that plant height and vegetation cover mainly affect expected risk. This tool may be useful to forecast and prevent pollinosis related events on a large scale, allowing risk mitigation measure in health protection perspective.

Keywords

Airborne pollen; Index of allergenicity; Vesuvius National Park, Ecosystem disservices.

1. Introduction

Urban and peri-urban forests, and urban green spaces *sensu lato*, are elements of the anthropized landscape whose inestimable value, in terms of providing ecosystem services, is globally accepted (Cariñanos and Casares-Porcel, 2011; Kasprzyk et al., 2019 (a); Wolf et al., 2020). Among the services provided, recreational ones and those for improving air quality through the removal of gaseous and particulate pollutants stand out (Dzierzanowski et al., 2011; Nowak et al., 2018). Urban forests represent, in this sense, a double-edged sword since they can generate problems related to air quality (Cariñanos and Casares-Porcel, 2011). Plants inserted in urban environments can undermine the human well-being by causing physical damage to property and people (Kasprzyk et al., 2019 (b)), and emitting substances related to their physiological processes: biogenic volatile organic compounds (BVOCs) involved in the ozone formation (Niinemets et al., 2011), and allergenic pollen (Cariñanos et al., 2019; Parmes et al., 2020). Allergenicity of vascular plant pollen is the most common and strongest disservices provided by urban forest (Kasprzyk et al., 2019 (b)). The World Health Organization (WHO) reported that 30–40% of the global population shows allergic sensitization (Cariñanos et al., 2017; Fernández-González et al., 2019). Pollen allergy has a remarkable clinical impact all over Europe, and the prevalence of pollen allergy is presently estimated to be up 40% (Bosch-Cano et al., 2011; D'Amato et al., 2012). In addition, there seems to be a parallel development between warmer temperature due to climate change and the rising of asthma and allergies since early spring are related to increased airborne pollen. Sensitization to pollen allergens is likely to have doubled during the last three decades, particularly in young people in many areas in Europe (Wirl and Puklová, 2007). In the Mediterranean area, the growing of typical vegetation with production of allergenic pollen is facilitated due to climatic conditions (mildness of winter, summer dryness, etc.). D'Amato et al.

(2012) highlighted that severe exacerbations could occur with thunderstorms during pollen season, and this becomes particularly important in the face of the climatic changes that the Mediterranean area is undergoing. Made these premises, forecasting of allergen risk has been becoming a fundamental tool to establish prevention and mitigation measures especially in densely populated areas. One of the most recent methodologies for assessing the allergenicity of urban green areas has been developed and proposed by Cariñanos et al. (2014). The method consists in carrying out a complete census of plant individuals in an urban park and, through the analysis of biological parameters (type of pollination, duration of pollen season and species-specific allergenicity of pollen grains) and biometric parameters (crown diameter and height), determine by summation the allergenicity index of urban green zones (I_{UGZA}) (Cariñanos et al., 2014; Cariñanos et al., 2016). Biological parameters allow to assign the potential allergenic value (VPA) to each species, while biometric parameters allow to calculate the allergen volume emission by comparing the tree crown to a simpler geometrical volume (Cariñanos et al., 2014). I_{UGZA} assessment represents an innovative strategy for the identification of risk situations linked to pollen ecosystem disservice in urban parks, and has been applied in various urban contexts of varying sizes, up to about 120 hectares (Cariñanos et al., 2017, 2019). The index, as it was constructed, requires a total census of the urban park arboreal flora, carried out *in situ*, or at least a catalog of tree individuals distinguished by species (Cariñanos et al., 2014, 2017, 2019). This feature makes I_{UGZA} difficult to apply to the growing size and naturalness of the urban park whose allergenic risk is to be known. In addition, allergenic risk characterization has been traditionally based on a deterministic approach (Cariñanos et al., 2017, 2019; Zong et al., 2020). However, this approach has the disadvantage that the magnitude of the potential problem is not known since they produce only estimates of the expected value. Contrariwise, probabilistic simulations can be useful model the variation of the involved parameters in risk assessment by making assumptions about the random component of a model, and results in estimates of the probability about the expected value.

The purpose of this work is to determine a methodological variant for the application of I_{UGZA} to urban and peri-urban green areas, regardless of their size, density, and specific composition. Within this mind, we assessed the allergenic potential of vegetation occurring in the Vesuvius National Park (Southern Italy), which is a wide area with a high population density.

To achieve this objective, the characteristics of the I_{UGZA} have been modified, specifically the biometric parameters necessary for determining the risk. The substantial modification lies in the replacement of the census with the estimation of vegetation cover in sampling areas, applying the Braun-Blanquet scaling method (Braun-Blanquet, 1932) to define a modified I_{UGZA} ($modI_{UGZA}$). We also aim at implement a probabilistic simulation in allergenic risk assessment to obtain a more accurate estimates.

2. Materials and Methods

2.1 Study site and sampling areas

The Vesuvius National Park, a peri-urban park of more than 8000 hectares (www.parconazionaledelesuvio.it, 2020), characterized by Mediterranean climatic conditions, (mean annual temperature: 13.2 °C; annual precipitation: 960 mm) (Memoli et al., 2019) has been chosen as a study area. Vesuvius National Park area falls in thirteen municipalities of the province of Naples in which approximately 350,000 people live (<http://dati.istat.it>, 2020), in addition approximately, 600,000 visitors per year can be counted inside the park during the touristic season (Memoli et al., 2019). The population density and the high number of visitors, together with the size and naturalness of the park, make it the ideal site for experimenting with $modI_{UGZA}$.

The entire area of the Vesuvius National Park was georeferenced and mapped in a GIS environment. The layer of the total park area was superimposed on the boundaries of the thirteen municipalities in which it falls, and the size of the park area falling within each municipality has been recorded (Figure 1). A regular mesh grid was used to divide the entire surface and a point was randomly selected within each mesh. On the proportion of the size of the park area falling within each municipality, two to ten points were randomly selected to act as centroids for the sampling areas in which to carry out the phytosociological survey. Each plot has been materialized *in situ* as a square of 20 meters per side (400 m² of surface).

Figure 1 – Vesuvius National Park. In red the park boundaries, and the municipalities boundaries. The municipalities names are abbreviated: E=Ercolano; SSV=San Sebastiano al Vesuvio; MS=Massa di Somma; PT=Pollena Trocchia; SA=Sant’Anastasia; SV=Somma Vesuviana; O=Ottaviano; SGV=San Giuseppe Vesuviano; T=Terzigno; BR=Boscotrecase; BT=Boscotrecase; TC=Trecase; TdG=Torre del Greco.

2.2 Phytosociological survey

The centroids of the sampling areas were reached with GPS, and sampling areas (400 m^2) have been materialized with the aid of a metric roll, marking tape and posts. The municipality in which each area fell, has been noted. The phytosociological survey operations were carried out from April to August, performing the surveys monthly on each sampling area. The vegetation present in the plots has been differentiated into "herbaceous" and "arboreal" strata, making the shrubs fall into the second category. In each sampling area, for each stratum, all the plant species present have been collected, determined (Pignatti, 2017) and recorded in a field schedule. Mean heights for each species have been estimated in each sampling area, and data have been averaged and recorded (Table S1 in Supplementary Material).

For each found species (in each sampling plot) cover has been estimated using the Braun-Blanquet scale (Braun-Blanquet, 1932) and recorded. Braun-Blanquet approach allows to assign a numerical value, comprised from 1 to 5, for each species in each stratum, considering the species occurrence and their estimated coverage (1 = <5%; 2 = 5%-25%; 3 = 25%-50%; 4 = 50%-75%; 5 = >75%). Once cover data collection has been completed for all the sampling areas, the average values at the municipality level has been recorded (Table S3 in Supplementary Material).

2.3 ModIUGZA

2.3.1 Deterministic model

The index was built, in form of a ratio, on the model of the original proposed by Cariñanos et al., (2014). For each plant species, recorded during the survey operations, the VPA has been determined multiplying the species-intrinsic biological parameters values: allergenic potential (ap), pollen emission (pe), and principal

pollination period (ppp) (Cariñanos et al., 2014). The values for the biological parameters of each species have been determined by converting the data found in the literature, in reports and database, (D'Amato and Lobefalo, 1989; Spieksma et al., 1992; Frenz, 1995; Ogren, 2002; Galan et al., 2007; Mari et al., 2009; Cariñanos and Casares, 2011; Cariñanos et al., 2014; Pignatti, 2017) with the scale proposed by Cariñanos et al. (2014).

The average height of each species (H_i), has been calculated as a mean of heights previously recorded in the physiological survey, and the results have been used as a biometric parameter. The central values of the Braun-Blanquet class, identified in the phytosociological survey, have been used to obtain the average percentage cover for each species (Tüxen and Ellenberg, 1937; Bimova et al., 2004; Wild et al., 2004). The obtained average value was reported in the Braun-Blanquet class it belongs to, and the central value of the resulting class has been used in the model. To calculate the area covered by each species (S_{EB}) in km^2 , the resulting percentage value has been transformed in proportion with the park or the municipalities surfaces. In modelling the allergenicity for the municipalities, only the covers data collected from the sampling plot falling in each municipal boundary have been used. Furthermore, in modelling the allergenicity of the whole Vesuvius National Park, the covers data from all the sampling sites have been used.

As a weighting factor, in modelling the allergenicity in the park, the product between the maximum height registered in the field surveys (maxH), the maximum of the VPA (maxVPA), and the total surface of the Vesuvius National Park (S_t) has been used (Equation 1). The S_t factor has been substituted with the surface of the park falling in each municipality boundary (S_m), in modelling the modIUCZA for each municipality (Equation 2). Both for the park and for the individual municipalities, two different modIUCZA have been calculated for the arboreal and herbaceous strata.

$$\frac{\text{modIUCZA}_{\text{arboreal}}}{\text{modIUCZA}_{\text{herbaceous}}} = \frac{\text{maxH} \times \text{maxVPA} \times S_t}{\text{maxH} \times \text{maxVPA} \times S_t}$$

According to Cariñanos et al. (2017, 2019) the index results in a value between 0 (null allergenicity) and 1 (maximum allergenicity) and 0.3 is considered the critical value which may pose allergic symptoms in the sensitive population.

2.3.2 Probabilistic model

As an extension of the deterministic approach, a probabilistic analysis of allergenic risk was performed. A probabilistic simulation considers uncertainty and variability of input variables and can lead to a more realistic risk assessment (Qu et al., 2019; Zuzolo et al., 2020). Probabilistic simulation consists in simulating probabilistic variables by selecting a random sample from each assigned distribution. After random sampling is performed, numeric results are arranged according to assigned mathematical relationships. In our study, a Monte Carlo method with Latin hypercube sampling was adopted to improve sampling efficiency, and ensure the sample values covering the entire distribution range of the input random variable (Iman, 2006). The simulation was applied using using Argo - Monte Carlo simulation Excel tool. The statistical distribution of the random variables was verified by the `fitdistrplus` routine within the R software package (Delignette-Muller et al., 2014) and are presented in Table S1 and Table S2 in the Supplementary Material. The optimal number of iterations needed in Monte Carlo Simulation was chosen using Normal distribution for the performance function (Bukaçi et al., 2016) and we observed that 10000 trials ensured stability of the estimations. Sensitivity analysis was also performed to determine the contribution of single uncertain parameters on the results of the allergenic risk assessment.

3. Results and Discussion

3.1 Phytosociological survey of the Vesuvius National Park

With phytosociological survey operations, 15 species in the arboreal stratum, and 25 species in the herbaceous stratum were identified (Table S3) across the various sampling areas. In the park, the most abundant species in the arboreal strata is *Pinus pinaster* Aiton., which was found in 75% of the surveys, and

is present in 9 out of 13 municipalities of the park. Another recurrent tree species is *Pinus nigra* Aiton. which was found in more than 50% of the surveys, in 7 municipalities. The most abundant broadleaf species is *Quercus ilex* L., found in 6 municipalities. In the herbaceous stratum, the most recurring species is *Poa annua* L., present in all the municipalities, followed by *Avena fatua* L., *Dactylis glomerata* L., *Papaver rhoeas* L., and *Taraxacum officinale* Weber ex Wigg., found in the 90% of the sampling areas. In Table S3 in the Supplementary Material the complete list of species found in the surveys, and the average covers in each municipality according to Braun-Blanquet scale are reported.

The municipality with the highest number of recorded species is Ercolano, where 28 species have been found, while the municipality with the lowest number of recorded species is Ottaviano, where 7 plant species have been found (Table S3).

3.2 Deterministic assessment of allergenic risk

Outcomes from deterministic approach in the assessment of allergenic risk both for the Vesuvius National Park and each municipality are summarized in Figure 2.

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Figure 2 – Results from allergenic risk assessment using a deterministic approach. The red line separates the low-risk scenarios (0-0.3) from the high-risk one (> 0.3), according to Cariñanos et al. (2017, 2019).

The results of the deterministic assessment of allergenic risk in the park show a low risk value for the herbaceous stratum (0.19) and a high risk level for the arboreal stratum (0.30) (Figure 2 and Table 1). Observing the data for each municipality the herbaceous stratum never exceeds the high risk threshold, while

there are critical issues, in some municipalities, regarding the arboreal stratum. Ottaviano municipality shows a risk of 0.38 (Figure 2 and Table 1), overcoming the 0.3 threshold, and representing the maximum values reached among all the municipalities. Trecase, Boscotrecase, and Boscoreale municipalities have the same risk in both strata, and the same is for Massa di Somma and San Sebastiano al Vesuvio (Figure 2 and Table 1). Similarities in their values occur because of the great similarity of the specific composition and coverage found in the sampling areas falling within each of these municipalities. Looking at Figure 2 and Table 1, the lowest recorded value for the herbaceous stratum is that of San Giuseppe Vesuviano (0.08), while the lowest one for the arboreal stratum is that of Pollena Trocchia (0.07).

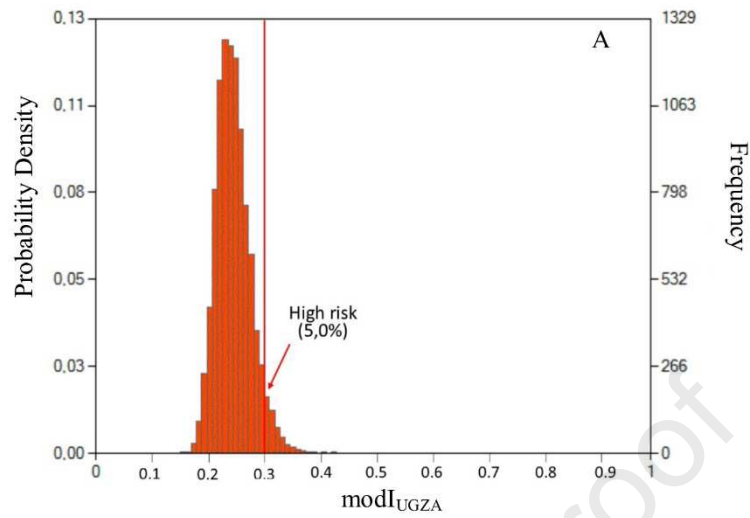
The results obtained are in line with what Cariñanos et al. (2017) stated about the negative correlation between the specific abundance of a site and its potential allergenic risk. Ottaviano municipality has the highest modI_{UZA} value (Figure 2 and Table 1) and the lowest number of species recorded (Table S2), while Ercolano municipality, in which the highest number of species have been found (Table S2), show a modI_{UZA} value falling in the low risk scenarios (Figure 2 and Table 1).

Table 1 shows and compares the results of the deterministic and probabilistic assessment of allergenic risk in the Vesuvius National Park, and in the areas of the park falling in each municipality.

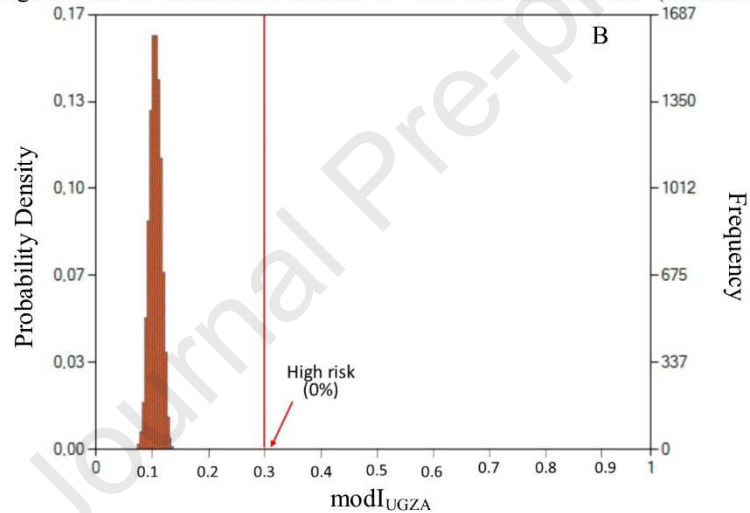
Overall, an allergenic risk due to arboreal vegetation for the Vesuvius National Parks is confirmed by the simulation, which depict a mean outcome of $\text{modI}_{\text{UGZA}} = 0.26$ and a probability of medium risk of about 5% (Fig. 3A). The absence of herbaceous stratum related high risk for the whole park is also confirmed by our probabilistic simulation (Fig. 3B). This result indicates that overall Vesuvius National Park does not pose high risks for people sensitive to pollen allergies with only the 5% of possibility above the 0.3 threshold for tree species present in the area. The sensitivity analysis chart discloses that the height of some tree species play a main role in determining the occurrence of a risk (Fig. 3C) as hereafter listed: *Pinus pinaster* (H2_a) > *Castanea sativa* (H1_a) > *Pinus nigra* (H7_a) > *Pinus halepensis* (H3_a) > *Robinia pseudoacacia* (H5_a) > *Quercus ilex* (H8_a) > *Pinus pinea* (H6_a).

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Allergenic risk for arboreal stratum in Vesuvius National Park (Southern Italy)



Allergenic risk for herbaceous stratum in Vesuvius National Park (Southern Italy)



Sensitivity Chart

Allergenic risk for arboreal stratum in Vesuvius National Park

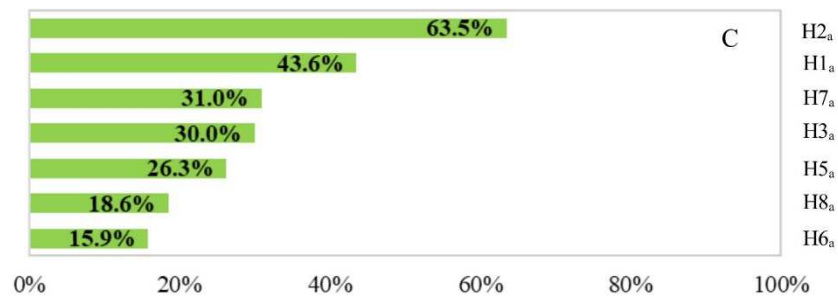
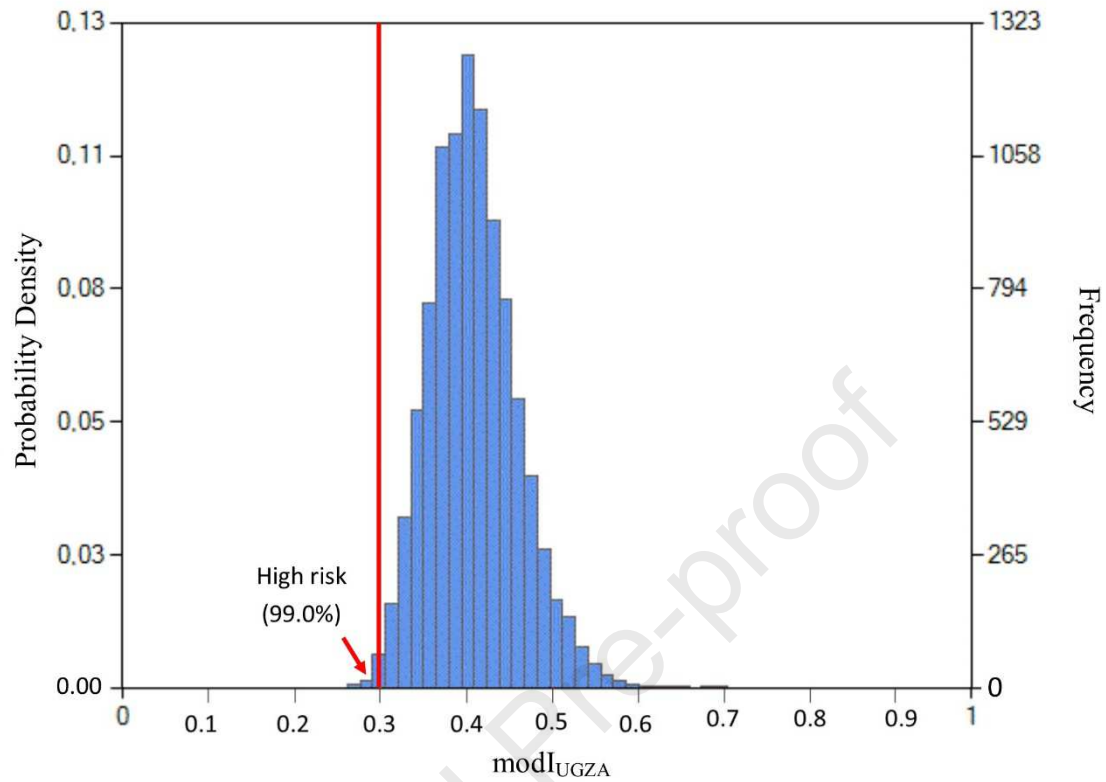


Figure 3 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Vesuvius National Park (Southern Italy) where the red lines depict the high risk

threshold set by Cariñanos et al. (2017, 2019); (C) sensitivity analysis of allergenic risk for arboreal stratum in Vesuvius National Park (Southern Italy).

However, shifting from a park to a local (municipality) scale, we observed that the mean risk values are in some cases by far greater. In contrast to the deterministic modelling outcomes, which reveal a risk only for Ottaviano municipality, we observed a certain probability of high allergenic risk for arboreal stratum in 11 municipalities: Boscoreale, Boscotrecase, Ercolano, Massa di Somma, Ottaviano, San Sebastiano al Vesuvio, Sant'Anastasia, Somma Vesuviana, Terzigno, Trecase, Torre del Greco (Figures S1-S14). In particular, according to our computations, we observed that there is a 99% probability that vegetation may rise to an allergenic risk over the 0.3 threshold in Ottaviano municipality, with a mean risk of 0.41 (Table 1 and Fig. 4A).

Allergenic risk for arboreal stratum in Ottaviano municipality (Naples, Southern Italy)



Sensitivity Chart
Allergenic risk for arboreal stratum in Ottaviano municipality

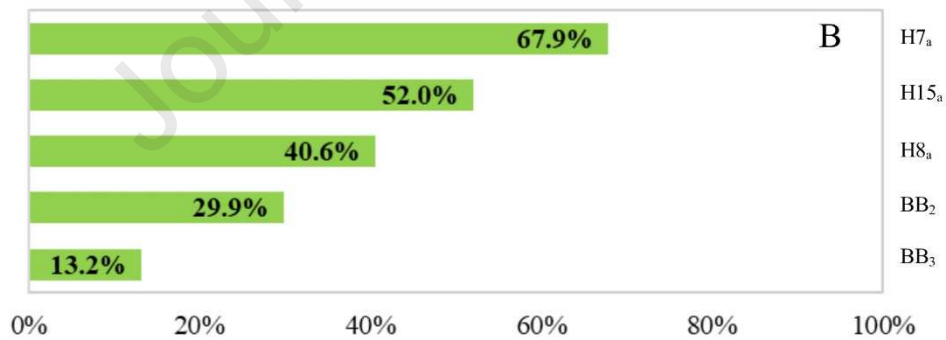


Figure 4 - (A) Predicted probability density functions of allergenic risk for arboreal stratum and (B) sensitivity analysis of Ottaviano municipality (Naples, Southern Italy). The red lines depict the high risk threshold set by Cariñanos et al. (2017, 2019)

Sensitivity analyses (Fig.4B) revealed that the greatest influence on the outcome of risk are in the heights of *Pinus nigra* (H7_a) > *Betula pendula* (H15_a) > *Quercus ilex* (H8_a) > the area covered by the previous mentioned species (BB₂ and BB₃). As these parameters increase, the volume that contains the biological emission potential of allergens increases (Cariñanos et al., 2014). As also suggested by Cariñanos et al. (2014) taxonomic diversity is another core factor that may minimize the allergenic potential of a park area. Vegetal diversity may have a positive feedback on pollen limitations since a massive occurrence of few species from the same families can lead to cross-reaction processes between their allergens in sensitized people (Álvarez-López et al., 2020). Gastaminza et al. (2009) observed that Pine pollen can have significant allergenic potential especially in those geographical areas where pines are very abundant and also noticed that a high degree of cross-reactivity between different pine pollen species. The data on the municipality of Ottaviano indicate that the arboreal species present in this area provide an ecosystem disservice that would affect the benefits provided by the urban forests (Cariñanos et al., 2019; Kasprzyk et al., 2019 (b)). The second municipality with the largest risk is Massa di Somma which shows a 49% probability of high risk (Figures S1-S14).

It is noteworthy that a probability of allergenic risk (even if low) for herbaceous stratum has been identified for three municipalities: Sant'Anastasia, Ottaviano and Somma Vesuviana with 8%, 3% and < 1% probability of exceeding the 0.3 threshold (respectively) (Table 1 and Figures S1-S14).

4. Conclusions

Starting from the Allergenicity Index of Urban Green Areas (I_{UGZA}), created by Cariñanos et al. (2014), our study introduces a reproducible method (named modI_{UGZA}) in the quantitative assessment of pollen related ecosystem disservices for large areas. The I_{UGZA} based approach can be considered as an important strategy for risk management and mitigation in health protection perspective.

The innovation of the methodology proposed in this study lies in the possibility it offers of being able to estimate the allergenic risk of urban and peri-urban forests, regardless of their size. The methodological approaches of the determination of sampling areas, and the use of the Braun-Blanquet scale for the estimation of plant coverings, make this method simple to implement with a minimum expenditure of energy if compared to the benefits deriving from the possibility of being able to determine the risk on such a large scale. The modI_{UGZA} is also useful to the preliminary screening of probable risk situations, in order to direct the efforts of more accurate investigations only on the riskiest areas.

Comparison of the deterministic and probabilistic estimates suggests that the second one leads to a more realistic interpretation of the outcomes. Our study reveals that an allergenic risk occurs through the whole park, with a 5 % of high risk probability due to arboreal stratum. In addition, the allergenicity of both arboreal and herbaceous strata at a municipality scale, shows a very high probability of risk for many areas (e.g., Ottaviano municipality) mainly related to *Pinus* species occurrence. Our research also highlights that morphological features (height and the plant covers) play a decisive role in risk magnitude results.

The data obtainable from this approach blend well with the management of urban areas and urban forests, with a view to maximizing ecosystem services and minimizing disservices. The management of urban forests can be directed in such a way as to intervene precisely on the parameters that determine the disservices.

Through the proposed methodology, tools can also be developed for prevent and forecast events related to pollinosis on a large scale, allowing a more accurate management of the health resources of a territory. Results obtained in this preliminary work allow the future correlations between allergenicity potential of extended green areas, and epidemiologic data. Therefore, the next step of this research will be focused on combining the obtained results with human allergenic pathologies (e.g. emergency hospital admissions for asthma) data in the investigated area.

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Figure captions

Figure 3 – Vesuvius National Park. In red the park boundaries, and the municipalities boundaries. The municipalities names are abbreviated: E=Ercolano; SSV=San Sebastiano al Vesuvio; MS=Massa di Somma; PT=Pollena Trocchia; SA= Sant’Anastasia; SV=Somma Vesuviana; O=Ottaviano; SGV=San Giuseppe Vesuviano; T=Terzigno; BR=Boscotrecase; BT=Boscotrecase; TC=Trecase; TdG=Torre del Greco.

Figure 2 – Results from allergenic risk assessment using a deterministic approach. The red line separates the low-risk scenarios (0-0.3) from the high-risk one (> 0.3), according to Cariñanos et al. (2017, 2019).

Figure 3 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Vesuvius National Park (Southern Italy) where the red lines depict the high risk threshold set by Cariñanos et al. (2017, 2019); (C) sensitivity analysis of allergenic risk for arboreal stratum in Vesuvius National Park (Southern Italy).

Figure 4 - (A) Predicted probability density functions of allergenic risk for arboreal stratum and (B) sensitivity analysis of Ottaviano municipality (Naples, Southern Italy). The red lines depict the high risk threshold set by Cariñanos et al. (2017, 2019)

Table captions

Table 1 – Results of modIUGZA assessment by deterministic and probabilistic approaches. Data are reported for the two strata (herbaceous and arboreal), for each municipality and for the whole park. In probabilistic assessment of allergenic risk the range of risk and the average risk are reported.

HIGHLIGHTS

- A reproducible allergenicity assessment for large urban green zones was proposed.
- Potential Allergenicity of Vesuvius National Park was estimated.
- Probabilistic simulation results in a more realistic interpretation of the outcomes.
- The results may be a useful tool to manage green spaces.

Ethical statements

Assessing allergenicity in the Vesuvius National Park through a modified Index of Urban Green Zones Allergenicity.

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On behalf of the authors of this paper, as corresponding author I hereby certify that:

- there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. The authors' freedom to design, conduct, interpret, and publish research is not compromised by any controlling sponsor as a condition of review and publication.
- The manuscript has not been submitted to more than one journal for simultaneous consideration.
- The manuscript has not been published previously (partly or in full).
- The present study has not been splitted up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time.
- No data have been fabricated or manipulated (including images) to support our conclusions.
- We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.
- Authors whose names appear on the submission have contributed sufficiently to the scientific work and therefore share collective responsibility and accountability for the results.

Sincerely,

Daniela Zuzolo

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

• The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

SM – Supplementary material

Assessing pollinosis risk in the Vesuvius National Park: a novel approach for Index of Urban Green Zones Allergenicity.

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Table S1. Specific model parameters for allergenic risk model (modI_{UGZA}); values used for both deterministic and stochastic approaches are reported.

Parameters	Symbol	Units	Deterministic	Probabilistic	Values
			Values	Distribution types	
Arboreal stratum weighting factor	K _a	km ⁻² *m ⁻¹	1/(VPA _{amax} *S _(x) *H _{amax})		1/(VPA _{amax} *S _(x) *H _{amax})
Herbaceous stratum weighting factor	K _e	km ⁻² *m ⁻¹	1/(VPA _{emax} *S _(x) *H _{emax})		1/(VPA _{emax} *S _(x) *H _{emax})
Braun-Blanquet Class 0	BB ₀		0	Uniform	0
Braun-Blanquet Class 1	BB ₁		2,5 ^a	Triangular	1 - 2.5 (5) ^b
Braun-Blanquet Class 2	BB ₂		15 ^a	Triangular	5.1 - 25 (15) ^b
Braun-Blanquet Class 3	BB ₃		37,5 ^a	Triangular	25.1 - 50 (37.5) ^b
Braun-Blanquet Class 4	BB ₄		62,5 ^a	Triangular	50.1 - 75 (62.5) ^b
Braun-Blanquet Class 5	BB ₅		87,5 ^a	Triangular	75.1 - 100 (87.5) ^b
Surface	S _(x)	km ²	^c	Constant	^c
VPA <i>Castanea sativa</i>	VPA1 _a		12	Constant	12
VPA <i>Pinus pinaster</i>	VPA2 _a		12	Constant	12
VPA <i>Pinus halepensis</i>	VPA3 _a		12	Constant	12
VPA <i>Corylus avellana</i>	VPA4 _a		4	Constant	4
VPA <i>Robinia pseudoacacia</i>	VPA5 _a		4	Constant	4
VPA <i>Pinus pinea</i>	VPA6 _a		12	Constant	12
VPA <i>Pinus nigra</i>	VPA7 _a		12	Constant	12
VPA <i>Quercus ilex</i>	VPA8 _a		18	Constant	18
VPA <i>Fraxinus ornus</i>	VPA9 _a		18	Constant	18
VPA <i>Olea europea</i>	VPA10 _a		24	Constant	24
VPA <i>Ailanthus altissima</i>	VPA11 _a		18	Constant	18
VPA <i>Ulmus minor</i>	VPA12 _a		18	Constant	18

VPA <i>Acer obtusatum</i> subsp. <i>neapolitanum</i>	VPA13 _a		8		Constant	8
VPA <i>Alnus cordata</i>	VPA14 _a		9		Constant	9
VPA <i>Betula pendula</i>	VPA15 _a		27		Constant	27
VPA <i>Avena fatua</i>	VPA1 _e		24		Constant	24
VPA <i>Dactylis glomerata</i>	VPA2 _e		24		Constant	24
VPA <i>Parietaria judaica</i> subsp. <i>judaica</i>	VPA3 _e		36		Constant	36
VPA <i>Chenopodium album</i>	VPA4 _e		27		Constant	27
VPA <i>Urtica urens</i>	VPA5 _e		36		Constant	36
VPA <i>Amaranthus retroflexus</i>	VPA6 _e		12		Constant	12
VPA <i>Trifolium pratense</i>	VPA7 _e		6		Constant	6
VPA <i>Rumex bucephalophorus</i>	VPA8 _e		12		Constant	12
VPA <i>Lolium perenne</i>	VPA9 _e		24		Constant	24
VPA <i>Poa annua</i>	VPA10 _e		36		Constant	36
VPA <i>Helianthus annuus</i>	VPA11 _e		8		Constant	8
VPA <i>Artemisia campestris</i> subsp. <i>variabilis</i>	VPA12 _e		12		Constant	12
VPA <i>Urtica dioica</i>	VPA13 _e		24		Constant	24
VPA <i>Lolium multiflorum</i>	VPA14 _e		36		Constant	36
VPA <i>Holcus lanatus</i>	VPA15 _e		24		Constant	24
VPA <i>Papaver rhoeas</i>	VPA16 _e		12		Constant	12
VPA <i>Phleum hirsutum</i>	VPA17 _e		24		Constant	24
VPA <i>Zea mays</i>	VPA18 _e		12		Constant	12
VPA <i>Mercurialis annua</i>	VPA19 _e		18		Constant	18
VPA <i>Plantago lanceolata</i>	VPA20 _e		27		Constant	27
VPA <i>Medicago sativa</i>	VPA21 _e		6		Constant	6
VPA <i>Taraxacum officinale</i>	VPA22 _e		6		Constant	6

VPA <i>Stellaria media</i>	VPA23 _e		0		Constant	0
VPA <i>Matricaria chamomilla</i>	VPA24 _e		12		Constant	12
VPA <i>Glebionis segetum</i>	VPA25 _e		4		Constant	4
Height <i>Castanea sativa</i>	H1 _a	m	18		Lognormal	18 ± 7^d
Height <i>Pinus pinaster</i>	H2 _a	m	20		Lognormal	20 ± 10^d
Height <i>Pinus halepensis</i>	H3 _a	m	15		Lognormal	15 ± 5^d
Height <i>Corylus avellana</i>	H4 _a	m	4,5		Lognormal	4.5 ± 0.5^d
Height <i>Robinia pseudoacacia</i>	H5 _a	m	15		Lognormal	15 ± 10^d
Height <i>Pinus pinea</i>	H6 _a	m	15		Lognormal	15 ± 10^d
Height <i>Pinus nigra</i>	H7 _a	m	15		Lognormal	15 ± 5^d
Height <i>Quercus ilex</i>	H8 _a	m	18		Lognormal	18 ± 2^d
Height <i>Fraxinus ornus</i>	H9 _a	m	6		Lognormal	6 ± 4^d
Height <i>Olea europea</i>	H10 _a	m	4		Lognormal	4 ± 1.8^d
Height <i>Ailanthus altissima</i>	H11 _a	m	9		Lognormal	9 ± 2^d
Height <i>Ulmus minor</i>	H12 _a	m	10		Lognormal	10 ± 6^d
Height <i>Acer obtusatum</i> subsp. <i>neapolitanum</i>	H13 _a	m	18		Lognormal	18 ± 2^d
Height <i>Alnus cordata</i>	H14 _a	m	6		Lognormal	6 ± 2^d
Height <i>Betula pendula</i>	H15 _a	m	20		Lognormal	20 ± 5^d
Height <i>Avena fatua</i>	H1 _e	m	0,8		Lognormal	0.8 ± 0.2^d
Height <i>Dactylis glomerata</i>	H2 _e	m	1,5		Lognormal	1.5 ± 0.5^d
Height <i>Parietaria judaica</i> subsp. <i>judaica</i>	H3 _e	m	0,3		Lognormal	0.3 ± 0.1^d
Height <i>Chenopodium album</i>	H4 _e	m	1,5		Lognormal	1.5 ± 0.8^d
Height <i>Urtica urens</i>	H5 _e	m	0,4		Lognormal	0.4 ± 0.1^d
Height <i>Amaranthus retroflexus</i>	H6 _e	m	1		Lognormal	1 ± 0.8^d
Height <i>Trifolium pratense</i>	H7 _e	m	0,3		Lognormal	0.3 ± 0.1^d

Height <i>Rumex bucephalophorus</i>	H8 _e	m	0,1		Lognormal	0.1 ± 0.05^d
Height <i>Lolium perenne</i>	H9 _e	m	0,3		Lognormal	0.3 ± 0.1^d
Height <i>Poa annua</i>	H10 _e	m	0,2		Lognormal	0.2 ± 0.05^d
Height <i>Helianthus annuus</i>	H11 _e	m	2,5		Lognormal	2.5 ± 0.5^d
Height <i>Artemisia campestris</i> subsp. <i>variabilis</i>	H12 _e	m	1		Lognormal	1 ± 0.5^d
Height <i>Urtica dioica</i>	H13 _e	m	0,8		Lognormal	0.8 ± 0.3^d
Height <i>Lolium multiflorum</i>	H14 _e	m	1		Lognormal	1 ± 0.5^d
Height <i>Holcus lanatus</i>	H15 _e	m	0,6		Lognormal	0.6 ± 0.2^d
Height <i>Papaver rhoeas</i>	H16 _e	m	0,4		Lognormal	0.4 ± 0.2^d
Height <i>Phleum hirsutum</i>	H17 _e	m	0,4		Lognormal	0.4 ± 0.2^d
Height <i>Zea mays</i>	H18 _e	m	2		Lognormal	2 ± 0.5^d
Height <i>Mercurialis annua</i>	H19 _e	m	0,25		Lognormal	0.25 ± 0.15^d
Height <i>Plantago lanceolata</i>	H20 _e	m	0,3		Lognormal	0.3 ± 0.2^d
Height <i>Medicago sativa</i>	H21 _e	m	0,3		Lognormal	0.3 ± 0.2^d
Height <i>Taraxacum officinale</i>	H22 _e	m	0,04		Lognormal	0.04 ± 0.02^d
Height <i>Stellaria media</i>	H23 _e	m	0,3		Lognormal	0.3 ± 0.1^d
Height <i>Matricaria chamomilla</i>	H24 _e	m	0,3		Lognormal	0.3 ± 0.2^d
Height <i>Glebionis segetum</i>	H25 _e	m	0,4		Lognormal	0.4 ± 0.2^d

^a Central value of Braun-Blanquet classes (Braun-Blanquet, 1932); ^b Braun-Blanquet classes range (Braun-Blanquet, 1932), central value of each class was used for triangular distribution; ^c See Table S2; ^d Mean and standard deviation were used for lognormal distributions.

Table S2. Surfaces used in modI_{UGZA} assessment

Parameters	Symbol	Units	Deterministic	Probabilistic	Values
			Values	Distribution types	
Vesuvius National Park Surface	S _t	km ²	80,17	Constant	80,17
Torre del Greco Surface	S _{TdG}	km ²	12,96	Constant	12,96
Trecase Surface	S _{TC}	km ²	2,35	Constant	2,35
Boscotrecase Surface	S _{BT}	km ²	3,95	Constant	3,95
Boscoreale Surface	S _{BR}	km ²	0,19	Constant	0,19
Terzigno Surface	S _T	km ²	16,32	Constant	16,32
San Giuseppe Vesuviano Surface	S _{SGV}	km ²	2,72	Constant	2,72
Ottaviano Surface	S _O	km ²	9,24	Constant	9,24
Somma Vesuviana Surface	S _{SV}	km ²	10,79	Constant	10,79
Sant'Anastasia Surface	S _{SA}	km ²	5,34	Constant	5,34
Pollena Trocchia Surface	S _{PT}	km ²	2,48	Constant	2,48
Massa di Somma Surface	S _{MS}	km ²	2,28	Constant	2,28
San Sebastiano al Vesuvio Surface	S _{SSV}	km ²	0,81	Constant	0,81
Ercolano Surface	S _E	km ²	10,75	Constant	10,75

Table S3. The complete list of the plant species found in the phytosociological survey. Average covers according to Braun-Blanquet scale are reported for each municipality.

	Torre del Greco	Trecase	Boscotrecase	Boscoreale	Terzigno	San Giuseppe Vesuviano	Ottaviano	Somma Vesuviana	Sant'Anastasia	Pollena Trocchia	Massa di Somma	San Sebastiano al Vesuvio	Ercolano
<i>Castanea sativa</i> Mill.	0	0	0	0	0	2	0	3	2	0	0	0	0
<i>Pinus pinaster</i> Aiton	3	3	3	3	2	1	0	0	0	0	2	2	2
<i>Pinus halepensis</i> Mill.	0	0	0	0	4	0	0	0	0	0	2	2	0
<i>Corylus avellana</i> L.	0	0	0	0	0	2	0	3	2	3	0	0	0
<i>Robinia pseudoacacia</i> L.	2	0	0	0	0	2	0	0	2	2	0	0	2
<i>Pinus pinea</i> L.	2	0	0	0	0	0	0	0	0	0	2	2	2
<i>Pinus nigra</i> Aiton	0	3	3	3	0	0	3	0	0	0	2	2	2
<i>Quercus ilex</i> L.	1	0	0	0	0	1	3	0	0	0	2	2	1
<i>Fraxinus ornus</i> L.	0	0	0	0	0	1	0	1	1	0	0	0	0
<i>Olea europea</i> L.	1	1	1	1	1	0	0	0	0	0	0	0	1
<i>Ailanthus altissima</i> (Miller) Swingle	1	0	0	0	0	1	0	1	2	2	0	0	0
<i>Ulmus minor</i> Mill.	0	0	0	0	0	1	0	0	1	1	0	0	1
<i>Acer obtusatum</i> subsp. <i>neapolitanum</i> (Ten.) Pax	0	0	0	0	0	1	0	1	1	1	0	0	0
<i>Alnus cordata</i> (Loisel.) Duby	1	2	2	2	0	0	0	0	0	0	0	0	0
<i>Betula pendula</i> Roth	0	0	0	0	0	0	2	0	0	0	0	0	0
<i>Avena fatua</i> L.	2	2	2	2	3	2	0	1	2	1	2	2	2
<i>Dactylis glomerata</i> L.	1	2	2	2	0	1	3	1	2	2	2	2	1
<i>Parietaria judaica</i> L. subsp. <i>judaica</i>	2	2	2	2	0	2	2	1	1	2	0	0	2
<i>Chenopodium album</i> L.	1	0	0	0	0	0	0	2	2	1	0	0	2
<i>Urtica urens</i> L.	1	0	0	0	0	0	0	2	1	1	0	0	1

[illegible]

Figure S1 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Torre del Greco municipality (Naples, Southern Italy).

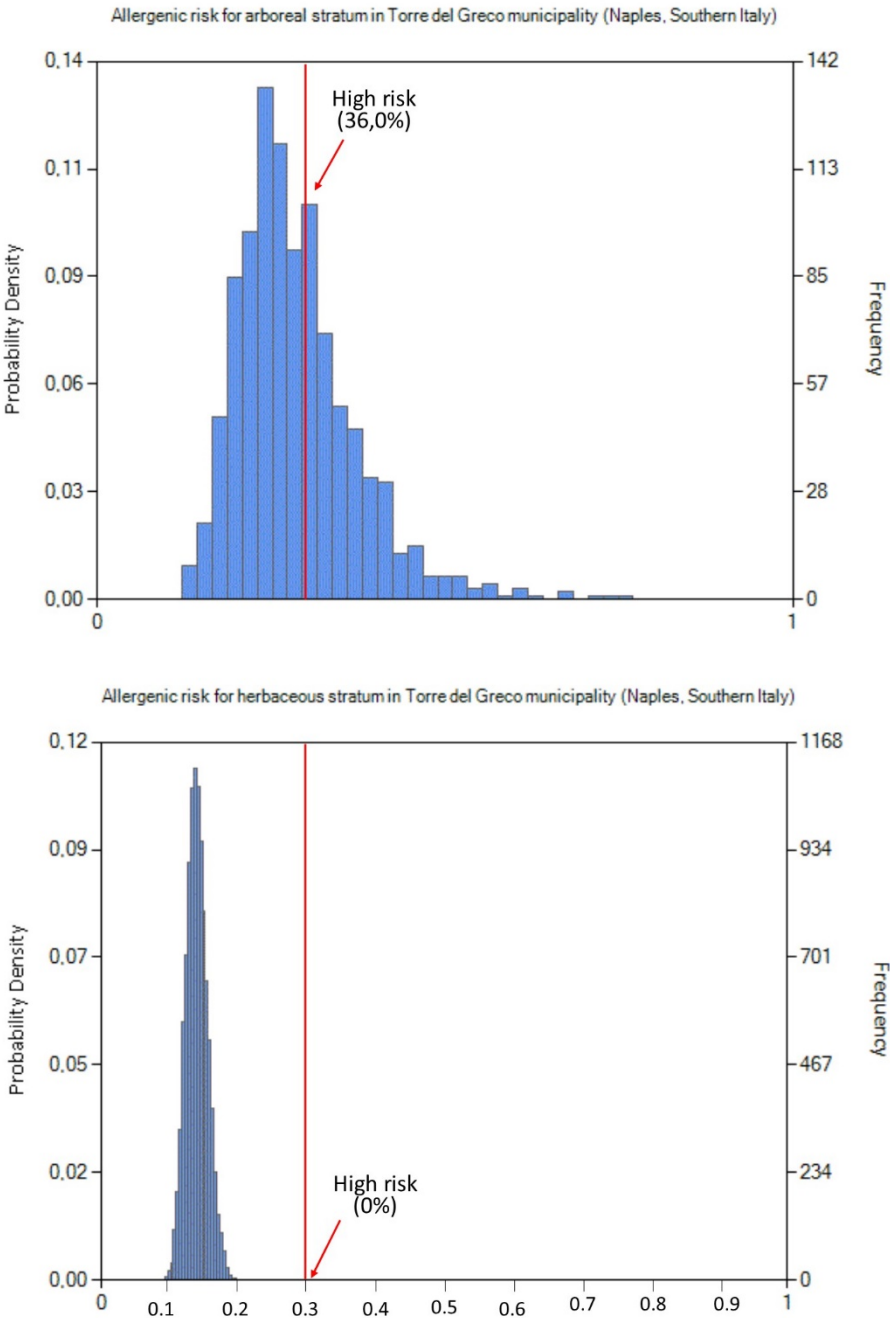


Figure S2 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Trecase municipality (Naples, Southern Italy).

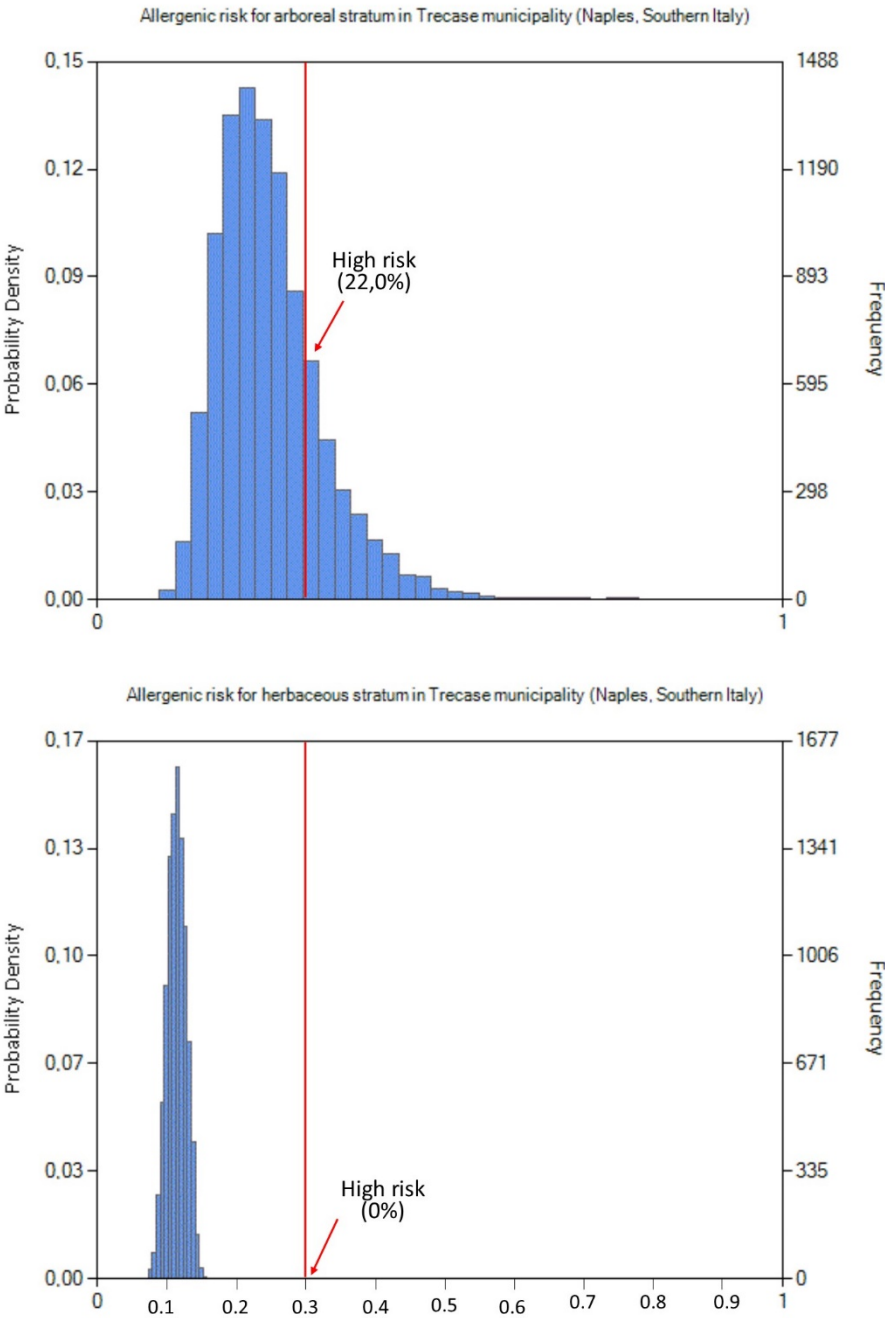


Figure S3 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Boscotrecase municipality (Naples, Southern Italy).

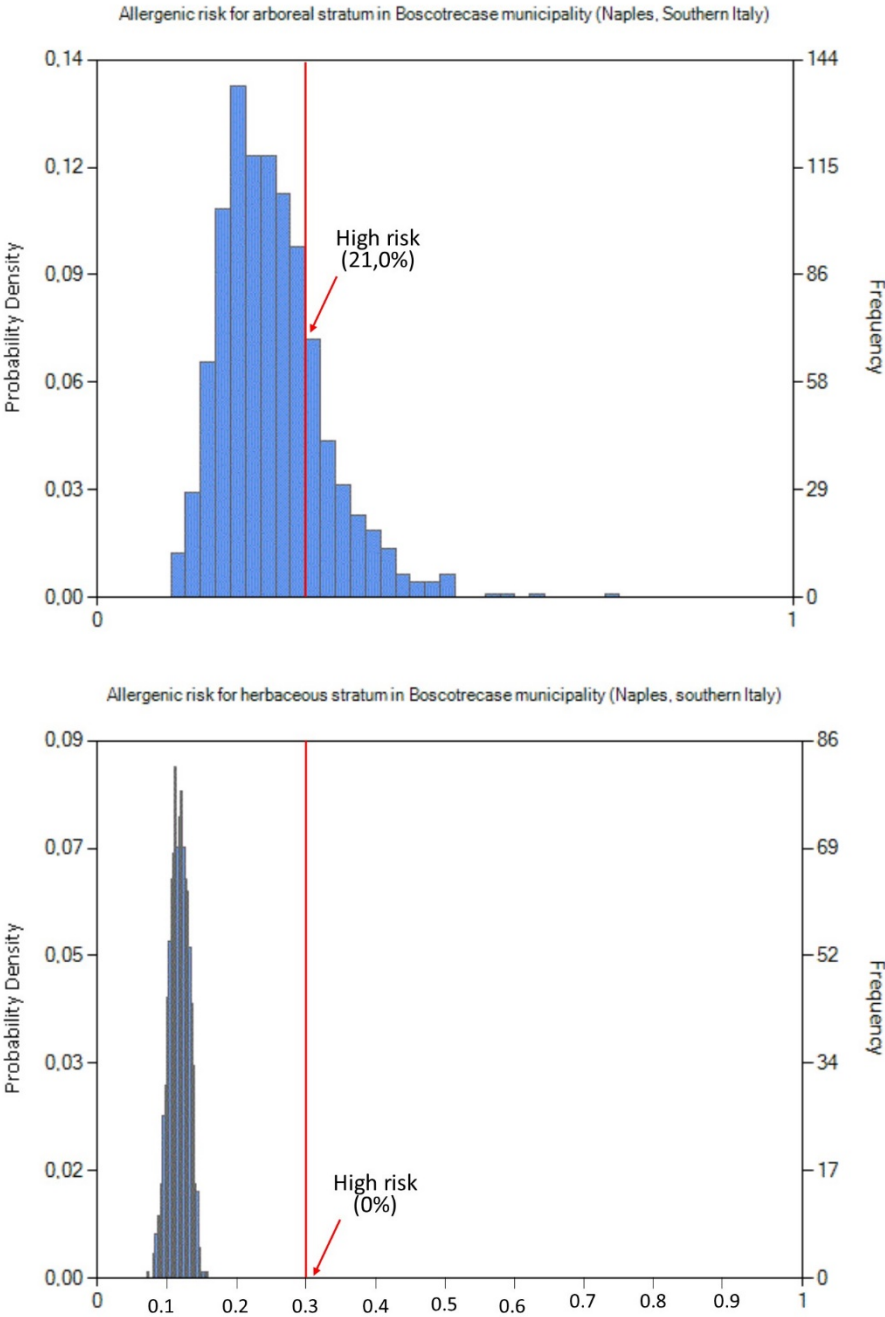


Figure S4 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Boscoreale municipality (Naples, Southern Italy).

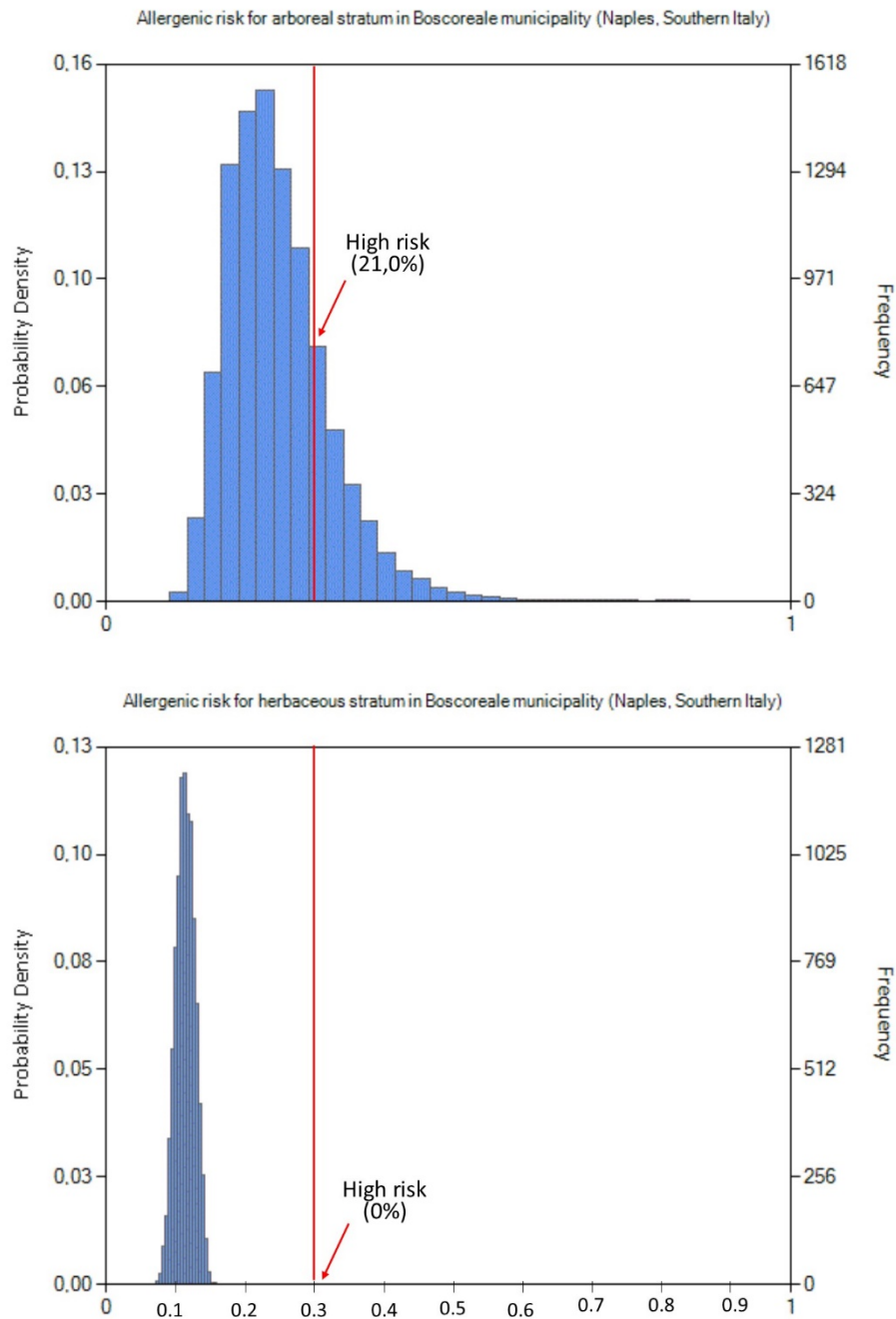


Figure S5 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Terzigno municipality (Naples, Southern Italy).

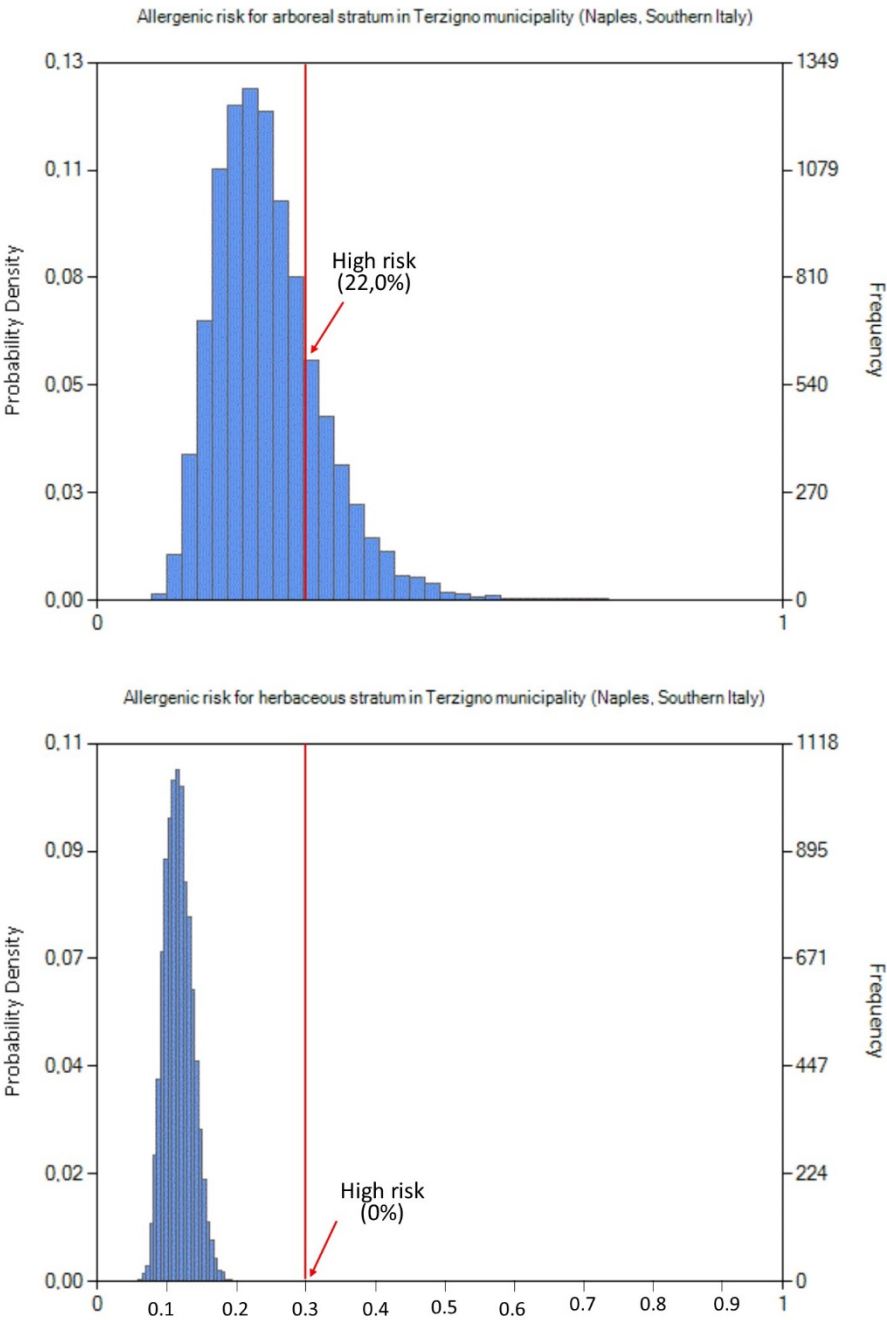


Figure S6 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in San Giuseppe Vesuviano municipality (Naples, Southern Italy).

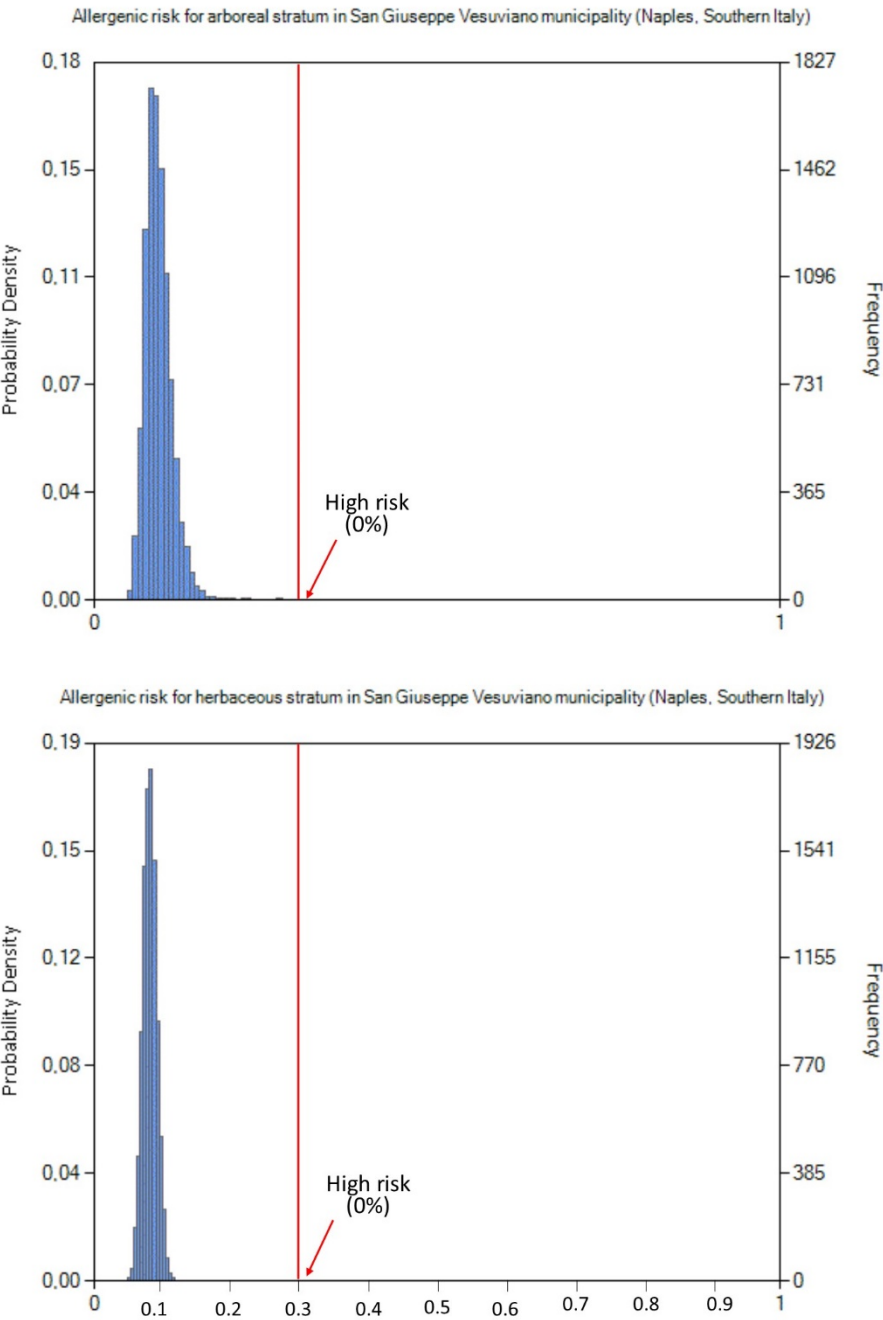


Figure S7 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Ottaviano municipality (Naples, Southern Italy).

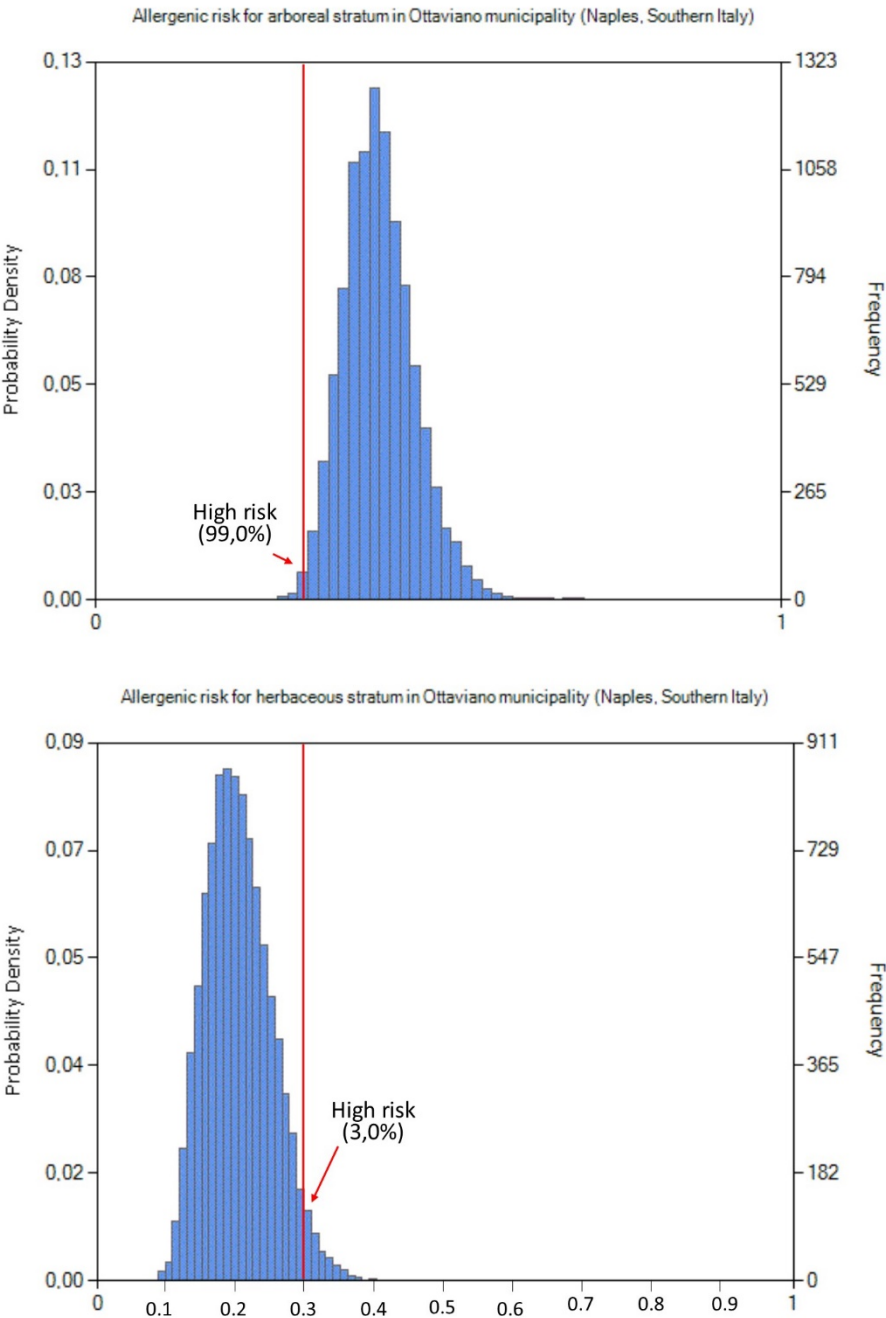


Figure S8 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Somma Vesuviana municipality (Naples, Southern Italy).

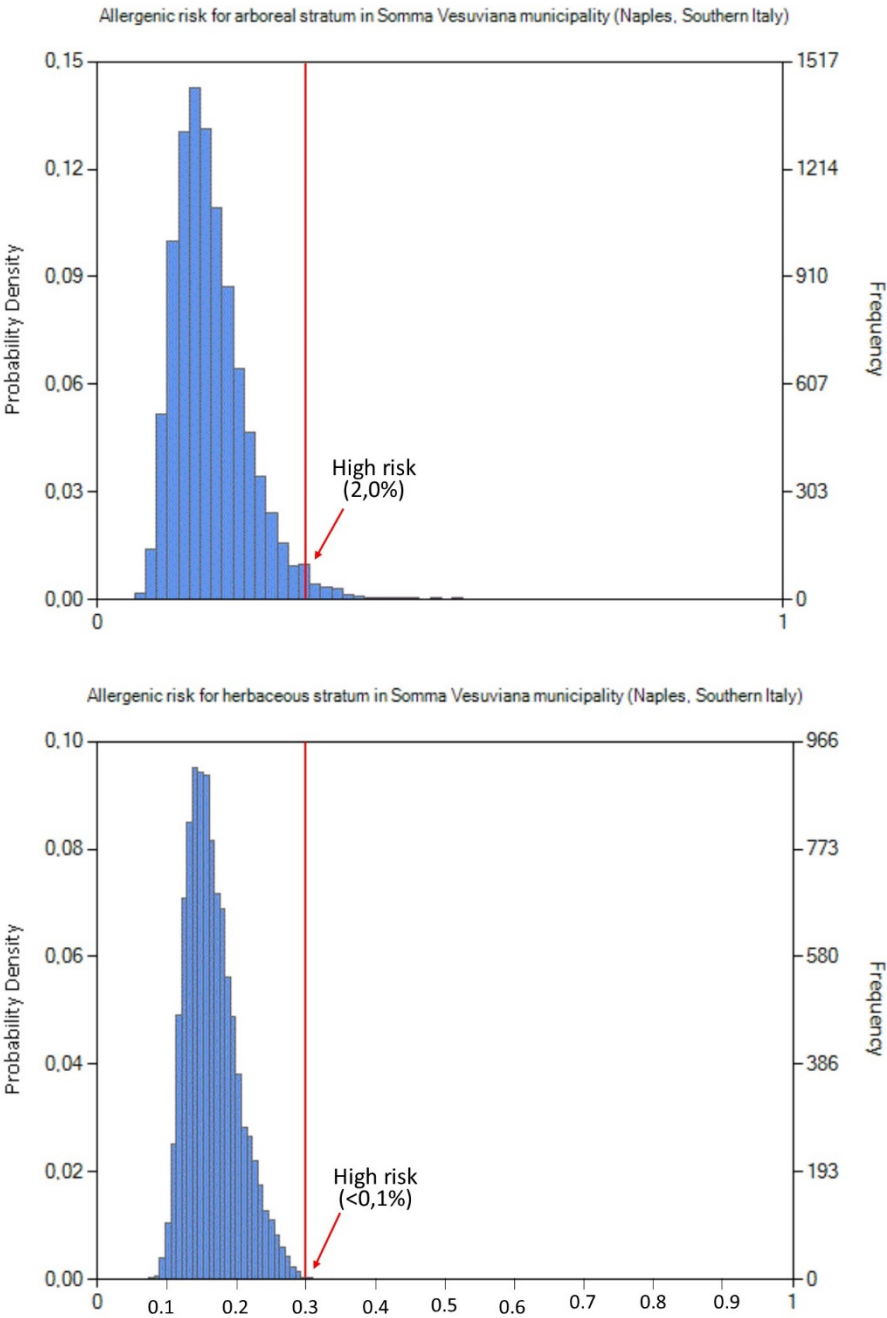


Figure S9 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Sant’Anastasia municipality (Naples, Southern Italy).

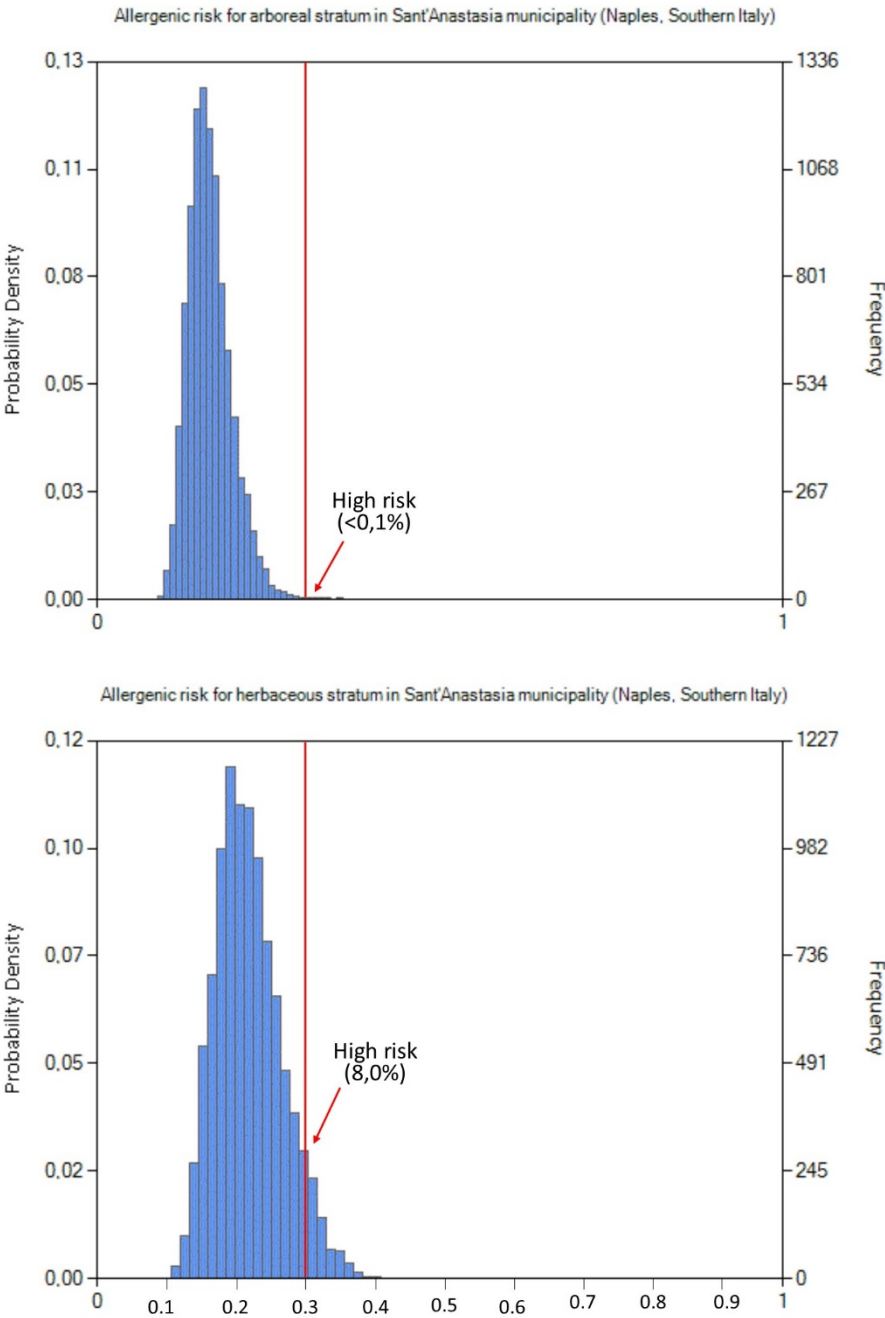


Figure S10 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Pollena Trocchia municipality (Naples, Southern Italy).

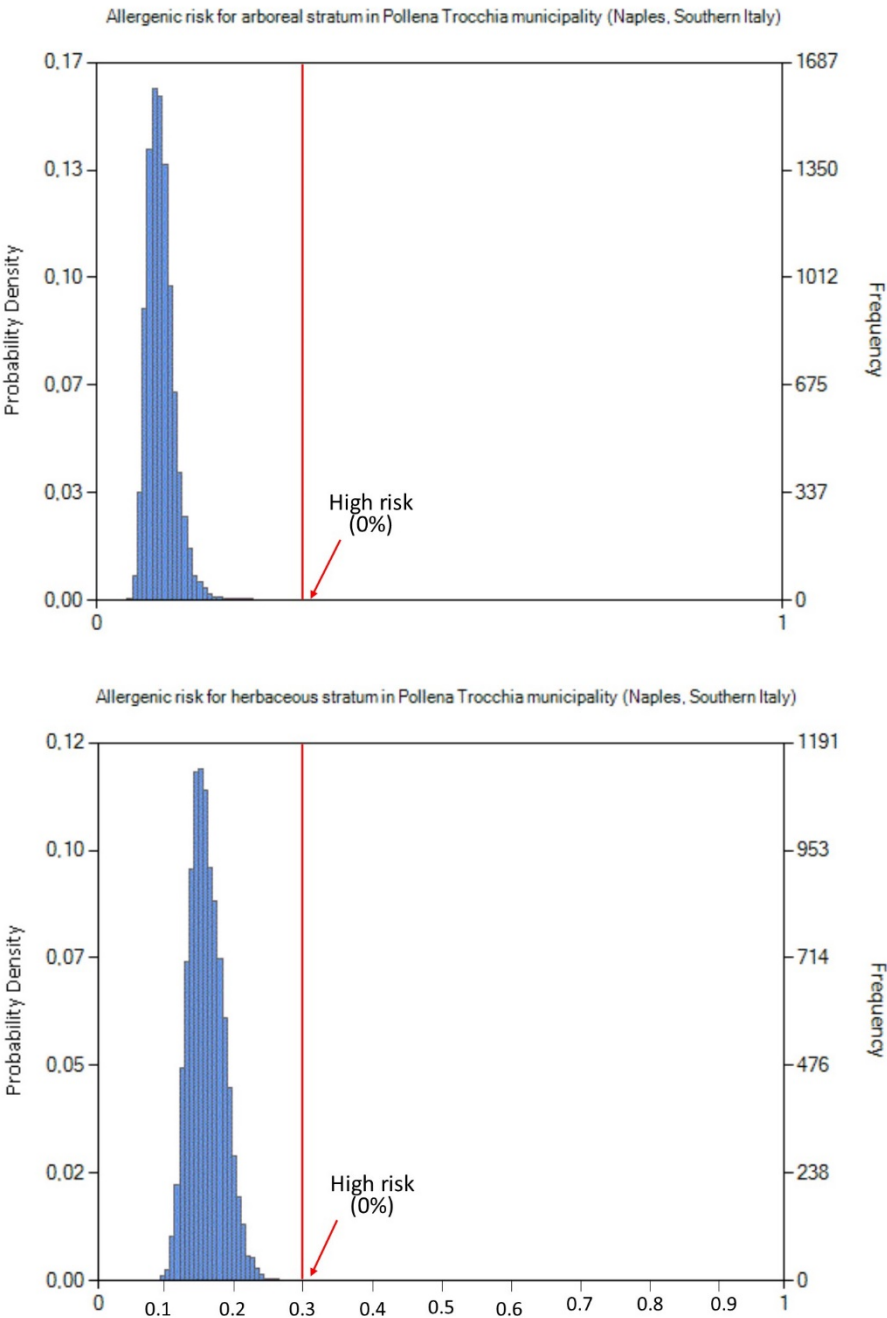


Figure S11 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Massa di Somma municipality (Naples, Southern Italy).

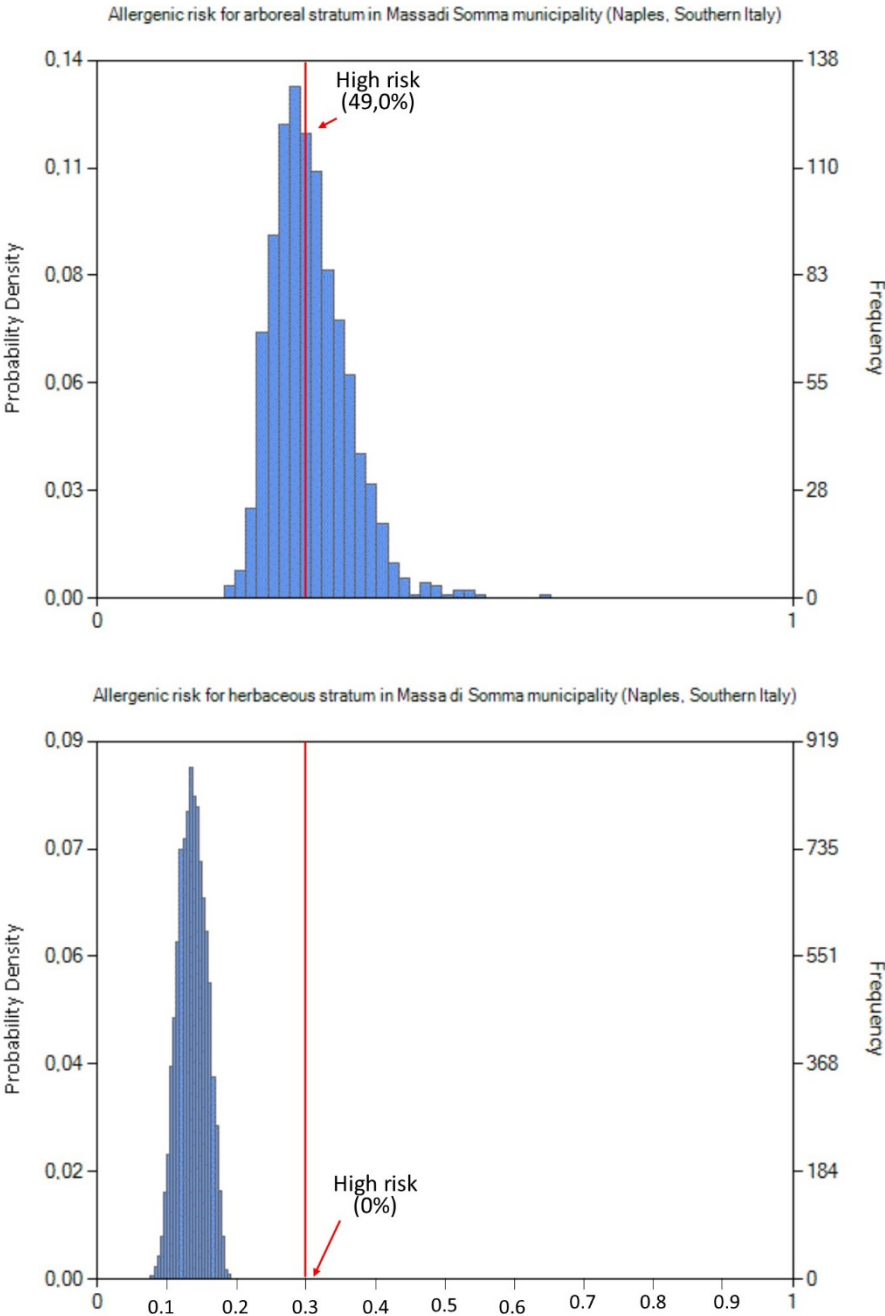


Figure S12 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in San Sebastiano al Vesuvio municipality (Naples, Southern Italy).

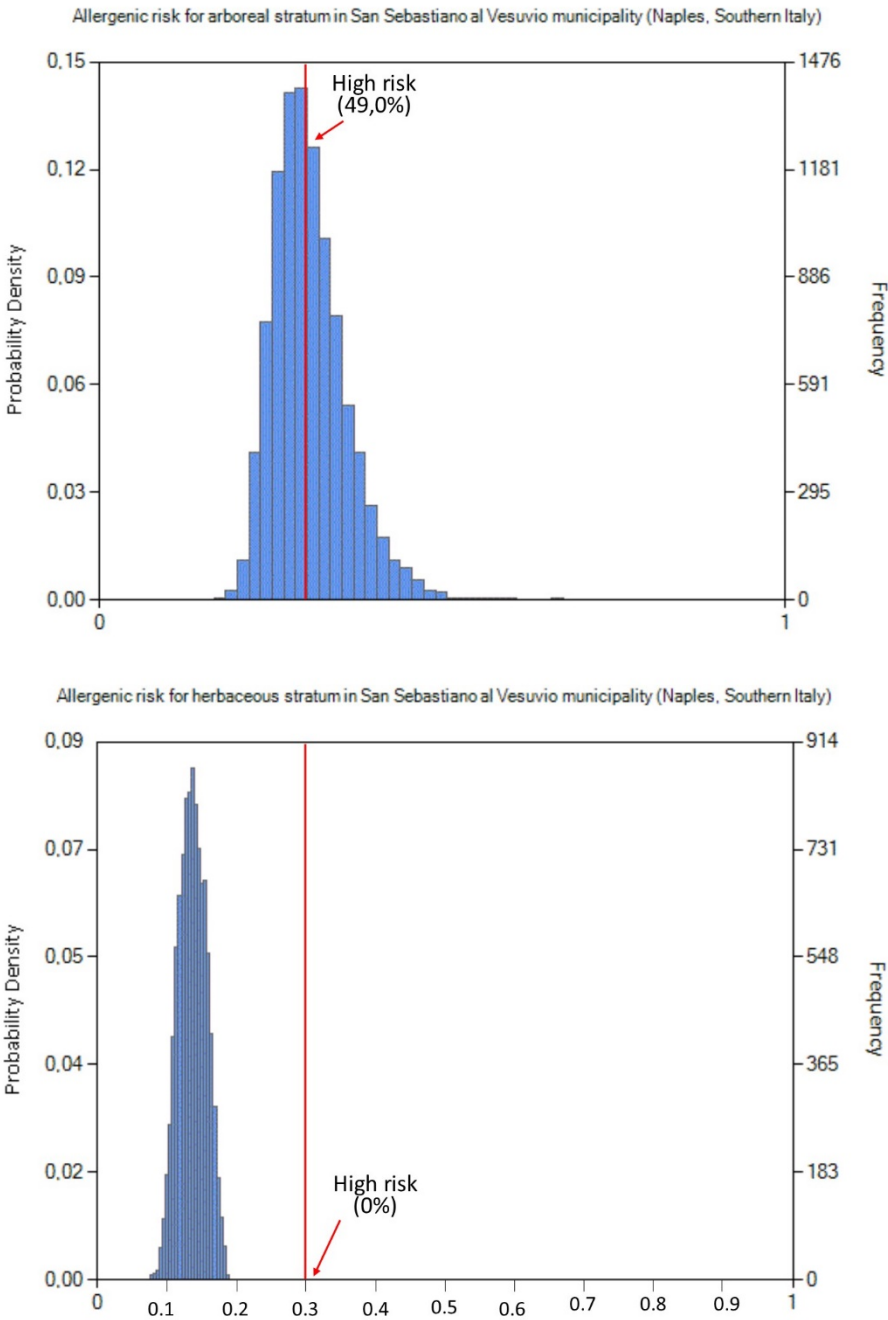


Figure S13 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Ercolano municipality (Naples, Southern Italy).

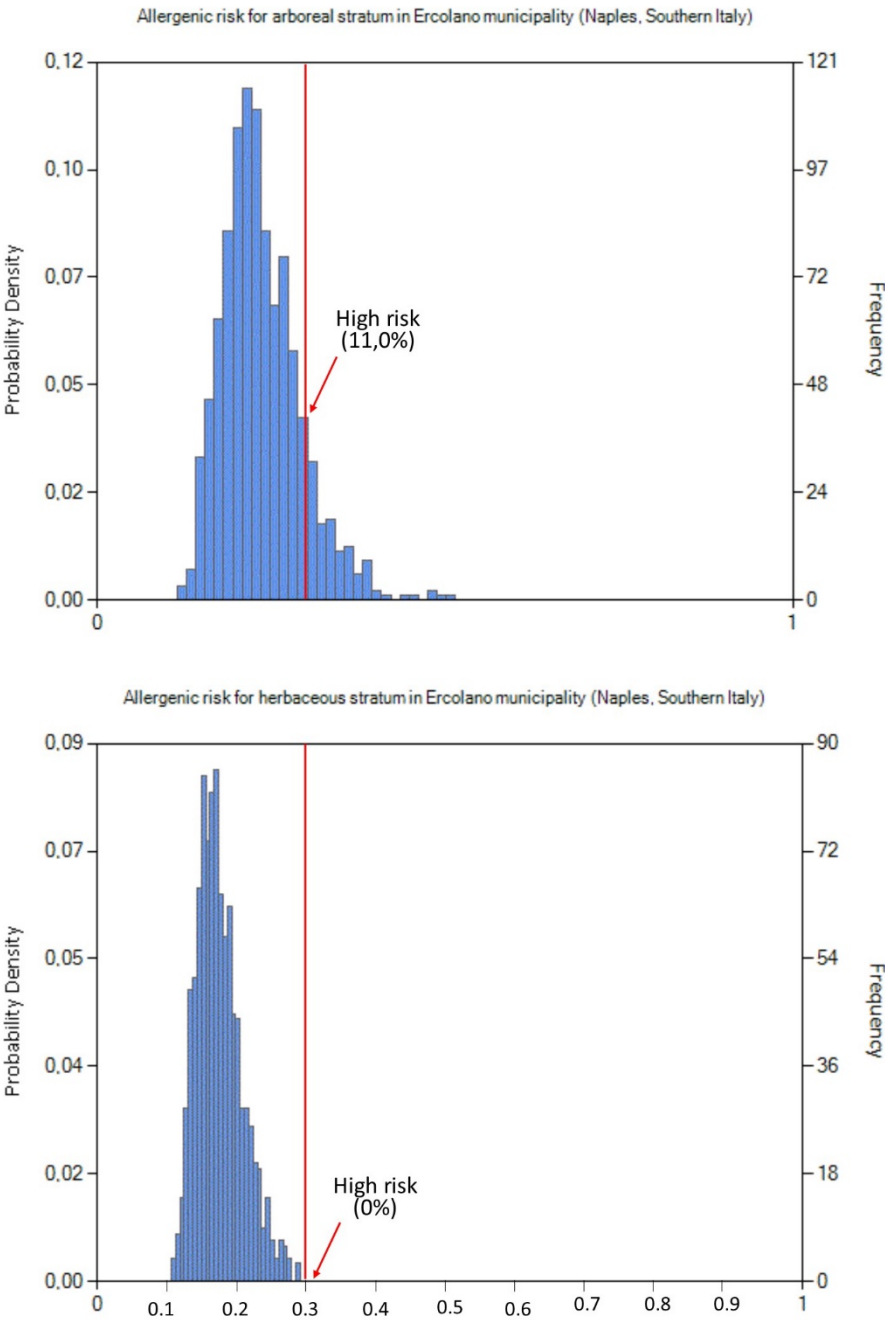


Figure S14 - Predicted probability density functions of allergenic risk for (A) arboreal stratum and (B) herbaceous stratum in Vesuvius National Park (Southern Italy).

