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Allergenic Pollen Monitoring at Sapienza University Campus (Rome, Italy): Patterns of Pollen Dispersal and Implications for Human Health

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Abstract: The Campus of the Sapienza University of Rome, frequented daily by several thousands of students and workers, collects allergenic airborne pollen from many sources. Here, we report the results of detailed pollen monitoring of 49 pollen types within the University Campus, allowing us to trace the main local and regional sources of airborne pollen throughout the year. The amount of allergenic pollen has been calculated for each daily record to evaluate the risk of exposure for students and workers on Campus in relation to academic activities and to suggest possible mitigation measures. Our results show that the maximum pollen concentrations are recorded from March to May, and the highest floristic richness occurs in April–June. We distinguish massive local pollen producers from pollen of regional origin and local ornamental and invasive taxa. Pollen with extreme allergenicity is dominant from mid-January to mid-March and in May with Cupressaceae/Taxaceae, *Corylus* and *Olea*; high allergenicity from late March to late April with *Platanus*, *Ostrya*, *Ginkgo* and Moraceae; and medium allergenicity from late April to the beginning of May with *Quercus* and *Pinus*. In August–December, pollen concentration is relatively low. Diversified mitigation actions are suggested in relation to the provenance, allergenicity and emission period of pollen.

Keywords: aerobiology; airborne pollen; outdoor monitoring; occupational health; allergy; Central Italy

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1. Introduction

Plants are ubiquitous not only in natural environments but also in urban contexts, and so is pollen, which is produced in huge amounts and can be dispersed over very long distances. Pollen is relevant for human activities, mainly those involving the use of plants, like agriculture and floriculture, in which appropriate pollination of cultivated species is crucial [1–3]. From the perspective of human health, pollen can be seen as a bio-contaminant of air since it can cause respiratory diseases in certain subjects, such as allergy-related asthma and rhinoconjunctivitis, due to allergens on the pollen wall and inside the grain [4–6]. In addition, climate change, modifying the intensity and duration of flowering periods and favoring the spread of invasive species can increase pollen-related illnesses [7–12]. This makes pollen a component of bioaerosols that can cause concern not only for matters of public health in cities but also for workers' health in occupational environments [13,14].

Several studies on pollen exposure in work environments have been carried out [15–17], but this line of research is still under-represented in the scientific literature [18]. In contrast, much attention has been paid to exposure to airborne pollen in cities, with the establishment of several aerobiological stations and pollen monitoring networks [19]. In general, networks intended for the general audience provide pollen calendars showing only qualitative levels of production and not detailed concentration values. In addition, they usually consider only the concentration of pollen groups of allergenic interest, with broad categories grouping different taxa, without distinguishing the contribution of each pollen type. This kind of approach, while useful for the sake of the evaluation of exposure to main allergens, does not offer a complete overview of the exposure to pollen.

The project to monitor allergenic pollen at the Sapienza Campus in relation to human health has several advantages that support a multifaceted research design: (a) a location near the center of Rome, an area under-investigated from the aerobiological monitoring point of view; (b) a large population of students and workers frequenting the Campus, with specific periods of presence; (c) the vicinity of highly frequented national research institutions and a highly frequented popular district; (d) a considerable variety of plants within 500 m of the sampling station, distributed in local green areas, tree-lined streets, an experimental botanical garden, and the monumental cemetery of Rome; (e) the presence on the Campus of a palynological laboratory and research facilities. These characteristics grant advantages in regard to the chosen location but also permit easier development of specific site-focused strategies to avoid exposure to allergenic pollen to the advantage of human health.

In this paper, we explore the interest in quantitative and taxonomically detailed allergenic pollen monitoring in the urban context of Rome (Italy) on the Campus of Sapienza University. Our aims are: (1) to define which plants contribute to allergenic airborne pollen through the year, (2) to identify pollen from both local ornamental and wild species, as well as from massive pollen producers located at some distance, and (3) to improve our knowledge of site-specific risks represented by allergenic airborne pollen and to develop adequate mitigation measures.

2. Materials and Methods

2.1. Study Area

The Campus of Sapienza University of Rome (41°54′10.32″ N, 12°30′51.72″ E, 45 m a.s.l.) is located in the urban center of Rome, a heavily urbanized city with a vegetation mainly composed of ornamental species, both native and non-native, as well as synanthropic and invasive species [20,21]. Within the city of Rome, stands of urban forests can be found that represent remnants of natural evergreen and deciduous vegetation. Cultivated fields dominate the lowlands within 20 km of the city (Roman Campagna), with olive groves and vineyards in hilly areas. Forest ecosystems, represented by mixed oak woods, are mostly confined to steep rocky slopes at the border of agrarian fields and in gorges. At over 20 km from the sampling point, chestnut coppices, especially located in the Alban Hills volcanic district SE of Rome, are found.

The Sapienza Campus is formed by an agglomerate of buildings, streets, and gardens and is circumscribed by walls and fences. It hosts several faculties for which educational and research activities are carried out by workers and students throughout the year. The academic calendar is organized in semesters, including crowded periods with classes (late September to mid-January and March to early June) and periods with exam sessions and sparse frequentation of students (mid-January to February and June to July). Students working on their thesis, doctorate students, post-docs, visiting researchers, and academic, technical and administrative staff operate on the Campus all over the year, with a decrease of frequentation in August, when there are no teaching activities and offices are mostly closed.

In the academic year 2021–2022, the official numbers of Sapienza University were as follows: 116,928 students, 3341 academics, 2104 administrative and technical personnel, and 2705 lecturers [22]. In addition to a potential number of ca. 50,000 university students/workers actively frequenting the Campus, the workers of the nearby central offices of the National Research Council (Consiglio Nazionale delle Ricerche, CNR) and the

Italian National Institute of Health (Istituto Superiore di Sanità, ISS) should be considered (Figure 1).

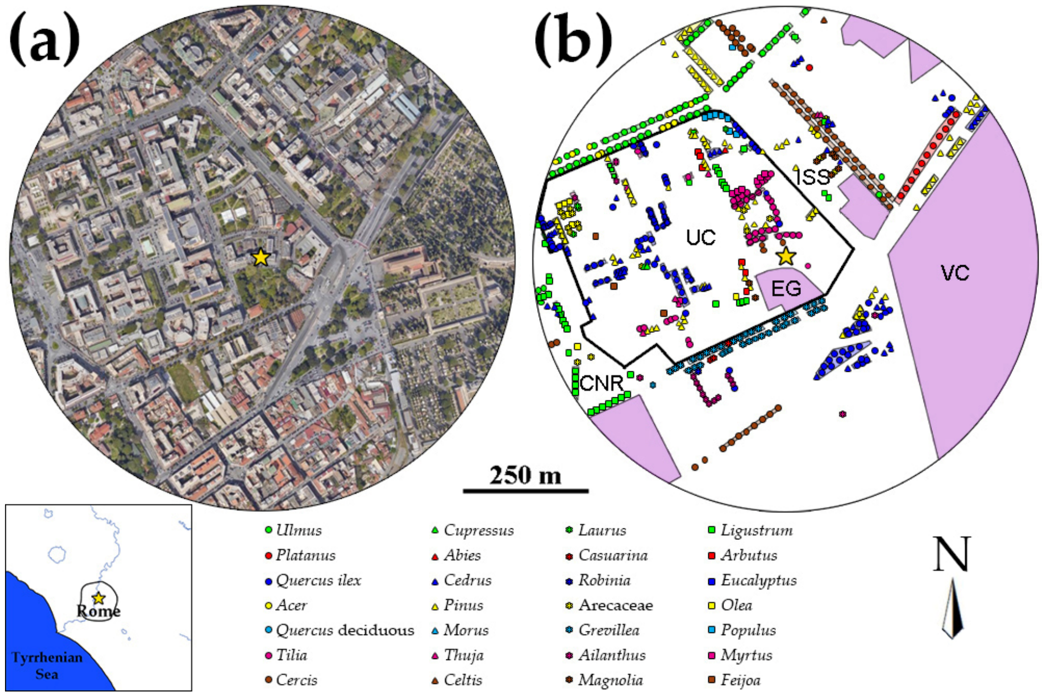

Figure 1. Map of a 500 m radius area around the sampler. (**a**) Satellite image (modified from Google Earth [23]); the yellow star indicates the position of the aerobiological sampler. (**b**) Location of arboreal species. The black line delimits the University Campus (UC). Purple areas indicate surfaces with dense species-rich vegetation. EG: Experimental Garden of Sapienza University, VC: Verano Cemetery, CNR: National Research Council, ISS: Italian National Institute of Health.

For the sake of this study, plants situated in the area within 500 m of the sampling point (Figure 1) are considered local sources of pollen, while plants living outside the area are considered extra-local sources. A radius of 500 m was chosen because it is the minimum distance that includes the entire Campus, where mitigation measures can be applied. The same distance was also used in previous aerobiological monitoring studies [24,25].

Within the Campus, many species of trees and shrubs are present (Figure 1). *Quercus ilex* is the most abundant tree, together with *Arbutus unedo*, *Cupressus sempervirens*, *Feijoa sellowiana*, *Tilia* × *vulgaris*, *Magnolia* spp., *Pinus pinea*, *Cedrus* sp., *Populus canadensis*, *Myrtus communis* and *Laurus nobilis*. There are also shrubby plants and vines that are often used as hedges, including *Buxus sempervirens*, *Ligustrum* spp., *Pyracantha coccinea*, *Nerium oleander*, *Pittosporum tobira*, *Parthenocissus quinquefolia*, *Hedera helix*, *Viburnum tinus* and *Prunus laurocerasus*. Several herbaceous plants are present, mainly belonging to the families Urticaceae, Ranunculaceae, Polygonaceae and Asteraceae, in the gardens and flowerbeds. The Experimental Garden, a green area located inside the Campus next to the sampling site, contains a large variety of plants (more than 500 taxa according to Pepe D'Amato et al., 2009 [26]), many of which are alien to the Italian flora.

Immediately outside the Campus, the most abundant plants are *Cupressus sempervirens*, *Pinus* spp., *Cedrus* sp. and *Platanus* sp., mainly in the eastern area; *Grevillea robusta*, *Casuarina equisetifolia* and *Robinia pseudoacacia* in the south; and *Acer negundo*, *Pinus pinea* and *Ulmus pumila* in the north. Other notable plants present all around are *Quercus ilex*, *Cercis siliquastrum*, *Ailanthus altissima*, *Ligustrum* sp., *Celtis australis*, *Eucalyptus* sp., *Olea europaea* and *Tilia* × *vulgaris* (Figure 1).

2.2. Aerobiological Monitoring

Aerobiological monitoring was carried out continuously from June 2021 to May 2022, with a short interruption between 29 December 2021 and 18 January 2022 due to restrictions related to the COVID-19 pandemic. The monitoring was performed using a Lanzoni VPPS 2000 Hirst-type sampler (Lanzoni S.r.l., Bologna, Italy) in accordance with the UNI 11108/2004 and UNI EN 16868:2019 norms [27,28]. The sampler was placed on the rooftop of the Botany and Genetics building within the Campus at about 15 m above ground level.

The daily samples obtained from the monitoring were collected weekly and immediately prepared and stored in the palynological laboratory adjacent to the sampling point in the Botany and Genetics building. The samples were observed under a light microscope at 250–630x magnification for identification and counting of pollen grains within a week of their collection. The daily concentration of each pollen type was calculated, taking into account the observed surface of the slide, which is at least 15% for a reliable estimate [29,30]. The monthly concentration (Figure 2) is based on the total count of allergenic and non-allergenic pollen grains.

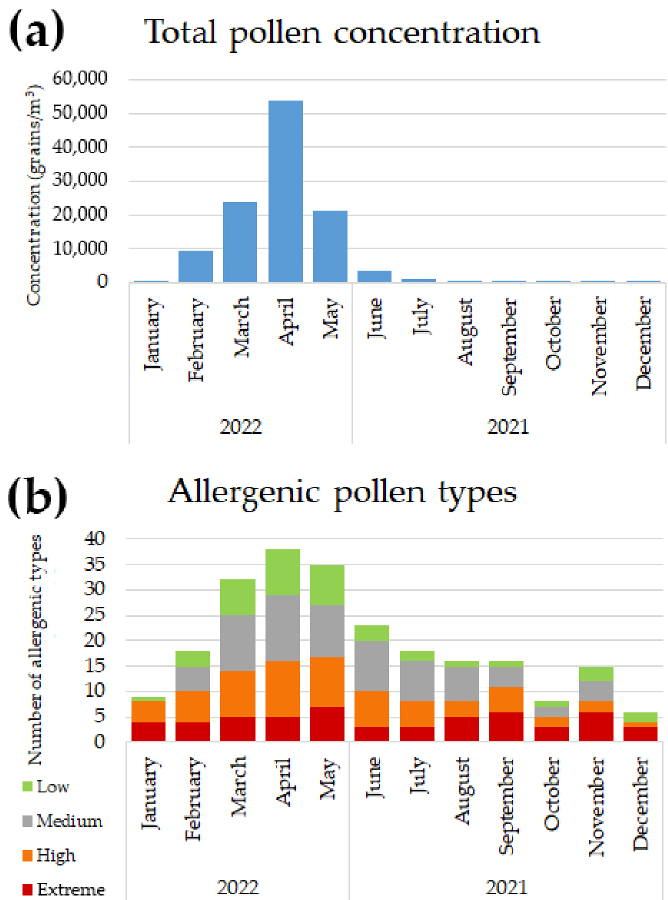

Figure 2. (**a**) Monthly total pollen concentration and (**b**) number of pollen types with low to extreme allergenicity throughout the sampling campaign. Different colors in (**b**) represent different levels of allergenicity in Table 1.

The identification of pollen grains was carried out in the finest possible taxonomical detail. "Cupressaceae/Taxaceae" may include pollen of different species of *Cupressus*, *Juniperus*, *Taxus*, and *Thuja*. "*Ostrya/Carpinus orientalis*" includes *Ostrya carpinifolia* and *Carpinus orientalis*, two species common in the natural woodlands of the region.

Table 1. Level of allergenicity of the main allergenic pollen types detected at Sapienza University Campus (classification modified from [31,32]).

Extreme	High	Medium	Low
Ambrosia artemisiifolia *Betula* Arecaceae *Carpinus betulus* *Casuarina equisetifolia* *Corylus avellana* Cupressaceae/ Taxaceae *Olea europaea* Urticaceae	*Ailanthus altissima* *Alnus* *Artemisia* *Fraxinus* *Ginkgo biloba* *Juglans* Moraceae *Ostrya/* *Carpinus orientalis* *Platanus* Poaceae *Salix* *Ulmus*	*Acer* Amaranthaceae Cannabaceae *Castanea sativa* *Celtis australis* *Eucommia ulmoides* *Fagus* *Ligustrum* Myrtaceae *Pinus* *Pistacia* *Populus* *Quercus* *Rumex* *Tilia*	*Acacia* *Aesculus hippocastanum* *Cedrus* Cichorioideae Ericaceae *Grevillea robusta* *Laurus nobilis* *Mercurialis* *Phillyrea angustifolia* *Plantago* *Robinia*

To better determine pollination periods, daily pollen concentrations were grouped into weekly totals and classified as temporal clusters based on pollen composition and abundance (Figure 3) using the Bray–Curtis method integrated into the Past 4.11 software [33], which calculates the similarity between samples based on taxa abundance. Urticaceae were excluded from the cluster analysis since they have high concentrations during most of the year and cannot be used to differentiate between different flowering seasons. The threshold for clusters was arbitrarily set at similarity = 0.2.

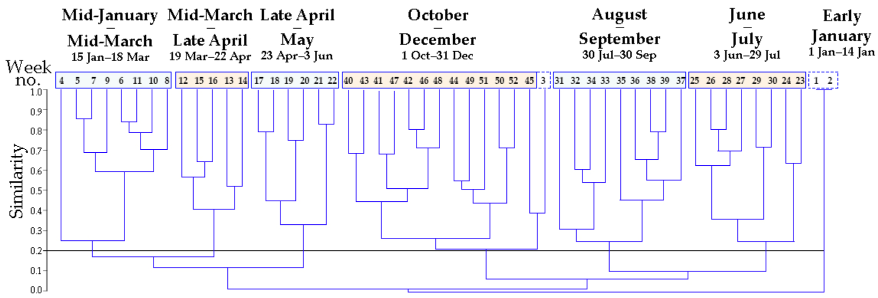

Figure 3. Cluster analysis of weekly pollen concentrations. Samplings of Weeks 1–3 are missing or incomplete.

Results are presented as monthly and daily concentrations of allergenic pollen types (Figures 2, 4 and 5). Monthly intervals are ordered from January to December, although the period June–December belongs to the year 2021 and January–May to 2022.

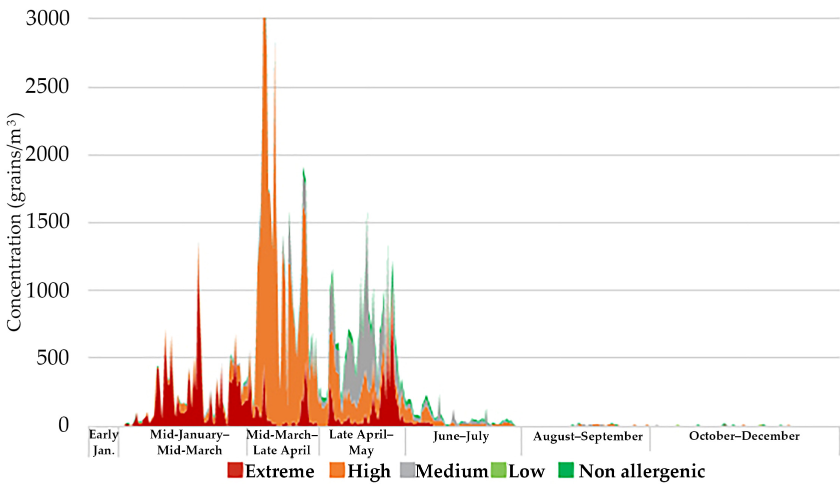

Figure 4. Concentration of allergenic and non-allergenic pollen types recorded during the monitoring campaign at the Sapienza University Campus. June–December belongs to 2021 and January–May to 2022.

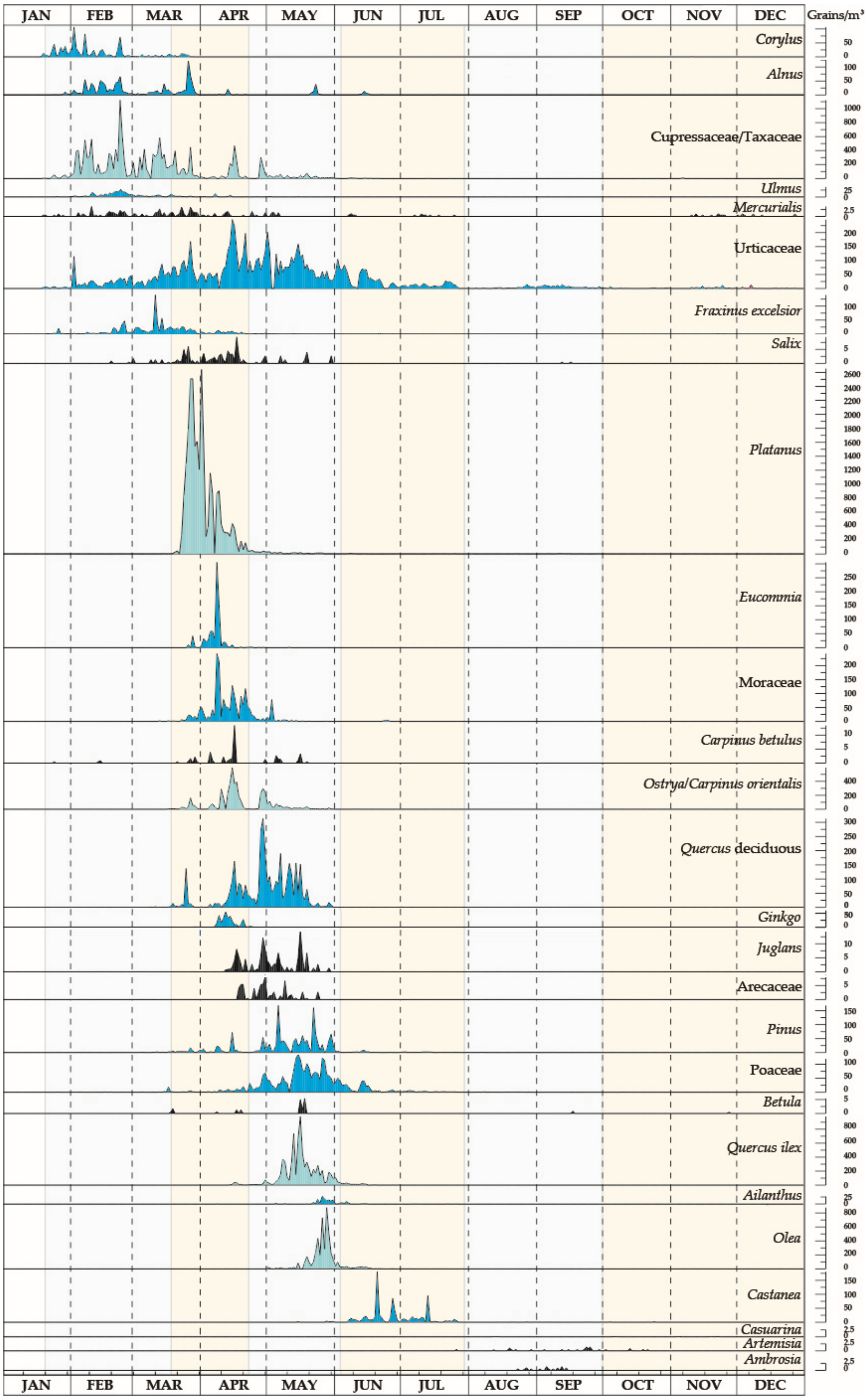

Figure 5. Daily concentration of pollen types with extreme and high allergenicity, as well as of pollen types with medium allergenicity reaching >100 grains/m^3 (Table 1). Results are ordered from January to December, although June–December belongs to 2021 and January–May to 2022. The colored bands in the background correspond to the pollination clusters of Figure 3. Three different concentration scales are used, corresponding to different colors filling the pollen curves: light blue, blue and black.

In order to assess the risk following exposure to allergic pollen on the Campus, we adopted a classification system based on Cariñanos and Marinangeli [31] and Suanno et al. [32], subdividing the level of allergenicity into 4 classes: extreme, high, medium, and low (Table 1).

It should be noted that there is no universal consensus among scientists concerning the level of allergenicity of different pollen types, as the allergenic potential of pollen can vary based on many factors, both intrinsic and extrinsic, like the variation between co-specific plants, the amount of pollen production and emission, meteorological factors, the state of health of each person, and its genetic predisposition [34–36].

Meteorological data on wind direction (Figure 6) were retrieved from the Meteostat website [37] (meteorological station placed at 1.2 km from the pollen sampling point) and compared with the vegetation map (Figure 1) and pollen concentration (Figures 5 and 6) to infer the provenance of airborne pollen. Wind rose diagrams were realized using the WindRose.xyz website [38]. The abbreviations for wind directions are as follows: N = North, NNE = North-northeast, NE = Northeast, ENE = East-northeast, E = East, ESE = East-southeast, SE = Southeast, SSE = South-southeast, S = South, SSW = South-southwest, SW = Southwest, WSW = West-southwest, W = West, WNW = West-northwest, NW = Northwest, NNW = North-northwest.

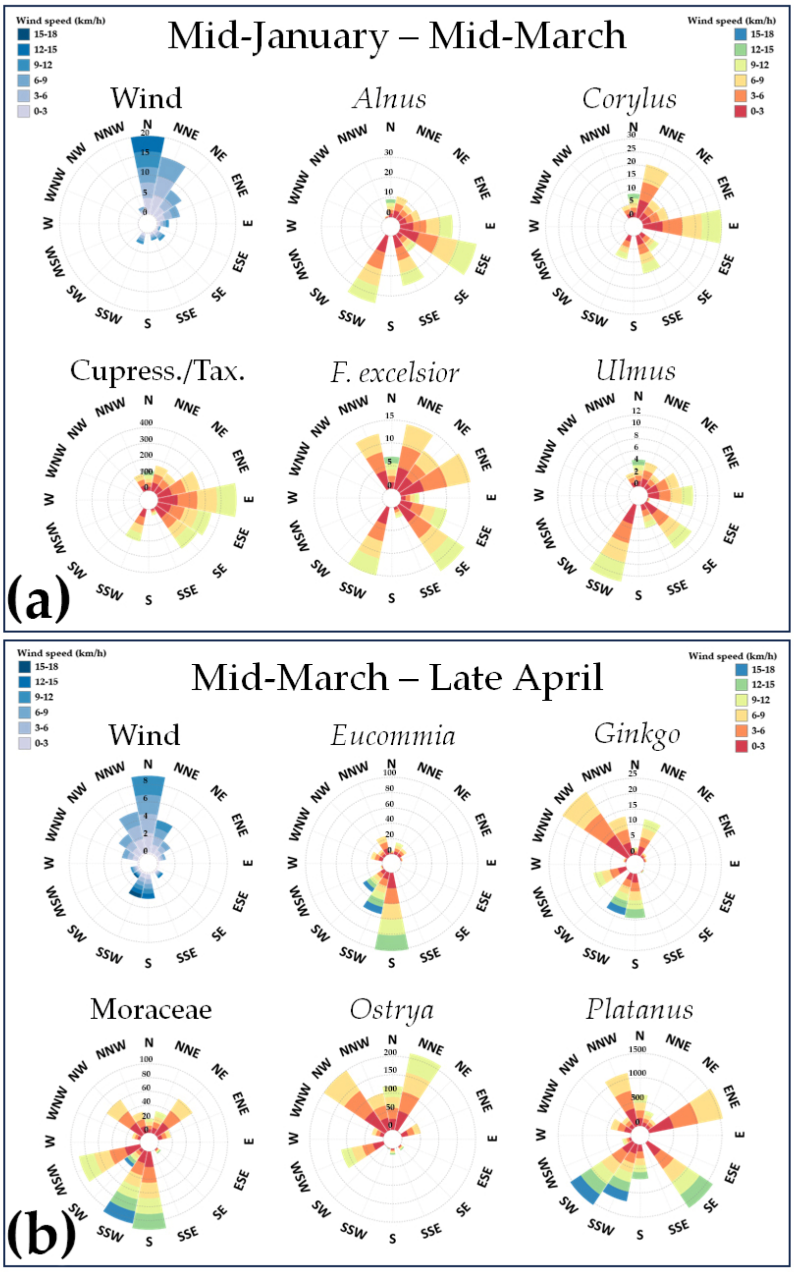

Figure 6. *Cont.*

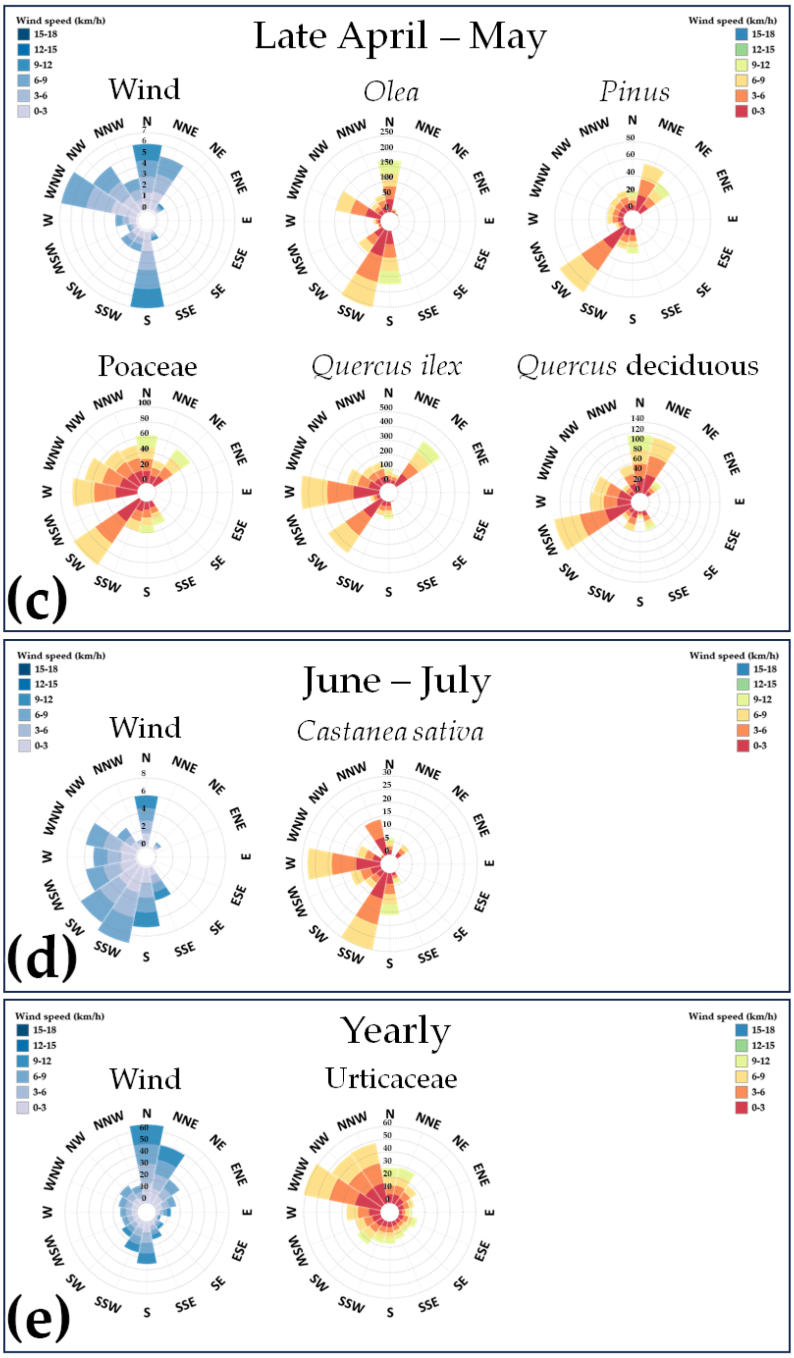

Figure 6. Concentration of the main allergenic pollen types recorded in relation to wind direction and wind speed, calculated for the temporal clusters with high pollen concentration: (**a**) Mid-January–Mid-March, (**b**) Mid-March–Late April, (**c**) Late April–May, (**d**) June–July, (**e**) Yearly concentration of Urticaceae.

3. Results and Discussion

The detailed analysis of one-year daily samples (344 samples in total) led to the identification of an approximate number of 230,000 pollen grains, averaging 627 grains per sample. The months with the highest pollen concentrations were April, March and May, with 53,775, 23,870 and 21,420 pollen grains/m^3, respectively, while December, October and November showed the lowest concentrations, with 68, 115 and 157 grains/m^3, respectively (Figure 2a). Extreme and high allergenic pollen types occurred throughout the year (Figure 2b). The months with the highest diversity of allergenic pollen types were April and May, with

38 and 35 pollen types, respectively, while the months with the lowest pollen richness were December, October and January, with 6, 8 and 9 allergenic pollen types, respectively (Figure 2b).

The cluster analysis of weekly pollen concentrations led to the identification of seven temporal clusters (Figure 3).

For each temporal cluster, the following subsections present the description of the pollen concentration and composition of major allergenic pollen types (Figures 4 and 5) and a discussion on the provenance of airborne pollen based on the daily pollen concentration of the main allergenic pollen types relative to the daily direction and speed of wind (Figure 6). The concentration of allergenic pollen, as well as its provenance and timing, is then compared to the activities on the University Campus to evaluate the risk of exposure to airborne pollen for students and workers and to suggest appropriate mitigation measures.

3.1. Mid-January–Mid-March

Main pollen types: Cupressaceae/Taxaceae, *Alnus*, *Corylus*, *Fraxinus excelsior* and *Ulmus*.

The pollen grains collected by the sampler were mostly extremely allergenic (Figure 4). The onset of noticeable pollen releases occurred by the end of January, with the flowering of *Corylus avellana*, *Alnus*, Cupressaceae/Taxaceae, *Ulmus*, *Mercurialis*, and Urticaceae (Figure 5). In February, Cupressaceae/Taxaceae showed two phases of pollen release, which may correspond to different species, with the highest concentration >1100 grains/m^3. *Corylus* reached its maximum value at the beginning of February, with a peak of 107 grains/m^3. *Alnus* showed multiple peaks > 50 grains/m^3. *Ulmus* had a single major peak (28 grains/m^3) before dropping to values of 9 grains/m^3 at the end of February. *Fraxinus excelsior* started flowering at the end of February, reaching a peak of 140 grains/m^3 in March, when *Salix* started its pollen emission. Cupressaceae/Taxaceae maintained high pollen concentrations throughout the month of March, with a monthly average of 186 grains/m^3.

Winds (Figure 6a) were mostly from N (20 days) and NNE (15 days), with the highest wind speed from N, E-SSE, and SSW (>9 km/h). Cupressaceae/Taxaceae show their highest pollen concentrations from E, despite the fact that winds were commonly from N. This indicates that their main source was in the nearby Verano Cemetery, right E of the Campus, where cypresses are conspicuously planted (Figure 1). *Corylus* (from E), absent from the Campus and rare in the city of Rome, may have had a regional origin. The same is true for *Alnus* (from ESE). *Fraxinus excelsior* came from several directions. Although a large number of elm trees can be found along an avenue N of the Campus (Figure 1), extensive pruning before the flowering period of 2022 resulted in the main provenance of *Ulmus* pollen from SSW.

According to the European Academy of Allergy & Clinical Immunology (EAACI) [39], concentrations of Cupressaceae >100 grains/m^3 are dangerous for human health. On the Campus, this value is exceeded on 33 days of the analyzed year. Eradicating Cupressaceae/Taxaceae trees from the Verano Cemetery is not a feasible option, given the historical, cultural, and religious value of that area. Mid-January to February coincides with the academic session of exams, which is characterized by a reduced presence of students on the Campus and is limited to a few days. The massive pollen production of Cupressaceae is, therefore, less harmful for students than for the academic, technical and administrative staff. An avoidance strategy for students is not applicable to March, when classes start again, and workers allergic to Cupressaceae must operate appropriate countermeasures (e.g., wearing masks or avoiding outdoor activities). Similar mitigation measures should be applied for *Alnus* and *Corylus*, whose provenance from distant and scattered sources prevents actions to remove the plants or reduce flowering. The pollen emission of local plants with high allergenicity (e.g., *Fraxinus excelsior* and *Ulmus*) and with medium allergenicity (e.g., *Populus*) can be lowered with direct control measures, such as pruning and removal of the flowers. The efficacy of this action is demonstrated by the fact that pollen concentrations of *Ulmus* from N were lowered by pruning (Figure 6a).

3.2. Mid-March–Late April

Main pollen types: *Platanus*, *Ostrya/Carpinus orientalis*, *Ginkgo*, *Eucommia* and Moraceae.

Highly allergenic pollen grains are the most abundant types, mostly due to *Platanus*, which started flowering in March and quickly reached peaks > 2500 grains/m^3, followed by a progressive decrease to very low values by the end of April. Other allergenic pollen producers started flowering at the end of March, peaking in April: *Eucommia ulmoides* (>300 grains/m^3), Moraceae (243 grains/m^3), *Carpinus betulus* (14 grains/m^3) and *Ostrya/Carpinus orientalis* (596 grains/m^3). Deciduous *Quercus* shows two separate peaks, possibly produced by different species (Figure 5). Urticaceae increased to its maximum value (247 grains/m^3). The entire flowering season of the ornamental species *Ginkgo biloba* is recorded in April, with a peak of 54 grains/m^3. *Juglans* and Arecaceae (mainly *Chamaerops*) started flowering by mid-April when *Pinus* also reached significant values (>70 grains/m^3).

Winds (Figure 6b) were mostly from N (9 days), with the highest mean wind speed from N and SW (17.9 km/h). *Eucommia* and Moraceae had high concentrations when winds came from S, which is related to the presence of these plants in the Experimental Garden, right S of the sampler (Figure 1). *Ginkgo*, besides originating from the garden, had high concentrations from NW, like *Ostrya*, implying a more distant pollen source. *Platanus* originated from various directions, which is expected given the presence of many plane trees in the city of Rome.

Platanus is considered highly allergenic by some authors [31,40] but only mildly allergenic by Ortolani et al. [41]. In any case, massive pollen emissions of *Platanus* for a lengthy period of time increase the impact on allergic subjects (causing symptoms related to allergic rhinitis and asthma), for which reason this pollen can be considered highly allergenic [31]. In mid-March–late April, since most students attend classes, the potential harm caused by *Platanus* cannot be ignored. At the same time, there is also a conspicuous amount of pollen of *Ostrya*, *Ginkgo biloba* and Moraceae with high allergenicity, and of *Eucommia ulmoides* with medium allergenicity. Since the rose wind plot shows that the Experimental Garden is an important source of pollen for *Ginkgo*, *Morus* and *Eucommia* (Figures 1 and 6b), local direct interventions like pruning may be used to lessen pollen emission. Controlling *Ostrya* is more difficult since its pollen source is extra-local. A peak of Cupressaceae/Taxaceae likely corresponds to the flowering of *Taxus*, an extremely allergenic pollen. Controlling *Taxus* would not be difficult, given its limited presence in the area (mainly the Experimental Garden).

3.3. Late April–May

Main pollen types: *Quercus*, *Olea*, *Pinus*, Poaceae.

Several pollen types successively peaked with different allergenic levels (Figure 4). These include *Juglans* (15 grains/m^3), *Pinus* (>150 grains/m^3), Poaceae (136 grains/m^3), *Betula* (5 grains/m^3), *Quercus ilex* (peak: 983 grains/m^3, monthly average: 227 grains/m^3), *Ailanthus* (26 grains/m^3) and *Olea europaea* (878 grains/m^3, followed by a sudden decrease) (Figure 5). Deciduous *Quercus* showed its maximum peak at the end of April (>300 grains/m^3), then it had a decreasing trend and eventually vanished by the end of May, together with *Platanus*, which was still continuously present in low concentrations (average 9 grains/m^3). Urticaceae maintained an average value of 78 grains/m^3, with a peak of 202 grains/m^3. Very low values of *Castanea* in the last days of May mark the onset of its flowering period.

Winds (Figure 6c) were mostly from S, WNW (7 days) and N (6), with the highest mean wind speed from NE, SSE and S (>10 km/h). Poaceae have high concentrations from all directions, indicating multiple sources, the most abundant being SW and W (>80 grains/m^3). Pollen of *Pinus* also came from several different directions, with a peak from SW, despite winds coming from that direction only for a few days with moderately high speed. *Olea* had its highest concentrations from SSW (>250 grains/m^3), followed by S and N (>160 grains/m^3). This might indicate multiple origins, including regional emissions and local plants, also considering the presence of olive trees within the Campus (Figure 1).

Pollen of deciduous *Quercus* came mainly from WSW (155 grains/m^3), while *Quercus ilex* came mainly from W (551 grains/m^3) and SW (449 grains/m^3). *Quercus ilex* is a common tree on Campus west of the sampler (Figures 1 and 6c), forming a dense canopy in gardens and sidewalks with benches.

Allergenic pollen concentrations were mainly determined by *Quercus*, especially *Quercus ilex*, with medium allergenicity. Students and workers often stop for long periods of time in the green areas with *Q. ilex* within the Campus. Prolonged stationing could amp up the allergenic effects of this medium-allergenic pollen. Appropriate trimmings before flowering periods can represent a countermeasure to diminish local pollen emission. Other arboreal pollen types that can be locally controlled in the same way are *Pinus*, with medium allergenicity, and *Juglans* and *Ailanthus*, with high allergenicity (Figure 5). At the end of May, the high concentration of *Olea* pollen is difficult to counteract because of its massive local and extra-local emission, so a concentration of over 100 grains/m^3, a pollen level that could be considered very harmful for allergic individuals [39], was maintained for 11 days in the recorded year from S and SSW. Another local pollen type with extreme allergenicity is Arecaceae (Figure 5), whose pollen production is, however, relatively low. Among herbaceous taxa, Poaceae, with high allergenicity, reaches a concentration above the allergenic threshold of 50 grains/m^3 [39] for a duration of 20 days. For herbaceous plants, an effective countermeasure to exposure could be the repeated cut of lawns and flowerbeds on the Campus, though a total removal seems impossible due to their ubiquitous presence, even in most of the city of Rome [42], confirmed by the wind rose diagram showing a provenance from many directions (Figure 6c).

3.4. June–July

Main pollen type: *Castanea sativa*.

Total pollen concentration progressively decreased to values around 4 grains/m^3 (Figure 4). *Castanea* reached its peak, with a value of 181 grains/m^3, and disappeared by the end of July (Figure 5). A decrease in concentration of several pollen types is recorded, matching the end of flowering periods of oaks, *Olea*, *Pinus*, and *Ailanthus*. Urticaceae and Poaceae decreased but were still present, with mean values of 20 and 7 grains/m^3, respectively. Similarly, a long tail of Cupressaceae/Taxaceae with low average values (2 grains/m^3) persisted until the end of the month.

Winds (Figure 6d) were mostly from S to SW, with the highest mean wind speed from SSE (>11 km/h). Correspondingly, *Castanea sativa* showed its highest mean concentrations from SSW (30 grains/m^3) and W (28 grains/m^3), certainly having an extra-local origin. The difference between wind provenance, wind speed and concentration of chestnut pollen could be explained considering that *Castanea* has very small, extremely volatile pollen grains (<20 μm) that come from far, extra-local sources and can be susceptible to wind turbulences.

In this period, there was no major concern for human health, considering the decrease in total pollen concentration (especially pollen with high and extreme allergenicity) and the sparse frequentation of the Campus in summer months. The main allergenic pollen type is *Castanea*, with medium allergenicity. *Castanea sativa* is absent from the local area but widely distributed on a regional scale. Considering that avoiding exposure to regional airborne pollen is very difficult if not impossible, only wise behaviors on the part of the workers (e.g., wearing face masks and working indoors) can mitigate the allergenic effects of chestnut. In this period, pollen types have been recorded that can cause proximity allergies (e.g., *Ligustrum*, *Tilia* and Myrtaceae). However, their low concentration is of no concern.

3.5. August–September

Main pollen types: *Ambrosia*, *Artemisia*, *Casuarina*.

Total pollen concentrations were very low (<500 grains/m^3; Figures 4 and 5), the most notable presence being Urticaceae, with average daily concentrations <3 grains/m^3. *Casuarina*, *Artemisia* and *Ambrosia* are worth noticing because of their high-extreme allergenicity level, although they show peaks of ca. 1 grain/m^3. Pollen composition in September was like that in August but with higher total concentration values (up to 295 grains/m^3).

Given the rarity of *Casuarina* in Rome, its origin is easily found in the few trees at the southern boundary of the Campus (Figure 1). The dispersal of the local *Casuarina* pollen may be risky for the Departments facing the trees but can be limited by pruning and avoided by using alternative paths. *Ambrosia artemisiifolia*, a highly allergenic plant that represents one of the main allergens in northeastern Italy and other parts of Europe [43], is only recorded in modest amounts that may not be sufficient to cause allergic reactions. This plant requires close observation since its proliferation throughout the city could be dangerous.

3.6. October–December

Main pollen types: Urticaceae and *Mercurialis*.

Total pollen concentration reached its minimum (<70 grains/m^3), with only Urticaceae and *Mercurialis* being recorded throughout the period. This period does not pose major concerns for human health.

Throughout the year, the highly allergenic Urticaceae pollen is present and abundant, reflecting the abundance of plants in the area. The highest concentration of this taxon occurred from the second half of March to the first half of June, showing a hint of seasonality that corresponds to the periods of the year in which total pollen production is at its highest. The concentrations of this pollen type were high from all wind directions (Figure 6e), with a prevalence from WNW to NNW, corresponding to the center of the city. The highest concentrations of Urticaceae were recorded from the second half of March to the first half of June but with a persistent presence even in December.

Urticaceae are herbaceous plants growing on different substrates, including the sides of roads and sidewalks, as well as walls and ruderal environments that are common in the study area and the Verano Cemetery. Similarly, *Mercurialis* also has a very long flowering season and is widespread. A frequent manual and mechanized clearing and cleaning of the urban streets and green areas can effectively reduce these synanthropic plants, although complete eradication seems very difficult.

4. Conclusions

In this paper, we consider the use of a site-specific protocol to reliably evaluate the exposure of individuals frequenting a specific area, leading to the development of site-specific mitigation measures to improve the quality of life and work. This kind of approach requires different datasets: detailed aerobiological monitoring, the acquisition of meteorological variables, a census of the vegetation present in the area, and a record of the hours of presence and of the specific activities of the individuals frequenting the area.

In this specific case, our detailed daily pollen record of 49 allergenic pollen types, interpreted in light of wind speed and direction, has allowed us to infer the provenance of airborne pollen grains and to suggest possible mitigation actions in relation to the academic activities of Sapienza University Campus.

Massive pollen inputs reflect the local presence of *Platanus*, *Cupressus* and *Quercus ilex*, which are located within the Campus and its vicinity. The presence of these pollen types in the environment is protracted beyond the main flowering period, represented by long-lasting tails of pollen at low concentrations whose effect on allergic subjects is potentially harmful. The local abundance of invasive and ornamental taxa is clearly depicted in the airborne pollen record, which is also enhanced by the diversity of species on the Campus. The comparison of pollen concentration and wind direction has allowed us to precisely define the provenance of some ornamental pollen types from the Experimental Garden (e.g., *Eucommia* and Moraceae) and the nearby Verano Cemetery (Cupressaceae), as the reliability of wind direction for identifying urban parks as sources of pollen of ornamental species has been previously tested in cities [44]. The feared pollen of *Ambrosia*, an extremely allergenic pollen producer, is fortunately recorded only in low concentration in August–September. Its provenance is from distant sources, as *Ambrosia artemisiifolia* is rarely represented in the flora of the urban area of Rome.

The amount of allergenic pollen, which is computed for each daily record, is especially high in some specific time intervals over the year, with different levels of risk. While the extreme allergenicity period from mid-January to mid-March is of low relative danger to students, as it matches a sparse frequentation of the Campus corresponding to an academic session of exams, the mid-March to late April period may be critical for allergic symptoms (e.g., asthma and rhinoconjunctivitis) of students because it corresponds to classes. The period from late April to the end of May could also be harmful because of the flowering of *Quercus ilex* in the central area of the Campus, where students often rest in the shade of the trees.

In regard to allergic symptoms, among the most important allergenic pollen types in the area, Cupressaceae (mainly *Cupressus*) often cause dry cough more than conjunctivitis [45,46], Betulaceae (*Betula*, *Alnus*, *Corylus*) are cross-reactive with each other and with Fagaceae (*Fagus*, *Quercus*, *Castanea*) [47], Oleaceae (mainly *Olea europaea*) are characterized more by rhinoconjuctivitis rather than bronchial asthma [48], Urticaceae (mainly *Parietaria*) have very small pollen grains and are able to penetrate deeply in the airways, causing asthma and severe coughs, and are associated with rhinoconjunctivitis [49], and grasses (Poaceae) can cause various symptomatology and are a major cause of pollinosis in the world [50].

The wealth of information collected from the Campus also offers a foundation of understanding for undertaking a variety of mitigation measures. An accurate cleaning of the ground under the trees and along the sidewalks may be an effective countermeasure to remove the cones of *Cupressus*, as well as the flowers of *Quercus ilex* and *Platanus*. After the flowering period of the most abundant pollen producers, periodic cleaning of the ground coupled with the removal of dry flowers left on branches could help reduce the influence of tails of residual pollen in subsequent months of the year; however, the effectiveness of this kind of operation could be evaluated only with a before–after study. A frequent manual and mechanized clearing of the urban streets and ruderal areas can strongly reduce the pollen emission of herbaceous plants. This measure applies to synanthropic plants such as *Urtica*, *Parietaria*, *Mercurialis*, *Artemisia* and other Asteraceae. Repeated cuts of lawns and flowerbeds on the Campus can be effective in reducing the flowering of Poaceae. Isolated individuals of highly allergenic species, such as *Eucommia ulmoides*, *Casuarina equisetifolia* and *Ginkgo biloba*, can be subjected to selective pruning to reduce their pollen emissions. The efficacy of this action was demonstrated by the low amounts of pollen produced by *Ulmus* trees pruned soon before monitoring. However, for a number of regionally diffused pollen types (e.g., *Corylus*, *Olea*, *Castanea* and *Alnus*), any direct measures addressed to reduce pollen emission are unworkable since pollen comes from distant and scattered sources. Only wise behavior on the part of sensitive students and workers can mitigate the allergenic effects through the use of personal protective equipment (PPE, e.g., dust masks) and the reduction of outdoor activities. It has to be noted that for all the mentioned cases of pruning, mowing and cleaning, these activities should be carried out by specialized workers, such as gardeners, who represent an occupational category that is greatly exposed to pollen in the workplace.

Our choice to adopt a taxonomically detailed representation of airborne allergenic pollen composition that is generally not available from routine analyses has allowed the definition of the flowering periods of many plant taxa and of the provenance of their airborne pollen. Additionally, taxonomically detailed records have the potential to identify allergenic taxa that are often ignored, including rare ornamental plants. This approach provides a baseline for the development of more accurate medical strategies targeted to site-specific allergenic risks.

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