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1997–2016, Twenty Years of Pollen Monitoring Activity in Rome Tor Vergata (Rome South-East): Trends Analysis

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Abstract: Global environmental change is rapidly altering the dynamics of terrestrial vegetation, with consequences for the functioning of the Earth system. Recent studies show that climate change is influencing the phenology and distribution of plants. Airborne pollen reflects the flowering period of the plant, which is influenced by meteorological variables such as temperature and rainfall. The analysis of pollen trends is a very useful tool for understanding the effects of climate change on vegetation. In fact, it is accepted that the onset and peak abundance of certain pollen types should be used as possible bioindicators of climate change. The aim of the work is to analyze the presence of various pollen in Rome—from their release from the anthers to their permanence in the atmosphere, the trends of phenological (start, length, and end of the pollen season) and production (pollen abundance and pollen peaks) pollen indicators, the trends of the meteorological variables mainly involved (temperature and precipitation), and any relationships between pollen and meteorological variables, also based on the variation in vegetation. In the period considered, the analysis of the pollen spectra shows an increasing trend in herbaceous *taxa*, probably attributed to a gradual abandonment of farming practices in the neighboring area, which in recent years has been the subject of intense new construction activity and to a progressive deterioration in the maintenance of green areas.

Keywords: pollen trend; aerobiology; air monitoring

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1. Introduction

The climatological history of our planet is not new to phenomena of variation [1]; however, in the last 100 years, the planet seems to be undergoing marked and more rapid changes than those observed in the past [2]. It is to study the phenomenon and, above all, to identify solutions. In 1988, the WMO (World Meteorological Organization) and UNEP (United Nations Environment Program) established the IPCC (Intergovernmental Program on Climate Change), the Intergovernmental Panel on Climate Change, which provides a scientific view on global climate change and the potential environmental and socioeconomic impacts and the possible mitigation. The IPCC has established that it is highly probable that the main cause of recent global warming can be attributed to human activity. Human interference with the climate system is ongoing, and climate change creates risks for human and natural systems [2].

As for many other complex phenomena, the understanding of climate change and its effects is subject to uncertainty. Uncertainty can result from a lack of information or disagreement about what is known.

Uncertainty about past and future climate changes depends on insufficient or imperfect measurements and the limited ability to understand and model many features of the climate system. Therefore, uncertainty reflects a limited ability to predict factors that underlie the various processes [2].

In the entire literature of the science of the last ten years, there are approximately 900,000 peer-reviewed journal articles that use at least one of the words model, modeled, or modeling; of these, 55% of the total include the use of the term climate change. Furthermore, within the field of climate change science, almost all the research (97%) refers to modeling. This shows that the use of models in science is indeed widespread and that climate research has focused almost exclusively on system simulation. The problem is that the scientific understanding of climate processes is far from adequate to support any kind of meaningful forecasting [3].

Climate change refers to variations in the Earth's climate that affect one or more environmental and climatic parameters such as temperature, precipitation, distribution, and development of plants and animals. These variations are both spatial, with global changes, hemispheric, continental, or regional changes, and temporal, with changes over millennia, secular, or every decade [1].

Global environmental change is rapidly altering the dynamics of terrestrial vegetation, with consequences for the functioning of the Earth system [4].

Recent studies [5–7] show that climate change is affecting the phenology and the distribution of plants; changes in weather conditions cause direct biophysical effects on agricultural production [8], for example, the grapevine and the olive [9,10], also influencing pollen production. Through the detection of airborne pollen, aerobiological monitoring provides data of interest in different fields of application, such as the monitoring of the flora of an area or in climatology for the study of climate change. The presence of airborne pollen is closely related to the flowering season and the phenological period of the plants: the qualitative and quantitative composition of the spectrum of airborne pollen grains depends mainly on the plant cover of the area of interest but also on climatic factors, environmental and temporal [11,12]; the pollination period, in fact, is influenced by latitude, height above sea level and climatic conditions, so much so that the start date of the pollen season can vary from one year to the next by up to several weeks.

Pollen monitoring has as its primary purpose the detection of pollen of the main plant taxa and their concentrations and allows the observation of variations in the flowering period in relation to the presence of pollen (start, length, and end of pollination), concentration levels and pollen production or the appearance of new species in a given site. Already in 2001, the World Allergy Organization (WAO) indicated allergenic pollen monitoring as a useful environmental indicator and recommended its use [4,13].

Among the meteorological variables, temperature mainly influences pollen concentrations in the atmosphere, as it is able to influence the exit from the dormancy phase and the beginning of the reproductive phase: it is known that temperature plays a fundamental role in the opening of the anthers and the release of pollen into the air. On the other hand, precipitation, in general, seems to negatively affect the values of pollen concentrations: pollen particles are much less abundant in the air when the air humidity is too high or in case of rain.

In light of recent studies showing how global climate changes affect plant phenology, pollen grain data from the aerobiological monitoring of the University of Rome *Tor Vergata* station in the period 1997–2016 were analyzed.

The aim of the work is to analyze the presence of various pollen taxa in Rome—from their release from the anthers to their permanence in the atmosphere, the trends of phenological (start, length, and end of the pollen season) and production (pollen abundance and pollen peaks) pollen indicators over the years, the trends of the meteorological variables mainly involved (temperature and precipitation), and any relationships between pollen and meteorological variables, with particular reference to their presence in the atmosphere, in order to assess any significant variations in pollen precipitation in Rome, also based on the variation in vegetation.

2. Materials and Methods

2.1. Study Area

The University of Rome "Tor Vergata", located between Rome and the Alban Hills, is on the orographic left side of the Tiber River, at the foot of the Lazio Volcano, 15 km from the city center. The surrounding area of the sampler consists of several green areas, which are partly distributed among recently constructed buildings.

Human presence has transformed the original landscape, especially in recent decades: pastures and cultivated fields, such as vineyards and olive groves, were partly abandoned and partly replaced by new residential buildings.

2.2. Land Use and Vegetation

Despite the continuous transformations that the territory of the city of Rome undergoes due to the persistent process of anthropization and incessant urbanization, with notable changes in the ecosystems of potential plant communities, Rome is considered a "green city", with a heritage of protected and safeguarded areas estimated at around 129,000 hectares [14,15]. The city's flora shows considerable plant biodiversity: 1649 entities belonging to 139 families and 677 genera are registered [16] deriving from a great variety of natural, semi-natural, and artificial environments; the typical and large street trees and extensive areas of synanthropic and ruderal weed-type vegetation [17] contrast with artificial environments hosting, according to its different typologies, urban greenery.

To analyze the land-use and vegetation cover changes, it used the Corine Land Cover (CLC) database, a thematic map available in the Copernicus Land Monitoring Service, which, through photointerpretation of satellite images, returns data capable of providing a real snapshot of the changes in vegetation cover and/or different types of land use [18] that occurred during the period considered.

2.3. Pollen Data

In March 1996, a volumetric sampler Hirst type, a seven–day pollen trap VPPS 2000 Lanzoni model, was installed on the roof of the Department of Biology building of the University of Rome Tor Vergata, about 15 m high, to 90 m a.s.l., to Lat.: 41°51′ N, Long.: 12°37′ E. The pollen data were obtained and analyzed using the standard method [19], which is referred to as the daily concentration expressed in pollen per m^3 of air (p/m^3) [20].

Twenty years of data were considered: from 1997 to 2016.

The different pollen types belonging to Species, Genera, or Families, were identified according to the literature. Of the 52 botanical *taxa* sampled [21], the most representative ones have been considered for statistical processing, with the average values of the pollen spectrum in the 20 years greater than 1% for arboreous *taxa* and greater than 0.3% for herbaceous *taxa*. The values 0.3% and 1% were chosen arbitrarily, and they are obtained by calculating the pollen spectrum that shows the percentage of each *taxon* of the total number of pollen grains for each of the reported years.

Carpinus betulus L. and *Ostrya carpinifolia* Scop. are considered in the only group *Carpinus/Ostrya* because the pollen grains are very similar, and in the early years of monitoring activity in Italy, they were not counted separately.

2.4. Meteorological Data

Meteorological data were obtained from the *Tor Vergata* University station (SP2000, CAE Bologna, Italy), located in the Laboratory of Experimental Ecology and Aquaculture (LESA) of the Department of Biology, currently managed by the Hydrographic Service of the Lazio Region. The following meteorological variables were considered: daily maximum and minimum temperature (°C), rain rate (mm), and the number of rainy days, the main meteorological parameters that influence the pollen grains of the air. These variables are considered as they are and cumulated, with the yearly sum values from January 1st to December 31st and monthly.

To analyze the influence of meteorological conditions on pollen season variations and trends, monthly and annual meteorological parameters were examined. The meteorological data were also processed to see if the variables' trends changed over the years.

Temperature trends in the years 1997–2016 were calculated over two seasons, January to April or April to August, and were associated with different species according to their flowering period [22] to evaluate whether meteorological variables influence the airborne pollen grains content.

2.5. Statistical Methods

Before proceeding with the statistical analyses, the pollen spectrum was calculated, which shows the percentage of each taxonomic unit compared to the total pollen grains in the 20 years. Based on the values obtained, the taxa considered in this study were chosen: >1% for arboreal taxa and >0.3% for herbaceous taxa.

For each taxon, daily pollen concentrations (p/m^3) were used to calculate pollen season indices: phenological indicators—start dates, end dates, length (number of days) of the pollen season—and productive indicators—the pollen season intensity (Annual Pollen Integral, APIn), the timing and magnitude of the peak day (the highest daily average pollen concentration during pollen season) [23]. The literature proposes different calculation methods regarding pollen season indices; in this study, pollen season limits were calculated by using the Jäger method [24]: pollen season starts the first day that has a daily count higher than 1% of the annual pollen, presupposing that no more than six subsequent days follow with a zero count; it ends when 95% of the total annual pollen is reached. For the Cupressaceae–Taxaceae group, this study also indicated that as the Cupressaceae family and Corylus avellana L. species, the pollen season is considered from 1 November to 31 October of the following year. The normality of the distribution of the data will be analyzed using the Shapiro–Wilk test.

Since the data did not adjust to normal distributions, nonparametric statistic tests were applied. Pollen trends were elaborated for each taxon, considering both phenological and productive indicators, as well as meteorological parameters. To assess the significance of the pollen parameters trend, Reduced Major Axis linear regression analysis (RMA) will be used.

Significant trends were further analyzed using Spearman's rank correlation statistic, a non-parametric test used to determine the degree of correlation between pairs of variables, and the Wilcoxon test for the verification of the significance values.

For the analysis, PAST (Paleontological Statistics) [25] and 26.0 IBM-SPSS Statistics Software [26] were used.

3. Results

CLC analysis for the *Tor Vergata* monitoring station was carried out using a 5-km radius in which the sampling site falls and 10 Level II land use types, showing an appreciable transformation: from an area with a predominance of grassland, agricultural activities, and open countryside to an area with a considerable percentage of urban construction and intense anthropization (Figure 1).

The aerobiological sampling covered 7.305 days in 20 years. The unavailable data represent 3.67%, which is 268 days. In the pollen spectrum analysis (Figure 2), the APIn values show significant changes only for herbaceous, with an increasing trend (linear regression $p = 0.032$—Table 1).

The *taxa* included in the statistical analysis are 18, 6 herbaceous (Amaranthaceae, Euphorbiaceae, Poaceae, Plantaginaceae, Polygonaceae, and Urticaceae) and 12 arboreous (*Carpinus*/*Ostrya*, *Castanea*, *Corylus*, Cupressaceae, *Fraxinus*, Myrtaceae, *Olea*, Pinaceae, Platanaceae, *Populus*, *Quercus*, and *Ulmus*), which are considered the most representatives (95.2% of total pollen concentration), as the pollen average concentration (grain/m^3) over the 20 years of this study is, respectively, >0.3% and >1% of total pollen (Table 2).

Table 1. Linear regression pollen production indicators (APIn; peak daily concentration, peak day). R^2—Correlation coefficient. b—Slope. *p*—Significance. Negative *p*-values indicate a decreasing trend. Bold numbers indicate statistically significant differences. * Regression is significant at 0.05 level. ** Regression is significant at 0.01. level.

	Taxon	Linear Regression								
		Production Indicators								
		APIn			Peak Daily Concentration (p/m^3)			Peak Day		
		R^2	b (Trend)	*p*	R^2	b (Trend)	*p*	R^2	b (Trend)	*p*
Herbaceous	Amaranthaceae	**0.301**	**−18.722**	**0.012 ***	**0.216**	**−0.812**	**0.039 ***	**0.229**	**−4818**	**0.033 ***
	Euphorbiaceae	0.005	−2645	0.769	0.009	−0.401	0.688	0.059	4813	0.302
	Poaceae	0.008	27.599	0.706	0.121	−8843	0.133	0.031	−0.385	0.457
	Plantaginaceae	**0.470**	**60.371**	**0.001 ****	**0.646**	**2131**	**0.001 ****	**0.202**	**2330**	**0.047 ***
	Polygonaceae	0.108	5648	0.158	0.024	0.187	0.513	0.001	−0.072	0.918
	Urticaceae	**0.407**	**366.460**	**0.002 ****	**0.393**	**10.520**	**0.003 ****	0.025	−0.530	0.508
	herbaceous TOTAL	**0.231**	**429.928**	**0.032 ***	-	-	-	-	-	-
Arboreous	*Carpinus/Ostrya*	0.042	51.101	0.401	0.013	5344	0.643	0.004	−0.140	0.797
	Castanea	**0.322**	**−122.600**	**0.009 ****	**0.260**	**−56.326**	**0.022 ***	0.038	−0.223	0.410
	Corylus	0.001	0.818	0.957	0.004	0.570	0.787	0.007	0.363	0.726
	Cupressaceae	0.003	−37.017	0.829	0.015	−12.617	0.613	0.020	−0.365	0.563
	Fraxinus	0.007	4260	0.751	0.060	1558	0.583	0.005	0.393	0.360
	Myrtaceae	**0.255**	**−24.098**	**0.023 ***	**0.203**	**−2151**	**0.046 ***	0.026	−0.311	0.497
	Olea	0.122	−94.343	0.132	0.112	−15.725	0.150	0.011	−0.143	0.654
	Pinaceae	0.008	−12.840	0.710	0.004	1846	0.792	0.110	−0.377	0.154
	Platanaceae	0.146	20.048	0.096	0.079	2324	0.232	0.002	0.072	0.843
	Populus	0.108	140.370	0.157	0.126	16.938	0.125	**0.315**	**−628.000**	**0.010 ****
	Quercus	0.027	22.961	0.491	0.041	7097	0.391	0.001	0.029	0.940
	Ulmus	0.052	18.439	0.334	0.069	3005	0.263	0.075	−0.671	0.243
	arboreous TOTAL	0.002	−61.950	0.853	-	-	-	-	-	-
POLLEN TOTAL		0.048	450.017	0.354	-	-	-	-	-	-

Table 2. *Taxa* included in the study and average relative percentage of airborne pollen (APIn) over the period 1997-2016 in Rome SE.

	Taxon	% (APIn *Taxon*/APIn Tot)
herbaceous	Amaranthaceae	1.4
	Euphorbiaceae	1.0
	Plantaginaceae	0.8
	Poaceae	12.0
	Polygonaceae	0.5
	Urticaceae	15.1
Arboreous	*Carpinus/Ostrya*	3.7
	Castanea	5.1
	Corylus	1.3

Table 2. *Cont.*

	Taxon	% (APIn *Taxon*/APIn Tot)
	Cupressaceae	24.8
	Fraxinus	1.2
	Myrtaceae	1.0
	Olea	6.3
	Pinaceae	6.6
	Platanaceae	1.2
	Populus	2.8
	Quercus	9.2
	Ulmaceae	1.4
Others		4.8
Total		**100.0**

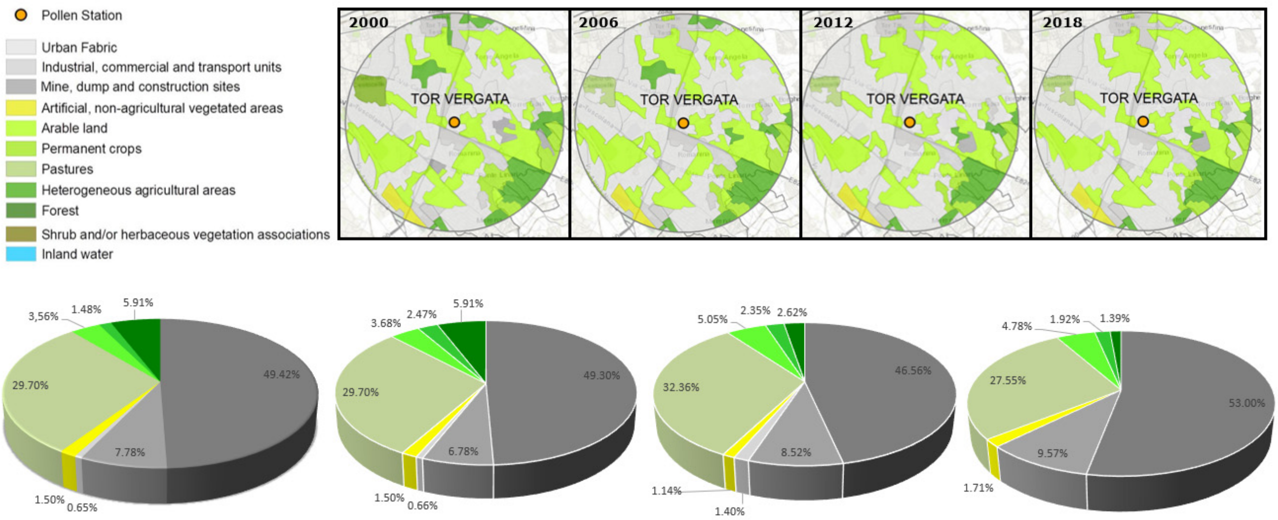

Figure 1. The figure shows the transformation of the area surrounding the pollen sampler at Tor Vergata (Rome SE) from the year 2000 to 2018, assessed using Corine Land Cover maps. Above are 4 images from the years 2000, 2006, 2012 and 2018, depicting the changes in the area within 5 km ⌀ buffer. At the bottom, pie charts describe the percentage changes in land use for the same years.The Shapiro–Wilk test results show a non-Gaussian distribution of all data.

Figure 2. Pollen spectrum: the pie charts depict the percentage changes of herbaceous (blue) and arboreous (red) APIn in the years 1997 (**left**), 2016 (**right**) and the average 1997–2016 (**centre**).

Table 3 shows the pollen season parameters for the 18 *taxa*: average of the phenological indicators and average of the production indicators values in the years.

Table 3. Average of the pollen season indicators values of the *taxa* included in the study in the years 1997–2016.

Taxon		Pollen Season					
		Phenological Indicators			Production Indicators		
		Start Dates	End Dates	Length (n Days)	APIn	Peak Daily Concentration (p/m^3)	Peak Day
Herbaceous	Amaranthaceae	25/5	20/10	149	621	23	23/7
	Euphorbiaceae	28/1	21/11	299	470	19	14/5
	Poaceae	23/4	16/7	85	5998	328	14/5
	Plantaginaceae	5/4	7/8	125	607	22	10/6
	Polygonaceae	29/3	17/7	112	257	14	18/5
	Urticaceae	17/3	28/9	196	8177	222	22/4
Arboreous	*Carpinus/Ostrya*	27/3	6/5	41	2034	284	12/4
	Castanea	11/6	16/7	35	2104	538	25/6
	Corylus	2/1	14/3	72	653	76	12/2
	Cupressaceae	1/2	26/4	85	11,717	1007	26/2
	Fraxinus	23/2	11/5	79	542	57	28/3
	Myrtaceae	26/5	12/8	79	419	37	5/7
	Olea	13/5	12/6	31	2900	389	27/5
	Pinaceae	14/4	11/6	59	2932	405	5/5
	Platanaceae	23/3	24/4	33	624	86	2/4
	Populus	2/3	5/4	35	1243	209	22/3
	Quercus	14/4	2/6	51	5048	383	12/5
	Ulmus	10/2	5/4	56	683	80	27/2

3.1. Linear Regression Analysis—RMA (Reduced Major Axis)

3.1.1. Pollen

The linear regression values for the pollen data are shown in Table 1: the slope of the regression (b), the coefficient of determination (R^2), and the probability level (p).

A total of 108 values were calculated for pollen, and only 13 were significant ($p < 0.050$); of these, the *APIn* increases in the herbaceous, as well as Plantaginaceae and Urticaceae *taxa*, while Amaranthaceae, *Castanea*, and Myrtaceae show a significant downtrend.

The daily peak concentration is also interesting: in all cases where the p values are significant, the trend is the same as in *APIn*.

3.1.2. Meteorological Data

The linear regression values for the meteorological data are shown in Tables 4 and 5: the slope of the regression (b), coefficient of determination (R^2), and probability level (p); 102 values were calculated, and 31 values were significant ($p < 0.050$).

Table 4. Meteorological variables linear regression. The table shows the monthly and annual rainfall trends (mm and number of rainy days), T max and T min at the Tor Vergata station—Rome SE. Negative slope-values indicate a decreasing trend. Bold numbers indicate statistically significant differences. R^2—Correlation coefficient. b—Slope. *p*—Significance. * Regression is significant at 0.05 level. ** Regression is significant at 0.01. level.

Months	Linear Regression											
	Meteorological Variables											
	mm Rain			Rainy Days			T max			T min		
	R^2	Slope	*p*	R^2	Slope	*p*	R^2	Slope	*p*	R^2	Slope	*p*
January	0.041	1.971	0.406	0.202	0.295	0.053	0.006	0.016	0.749	0.004	0.020	0.8
February	0.193	2.921	0.060	**0.209**	**0.332**	**0.049** *	0.001	0.003	0.996	0.005	0.028	0.773
March	0.170	2.856	0.079	**0.224**	**0.342**	**0.041** *	0.122	0.092	0.148	0.014	0.028	0.65
April	0.004	−0.348	0.810	0.081	−0.214	0.252	**0.709**	**0.274**	**0.001** **	0.039	0.034	0.395
May	0.134	2.658	0.124	0.093	0.191	0.203	0.173	0.114	0.078	0.158	−0.080	0.093
June	0.203	3.676	0.053	**0.233**	**0.167**	**0.036** *	**0.276**	**0.166**	**0.021** *	0.020	−0.031	0.578
July	0.118	1.833	0.150	0.100	0.137	0.187	**0.420**	**0.246**	**0.003** **	0.090	0.063	0.212
August	0.079	−1.108	0.245	0.073	−0.098	0.262	0.195	0.185	0.058	0.007	−0.016	0.738
September	0.002	−0.365	0.865	0.071	0.130	0.271	**0.254**	**0.138**	**0.029** *	**0.206**	**0.0945**	**0.047** *
October	0.049	−1.981	0.363	0.001	0.007	0.965	0.090	0.056	0.215	0.020	0.0255	0.586
November	0.012	1.345	0.657	0.030	−0.121	0.478	0.167	0.095	0.075	0.023	0.0436	0.533
December	0.035	−6.275	0.445	0.005	−0.060	0.764	0.017	0.028	0.619	0.000	−0.004	0.980
annual	0.024	5.958	0.515	0.162	1.241	0.079	0.520	0.116	0.000	0.022	0.015	0.499

Table 5. Cumulated meteorological variables linear regression. The table shows the monthly and annual cumulated rainfall trends (mm and number of rainy days), T max and T min at the Tor Vergata station—Rome SE. Bold numbers indicate statistically significant differences. * Regression is significant at 0.05 level. ** Regression is significant at 0.01. level. R^2—Correlation coefficient. b—Slope. *p*—Significance.

Months	Linear Regression											
	Cumulated Meteorological Variables											
	mm Rain			Rainy Days			T max			T min		
	R^2	Slope	*p*	R^2	Slope	*p*	R^2	Slope	*p*	R^2	Slope	*p*
January	0.041	1.971	0.406	0.202	0.295	0.053	0.001	0.280	0.886	0.003	0.568	0.824
February	0.186	4.874	0.066	**0.239**	**0.626**	**0.034** *	0.000	0.257	0.940	0.005	1.320	0.769
March	**0.359**	**7.730**	**0.007** **	**0.327**	**0.968**	**0.011** *	0.035	3.453	0.446	0.010	2.250	0.687
April	0.203	7.378	0.061	0.135	0.746	0.134	**0.287**	**13.483**	**0.022** *	0.039	5.160	0.431
May	**0.282**	**10.899**	**0.019** *	0.199	1.091	0.056	**0.463**	**23.722**	**0.001** **	0.024	4.059	0.523
June	**0.341**	**14.574**	**0.009** **	**0.228**	**1.258**	**0.039** *	**0.500**	**28.685**	**0.001** **	0.014	3.145	0.630
July	**0.349**	**16.407**	**0.008** **	**0.269**	**1.395**	**0.023** *	**0.585**	**36.296**	**0.001** **	0.034	5.109	0.448
August	**0.311**	**15.314**	**0.013** *	**0.261**	**1.297**	**0.025** *	**0.542**	**42.043**	**0.001** **	0.023	4.627	0.532
September	**0.281**	**15.745**	**0.020** *	**0.292**	**1.426**	**0.017** *	**0.557**	**46.631**	**0.001** **	0.063	7.846	0.299
October	0.192	14.642	0.060	**0.260**	**1.433**	**0.026** *	**0.531**	**47.475**	**0.001** **	0.060	7.991	0.311
November	0.171	16.254	0.073	0.176	1.326	0.078	**0.538**	**50.331**	**0.001** **	0.062	9.036	0.303
December	0.063	10.126	0.301	0.146	1.265	0.106	**0.527**	**50.807**	**0.001** **	0.041	7.628	0.409
annual	0.024	5.958	0.515	0.162	1.241	0.079	**0.628**	**1.702**	**0.001** **	0.075	0.323	0.247

A total of 104 values were calculated for meteorological variables, and 31 were significant ($p < 0.050$); of these, the cumulated meteorological variables are interesting. *T max* increases from April to December and annual value ($p < 0.010$), and mm rain in March, June, and July ($p < 0.010$).

3.2. Spearman's Correlation Test

For each *taxon*, Spearman's correlation coefficients were calculated between all the variables used, both pollen and meteorological. A total of 2430 values were calculated, and 304 values were significant ($p < 0.050$).

Only the *taxon* Cupressaceae/Taxaceae has no significant correlation between pollen and meteorological variables.

All Spearman's correlations between the pollen variables *start*/*length* were significant ($p < 0.050$), except that for *taxa Castanea*, *Corylus*, and Poaceae, and all with coefficient values negative; and all *Spearman's* correlations between the pollen variables *APIn*/*maximum daily peak concentration* were significant ($p \leq 0.050$), except that for *taxon* Poaceae, and all with positive coefficient values.

The pollen production indicators were correlation coefficient significant ($p < 0.050$) with the temperature variables, except for the Euphorbiaceae family.

3.3. Wilcoxon Test

Before applying the Wilcoxon's test, the significant Spearman's correlations were assessed according to the season of the phenological indicators and the production indicators. To evaluate the relationship between pollen and meteoclimate parameters, Wilcoxon's test was applied to 19 pairs of variables, and significant correlations are 18 (Table 6).

Table 6. Results of Wilcoxon test statistical analysis carried out between pollen indicators and meteoclimate variables. In red (mm rain *vs* Urticaceae APIn) Spearman correlation not verified, i.e., not statistically significant: *p*-values > 0.05.

		Pollen Indicator	Wilcoxon's Test	
			Z	*p*
Tmax JFM	*vs*	Ulmus START	−3.358	0.005
		Platanaceae START	−2.192	0.011
		Populus START	−3.892	0.028
		Populus LENGTH	−3.268	0.008
mm rain JFM	*vs*	Quercus APIn	−3.421	0.001
		Urticaceae APIn	−0.747	0.455
		Polygonaceae APIn	−3.810	0.001
		Plantaginaceae APIn	−3.920	0.000
		Poaceae START	−3.660	0.002
mm rain JAS	*vs*	Olea LENGTH	−2.890	0.011
		Platanaceae LENGTH	−2.483	0.002
		Euphorbiaceae APIn	−3.710	0.001
mm rain OND	*vs*	Castanea START	−2.782	0.004
		Euphorbiaceae APIn	−3.531	0.001
		Olea LENGTH	−2.781	0.010
		Urticaceae APIn	−3.781	0.002

4. Discussion

Aerobiological monitoring and pollen trend analysis are important to evaluate the different behavior of *taxa* over the years in relation to climate conditions [27–29], pollen [30–34], and flowering season [35,36].

In the period considered, the analysis of the pollen spectra shows an increasing trend for the herbaceous *taxa*, probably attributed to a gradual abandonment of agricultural practices in the neighboring area, which has been the subject of intense new building activity in recent years and a progressive deterioration of maintenance of green areas.

In particular, the growing trend is statistically significant for the herbaceous families Plantaginaceae and Urticaceae, whose individuals exhibit a high capacity to live in stressful conditions with high levels of nitrogen in the soil and areas with strong anthropic impact. In addition, these *taxa* are able to withstand high temperatures and drought, and the significant increase in summer temperatures (T max between April and August: $p = 0.002$) confirms that high temperatures do not affect their reproductive cycle.

However, the lack of water availability in southern Europe may induce a trend towards a lower flowering intensity, especially in herbaceous plants [4], as in the case of Amaranthaceae in this study: the decreasing trend significant of APIn ($p = 0.012$) is positive for health, whose pollen represents the first cause of allergic reactions during the summer season [37,38].

During the last decade, in most of Europe, a shift in flowering season has been evidenced; anticipation of the start of pollen season [27,39–41] or a late start of flowering in some parts of south Europe [42,43] because of a lack of water in the soil that can influence growth and development of plants [44,45]; in this study only the Poaceae family has a significant shift: the start of pollen season is 11 days in advance.

Corine Land Cover data analysis is in line with what emerges from the calculation of APIn values showing growth in pollen produced by herbaceous species: in the last decades, the suburban area of *Tor Vergata* has been characterized by incessant urbanization resulting in an increase in ruderal herbaceous plant species, as the graphs in Figure 1 show.

From the results of linear regression, no significant trends emerge that could potentially affirm any climate change phenomena for the city of Rome. Indeed, in the Mediterranean area, it may be difficult to distinguish the effect of different environmental factors, i.e., the balance between increased CO_2 emissions and reduced water supply for plants. Furthermore, trends do not depend only on CO_2 levels and climate change but also on other factors, including changes in land use and in the design of urban green spaces [15], as reflected in the Corine Land Cover maps (Figure 1).

The Spearman's correlation between the phenological indicators shows a significant correlation with a negative r_s coefficient between the start of the pollination and the pollen season length: an earlier start of the pollen season results in a longer duration of pollen grains in air and vice versa, In case of delay, the pollen season will be shorter. Furthermore, correlation data indicate that rainfall falling in the months before flowering affects pollen production. Additionally, temperature is the variable that most influences pollen dispersion in the air, which is in line with other studies [35,46].

5. Conclusions

It is true that the Earth's average temperature has increased by about 0.56 °C during the 20th century, but we must also consider the location of the meteorological stations, mainly located in major cities, in which urbanization since the second half of the last century has modified the territory, generating the known effect urban heat island [2].

Climate change is a process that determines effects on vegetation phenology, especially in relation to an increase in T max values. Although the results of this study show a significant upward trend in T max and mm rain for some months, the pollen data seem to be different with respect to previous papers that show an actual increase in airborne quantities of pollen—*APIn* [41,47,48], and an anticipation of the start of the pollen season [27,40,49].

Currently, with the statistical elaborations of the Rome pollen data, it is not possible to affirm that the climatic variations observed in the last years determine appreciable changes in pollen grain dispersion in air.

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