



Trend analysis of aerobiological indicators associated with allergenic pollens in Emilia-Romagna, Northern Italy

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Abstract This study is related to an overall analysis of the most relevant pollen season modifications as they emerge from the aerobiological monitoring activity in the network of stations in Emilia-Romagna, a region located in Northern Italy. The taxa selected for the study are among the most important from an allergenic point of view. The selected period goes from 1991 to 2017 in order to have a similar length for all the different taxa in all the stations, regardless of their date of activation. Statistical analysis of the time series of some pollen season indicators has been carried out in the period, with the aim of pointing out the most relevant changes in the ensemble of the monitoring stations. The available database lasting more than 25 years can be the basis for a robust statistical analysis of the long-term trends in the time series of pollen seasonal indicators. The stations are operating throughout the whole Emilia-Romagna territory, spanning a range of climatic conditions from the inner Po Valley to the coastal area. Results of the trend analysis indicate that the starting and the peak

dates of the pollen season are in prevalent advance. This is true both for most herbaceous taxa, as well as for several arboreal ones. As for pollen production, a different behaviour characterizes herbaceous and arboreal taxa; in fact, a generally decreasing trend interests all herbaceous taxa, while a prevalent increasing trend is present in several of the latter. Pollen season indicators are certainly more directly affected by the changes associated with the meteorological forcing and are possibly more influenced by climatic change.

Keywords Aerobiological monitoring · Pollen season · Pollen production · Temporal trend analysis

1 Introduction

Plant phenology provides a very important signal of climate variability and climate change. The extent to which plant phenology responds to local changes in temperature and rainfall patterns is gaining increasing interest. In general, the response is both location- and taxon-specific. Several studies related to the effects of climate change on botanic species in different geographical areas have been published during recent years. Results from this kind of studies show diversified situations in Europe. Ziello et al. (2012) represents a paradigmatic study of this kind, being

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based on 23 pollen taxa collected at 97 stations located in 13 European countries; the general results indicate that increasing trends for pollen production by arboreal taxa are more widespread than for herbaceous taxa.

Other recent studies often show inconsistent trends between pollen of the same taxon at different locations (geographically and, consequently, climatically). As an example, Spieksma et al. (2003) compared five pollen taxa in five monitoring stations in western Europe; all the significant trends for Urticaceae, *Betula* and *Quercus* are associated with an increase in pollen levels. On the other hand, Graminaceae do not show any significant trend, and *Artemisia* shows significant trends in all the stations, both positive and negative.

However, southern Europe meteo-climatic conditions may be the cause of a different behaviour in this region. Galán et al. (2016) analyse annual pollen index trends in 12 stations in Spain revealing quite pronounced differences in the variation of pollen season for arboreal and herbaceous taxa, the latter being probably more subject to year-to-year variations in the meteorological conditions. However, a general increase in pollen from arboreal taxa and a decrease in pollen from herbaceous taxa can be pointed out. More specifically, Garcia-Mozo et al. (2010) show an advancing trend for the pollen season starting date and peak date for Graminaceae together with an increase in the annual pollen index in Andalusia (Spain), while Recio et al. (2009) point out that the climate change impact on Urticaceae pollen season in two Spanish stations is very different. The main feature which emerges from another study with focus on Greece (Damialis et al. 2007) is the increase in pollen concentration for most taxa, especially for arboreal ones; on the other hand, no significant change is related to phenological characteristics of pollen season.

The present analysis deals with a description of the most relevant temporal trends related to the main features of the pollen season for different taxa (herbaceous and arboreal). The pollen season characteristics are defined using some annual pollen indicators, which are computed starting from the database of daily pollen concentrations collected in the monitoring stations of the aerobiological network managed by the Regional Agency for Prevention, Environment and

Energy (hereafter Arpa-ER) in Emilia-Romagna, Italy.

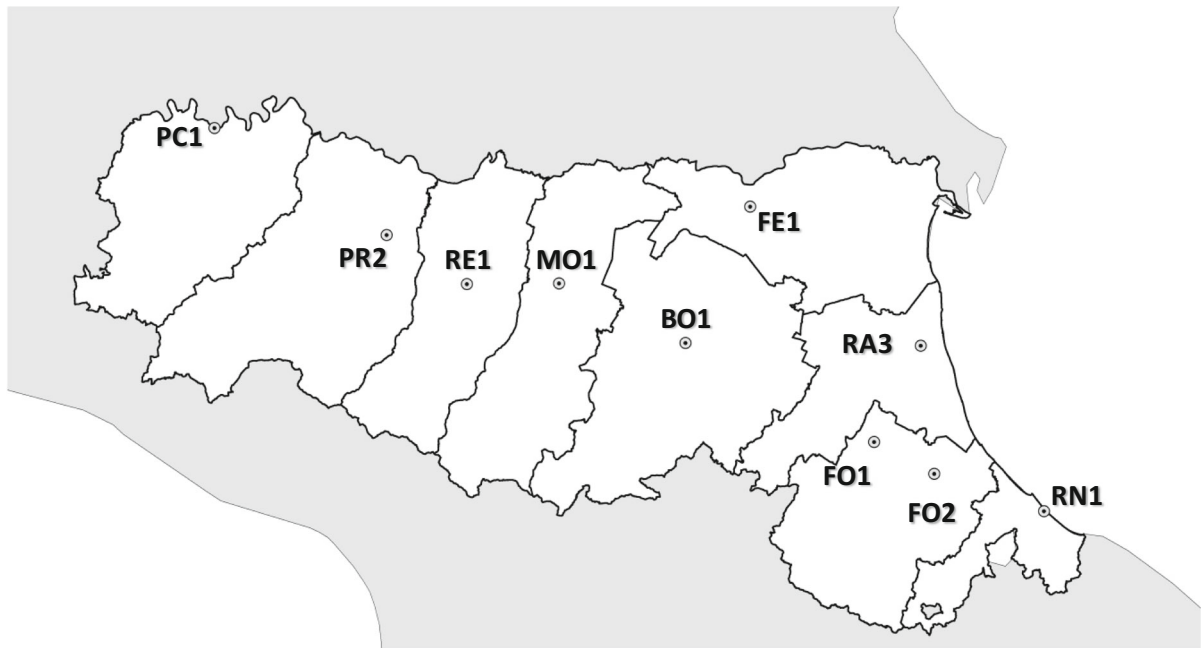
The period for the analysis extends from 1991 to 2017 (27 years in total), and ten stations of the network are selected. The main purpose of the study is to assess the most evident changes in the pollen season characteristics in Emilia-Romagna. Signals characterizing a large number of stations can be considered as a good proxy for modifications induced by climatic effects, also taking into account the fairly homogeneous meteo-climatic conditions in Emilia-Romagna.

2 Methods

Arpa-ER is in charge of managing a network of stations for aerobiological monitoring listed in Fig. 1. In this study, ten stations of the network have been considered, and the period from 1991 to 2017 was selected for the analysis in order to have the longest possible data coverage for the pollen taxa which are more widespread in Emilia-Romagna. The geographical position of the stations is shown in Fig. 1. (See also Figure 1-S in the Supplementary Materials for the geographical localization of Emilia-Romagna on a larger spatial scale).

The climate in Emilia-Romagna is temperate, subcontinental type according to Köppen–Geiger classification (Peel et al. 2007), with hot and humid summers and cold and freezing winters. The Adriatic Sea is typically shallow therefore not affecting in a relevant way the thermal conditions of Emilia-Romagna except for a narrow area along the coast. Annual mean temperature range is quite large: around 24 °C during summer and 4 °C during winter; autumn is usually cool and rainy (often misty and foggy), while springs are generally mild. Precipitation in the plain is not very large (600–750 mm/year on average) and shows a remarkable increase in the Apennines area to the south (up to 2000 mm/year next to the Emilia-Romagna/Toscana border).

Arpa-ER aerobiological network is a part of the Italian Aerobiological Monitoring Network POLLnet. The stations belonging to Arpa-ER network considered in this study are equipped with a volumetric, Hirst-type sampler (Hirst 1952). Monitoring stations are installed at the centre of flat areas on the top of buildings away from any obstacles, usually 15–20 m above the ground level.



Station name	Code	Longitude [°]	Latitude [°]	Height a.s.l [m]	Activation Year
Piacenza	PC1	9.71	45.06	55	1987
Parma	PR2	10.32	44.78	50	1987
Reggio Emilia	RE1	10.60	44.66	94	1990
Modena	MO1	10.97	44.68	28	1987
Bologna	BO1	11.33	44.50	80	1987
Ferrara	FE1	11.62	44.83	8	1987
Ravenna	RA3	12.21	44.47	2	1991
Forlì'	FO1	12.03	44.23	30	1991
Cesena	FO2	12.24	44.14	31	1991
Rimini	RN1	12.62	44.03	7	1993

Fig. 1 (upper panel) Maps of the aerobiological stations belonging to Arpae Emilia-Romagna aerobiological network (upper panel). PC1: Piacenza; PR2: Parma; RE1: Reggio Emilia; MO1: Modena; BO1: Bologna; FE1: Ferrara; RA3: Ravenna; FO1: Forlì; FO2: Cesena; RN1: Rimini). (lower panel) Monitoring stations belonging to Arpae-ER aerobiological

network. Geographical coordinates and height data are obtained from Arpae database (<https://simc.arpae.it/dext3r/>). See also Figure 1-S in the Supplementary Materials showing a map with the geographical position of Emilia-Romagna in Northern Italy with the surrounding countries

The sticks collected at the volumetric samplers are analysed with a light microscope, and the pollen counts obtained are subsequently converted in the daily pollen concentration (expressed as the number of pollen grains per air cubic metre per day). A common monitoring procedure characterizes the stations in the network (Bucher et al. 2017).

Daily time series of pollen concentration are then converted in the annual value of pollen indicators

introduced in order to summarize the main features of the pollen season; some of them are related to the amount of pollen of various taxa produced during the year and others are associated with the definition of the pollen season.

In the first group, the pollen index and the peak value have been considered, defined as the sum of the daily pollen concentration and the maximum value for daily concentration during the whole year,

respectively. As for the other type of indicators, a main pollination period (Main Pollen Season—MPS) has been defined as the period during which the 90% of the annual pollen index is recorded (Nilsson and Persson 1981); according to this definition, the starting and the ending date of the MPS have been considered as the day when the 5% and the 95% of the annual pollen indexes are recorded, respectively. In addition, the MPS length defined as the number of days between the starting and ending date included has been considered among the pollen season indicators. Finally, the peak date of the season is considered, which indicates the day when the peak value is recorded.

Each year is considered in the annual time series only when at least 75% of daily pollen concentration data are available during the year. This constraint based on the minimum percentage of data could be inadequate when pollen taxa are characterized by low daily concentrations and/or by a short pollen season at a certain location, where advection of pollen from the surroundings may become relevant. Therefore, years must also have more than 10 days with positive pollen concentration (even if not consecutive) in order to be considered.

The annual time series of the above described indicators have been considered in the nonparametric Kendall test (Kendall 1976) in order to evaluate the presence of a monotonic trend (either decreasing or increasing) in each station; the test is based on the value of the so-called Kendall τ coefficient, which measures the degree of association based on the rank between the independent variable (time) and the dependent one (the annual indicator). The null hypothesis of the test is that the pollen indicator time series is time independent; in the following, results are considered significant at a 95% confidence interval (p level < 0.05) and highly significant at a 99% confidence interval (p level < 0.01) in order to reject the null hypothesis.

As for pollen production indicators, the positive(negative) sign of Kendall τ coefficient indicates the presence of an increasing(decreasing) trend for the indicator; on the other hand, a negative(positive) sign of Kendall τ coefficient associated with the pollen season indicators indicates the presence of an advance(delay) in the associated indicator.

The time series of the selected pollen indicators in the period 1991–2017 is submitted to the Kendall tau

test only when more than 75% of years are available (at least 21 years).

In order to have a quantitative indication of the general situation in the ensemble of the ten monitoring stations, the median of the distribution of Kendall τ coefficients for each pollen indicator and for each taxon is submitted to Mann–Whitney test (Mann and Whitney 1947); in the one-sample case, the median of the distribution is tested to be different from zero with a certain confidence level. If the test shows an acceptable confidence level (at least 95%), the distribution of Kendall τ coefficients in the ensemble of the stations is characterized by a prevalence of positive or negative values for the trend of the specified pollen indicator and taxon.

The statistical analysis has been performed using R software (R Core Team 2018).

3 Results

Kendall tau for the pollen season indicators in each of the ten monitoring stations is shown in Table 1-S (a)–(e) in the Supplementary Materials. The criterion of having at least 75% of years is met in almost the totality of cases. The only exclusions are for *Aceraceae* pollen family in FO1 and FO2, while all the remaining pollen taxa and stations can be considered in the analysis. In order to summarize the results of the study, box-and-whiskers plots of the distribution of the ten values of Kendall τ coefficients for each pair (taxon, indicator) are shown synoptically for all taxa in Figs. 2 and 3.

As for pollen production, the pattern is very similar for pollen index and peak value (Fig. 2). Pollen production for herbaceous taxa show a general decrease since the median of the Kendall τ coefficients distribution is negative and significantly different from zero for *Graminaceae*, *Urticaceae*, *Cheno-Amaranthaceae* and *Compositae* for both indicators.

On the other hand, most arboreal taxa are characterized by a prevalent increasing trend of pollen index and peak value; the median of Kendall τ coefficients is significantly positive for *Platanaceae*, *Oleaceae* and *Ulmaceae*. *Betulaceae* pollen, on the contrary, is the only arboreal taxon for which pollen production is decreasing; the median of Kendall τ coefficients is negative for both indicators and is significantly different from zero only for the pollen index.

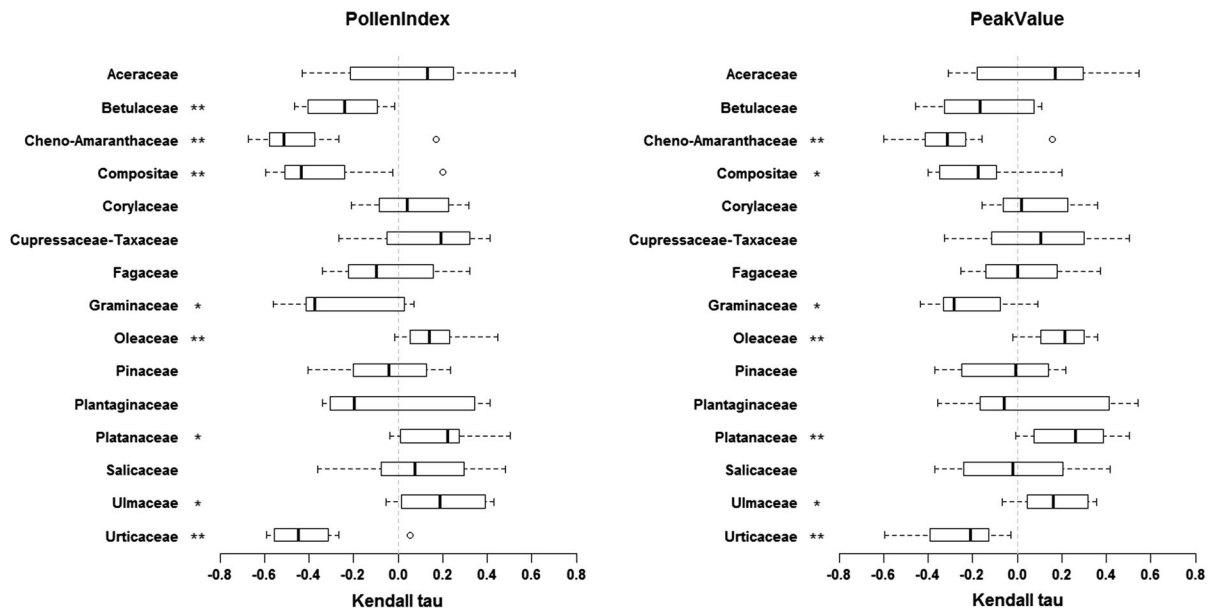


Fig. 2 Box-and-whiskers plot of Kendall τ coefficients in the ten monitoring stations for the pollen index (left panel) and for the peak value (right panel) calculated in the period 1991–2017. Symbols “*” and “**” indicate that the median of the distribution is significantly different from zero at 95% or 99% confidence level, respectively. Boxes extend from 25 to 75th

As for the pollen season indicators, trends are generally more varied. Figure 3 shows the box-and-whiskers plots for the start date of the MPS (left panel) and for the peak date (right panel). Among the herbaceous taxa, Graminaceae and Urticaceae show very relevant advancing trends for both indicators. Kendall τ coefficients are, in fact, negative in all the stations for both indicators. In addition, negative Kendall τ coefficients are statistically significant in all the stations for Urticaceae start date and in six stations for Graminaceae start date; as for the peak date, eight values of Kendall τ coefficients are statistically significant for Graminaceae and five for Urticaceae (Table 1-S(a) and (d)). On the other hand, start and peak dates for Compositae pollen season are in prevalent delay, even if statistically significant signals in the single stations are present only for the MPS peak date (Table 1-S(d)).

Also for several arboreal taxa, a general advancing trend is present for the start date (Pinaceae, Platanaceae and Salicaceae) and for the peak date (Fagaceae, Platanaceae and Ulmaceae), even if few statistically significant values in the stations are present only for the peak date (Table 1-S(d)).

percentile of the distribution, while the black vertical bars inside the boxes represent the 50th percentile (median) of the distribution. The whiskers extend from -1.5 to 1.5 times the inter-quartile range of the distribution. Kendall τ values exceeding this range are considered outliers and are indicated with a “o”

Box plots for the pollen season length are shown in Fig. 3. For Graminaceae and Urticaceae, MPS tends to become longer; for Urticaceae, the MPS is lengthening in all the stations, and the signal is statistically significant in six of them; for Graminaceae, the τ coefficients are statistically significant in half of the stations. In Fig. 3, most of the remaining taxa show negative trends, indicating a shortening of pollen season length; the median of τ distribution is significantly different from zero for four taxa, both herbaceous (Plantaginaceae) and arboreal (Betulaceae, Platanaceae and Fagaceae). Only few stations are characterized by Kendall τ coefficients for these taxa reaching statistically significant confidence level (four for Plantaginaceae and three for the arboreal taxa).

4 Discussion and conclusions

Several pollen taxa monitored in ArpaE-ER aerobiological network show relevant variations in terms of pollen production and of the timing of the pollen season.

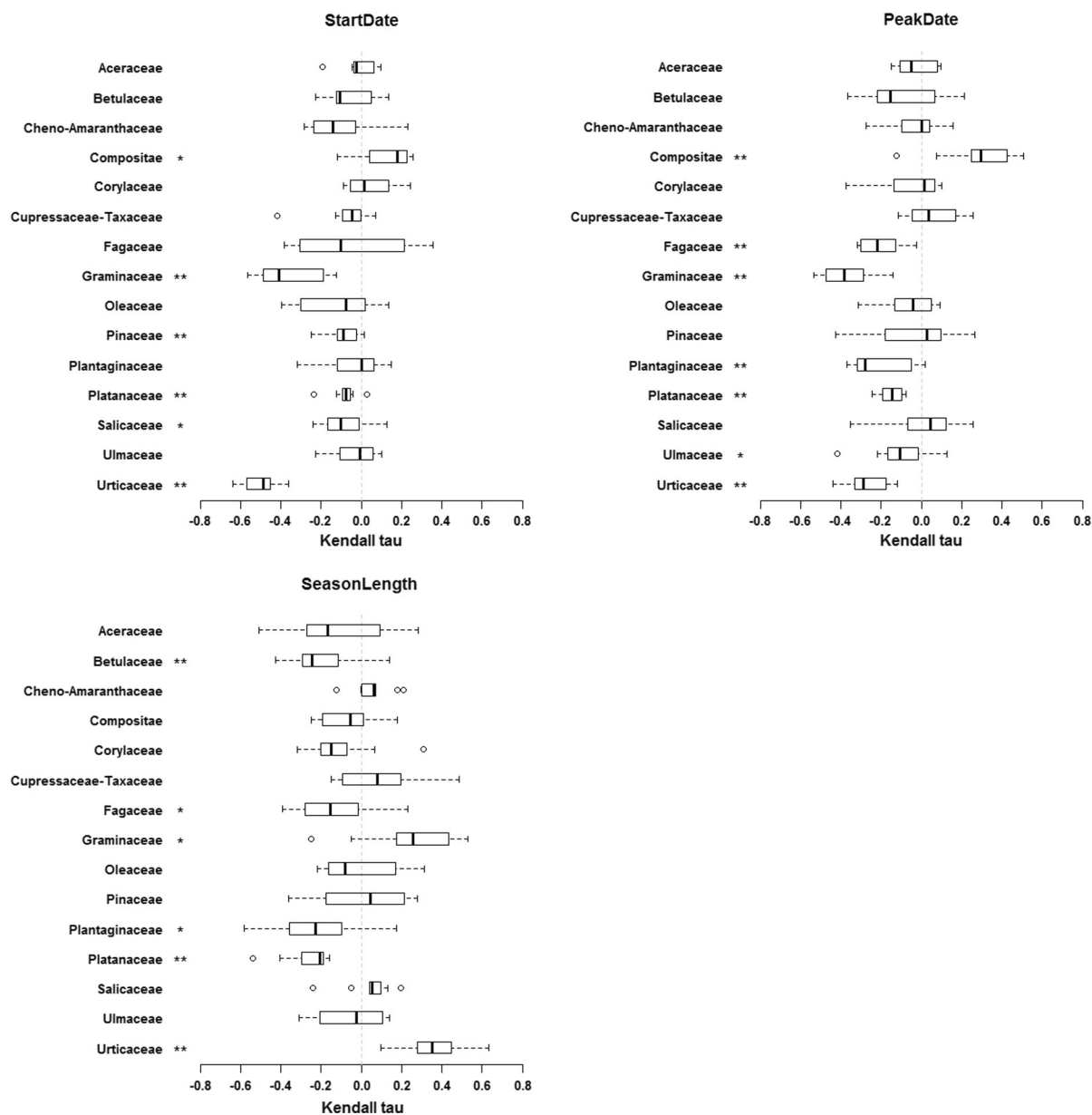


Fig. 3 Same as Fig. 2, for MPS start date (upper left panel), peak date (upper right panel) and MPS length (lower left panel)

Graminaceae and Urticaceae are certainly interested by the most relevant variations in Emilia-Romagna, showing a decreasing trend for the pollen amount during a pollen season which tends to increase in length, mainly due to an advance in the MPS start date. In addition, concentration peaks for these two taxa tend to appear earlier during the year. As for the clear decrease in Graminaceae and Urticaceae pollen production in Emilia-Romagna, results are in

accordance with the findings in the European study presented in Ziello et al. (2012). However, findings in Spain (Garcia-Mozo et al. 2010; Galán et al. 2016) and Greece (Damialis et al. 2007) show quite a different situation in the Mediterranean area, suggesting some specific traits for Emilia-Romagna.

The other herbaceous taxa are showing in turn a decrease in pollen production, though season length trends are contrasting; a shortening trend for

Plantaginaceae (with advancing peak dates), while no important trend characterizes Chenopodiaceae and Compositae. For the latter taxon, starting and ending dates are in prevalent delay and both tendencies together shift the MPS towards the end of the year.

An increase in the pollen production over time is observed for pollen produced by most arboreal families. In particular, trends generally reach statistical significance for Platanaceae, Oleaceae and Ulmaceae. This signal is again present also in Ziello et al. (2012), but also in Spain for *Platanus* and *Olea* (Galán et al. 2016). Among the above mentioned taxa, only Platanaceae pollen season is characterized by relevant modifications (shortening of the season); the trends of advancing start and end dates shift the season towards the beginning of the year. However, Betulaceae and Fagaceae pollen seasons tend to shorten together with a decreasing trend for the pollen amount. As for the latter, no clear trends are present in the European scale study, while a trend towards an increase in *Betula* pollen production is shown in Spain.

The results obtained in Emilia-Romagna can contribute to the environmental analysis of the long-term trend in an area located in southern Europe, where relevant changes of the pollen season characteristics have already been pointed out. The present study shows both similarities and differences with other studies that can be related to different aspects, such as geography and territory, period of data availability and pollen types considered in the analysis. Straightforward developments and in-depth analysis of the impact of climate change on botanic species will be the analysis of the relationships between pollen indicators and meteorological variables, as well as the integration with reliable land-use data in the study area, also derived from satellite imagery and repeated digital photography.

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Figure 1-S. Geographical position of Emilia-Romagna Region in northern Italy and the surrounding countries. The location of aerobiological stations belonging to Arpae-ER network are indicated with a symbol; names, codes and geographical coordinates of the stations are shown in Figure 1.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	0.05	-0.19	-0.03	-0.02	0.09	-0.03	-0.05			0.07
Betulaceae	-0.09	-0.12	-0.23	-0.12	0.03	0.14	0.05	-0.12	-0.12	0.07
Cheno-Amaranthaceae	0.23	-0.06	-0.03	-0.24	0.08	-0.17	-0.17	-0.11	-0.24	-0.28
Compositae	0.23	0.20	0.23	0.07	-0.12	-0.12	0.04	0.21	0.26	0.16
Corylaceae	0.02	-0.07	-0.09	0.04	-0.06	0.01	0.00	0.24	0.20	0.14
Cupressaceae-Taxaceae	-0.06	-0.42 **	-0.07	-0.03	-0.13	0.04	-0.09	0.00	0.07	-0.03
Fagaceae	-0.04	-0.30 *	-0.12	-0.13	-0.36 **	0.21	-0.08	0.36 *	0.27	-0.38 **
Graminaceae	-0.48 **	-0.52 **	-0.45 **	-0.57 **	-0.49 **	-0.37 **	-0.24	-0.19	-0.12	-0.19
Oleaceae	0.02	-0.07	-0.30 *	-0.08	-0.11	-0.31 *	0.03	-0.39 **	-0.06	0.13
Pinaceae	-0.10	-0.03	-0.08	-0.10	-0.07	0.01	-0.12	-0.13	0.02	-0.25
Plantaginaceae	-0.25	-0.32 *	0.06	-0.12	0.14	0.15	0.03	-0.03	-0.12	0.04
Platanaceae	-0.10	-0.06	-0.12	-0.08	-0.08	-0.10	-0.24	-0.04	0.03	-0.05
Salicaceae	-0.11	-0.15	0.00	-0.10	-0.17	-0.01	-0.10	-0.23	-0.24	0.13
Ulmaceae	0.10	-0.11	0.04	0.08	-0.05	0.03	-0.23	-0.06	-0.12	0.06
Urticaceae	-0.64 **	-0.63 **	-0.57 **	-0.36 **	-0.45 **	-0.45 **	-0.53 **	-0.45 **	-0.52 **	-0.45 **

Table 1-S (a). Values of Kendall τ coefficients in the 10 monitoring stations of Arpae-ER aerobiological network for the annual time-series of MPS start date computed for the period 1991-2017. Symbols “*” or “**” indicate that the Kendall τ coefficients are statistically significant at 95% or 99% confidence level, respectively.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	-0.09	-0.06	0.18	-0.31 *	-0.13	-0.44 **	-0.29 *			0.30 *
Betulaceae	-0.20	-0.03	-0.01	-0.29 *	-0.52 **	-0.21	-0.09	-0.50 **	-0.39 **	-0.39 **
Cheno-Amaranthaceae	0.34 *	-0.03	0.02	-0.02	0.11	0.12	-0.17	-0.11	0.00	-0.21
Compositae	0.47 **	0.30 *	0.34 *	0.29 *	0.13	0.48 **	0.05	-0.18	-0.18	-0.03
Corylaceae	0.10	-0.30 *	0.13	-0.10	-0.12	-0.18	-0.39 **	-0.21	-0.16	-0.34 *
Cupressaceae-Taxaceae	-0.07	0.47 **	0.07	0.42 **	0.06	0.30 *	-0.03	-0.17	-0.17	-0.24
Fagaceae	-0.40 **	-0.40 **	-0.41 **	-0.28 *	-0.21	-0.34 *	-0.44 **	-0.22	-0.24	-0.45 **
Graminaceae	0.23	-0.02	-0.06	-0.12	0.12	0.26	0.16	0.09	-0.04	-0.38 *
Oleaceae	-0.14	-0.21	-0.14	-0.37 **	-0.15	0.01	-0.24	-0.33 *	-0.26	-0.19
Pinaceae	0.32 *	0.14	-0.28 *	0.14	-0.42 **	0.29 *	0.18	-0.12	-0.08	-0.41 **
Plantaginaceae	-0.45 **	-0.56 **	-0.39 **	-0.35 *	-0.01	-0.63 **	-0.09	0.10	-0.08	-0.39 **
Platanaceae	-0.20	-0.25	-0.19	-0.19	-0.28 *	-0.30 *	-0.39 **	-0.37 **	-0.32 *	-0.58 **
Salicaceae	-0.09	-0.22	0.02	0.06	0.04	-0.28 *	-0.13	-0.17	-0.12	0.05
Ulmaceae	-0.02	-0.03	0.29 *	-0.20	0.18	-0.33 *	-0.38 **	0.05	0.10	-0.16
Urticaceae	0.14	-0.03	0.22	-0.04	0.06	0.19	0.16	0.04	0.00	-0.23

Table 1-S (b). Same as Table 1-S (a), for MPS end date.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	-0.12	0.00	0.19	-0.33 *	-0.21	-0.51 **	-0.21			0.28
Betulaceae	-0.20	-0.01	0.14	-0.23	-0.43 **	-0.27	-0.11	-0.26	-0.29 *	-0.30 *
Cheno-Amaranthaceae	-0.13	0.07	0.00	0.07	0.06	0.18	0.00	0.06	0.21	0.03
Compositae	-0.07	-0.09	-0.04	0.01	0.15	0.18	-0.02	-0.24	-0.25	-0.19
Corylaceae	0.07	-0.16	0.31 *	-0.14	-0.07	-0.08	-0.17	-0.32 *	-0.20	-0.22
Cupressaceae-Taxaceae	0.06	0.48 **	0.10	0.33 *	0.18	0.20	0.00	-0.15	-0.14	-0.09
Fagaceae	-0.28 *	0.02	-0.10	-0.11	0.23	-0.39 **	-0.20	-0.35 *	-0.24	-0.02
Graminaceae	0.53 **	0.43 **	0.30 *	0.18	0.28 *	0.45 **	0.24	0.20	-0.05	-0.25
Oleaceae	-0.13	-0.10	0.17	-0.22	-0.03	0.29 *	-0.16	0.31 *	-0.06	-0.20
Pinaceae	0.26	0.16	-0.18	0.21	-0.21	0.28 *	0.19	-0.07	-0.13	-0.36 *
Plantaginaceae	-0.22	-0.36 **	-0.36 *	-0.24	-0.14	-0.58 **	-0.10	0.17	-0.06	-0.30 *
Platanaceae	-0.17	-0.16	-0.19	-0.19	-0.22	-0.21	-0.20	-0.41 **	-0.30 *	-0.54 **
Salicaceae	0.07	-0.05	0.04	0.13	0.20	-0.24	0.05	0.05	0.10	0.05
Ulmaceae	-0.14	0.03	0.09	-0.29 *	0.14	-0.31 *	-0.08	0.10	0.12	-0.21
Urticaceae	0.63 **	0.45 **	0.55 **	0.10	0.31 *	0.40 **	0.42 **	0.29 *	0.28	0.15

Table 1-S (c). Same as Table 1-S (a), for MPS length.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	-0.10	-0.11	-0.04	-0.15	0.10	0.07	-0.06			0.09
Betulaceae	0.07	-0.14	-0.37 **	0.21	-0.20	-0.18	0.02	-0.33 *	-0.22	0.20
Cheno-Amaranthaceae	0.06	0.02	-0.28	0.16	-0.04	0.03	-0.02	0.04	-0.10	-0.26
Compositae	0.48 **	0.51 **	0.42 **	0.26	0.31 *	0.39 **	0.07	0.28 *	-0.12	0.25
Corylaceae	0.07	0.05	0.09	0.06	-0.14	0.10	-0.14	-0.10	-0.02	-0.38 *
Cupressaceae-Taxaceae	0.03	-0.12	0.04	-0.05	0.03	0.26	-0.06	0.23	0.17	0.08
Fagaceae	-0.16	-0.21	-0.22	-0.24	-0.30 *	-0.09	-0.32 *	-0.03	-0.13	-0.32 *
Graminaceae	-0.38 **	-0.54 **	-0.47 **	-0.45 **	-0.52 **	-0.35 *	-0.39 **	-0.29 *	-0.14	-0.21
Oleaceae	0.09	0.05	-0.31 *	-0.02	-0.13	-0.08	-0.03	0.06	-0.05	-0.27
Pinaceae	0.04	0.26	0.10	0.26	0.08	0.01	-0.13	-0.18	-0.33 *	-0.43 **
Plantaginaceae	-0.37 **	-0.30 *	-0.26	-0.31 *	-0.05	-0.35 *	-0.25	-0.32 *	0.02	0.00
Platanaceae	-0.14	-0.20	-0.16	-0.08	-0.13	-0.19	-0.25	-0.10	-0.09	-0.17
Salicaceae	0.05	0.13	0.08	0.26	0.04	-0.02	-0.07	-0.24	-0.36 *	0.12
Ulmaceae	-0.10	-0.11	0.13	-0.01	-0.17	-0.22	-0.42 **	-0.02	-0.11	-0.10
Urticaceae	-0.13	-0.18	-0.33 *	-0.44 **	-0.43 **	-0.12	-0.33 *	-0.27	-0.30 *	-0.22

Table 1-S (d). Same as Table 1-S (a), for peak date.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	0.11	0.23	-0.18	0.24	-0.31 *	0.55 **	0.35 *			-0.18
Betulaceae	0.03	0.08	-0.46 **	0.11	-0.26	0.08	-0.33 *	-0.37 **	-0.32 *	-0.08
Cheno-Amaranthaceae	-0.16	0.16	-0.60 **	-0.41 **	-0.45 **	-0.31 *	-0.23	-0.32 *	-0.34 *	-0.26
Compositae	-0.09	0.20	-0.40 **	-0.38 **	-0.35 *	-0.31 *	-0.21	-0.15	-0.14	-0.05
Corylaceae	-0.07	0.25	-0.05	-0.02	-0.09	0.05	-0.16	0.22	0.36 *	0.21
Cupressaceae-Taxaceae	0.07	-0.18	0.30 *	0.14	-0.06	-0.33 *	-0.11	0.50 **	0.30 *	0.30 *
Fagaceae	-0.19	0.37 **	0.15	0.01	-0.25	-0.14	-0.03	-0.01	0.19	0.18
Graminaceae	-0.33 *	-0.08	-0.29 *	-0.36 **	-0.43 **	0.07	-0.30 *	-0.28 *	-0.18	0.09
Oleaceae	-0.02	0.34 *	0.29 *	0.19	0.11	0.05	0.24	0.11	0.30 *	0.36 *
Pinaceae	-0.25	0.20	-0.37 **	0.02	-0.25	-0.04	0.08	-0.11	0.14	0.22
Plantaginaceae	-0.36 *	0.41 **	-0.14	0.00	-0.22	0.54 **	-0.17	0.36 **	0.43 **	-0.12
Platanaceae	0.50 **	0.42 **	0.10	0.24	-0.01	0.28	0.08	0.29 *	0.03	0.39 **
Salicaceae	-0.24	0.09	-0.37 **	-0.25	-0.18	0.38 **	-0.10	0.42 **	0.21	0.06
Ulmaceae	0.04	0.32 *	-0.07	0.20	0.12	0.33 *	0.36 *	0.04	0.01	0.31 *
Urticaceae	-0.32 *	-0.03	-0.59 **	-0.04	-0.50 **	-0.39 **	-0.20	-0.22	-0.14	-0.13

Table 1-S (e). Same as Table 1-S (a), for peak value.

	PC1	PR2	RE1	MO1	BO1	FE1	RA3	FO1	FO2	RN1
Aceraceae	0.19	0.15	-0.19	0.11	-0.43 **	0.53 **	0.30 *			-0.24
Betulaceae	-0.04	-0.02	-0.46 **	-0.17	-0.40 **	-0.10	-0.31 *	-0.44 **	-0.41 **	-0.13
Cheno-Amaranthaceae	-0.26	0.17	-0.53 **	-0.60 **	-0.58 **	-0.68 **	-0.52 **	-0.43 **	-0.51 **	-0.37 **
Compositae	-0.02	0.20	-0.59 **	-0.50 **	-0.54 **	-0.49 **	-0.51 **	-0.32 *	-0.38 **	-0.24
Corylaceae	-0.09	0.32 *	-0.07	0.06	-0.13	0.01	-0.21	0.22	0.27	0.10
Cupressaceae-Taxaceae	0.10	0.05	0.32 *	0.38 **	-0.07	-0.27	-0.05	0.41 **	0.29 *	0.30 *
Fagaceae	-0.25	0.32 *	-0.10	-0.23	-0.34 *	-0.21	-0.09	-0.04	0.16	0.23
Graminaceae	-0.41 **	0.07	-0.35 *	-0.40 **	-0.56 **	0.07	-0.42 **	-0.39 **	-0.36 *	0.03
Oleaceae	-0.01	0.45 **	0.23	0.05	0.11	0.17	0.05	0.06	0.21	0.23
Pinaceae	-0.20	0.24	-0.38 **	0.13	-0.41 **	-0.10	-0.02	-0.07	0.08	0.23
Plantaginaceae	-0.33 *	0.34 *	-0.27	-0.30 *	-0.19	0.38 **	-0.34 *	0.24	0.41 **	-0.21
Platanaceae	0.45 **	0.50 **	0.01	0.25	-0.04	0.22	0.09	0.22	0.00	0.27
Salicaceae	-0.08	0.29 *	-0.36 *	-0.01	0.05	0.48 **	-0.08	0.29 *	0.37 **	0.10
Ulmaceae	0.17	0.40 **	-0.05	0.21	0.05	0.43 **	0.39 **	0.01	-0.02	0.30 *
Urticaceae	-0.59 **	0.05	-0.59 **	-0.26	-0.55 **	-0.56 **	-0.42 **	-0.48 **	-0.31 *	-0.42 **

Table 1-S (f). Same as Table 1-S (a), for pollen index.