



Temporal trends in airborne pollen seasonality: evidence from the Italian POLLnet network data

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Received: 14 December 2018 / Accepted: 10 August 2019
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Abstract Airborne pollen reflects local vegetative composition and is a proxy for flowering phase. Long-term pollen data might reflect changes in biodiversity and phenology, attributable also to the effect of climate change. The present study, based on pollen data collected within the Italian aerobiological network *POLLnet*, aimed to verify whether there is any evidence of temporal changes in pollen season timing and its relation with meteorological variables. To this purpose, nine stations located in North and Central

Italy were selected, and twelve pollen taxa, both arboreal and herbaceous, were considered. For each taxon and station, 11–17-year datasets of airborne pollen concentration within the period 2000–2016 were analysed. Four different pollen season descriptors were elaborated (start, end and peak date, season length) and analysed their temporal trend, also in relation to temperature and precipitation. Overall, the results showed a negative temporal trend in pollen season starting date, which indicates a tendency

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towards an earlier flowering for *Corylus*, *Quercus*, Gramineae and Urticaceae in all stations (even if statistically significant in six out of 36 cases). The effect of meteorological parameters was evidenced by negative correlations between pollen season starting date and temperature. With the exception of *Olea*, *Ambrosia* and *Artemisia*, all the remaining pollen taxa showed significant (negative) correlations between pollen season start date and average temperature of the previous months in at least half of the stations. As for precipitation, no relevant correlations were detected with pollen season parameters. The results are also interpreted considering the different biogeographic areas in which the nine stations are located. Long-term pollen dataset is useful in phenological studies and for the detection of climate change effects.

Keywords POLLnet · Pollen season trend · Pollen season start · Climate change

1 Introduction

Human activities leading to an increase in atmospheric greenhouse gases are influencing the global climate. Climate change is a fact (IPCC 2014) and is receiving much attention due to its worldwide social and economic implications. The distribution of species, their life cycles and associations are altered by rising temperatures, with adverse effects on agricultural productions as well as on human health.

Flowering time is a frequently observed phenological phase in researches on climate change. Pollen data from aerobiological monitoring networks permit the investigation of the flowering phase of anemophilous plants and document changes regarding the presence of allergenic pollen in the air. Allergic diseases like allergic rhinitis and asthma are nowadays a notable public health problem (WAO 2013). Besides air pollution and changes in recent lifestyles, global warming is suspected to play a role in increasing the prevalence of these diseases (D'Amato et al. 2018), given its impact on amount (Ziello et al. 2012), season duration (Ziska 2016) and allergenicity of pollen (Frank and Ernst 2015). Long-term airborne pollen monitoring produces highly informative data, enabling the detection of temporal changes.

The flowering phase is sensitive to meteorological factors, and therefore, airborne pollen may be used as an indicator of the reaction of plants to climate change (Clot 2003; Galan et al. 2016; Zhang et al. 2015). Some studies have focused on the increase in pollen amount associated with rising CO₂ (Rogers et al. 2006) and temperature (Ziska 2016; Wan et al. 2002). Although regional differences exist, long-term trends in pollen data seem to confirm the phenological observations: generally, early flowering species show a tendency to start blooming earlier (Lind et al. 2016; Clot 2003; Ziska 2016), while late flowering species tend to extend their pollen season (Ziska 2016).

However, other studies reported no clear systematic pattern on pollen season dates (i.e. Damialis et al. 2007; Ugolotti et al. 2015) or different responses depending on regional characteristics (Recio et al. 2009).

The present study aims to verify whether there are temporal trends in the flowering periods in Italy by examining the main parameters that describe the pollen season (start, end and peak dates, season length). To explore how pollen seasons could be influenced by climate, correlations between pollen starting date and meteorological factors are also investigated. The results are also interpreted referring to the different biogeographic areas in which the aerobiological stations are located.

2 Materials and methods

Eight aerobiological monitoring stations belonging to POLLnet, the Italian aerobiological monitoring network (<http://www.pollnet.it>), and one from R.I.M.A.[®], the network of the Italian Aerobiology Association, were considered for this study. The stations are located in northern and central Italy, in three different biogeographic regions (EEA 2016a) (Table 1).

Aerobiological monitoring followed a common procedure (Bucher et al. 2017). Pollen data concentrations, expressed as daily number of pollen grains per cubic meter of air ($P \cdot m^{-3}$), were collected between 2000 and 2016 (min 11–max 17 years) (Table 1). Pollen taxa considered for this study were selected considering (1) their known allergenicity, (2) the coverage of both arboreal and herbaceous species and (3) different pollen seasons. Overall, twelve

Table 1 Geographical coordinates and altitude for each aerobiological and meteorological station. For each aerobiological station, the period with available data is reported and its

biogeographic regions according to EEA (2016a, b). The map represents each station's location; blue symbol for POLLnet stations, green symbol for R.I.M.A.[®] station

Aerobiological station							Meteorological station			
	name	lat	long	elevation m a.s.l.	time series of data	Biogeographical regions (*)	lat	long	elevation m a.s.l.	
1	Aosta - St. Cristophe	45.7426	7.3569	560	2000-2016	Alpine	45.7393	7.3634	545	
2	Bolzano	46.4993	11.3421	275	2000-2016	Alpine	46.4968	11.3126	254	
3	S. Michele a/A	46.1899	11.1346	228	2000-2016	Alpine	46.1818	11.1191	203	
4	Pordenone	45.9536	12.6814	24	2005-2016	Continental	45.954	12.682	24	
5	Trieste	45.6469	13.7731	55	2006-2016	Continental	45.651	13.753	55	
6	Parma	44.7833	10.3166	50	2000-2016	Continental	44.808	10.3304	79	
7	Bologna	44.5012	11.3282	80	2000-2016	Continental	44.5007	11.3287	78	
8	Rimini	44.0333	12.6167	7	2000-2016	Continental	44.0591	12.5735	16	
9	Roma	41.8542	12.6040	64	2000-2016	Mediterranean	41.8512	12.6309	80	

(*) Biogeographical regions in Europe - European Environmental Agency (EEA, 2016)

pollen taxa were considered: eight arboreal and four herbaceous.

For each taxon, the following indicators were calculated: the start and end date of pollen season (StartDate, EndDate), which represent the day of year (DOY) when the sum of daily pollen concentrations reaches, respectively, the 2.5% and 97.5% of the annual concentration; the pollen season length (SeasonLength), that is the number of days between the pollen season start and end; and the pollen season peak (PeakDate), which represents the DOY when the maximum daily concentration is recorded.

The adopted QA procedure complies with the minimum requirements described by the European Aerobiology Society's (ESA) Working Group on Quality Control (Galan et al. 2014). The mean completeness of the dataset is 96.9%; years with less than 75% of the data available for the main pollen season were not considered for the analysis.

Trend analyses of the pollen indicators were performed using the nonparametric Mann–Kendall test for the detection of monotonic increasing or decreasing trends in annual time series; Kendall τ coefficients were evaluated together with statistical significance (p level < 0.05).

Relationships between meteorological variables (daily mean temperature; total precipitation) and the starting date of the pollen season for the different taxa were investigated using the nonparametric Spearman

correlation test. Data were collected from the meteorological station closest to each aerobiological site (Table 1). Since the effect of meteorological conditions on plants is not strictly limited to the period in which the main pollen season actually occurs, but is often delayed in time (Stach et al. 2008; Fuhrmann et al. 2016), monthly values of the meteorological variables were considered starting from October of the previous year up to the month when pollen emission starts.

All statistical analyses were carried out using R (R Core Team 2018) and Statistica 13.1.

3 Results

Stations were aggregated by cluster analysis considering the mean pollen season start date of the taxa common to all sites (Fig. 1). The different timing of pollen appearance reflects the bioclimatic location of the stations (EEA 2016a). At a linkage distance of less than 3, it is possible to identify two main groups: the first one is represented by Bolzano and San Michele a/A, located in the Alpine area and the second group consists in the more continental stations of Parma, Pordenone, Rimini, Bologna and Trieste. In the two extreme positions of the cluster, there are Aosta that also lies in the Alpine area (separated in the cluster probably because of its higher altitude) and Rome, the

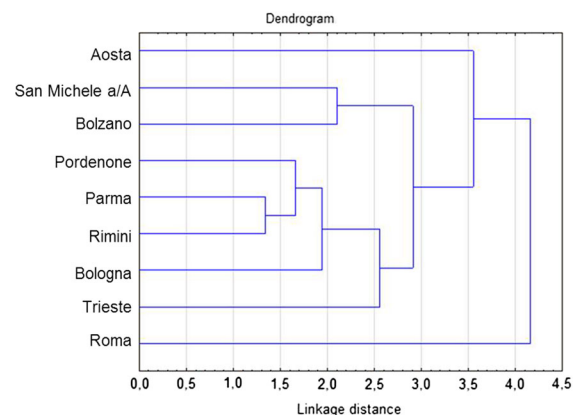


Fig. 1 The dendrogram summarizes the tree cluster solution starting from the mean StartDate DOY of the common taxa. The horizontal axis shows the linkage distance (low value height similarity)

only station of this study located in the Mediterranean area.

All the results related to the temporal trend analysis (τ values—Mann–Kendall test) carried out on the parameters describing the pollen season (StartDate, EndDate, PeakDate, SeasonLength), for all taxa ($n = 12$) and stations ($n = 9$), are reported in Fig. 2. Positive values indicate an increasing trend, and vice versa. Overall, 27 cases resulted significantly negative and 9 positive, indicating a more evident trend of anticipated pollen season.

As for arboreal taxa flowering in late winter—early spring (Fig. 2, first row), *Corylus* showed a trend of early start of the pollen season in all stations, significant only for Bologna. Also for Cupressaceae/Taxaceae, pollen season start showed a negative (but not significant) trend in 7 out of 9 stations. *Betula* pollen season tended to end earlier in all eight stations (significantly for three); consequently, pollen season length resulted shorter for most of stations, significantly for three.

Among late flowering arboreal taxa (Fig. 2, second row), only *Quercus* showed an early pollen season start trend in all stations, significant only for Rimini; in addition, this species tended to have an earlier peak date, significant in 4 out of 9 stations.

Within the herbaceous taxa (Fig. 2, third row), there was a general trend of early pollen season start in all stations for Gramineae (significant for Pordenone) and Urticaceae (significant for Pordenone, Parma and Bologna); concurrently, Gramineae showed an earlier

Fig. 2 Eight arboreal and four herbaceous taxa are considered. Each graph shows the τ coefficient values that derive from the Mann–Kendall nonparametric trends analysis related to the StartDate (blue circle), EndDate (gray circle), PeakDate (orange square) and the SeasonLength (green triangle) for each taxon and for each station considered. N = number of years considered. Positive values indicate an increasing trend, and vice versa; statistically significant trends are highlighted with a larger symbol

peak date in almost all stations (8 out of 9). On the contrary, *Artemisia* showed a general positive trend for the pollen season StartDate, significant for Bolzano, where—as in San Michele a/A—also the peak date tended to occur later.

Overall, a clear pattern in pollen season parameters' trends in relation to the biogeographic areas was not detected except for *Betula* that showed a shorter pollen season in the Alpine area and Urticaceae which showed a trend of anticipated pollen season start in the continental area.

On the contrary, a greater coherence in pollen season parameters' trends was evident within the same pollen taxa, independent of biogeographic area: *Corylus*, *Quercus*, Gramineae and Urticaceae displayed a negative trend for the pollen season start in all stations.

Figure 3 reports the significant correlations between pollen season StartDate for each taxon and station, and monthly mean temperature and total precipitation, from October of the year before up to the month when flowering starts.

Overall, the most significant correlations were with temperature, mainly negative (142 out of 148). Significant correlations with precipitation were less frequent, both positive (25) and negative (24).

The most noticeable results of the correlation matrix were: (I) the high frequency of negative correlations between start date of *Corylus*, *Alnus* and Cupressaceae/Taxaceae and the mean temperature in January and February; (II) the high frequency of negative correlations between start date of *Betula*, *Fraxinus* and *Quercus* and the mean temperature in February and March; (III) mean temperature in May were correlated with StartDate of *Castanea* in 7 out of 9 stations; (IV) among herbaceous taxa, StartDate of *Ambrosia* and *Artemisia* was scarcely correlated with the meteorological variables considered; instead, mean monthly temperature between February and April showed negative correlations in all stations for



Arboreal taxa

Herbaceous taxa

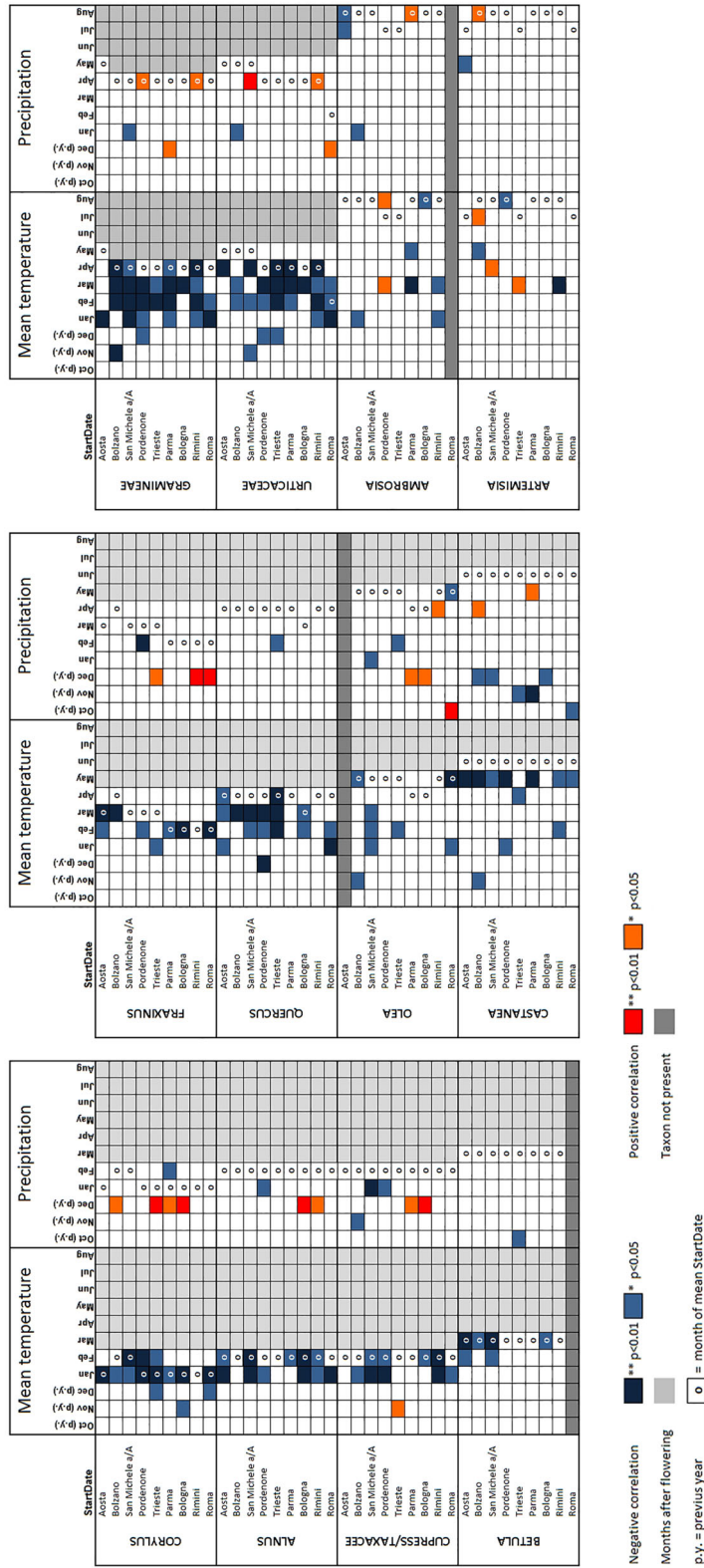


Fig. 3 Correlation matrix between StartDate for each station mean monthly temperatures (Tmean) and precipitation (rain) separated by taxon. Only significant correlations are reported: negative correlations in blue (dark blue = $p < 0.01$; light blue = $p < 0.05$); positive correlations in red (dark red = $p < 0.01$; light red = $p < 0.05$). The correlations were calculated from October of the previous year (previous year = p.y.) until the months after flowering (grey = not considered for the analysis; white = absence of significant correlations). The circle indicates the month of mean StartDate for each taxon and station

Gramineae and Urticaceae; (V) total precipitations in December showed the largest number of positive correlations (15 out of 18), mostly with StartDate of arboreal taxa.

As for the relation between start date and meteorological variables, a clear biogeographic pattern did not seem to exist, except for few cases: (1) for *Betula*, correlations with February–March mean temperature mostly occurred in Alpine stations; (2) precipitation in December showed positive correlations mostly in stations located in the continental and Mediterranean (Rome) stations; (3) the Rome station is the only one that displayed a positive correlation between October precipitation and StartDate of *Olea*.

4 Discussion and conclusions

Nowadays, the effects of climate change on ecosystems are largely evident and documented (EEA 2016b). Among these effects, phenological events occurring in spring, for both animals and plants, tend to anticipate by 2.3 days every decade (Parmesan and Yohe 2003). Such phenomena have been observed also on the flowering phase (Walther 2010). As for the airborne pollen season (proxy of flowering phase), the starting date tends to occur earlier (Lind et al. 2016; Clot 2003; Ziska 2016) and last longer (Ziska et al. 2019).

This study confirmed a trend of earlier pollen season start date for *Corylus*, *Quercus*, Gramineae and Urticaceae (4 taxa out of 12) in all the 9 aerobiological stations, even if it was statistically significant only for 6 cases out of 36.

The influence of temperature on pollen season was confirmed by the numerous negative correlations between the starting date of pollen season and mean temperatures occurring in the previous months. The role of temperature as the main climate driver on the timing of pollen season has been already underlined by other studies (Garcia-Mozo et al. 2010; Majeed et al. 2018).

On the contrary, precipitation was rarely correlated with pollen season start in all stations considered (included the Mediterranean Rome). Galan et al. (2016), however, report that rains play a greater role in Mediterranean areas, together with water availability.

The beginning of pollination for the herbaceous taxa *Ambrosia* and *Artemisia* seems scarcely

influenced by meteorological factors. In fact, the flowering of these species is influenced also by the photoperiod (Richardson et al. 2017).

Flowering phenology (i.e. StartDate) allowed to group the stations in different biogeographic areas; nevertheless, such clusters were not confirmed when temporal trends of pollen season descriptors were considered. This suggested that plant responses to environmental (climate) factors may be more species- than site-specific.

Time series of data available for this study were not so long (max 17 years) to allow a robust temporal trend analysis. Furthermore, number and location of stations do not completely represent the large biogeographic variability of Italy. Nevertheless, the results obtained from the analysis of 12 pollen taxa of 9 stations represent a novelty for Italy and permit to draw a first broad picture on pollen season trends at national scale.

Considering the important implications that changes in pollen season patterns may have on human health, it is necessary to continue these investigations, hopefully increasing temporal and spatial coverage. This would contribute to better understand the effects of climate change on the flowering phase, or if uneven trends may be explained by the resilience of plants that would counteract and mitigate the effects of environmental changes.

Acknowledgements The authors thank all the data contributors, in particular Maria Cristina Viola, Antonella Cristofori, Fabio Zottele, Giambattista Toller, Christian Vian, Veronika Kofler, Giancarlo Pinto, Federica Fontana.

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