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ORIGINAL PAPER

Characteristics and trends of selected pollen seasons recorded in Parma (Northern Italy) from 1994 to 2011

Manuela Ugolotti · Cesira Pasquarella · Pietro Vitali · Matt Smith · Roberto Albertini

Abstract This study examines variations in the start date, end date, duration, date of peak, peak value and Seasonal Pollen Index (SPI) of airborne pollen seasons recorded in Parma, Northern Italy, in relation to meteorological data (1994–2011). Pollen data were collected in the city of Parma by volumetric spore trap. The following taxa were analysed: *Alnus, Ambrosia, Artemisia, Betula*, Amaranthaceae, *Corylus,* Cupressaceae, *Plantago, Platanus,* Poaceae and Urticaceae. Spearman's rank correlation tests were used to establish whether significant relationships existed between the different characteristics of the pollen seasons. Simple linear regression analysis was also carried out in order to investigate trends over time. Only 12 % of the 66 characteristics examined showed significant changes over the study period. Temperatures increased significantly during the spring, but this did not appear to have a corresponding impact on seasonal characteristics related to the timing of pollen seasons (i.e. start date, peak date and end date). All of the observed changes were associated with characteristics that can be related to exposure (i.e. duration, peak value and SPI). For arboreal taxa, the SPI of *Betula* decreased significantly, and *Platanus* pollen seasons became significantly shorter. For herbaceous species, the SPI and peak values of *Artemisia* became significantly lower, whereas the SPI and peak values of *Ambrosia* became significantly higher. The SPI of Poaceae and Urticaceae also decreased significantly. The results of correlation analysis showed that various characteristics of pollen seasons are significantly related. This study provides an essential baseline for determining exposure of the allergic population to allergenic pollen and aids understanding of the incidence of pollinosis in Parma. Gaps still exist in current knowledge; not least, the need to quantify the degree of influence exerted by some of the principal factors driving environmental change, climate and land use.

Keywords Aerobiology · Allergenic pollen · Climate change · Plant phenology · Trends

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1 Introduction

Pollen grains, due to their allergens, play an important role in the etiopathogenesis of respiratory allergies, which are increasing in prevalence and severity (D'Amato et al. 1998, 2007; Bousquet et al. 2011). Several factors are involved in this increase (Rosenzweig et al. 2007, 2008). These include climate change that may alter the timing (Emberlin 1994; Huynen et al. 2003; Beggs 2004; Beggs and Bambrick 2005) and intensity (Ariano et al. 2010; Myszkowska et al. 2011; Ziello et al. 2012) of pollen seasons or increase pollen allergenicity (Pasqualini et al. 2011), which could modify the incidence of clinical symptoms in patients affected by pollinosis (D'Amato et al. 2013).

Pollen count data are considered to be a proxy for aeroallergen exposure (Buters et al. 2012), although the presence of allergens does not always correlate with the presence of pollen (Schappi et al. 1997; Buters et al. 2012; Galán et al. 2013). A number of studies have examined the effects of climate change on characteristics of pollen seasons (e.g. Ziska et al. (2011); Grewling et al. (2012), and Bogawski et al. (2014)) as well as the subsequent impact on pollinosis (e.g. Ridolo et al. (2007) and Negrini et al. (2011)).

Short time series of pollen data have been studied (e.g. Ceter et al. (2012)), but longer data sets allow the variability in seasonal characteristics to be investigated and provide an opportunity for examining trends over time. In Italy, Ariano et al. (2010) analysed long-term variations in airborne pollen seasons. Other studies focused on a limited number of pollen families (Voltolini et al. 2000; Frenguelli et al. 2002), whilst studies examining pollen data in the Po Valley geo-climatic area in Northern Italy have been over limited time periods (Ciancianaini et al. 2000; Albertini et al. 2001; Ridolo et al. 2007). This study examines temporal variations in various characteristics of airborne pollen seasons recorded over an 18-year period (1994–2011) in Parma, Northern Italy, in relation to meteorological data.

2 Materials and methods

2.1 Location of the study

The study was performed in the city of Parma (Fig. 1), which has 180,000 inhabitants and lies in the Po Valley, close to the southern bank of the Po River,
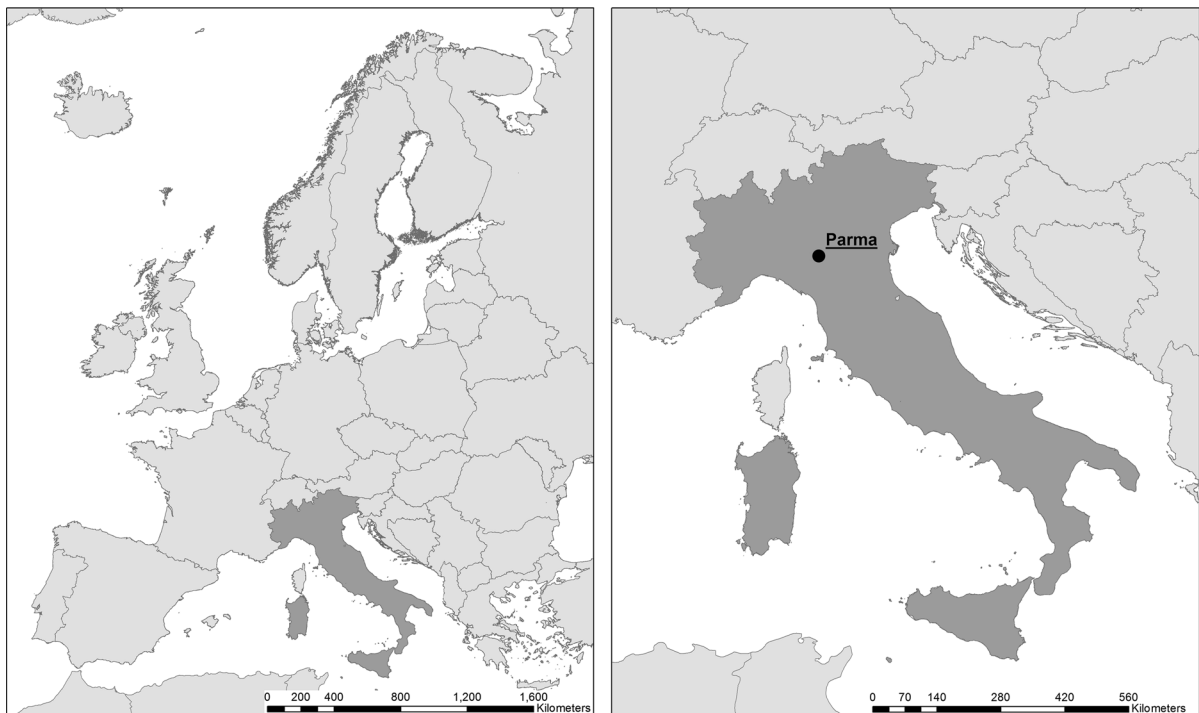
Fig. 1 Location of the pollen-monitoring site used in this study

100 km from the Tyrrhenian coast and 200 km from the Adriatic coast, 52 m above sea level.

2.2 Aerobiological data

In this study, we have used pollen data collected over an 18-year period. Airborne pollen was monitored from 1994 to 2011 by the survey centre PR1 of the Italian Monitoring Network in Aerobiology (R.I.M.A.®) in accordance with standard methods of the Italian Aerobiology Association (AIA) (Travaglini et al. 2009). Airborne pollen was collected using a Hirst type 7-day recording volumetric spore trap (Hirst 1952), which is the standard equipment used for aerobiological sampling worldwide. The device was placed at 18.2 m above ground level on the meteorological tower of Parma University in the town centre near the Ducal Park, latitude 44°48′N, longitude 10°16′E. We have considered pollen data from 11 taxa that are most frequently recorded in the air of Parma and include pollen from local and distant sources. The arboreal pollen types considered were *Alnus* spp., *Betula* spp., *Corylus* spp., the Cupressaceae–Taxaceae families (hereinafter Cupressaceae) and *Platanus* sp.. The pollen types from herbaceous plants considered were *Ambrosia* spp., *Artemisia* spp., the Amaranthaceae family, *Plantago* spp., the Poaceae family and the Urticaceae family (APGIII 2009). The following characteristics of the season were examined, according to Jäger et al. (1996): start date, end date, duration, date of peak, peak value and Seasonal Pollen Index (SPI).

The concept of the pollen season is well established in aerobiology. It represents the portion of the year in which the pollen can be captured in the atmosphere. For our purposes, it is preferable to use a definition that identifies the beginning and the end of the pollen season as the days of the calendar year in which a certain percentage of the total pollen load is reached. This approach reduces the impact of pollen recorded before or after the main pollen season that may be linked to advection from different areas and does not necessarily represent the presence of pollen caused by local flora, and also removes long "tails" to the season that might influence statistical analysis (Sánchez-Mesa et al. 2003). In this study, the onset of the pollen season was defined as the first day when the cumulative pollen count exceeding 1 % of the annual total, providing this was not followed by more than six consecutive days with zero values. The end of the season was defined as the day upon which 95 % of the annual total was reached (Galán et al. 2001). The duration of the season is the difference in days between the start date and the end date of the season.

Temporal variations in pollen seasons (i.e. start date, end date and date of peak) are displayed as the number of days from January 1 (DOY). Daily average pollen concentrations are expressed as the number of grains/m^3, and the SPI is expressed as grains (Comtois 1998).
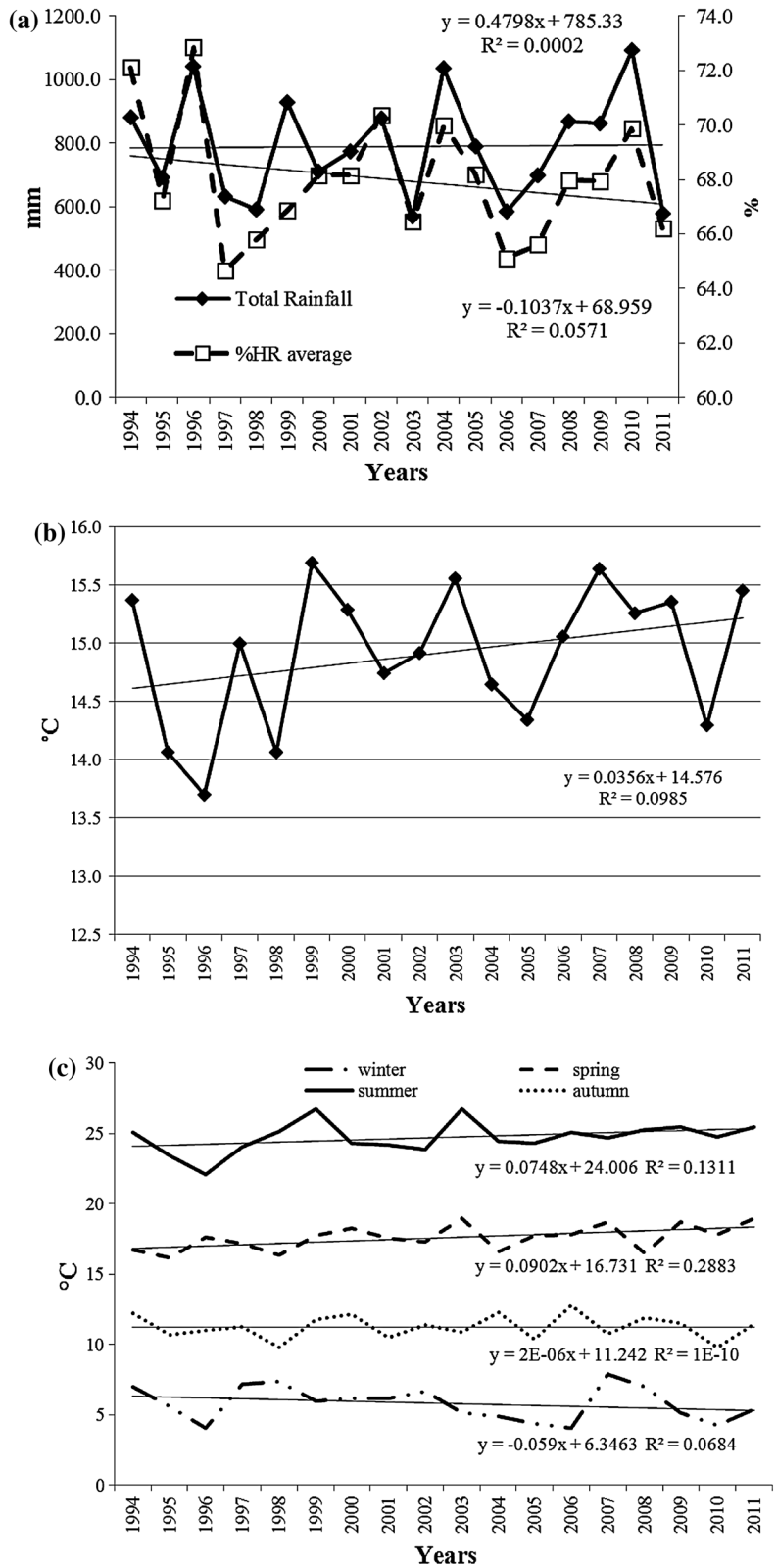
2.3 Meteorological data

Daily averages of temperature (°C), relative humidity (%) and total rainfall (mm) transformed into annual or seasonal averages were taken into consideration. The meteorological data were obtained from the Meteorological Station (Physics Department) at the University of Parma located at the same site that the pollen data were recorded. Means of annual meteorological data recorded during the study period were as follows (minimum and maximum values shown in parenthesis): relative humidity 68.0 % (63.9–72.8 %), rainfall 792.5 mm (569–1,091.1 mm) and temperature 14.9 °C (13.8–15.7 °C) (Fig. 2a, b).

2.4 Statistical analysis

The Kolmogorov–Smirnov and Shapiro–Wilk tests were used to assess the type of distribution of pollen parameters. The tests showed that the pollen data were not normally distributed and so Spearman's "ρ" correlation tests were used to establish whether any significant relationships existed between the different characteristics of the pollen seasons examined (Zar 1999): (a) start date/end date; (b) start date/duration; (c) start date/peak value; (d) start date/SPI; (e) start date/date of peak; (f) end date/duration; (g) end date/peak value; (h) end date/SPI; (i) end date/date of peak; (j) duration/SPI; (k) duration/peak value; (l) duration/date of peak; (m) SPI/date of peak; (n) SPI/peak value; and (o) peak value/date of peak.

Following the methodology used in a number of prominent studies that have looked at long-term trends in pollen seasons and phenology (e.g. Thackeray et al. (2010); Ziello et al. (2012); Smith et al. (2014)), simple linear regression analysis was carried out in order to investigate trends in certain characteristics of

Fig. 2 Variations and trends of selected meteorological data recorded in Parma during the study period: **a** annual total rainfall (mm) and average of relative humidity (%), **b** annual average temperatures, **c** seasonal average temperatures

selected pollen seasons and meteorological data over time. Although it could be argued that the use of non-parametric statistics would be more appropriate (Fernández-Llamazares et al. 2014). The following statistics are presented: the mean, standard deviation (SD), R^2 value, slope of the regression over time, standard error of the regression slope (SE), probability level (p) and number of years in the analysis (N). Results were considered to be significant when $p < 0.05$. The tests were performed using Microsoft Excel and IBM SPSS 19 software.

3 Results and discussion

3.1 General characteristics of the pollen seasons

Artificial indicators were used to highlight the salient features of the pollen season, such as start and end dates. The analysis of data from 18-years of observations shows that, on average, the earliest pollen grains to appear in the air of Parma were those of arboreal taxa *Corylus* (DOY 33), *Alnus* (DOY 39), Cupressaceae (DOY 39) and *Betula* (DOY 72). The pollen grains that appeared later were those of herbaceous *Plantago* (DOY145), Amaranthaceae (DOY 166), *Artemisia* (DOY 210) and *Ambrosia* (DOY 213). Similarly, the pollen seasons that ended the earliest were those of *Corylus* (DOY 80), *Alnus* (DOY 107), *Platanus* (DOY 119) and *Betula* (DOY 122). The pollen seasons that ended the latest were those of Urticaceae (DOY 242), *Artemisia* (DOY 264), Amaranthaceae (DOY 264) and *Ambrosia* (DOY 266). The first and last days of peak concentrations for individual taxa were for *Corylus* (DOY 49) and *Ambrosia* (DOY 241), respectively (Table 1).

On average, the shortest pollen seasons were those of *Platanus*, *Corylus* and *Betula*, with average durations of 26, 47 and 50 days, respectively. The longest pollen seasons were those of Amaranthaceae (98 days), Cupressaceae (111 days) and Urticaceae (131 days). The pollen types with the lowest average peak value were *Plantago* (31 grains/m^3), Amaranthaceae (34 grains/m^3), *Artemisia* (36 grains/m^3) and *Ambrosia* (44 grains/m^3). The pollen types with the highest average peak value were Cupressaceae (368 grains/m^3), Poaceae (716 grains/m^3), *Platanus* (854 grains/m^3) and Urticaceae (2,377 grains/m^3). The taxa with the lowest (286 grains) and highest

(19,068 grains) average SPIs were *Ambrosia* and Urticaceae, respectively (Table 2). It should be noted that due to the retrospective method used for defining season start and end dates, low amounts of pollen can extend the season at sites with low annual sums. This is unlikely to be the case of Urticaceae, however, which had the longest pollen season and the highest SPI of those examined (note that, on average, Cupressaceae had the second longest season and the fourth highest SPI).

Our data showed that the average duration of the pollination period was 60.4 days for arboreal taxa and 86.5 days for herbaceous plants. One reason for this is that tree pollen seasons are often caused by one or two dominant species that flower simultaneously, whereas the pollen seasons of herbaceous plants are often longer because they represent multiple species that flower at different times. During the period studied, the lowest and highest amounts of variability (minimum and maximum values shown in parenthesis) were for: (1) start date–*Alnus* (DOY 19–62) and Amaranthaceae (DOY 102–253); (2) end date–Amaranthaceae (DOY 253–273) and Cupressaceae (DOY 97–306); (3) duration–*Corylus* (18–68 days) and Cupressaceae (45–277 days); (4) peak date–*Platanus* (DOY 79–150) and Urticaceae (DOY 101–259); (5) SPI–*Ambrosia* (6–793 grains) and Urticaceae (4,315–35,045 grains); and (6) peak value–Amaranthaceae (12–93 grains/m^3) and Urticaceae (206–5,885 grains/m^3).

3.2 Trends and correlations between pollen season parameters

Temporal variations in the characteristics of airborne pollen seasons recorded in Parma (1994–2011) were investigated. This study is novel, it is not only the first time that trends in airborne pollen have been examined in Parma for almost a decade (Ridolo et al. 2007), but selected meteorological data recorded over the same time period were also examined in order to put this analysis into context (Fig. 2). There was a general decrease in annual values of total rainfall and average relative humidity (Fig. 2a), and a concurrent increase in annual temperatures (Fig. 2b). However, the only significant trend was towards warmer spring temperatures ($p = 0.02$) (min 16.2 °C–max 19.0 °C) (Fig. 2c). With this in mind, it is interesting to note that only 12 % ($N = 8$) of the 66 trends examined were significant. There were no significant trends in

Table 1 Seasonal characteristics (i.e. start date, peak date and end date) and trends of selected pollen taxa recorded in Parma, Northern Italy, from 1994 to 2011

Pollen types	Start date (DOY)							Peak date (DOY)							End date (DOY)						
	Mean	SD	R^2	Slope	SE	p	N	Mean	SD	R^2	Slope	SE	p	N	Mean	SD	R^2	Slope	SE	p	N
Alnus	39	11.55	0.00	0.05	0.54	0.93	18	54	10.14	0.04	0.39	0.46	0.41	18	107	41.83	0.09	2.38	1.87	0.22	18
Ambrosia	213	22.29	0.02	−0.57	1.24	0.65	16	241	8.73	0.02	0.23	0.49	0.64	16	266	15.70	0.06	−0.79	0.86	0.37	16
Artemisia	210	21.81	0.18	1.74	0.08	0.92	18	233	13.98	0.07	0.69	0.63	0.29	18	264	18.50	0.17	1.44	0.79	0.09	18
Betula	72	20.29	0.22	1.79	0.84	0.05	18	100	11.65	0.02	0.33	0.54	0.55	18	122	7.46	0.01	0.14	0.35	0.70	18
Chenopodiaceae	166	31.53	0.04	1.19	1.45	0.42	18	238	21.70	0.12	1.40	0.95	0.16	18	264	5.48	0.16	0.41	0.24	0.10	18
Corylus	33	12.19	0.05	−0.59	0.74	0.44	15	49	16.63	0.02	−0.51	1.02	0.63	15	80	14.15	0.06	0.77	0.85	0.38	15
Cupressaceae	39	14.81	0.03	−0.50	0.68	0.47	18	70	12.28	0.00	−0.06	0.58	0.92	18	162	51.17	0.04	1.93	2.35	0.42	18
Plantago	145	20.25	0.13	1.38	0.88	0.14	18	188	29.05	0.01	−0.50	1.35	0.72	18	238	12.77	0.03	−0.44	0.59	0.46	18
Platanus	91	19.59	0.03	0.63	0.90	0.49	18	103	13.81	0.11	0.86	0.61	0.18	18	119	24.83	0.05	−1.08	1.13	0.35	18
Poaceae	113	10.64	0.01	0.17	0.50	0.73	18	125	7.44	0.00	−0.03	0.35	0.93	18	203	18.04	0.13	1.22	0.79	0.14	18
Urticaceae	111	10.51	0.04	0.37	0.48	0.45	18	123	34.43	0.03	1.16	1.59	0.48	18	242	17.91	0.07	−0.88	0.81	0.29	18

The following statistics are included: the mean, standard deviation (SD), R^2 value, slope of the regression over time, standard error of the regression slope (SE), probability level (p) and number of years in the analysis (N)

Slope considered to be significant when $p < 0.05$

Table 2 Seasonal characteristics (i.e. duration, peak value and SPI) and trends of selected pollen taxa recorded in Parma , Northern Italy, from 1994 to 2011

Pollen types	Duration (DOY)							Peak value (grains/m³)							SPI (grains)						
	Mean	SD	R^2	Slope	SE	p	N	Mean	SD	R^2	Slope	SE	p	N	Mean	SD	R^2	Slope	SE	p	N
Alnus	68	45.26	0.08	2.34	2.04	0.27	18	116	70.37	0.05	−2.92	3.21	0.38	18	724	490.49	0.12	−31.27	21.60	0.17	18
Ambrosia	53	20.75	0.00	−0.21	1.16	0.86	16	44	33.95	0.47	4.91	1.38	**0.00**	16	286	239.18	0.62	39.56	8.28	**0.00**	16
Artemisia	54	19.96	0.01	−0.44	0.93	0.64	18	36	28.29	0.30	−2.92	1.11	*0.02*	18	361	305.72	0.38	−35.29	11.27	**0.01**	18
Betula	50	20.61	0.18	−1.65	0.87	0.08	18	106	83.41	0.19	−6.79	3.52	0.07	18	884	693.45	0.28	−68.68	27.56	*0.02*	18
Chenopodiaceae	98	29.15	0.02	−0.79	1.35	0.57	18	34	23.11	0.00	−0.17	1.08	0.88	18	457	252.57	0.05	−10.73	11.52	0.37	18
Corylus	47	16.72	0.13	1.36	0.97	0.18	15	93	53.32	0.10	−3.79	3.14	0.25	15	647	321.06	0.14	−27.33	18.41	0.16	15
Cupressaceae	111	61.52	0.04	2.43	2.82	0.40	18	368	233.47	0.08	12.27	10.49	0.26	18	2,545	1,099.71	0.04	−41.91	50.42	0.42	18
Plantago	93	27.54	0.13	−1.83	1.21	0.15	18	31	30.41	0.09	−1.75	1.36	0.22	18	401	232.08	0.12	−14.79	10.22	0.17	18
Platanus	26	20.40	0.31	−2.12	0.80	*0.02*	18	854	546.97	0.13	37.33	23.85	0.14	18	4,250	2,438.38	0.15	179.48	105.00	0.11	18
Poaceae	90	17.93	0.10	1.04	0.80	0.21	18	716	329.07	0.09	−18.30	14.72	0.23	18	8,219	3,438.00	0.46	−434.83	118.76	**0.00**	18
Urticaceae	131	19.73	0.11	−1.25	0.87	0.17	18	2,377	1,271.02	0.07	62.40	57.44	0.29	18	19,068	8,929.19	0.24	−816.65	364.92	*0.04*	18

The following statistics are included: the mean, standard deviation (SD), R^2 value, slope of the regression over time, standard error of the regression slope (SE), probability level (p) and number of years in the analysis (N)

Slope considered to be significant when $p < 0.05$. We report in italic letters $p < 0.05$, in bold letters $\boldsymbol{p < 0.01}$ and italic and bold letters $\boldsymbol{p < 0.001}$

season characteristics related to the timing of pollen seasons (i.e. start date, peak date and end date) (Table 1), but there were a number of significant trends in pollen season characteristics related to exposure (i.e. duration, peak value and SPI) (Table 2). There were also a large number of significant Spearman's rank correlations between different pollen season characteristics (Table 3), and examples are presented with particular focus on pollen types with significant trends.

3.2.1 Characteristics related to the timing of pollen seasons

Plants that flower early in spring are the most affected by warming (Ahas et al. 2002; Fitter and Fitter 2002), and changes in spring phenophases are more pronounced than those that occur in summer and autumn (Fitter and Fitter 2002; Walther et al. 2002; Aasa et al. 2004; Solomon et al. 2007; Bertin 2008). One would therefore expect that the significant increases in spring temperatures seen in this study would have a corresponding affect on early-flowering plants, such as those belonging to the Betulaceae and Cupressaceae families. For instance, advances in the timing of pollen seasons have been seen for spring flowering trees such as *Corylus* (Jäger et al. 1996) *Alnus* (Smith et al. 2007) and *Betula* (Emberlin et al. 2002) in Central and Northern Europe. One possible explanation for the lack of significant trends at Parma is that advances in spring flowering might be approaching a limit, as suggested for *Betula* pollen seasons in the UK (Newnham et al. 2013). In addition, the flowering phenology of herbaceous weed species that release their pollen later in the year, such as *Ambrosia artemisiifolia,* often relies on day length (Allard 1945).

Nevertheless, it is important to establish the beginning and the end of the period of pollination for the various taxa (Jäger et al. 1996) and to determine whether this is changing over time, particularly in relation to specific immunotherapy (Calderon et al. 2007; Horak et al. 2009; Gokmen et al. 2012). Immunotherapy is the only treatment for allergic respiratory disease with the long-term effect, but current treatment protocols require an initiation phase before the onset of the pollen season. Data from one of the studies with grass pollen tablet immunotherapy suggested that the duration of the pre-seasonal

Table 3 The results of Spearman's rank correlation test between different pollen season parameters

Pollen type	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Alnus	ns	ns	ns	ns	0.533 *	0.874 ***	ns	−0.546 *	ns	−0.628 **	ns	ns	ns	ns	ns
Ambrosia	ns	−0.504 *	ns	ns	ns	0.569 *	ns	−0.659 **	ns	−0.539 *	ns	ns	ns	0.926 ***	ns
Artemisia	ns	ns	ns	−0.551 *	ns	0.592 **	−0.685 **	−0.735 ***	ns	ns	ns	ns	ns	ns	ns
Betula	ns	−0.932 ***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.740 ***	ns
Amaranthaceae	ns	−0.933 ***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.789 ***	ns
Corylus	ns	−0.514 *	ns	ns	0.736 **	0.659 **	ns	ns	ns	ns	ns	ns	ns	0.911 ***	ns
Cupressaceae	ns	ns	ns	ns	ns	0.523 *	ns	ns	ns	ns	ns	ns	ns	0.852 ***	ns
Plantago	ns	−0.835 ***	ns	ns	ns	0.527 *	ns	ns	ns	ns	ns	ns	ns	0.815 ***	ns
Platanus	0.765 ***	ns	ns	ns	0.675 **	0.908 ***	ns	ns	0.798 ***	ns	ns	ns	ns	0.858 ***	ns
Poaceae	ns	ns	ns	ns	0.551 *	ns	−0.615 **	ns	ns	ns	−0.535 *	ns	ns	0.692 ***	ns
Urticaceae	ns	−0.641 **	ns	ns	0.624 **	0.581 **	−0.706 ***	ns	ns	ns	ns	ns	ns	0.488 *	ns

A start date/end date; *B* start date/duration; *C* start date/peak value; *D* start date/SPI; *E* start date/peak date; *F* end date/duration; *G* end date/peak value; *H* end date/SPI; *I* end date/peak date; *J* duration/SPI; *K* duration/peak value; *L* duration/date of peak; *M* SPI/date of peak; *N* SPI/peak value; *O* peak value/date of peak

$*$ $p < 0.05$, $**$ $p < 0.01$, $***$ $p < 0.001$, *ns*: not significant

treatment period might influence the magnitude of the clinical effect. The rationale for initiating treatment before the expected start of the season is to allow time for the activation of suppressor T cells, regulate the Th1/Th2 cytokine balance and shift it towards the Th1 cells, which relieves hypersensitivity to the target allergen. Indeed, studies for immunotherapy products for the treatment of grass pollen-induced allergic rhinitis have found that treatment must begin 4 months before the pollen season for maximal effect and at least 8 weeks before the season to provide any evidence of efficacy. The results of this study will therefore provide invaluable information for planning treatment (Emberlin et al. 1999).

3.2.2 Characteristics related to exposure

There was a significant decrease in the SPI of *Betula* (slope -68.68, $p = 0.02$) during the study period. Temperature has been shown to influence the intensity of airborne *Betula* pollen seasons. This is related to pollen production as the influence often manifests itself as a positive correlation between the amount of pollen recorded in a season and temperatures recorded the year before pollination (Rasmussen 2002; Stach et al. 2008). On the other hand, rainfall during the season affects the release and subsequent dispersal of pollen as it effectively removes bioaerosols from the air (Cox and Wathes 1995). However, analysis suggests that the observed decreases cannot be related to meteorology because temperatures have generally been increasing, particularly in the spring, and there has been no significant change in the amount of rainfall during spring when pollen grains are released into the atmosphere (Fig. 2). The magnitude of airborne pollen concentrations is also influenced by a number of other factors, such as land use and farming practices (Emberlin et al. 1993; Ziello et al. 2012), which could be responsible for the observed decrease in the SPI of pollen types like *Betula* in Parma.

Further investigation showed that, for *Betula,* there was a significant negative correlation between the start date and duration of pollen seasons ($\rho = -0.932$), and a significant positive correlation between SPI and peak values ($\rho = 0.740$) (Table 3). This shows that the various characteristics of the *Betula* pollen season are correlated, for instance, later start dates are related to shorter *Betula* pollen seasons, and a higher SPI is related to higher peak values. The latter is unsurprising as higher peak values

can be expected during high magnitude pollen seasons. This has been witnessed in other studies focusing on *Betula* (Piotrowska and Kubik-Komar 2012) and was also seen for other pollen types examined in this study, i.e. *Ambrosia* ($\rho = 0.926$), Amaranthaceae ($\rho = 0.789$), *Corylus* ($\rho = 0.911$), Cupressaceae ($\rho = 0.852$), *Plantago* ($\rho = 0.815$), *Platanus* ($\rho = 0.858$), Poaceae ($\rho = 0.692$) and Urticaceae ($\rho = 0.488$).

Continuing with arboreal taxa, *Platanus* pollen seasons became significantly shorter (slope -2.12, $p = 0.02$) over the study period. For *Platanus*, there were significant positive correlations between start dates and end dates ($\rho = 0.765$) as well as between start dates ($\rho = 0.675$) and end dates ($\rho = 0.798$) and the date of peak value, which means that the whole season can effectively shift in response to environmental conditions.

The response of arboreal and herbaceous taxa to a changing climate can vary. For example, Frei and Leuschner (2000) showed that the airborne pollen concentrations from trees like *Corylus* and *Betula* in Switzerland increased, whilst the amount of pollen recorded from herbaceous plants like *Artemisia* did not change. In this study, the SPI of *Artemisia* (slope -35.29, $p = 0.01$), Poaceae (slope -434.83, $p = 0.00$) and Urticaceae (slope -816.65, $p = 0.04$) decreased significantly over the study period, which was similar to the decrease seen in *Betula*. This general decrease in the total pollen count and concentration peaks of grass pollen in Parma has previously been related to the decreasing trend of rhinoconjunctivitis in the region (Ridolo et al. 2007). A recent study into geographic and temporal variations in pollen exposure across Europe also showed that the intensity of Poaceae pollen seasons was changing at some sites, but this change was not consistent, and there was actually a significant increase in the amount of Poaceae pollen recorded in the Province of Milan in Northern Italy (Smith et al. 2014), which suggests that it is a regional phenomena.

For *Artemisia*, there was also a corresponding decrease in the peak values (slope -2.92, $p = 0.02$). Moreover, a significant negative correlation between start dates and SPI of *Artemisia* pollen seasons showed that later start dates are related to less intense seasons ($\rho = -0.551$). The SPI ($\rho = -0.735$) and peak values ($\rho = -0.685$) of *Artemisia* were also significantly lower when the season ended later. In addition, later end dates are related to longer

Artemisia pollen seasons ($\rho = 0.592$). Poaceae and Urticaceae pollen seasons exhibited similar significant negative relationships between peak values and end dates (Poaceae $\rho = -0.615$; Urticaceae $\rho = -0.706$) and significant positive relationships between end dates and duration (Poaceae $\rho = 0.908$; Urticaceae $\rho = 0.581$) (Table 3).

The significant negative correlation between the end dates of the pollen season and SPI was also seen in *Ambrosia* ($\rho = -0.659$), which like *Artemisia* is also a member of the Asteraceae family. Interestingly, there was also a significant negative correlation between the duration and SPI of *Ambrosia* ($\rho = -0.539$), which suggests that high magnitude *Ambrosia* pollen seasons are shorter and end earlier (Table 3). In contrast to other herbaceous taxa, peak values (slope 4.91, $p = 0.00$) and SPI (slope 39.56, $p = 0.00$) of *Ambrosia* became significantly higher over the study period. *Ambrosia artemisiifolia* L. is a noxious invasive alien species that is a source of highly allergenic pollen (Smith et al. 2013). Observations conducted in the early 1990s showed that *Ambrosia* spp. pollen appeared sporadically in the air of Parma, but since 1996, there has been a significant increase in *Ambrosia* spp. pollen as well as a corresponding growth in the number of patients with positive skin prick tests (SPT) to *Ambrosia* pollen allergens, and among these, a significant increase of asthma (Albertini et al. 2012). These results correspond to the well-documented expansion of this invasive alien species in Northern Italy (D'Amato et al. 2007; Albertini et al. 2012; Smith et al. 2013).

4 Conclusions

The aim of this aerobiological study was to quantify the regional pollen spectrum observed over an 18-year period. Only 12 % of the characteristics examined showed significant changes over the study period. Temperatures increased significantly during the spring, but this did not appear to have a corresponding impact on the timing of pollen seasons. All of the observed changes were associated with characteristics that can be related to exposure (i.e. duration, peak value and SPI). These included important aeroallergens among the arboreal (i.e. *Betula* and *Platanus*) and herbaceous (i.e. *Ambrosia, Artemisia,* Poaceae and Urticaceae) taxa. The results presented here therefore

provide an essential baseline for determining exposure of the allergic population to allergenic pollen and aid understanding of the incidence of pollinosis in Parma. Unlike other studies concerned with changes to airborne pollen counts across Europe, we did not find evidence of a clear tendency towards an increase in atmospheric pollen (Ziello et al. 2012). In fact, many of the trends were towards lower airborne pollen concentrations of some important aeroallergens (i.e. *Betula, Artemisia,* Poaceae and Urticaceae). These decreases could not be explained by meteorology. This highlights gaps in current knowledge, not least the need to quantify the degree of influence exerted by some of the principal factors driving environmental change, climate and land use.

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