

Thirty-four years of pollen monitoring: an evaluation of the temporal variation of pollen seasons in Belgium

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Abstract For the first time in Belgium, fluctuations in airborne pollen quantities over a 34 years period have been analyzed. Seven pollen types have been selected comprising the most clinically relevant in Belgium nowadays (birch, alder, hazel and grasses) and others that are known to be allergenic in other European countries and frequently found in Belgium (plane, ash and mugwort). Pollen monitoring was performed with a seven-day recording volumetric spore trap placed in Brussels. We measured increasing airborne pollen for four trees, namely alder, hazel, ash and plane. Although the total pollen index for birch

has not increased significantly, an increasing trend in the annual amount of days above the concentration threshold of 80 pollen grains/m³ was clearly observed. Concerning temporal variations, the pollen season has tended to end earlier for birch, ash and plane and the peak concentration of the pollen of plane has been appearing earlier in the year. In the investigated period, the pollen seasons of grasses and mugwort have tended to become less severe. Furthermore, we reported a temporal shift of the grass pollen season, beginning and ending earlier, together with an advance of the annual peak date.

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1 Introduction

Airborne pollen grains are a predominant cause of respiratory allergy (Bachert et al. 2006; Bauchau and Durham 2004; D'Amato et al. 2007) and raises of its concentration is associated with an increase in seasonal allergic rhino-conjunctivitis (Caillaud et al. 2015). The pattern of the pollen season determines the severity and timing of the allergic reactions for sensitized people (Ariano et al. 2010; Irani et al. 2013; Silverberg et al. 2015). Therefore, a comprehensive characterization of this period is undeniably essential for an accurate diagnosis, effective

prevention and treatment of the symptoms of such allergic reaction (Pfaar et al. 2017).

As already suggested by several aerobiological studies, the pollen seasons have the tendency to begin relatively earlier over the years (Ariano et al. 2010; Emberlin et al. 2002; Jäger et al. 1996; Rasmussen 2002; Spieksma et al. 1995, 2003). This is for example the case for the start of the pellitory-of-the-wall and birch pollen seasons in Italy where an advance of, respectively, 83 and 27 days was observed for the period between 1981 and 2007 (Ariano et al. 2010). Several studies indicate that the annual total pollen concentrations increase every year in different European countries (Ariano et al. 2010; Emberlin et al. 2002; Makra et al. 2011). However, this trend seems to depend on the localization and the investigated taxon. Makra et al. (2011) noticed that a similar increase in the annual pollen index in three locations (Hungary, Switzerland and Greece) is only observed for one taxon (*Taxus/Cupressaceae*) of the 19 taxa investigated. Opposite trends were also observed, for instance in Switzerland, for birch in the period 1991–2007 (Frei and Gassner 2008). In order to reach consistent conclusions about the evolution of the pollination seasons in a specific area and in the context of global climate change, it is mandatory to monitor airborne pollen both on the long term and on a local scale. In a previous study in Belgium, 16 years of pollen monitoring has not revealed any significant increase in the annual pollen index. However, cyclic variations in the annual pollen index of tree pollen measured each year were observed (Detandt and Nolard 2000).

In this work, we investigate the evolution of the pollen seasons in Belgium for a time lapse of 34 years (from 1982 to 2015). Annual records of total pollen concentrations, pollen concentration maxima as well as evolutions of pollen concentrations were analyzed, not only for the most clinically relevant pollen (birch, hazel, alder and grasses) but also for pollen that are responsible for allergy problems in other European countries but currently less clinically relevant in Belgium (ash, plane and mugwort).

2 Materials and methods

2.1 Pollen data

Airborne pollen monitoring in Brussels has been performed daily from 1982 to 2015 by the Belgian Aerobiological Surveillance Network (<http://www.airallergy.be>). The pollen trap is located at the Scientific Institute of Public Health (WIV-ISP, site Elsenne-Ixelles, 50°51'N 04°21'E), on the top of a flat roof at a height of about 16 m and with no higher buildings surrounding.

Airborne pollen was collected with a *Burkard* 7 day recording volumetric spore trap (Hirst type). The air is aspirated by the trap through an orifice (2 mm x 14 mm) with airflow of 10 L/min, reflecting the human ventilator flow. Airborne particles are projected on a drum which rotates at the speed of 2 mm/h. By the presence of a weather vane, the orifice is always positioned in the direction of the prevailing wind. The surface of drum is covered with a tape coated with a layer of petroleum jelly on which the particles contained in the air adhere. After sampling, the tape is removed from the drum and cut into 24-h daily sections, which are then mounted on glass slides. Identification of all collected pollen grains was performed by light microscopy at a magnification of 400× (Galán et al. 2014). The methodological guidelines requirements by the European Aerobiology Society (EAS) were followed to the best ability (Galán et al. 2014), except that two slide lines were read in longitudinal transects to determine the average daily pollen concentration (pollen grains/m³ air).

The pollen datasets used in this study are related to the seven following plant taxa: alder (*Alnus* spp.), hazel (*Corylus avellana*), birch (*Betula* spp.), ash (*Fraxinus excelsior*), plane (*Platanus* spp.), grasses (Poaceae family) and mugwort (*Artemisia* spp.).

2.2 Meteorological data

Monitoring of the meteorological parameters was performed at the Uccle Observatory (in place since 1886) by the Belgian Royal Meteorological Institute (KMI-IRM). Average daily data were calculated for maximum and minimum temperature (°C), total radiation (W/m²), maximum and minimum relative humidity (%), rainfall (mm) and wind speed (m/s).

2.3 Statistical analysis

The analysis of the long-term variation in airborne pollen seasons was performed following three distinct aspects. First, the timing of the season which is characterized by the season start/end dates and the peak date. Dates are labeled by consecutive day numbers, starting from day one on January 1st. The season start/end dates are defined from the day when the sum of daily concentrations reaches 5%/95% of the total pollen amount (Nilsson and Persson 1981). The peak date corresponds to the day when the maximum daily pollen concentration was recorded in the given year (Alcazár et al. 2011). The second aspect is the intensity of the pollen season, which may be expressed by the annual sum of the daily airborne pollen concentration, more recently defined as the Annual Pollen Index (API) (Galán et al. 2016), and by the peak value, which is the highest daily pollen concentration measured in 1 year. Finally, we alternatively analyzed the pollen season length by using an indicator of exposure. This annual exposure duration is defined by the amount of days for which at least one pollen grain per cubic meter air was measured. Moreover, for birch and grass pollen, we extended this exposure definition to daily concentrations of, respectively, 80 and 50 pollen grains/m³, which are more relevant in terms of health risk. These specific thresholds are routinely used by the Belgian Aerobiological Surveillance Network to consider that most sensitized people are at risk to develop allergy symptoms (de Weger et al. 2013).

Temporal trends were calculated by the nonparametric Mann–Kendall test and the linear regression model. The null hypothesis rejects any monotonic trend. The coefficient Tau obtained by the Mann–Kendall test has a range of -1 to $+1$ and is similar to the correlation coefficient. Positive value indicates a trend of increase and negative value indicates a trend of decrease. The results are considered statistically significant if the p value is inferior to 0.05. Statistical analyses and plots generation were performed by using the R programming environment 3.3.3 (Foundation for Statistical Computing, Vienna, Austria) and GraphPad Prism software 5.0 (San Diego, CA, US).

3 Results

3.1 Evolution of the timing, length and intensity of pollen seasons

Alder and hazel trees bloom from January to March. The alder pollen season showed one of the most stable timing among all the selected taxa. Despite wide inter-annual variations, the long-term change in start and end dates was very low, as expressed by low Tau values and low slope values (Table 1, Fig. 1). For hazel, the timing of the pollen season was also relatively stable and the apparent advance of the season start date was shown to be not significant. Nonetheless, the API of both trees presented a significant increase in 34 years (Table 1, Fig. 2), most likely independent from the low variations observed in peak values.

In Belgium, the ash pollen season has always been considered to be precursor of the birch pollen season, as their timing is closely related and with a narrow overlap. Both seasons are then generally followed by the plane pollen season on mid-April. For the three last decades, an apparent timing shift of the pollen season has been observed for these three taxa, with earlier end dates (with significant negative Tau values), and relatively earlier start dates (with negative Tau and slope values although not significant) (Table 1, Fig. 1). In terms of season intensity, a significant increase in the API was observed for ash and plane. Particularly for plane trees, this positive trend in airborne pollen was supported by a significant increase in the peak value, which was clearly noticeable in 2007, 2011 and 2015 (Fig. 2). These maximum daily concentration values notably accounted for approximately 23, 31 and 36% of their respective API value. Moreover, this recent outbreak in plane pollen emission was joined by earlier apparition of the peak days in the season, as shown by significantly negative Tau and slope values (Table 1, Fig. 1).

Regarding birch pollen season, the increase in the API was shown to be not significant though the slope value calculated by linear regression was clearly the highest among all the selected taxa, i.e., 97.75 (Table 1). Furthermore, the analysis of the exposure duration revealed contrasted trends depending on the selected threshold. The annual amount of days for which at least one birch pollen grain per cubic meter was measured has not widely varied for 34 years

Table 1 Characteristics and trends of pollen season start/end date, peak date and value, Annual Pollen Index (API), and exposure duration (amount of days for which pollen concentration exceeded the critical threshold, i.e., 80 grains/m³ for birch and 50 grains/m³ for grasses), for seven pollen taxa from 1982 to 2015

Seasonal pollen features	Mean	Median	SD	Mann–Kendall Tau value	Linear regression	
					R ²	Slope
<i>Alder</i>						
Start season date	44	40	13.3	− 0.047	0.004408	− 0.089
End season date	80	80	12.3	0.027	0.0004	− 0.025
Peak date	64	66	14.3	− 0.234	0.1121	− 0.479
Peak value	236	172	291.8	0.216	0.003533	1.742
Annual Pollen Index	1276	993	897.8	0.237*	0.06513	23.01
<i>Hazel</i>						
Start season date	27	21	17.9	− 0.171	0.05519	− 0.423
End season date	77	77	13.5	0.0199	0.00369	− 0.083
Peak date	51	54	19.1	− 0.0628	0.00599	− 0.148
Peak value	89	72	66.5	0.225	0.05957	1.629
Annual Pollen Index	497	368	354.4	0.278*	0.2254**	16.893
<i>Ash</i>						
Start season date	90	88	12.4	− 0.145	0.09905	− 0.393
End season date	113	114	8.5	− 0.371**	0.2369**	− 0.417
Peak date	98	96	11.9	− 0.193	0.1131	− 0.401
Peak value	293	198	318.1	0.201	0.07974	9.02
Annual Pollen Index	1256	1076	988.1	0.255*	0.1359*	36.57
<i>Birch</i>						
Start season date	97	95	9.9	− 0.146	0.09235	− 0.303
End season date	119	120	7.5	− 0.242*	0.09743	− 0.234
Peak date	106	106	8.8	− 0.212	0.1199	− 0.306
Peak value	1299	1270	897.6	0.152	0.03773	17.51
Annual Pollen Index	6307	5588	4052	0.184	0.05772	97.75
Days ≥ concentration threshold	13.7	13	6.0	0.262*	0.1366*	0.22353*
<i>Plane</i>						
Start season date	112	112	10.7	− 0.217	0.09925	− 0.34
End season date	133	134	8.5	− 0.358**	0.2593**	− 0.436
Peak date	119	118	11.6	− 0.33**	0.1517*	− 0.455
Peak value	69	31	96.7	0.392**	0.285**	5.185
Annual Pollen Index	306	158	354	0.386**	0.2775**	18.723
<i>Grasses</i>						
Start season date	145	144	9.2	− 0.252*	0.208**	− 0.421
End season date	209	208	8.4	− 0.244*	0.1396*	− 0.314
Peak date	163	161	10.3	− 0.241*	0.158*	− 0.409
Peak value	204	178	86.7	− 0.153	0.1153	− 2.957
Annual Pollen Index	3024	2868	1037	− 0.278*	0.2019**	− 46.79
Days ≥ concentration threshold	19.9	20.5	7.1	− 0.251*	0.1658*	− 0.2883*
<i>Mugwort</i>						
Start season date	206	207	6.7	− 0.197	0.09874	− 0.211
End season date	237	235	7.1	0.155	0.08184	0.2047
Peak date	221	222	4.8	− 0.0954	0.02493	− 0.076

Table 1 continued

Seasonal pollen features	Mean	Median	SD	Mann–Kendall Tau value	Linear regression	
					R ²	Slope
Peak value	18	16	7.9	– 0.468***	0.4229***	– 0.5132
Annual Pollen Index	163	156	58.1	– 0.478***	0.4423***	– 3.882

SD standard deviation

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

(Fig. 3). In contrast, the trend observed for the annual amount of days with at least 80 pollen grains per cubic meter was significantly positive (Table 1, Fig. 3). This reflects a clear increase in the intensity of exposure to birch pollen within a relatively steady season length (Figs. 1, 3), which is consistent with the apparent trend of increase in API (Fig. 2).

From end May, tree pollen seasons gradually fade out and are rapidly followed by pollen seasons from herbaceous plants, e.g., grasses. Since 1982, the grass pollen season has presented so far the most significant shift in timing, in extension with earlier start and end, and with the earlier apparition of the annual peak value (Table 1, Fig. 1). This pollen season is particularly long compared to other taxa, as shown by the large interval between start and end dates (Fig. 1) or by the high amount of days with exposure to at least one grass pollen per cubic meter (Fig. 3). However, the positive slope observed for this last indicator was notably inverted when the exposure threshold set to 50 pollen grains per cubic meters. In fact, we observed a significantly negative trend for the annual amount of days above this concentration (Table 1, Fig. 3), which is in line with the significantly negative values calculated for the long-term trend in API (Table 1, Fig. 2). This highlights the apparition of different dynamics between what we may consider the “high season” and the “low/overall season” for grass pollen. While the overall season has been tending to advance over time but without significant change in total duration, the “high season,” approximately one third shorter in time (Fig. 3) and reflecting high risk to develop allergy symptoms, has progressively decreased in duration and intensity.

Finally, the analysis of the mugwort pollen season revealed a distinct long-term evolution of its timing

pattern. Generally defined between end of July and end of August, the season length has tended to expand with the years (Figs. 1, 3). Indeed, despite nonsignificant trend values calculated for the season start and end dates (Table 1), the linear trend value of the exposure duration appeared to be significantly positive (not shown). Regarding the season intensity, the Tau and slope values calculated for the API and the annual maximum concentration were found to be significantly negative (Table 1). However, the high decrease measured for the API does not seem to be highly related to the decrease in peak value because, unlike our previous statement for plane pollen, the maximum daily concentration measured for mugwort pollen has only accounted from 6 to 16% of the API value since 1982 (Fig. 2). Overall, the mugwort pollen season has tended to spread out its distribution curve, showing lower daily concentrations but within a longer period of time.

3.2 Correlation with mean monthly meteorological parameters

The impact of the weather conditions on pollen emission and dispersal was assessed by correlating the season start date (Table 2) or the API (Table 3) of each taxon with the mean monthly data of several meteorological parameters.

For alder and hazel pollen, the timing of the season start appeared to be significantly correlated with the mean monthly maximum and minimum temperature measured on January, and more extensively to February and March for alder (Table 2). This correlation was highly negative for both pollen taxa, meaning that elevated temperature would likely be related with an advance of the season start date. Furthermore, alder

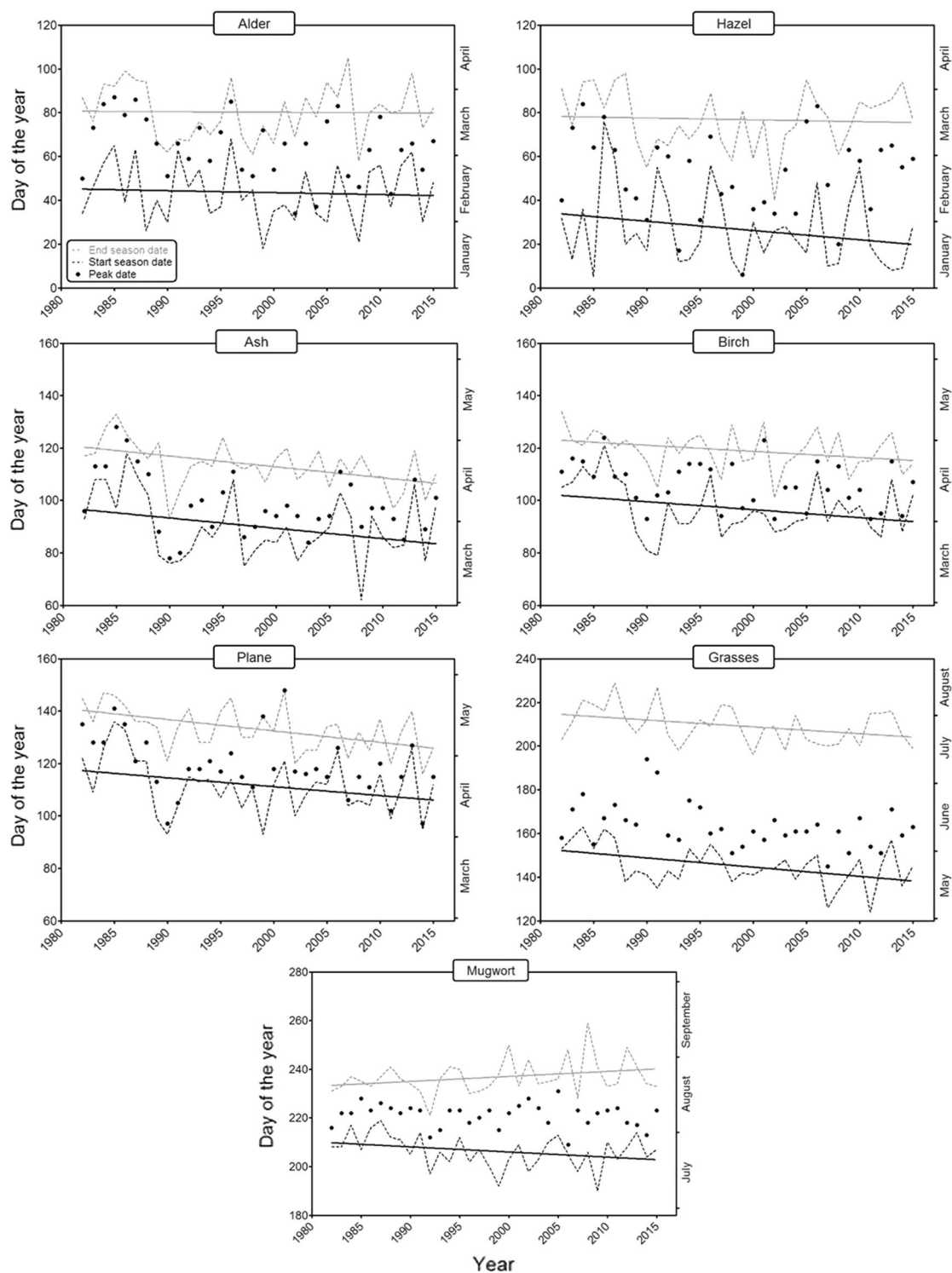


Fig. 1 Pollen season start dates (dashed black curve), end dates (dashed gray curve) and peak dates (black dots) for seven pollen taxa from 1982 to 2015. Linear trends of the start and end dates are represented by regression lines in their respective color

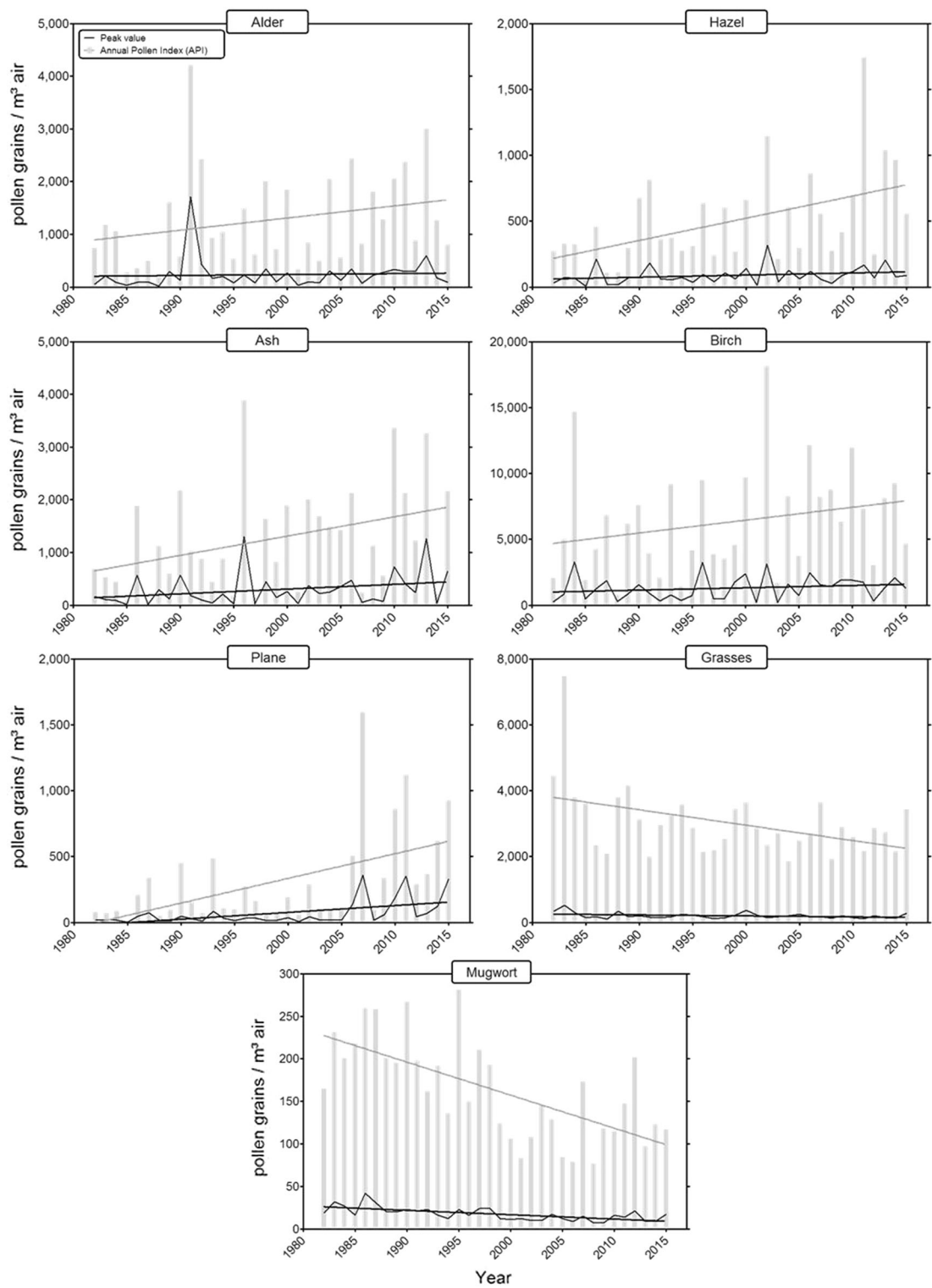


Fig. 2 Peak value (maximum daily pollen concentration) (black curve) and Annual Pollen Index (API) (gray histograms) for seven pollen taxa from 1982 to 2015. Linear trends are represented by regression lines in their respective color

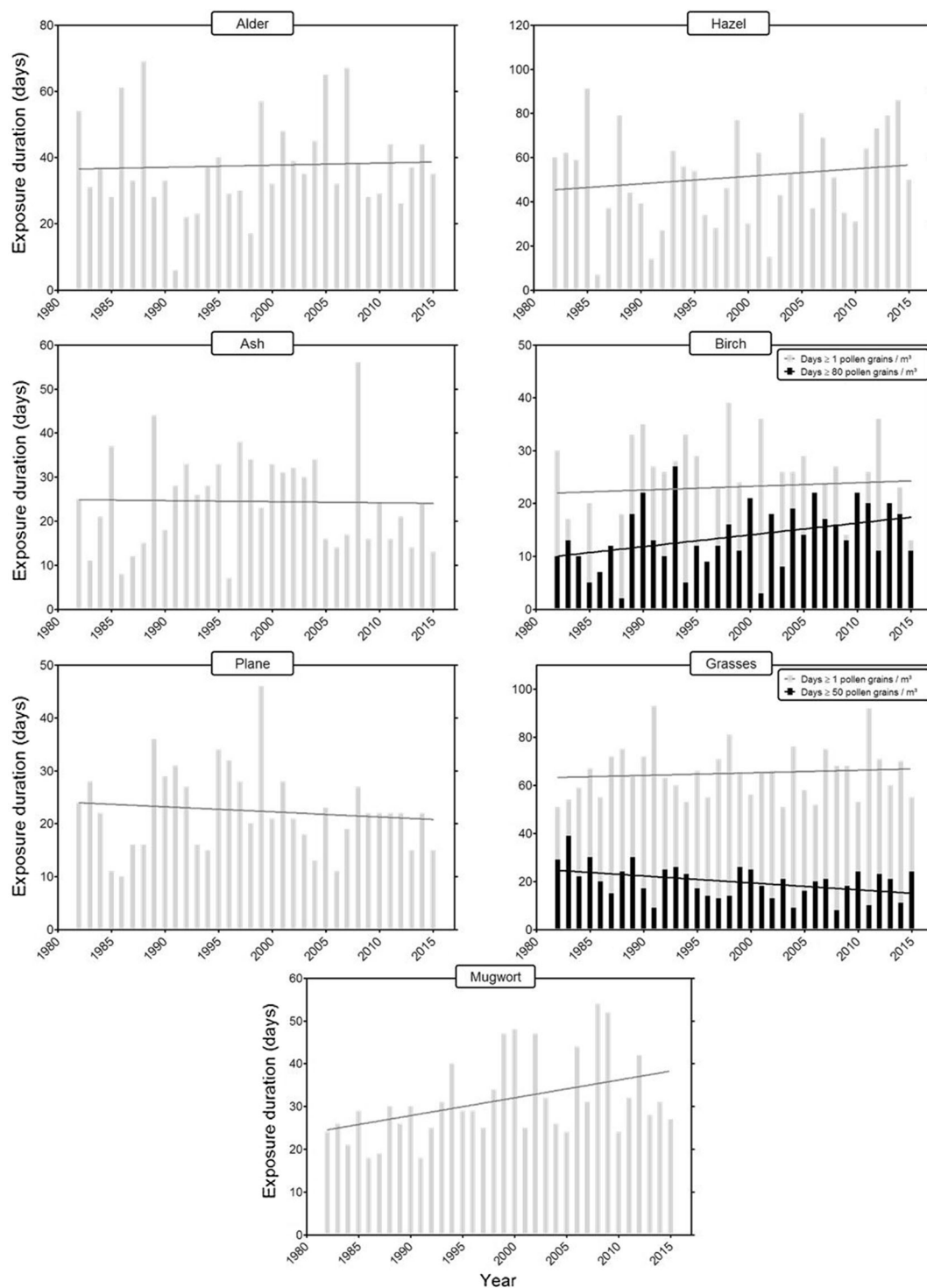


Fig. 3 Exposure duration for seven pollen taxa from 1982 to 2015 as expressed by the amount of days for which at least 1 pollen grain/m³ was measured (gray histograms) and by the amount of days for which pollen concentration exceeded the

critical threshold (i.e., 80 grains/m³ for birch, 50 grains/m³ for grasses) (black histograms). Linear trends are represented by regression lines in their respective color

Table 2 Spearman correlation between pollen season start date and mean monthly meteorological parameters

Pollen season start	Meteorological parameter	January	February	March	April	May	June	July	August	September
Alder	Max. temperature	− 0.704***	− 0.556***	n.s.						
	Min. temperature	− 0.714***	− 0.494**	− 0.359*						
	Radiation	n.s.	n.s.	n.s.						
	Max. relative humidity	n.s.	n.s.	n.s.						
	Min. relative humidity	n.s.	n.s.	n.s.						
	Rainfall	n.s.	n.s.	n.s.						
	Wind force	− 0.498**	− 0.372*	n.s.						
Hazel	Max. temperature	− 0.636***	n.s.	n.s.						
	Min. temperature	− 0.596***	n.s.	n.s.						
	Radiation	n.s.	n.s.	n.s.						
	Max. relative humidity	n.s.	n.s.	n.s.						
	Min. relative humidity	n.s.	n.s.	n.s.						
	Rainfall	n.s.	n.s.	n.s.						
	Wind force	− 0.465**	n.s.	n.s.						
Ash	Max. temperature	n.s.	− 0.626***	− 0.758***	n.s.					
	Min. temperature	n.s.	− 0.521**	− 0.790***	n.s.					
	Radiation	n.s.	n.s.	n.s.	n.s.					
	Max. relative humidity	n.s.	n.s.	n.s.	n.s.					
	Min. relative humidity	n.s.	n.s.	n.s.	n.s.					
	Rainfall	n.s.	n.s.	n.s.	n.s.					
	Wind force	n.s.	n.s.	n.s.	n.s.					
Birch	Max. temperature	− 0.356*	− 0.380*	− 0.895***	n.s.					
	Min. temperature	n.s.	− 0.349*	− 0.887***	n.s.					
	Radiation	n.s.	n.s.	− 0.447**	n.s.					
	Max. relative humidity	n.s.	n.s.	n.s.	n.s.					
	Min. relative humidity	n.s.	n.s.	n.s.	n.s.					
	Rainfall	n.s.	n.s.	0.401*	n.s.					
	Wind force	n.s.	n.s.	n.s.	n.s.					
Plane	Max. temperature	− 0.513**	− 0.472**	− 0.823***	n.s.	n.s.	n.s.			
	Min. temperature	− 0.483**	− 0.453**	− 0.692***	n.s.	n.s.	n.s.			
	Radiation	n.s.	n.s.	− 0.469**	n.s.	− 0.432*	n.s.			
	Max. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
	Min. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			

Table 2 continued

Pollen season start	Meteorological parameter	January	February	March	April	May	June	July	August	September
Grasses	Rainfall	n.s.	n.s.	n.s.	n.s.	0.376*	n.s.			
	Wind force	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
	Max. temperature	- 0.519**	- 0.509**	- 0.617***	n.s.	- 0.490**	n.s.			
	Min. temperature	- 0.518**	- 0.508**	- 0.499**	n.s.	- 0.427*	n.s.			
	Radiation	n.s.	n.s.	n.s.	n.s.	- 0.478**	n.s.			
	Max. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
	Min. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
	Rainfall	n.s.	n.s.	n.s.	n.s.	0.450**	n.s.			
Mugwort	Wind force	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
	Max. temperature	n.s.	- 0.411*	- 0.382*	- 0.381*	n.s.	n.s.	n.s.		
	Min. temperature	n.s.	- 0.356*	n.s.	- 0.560**	- 0.587***	- 0.417*	n.s.		
	Radiation	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
	Max. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
	Min. relative humidity	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
	Rainfall	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		
	Wind force	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		

n.s. nonsignificant

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3 Spearman correlation between Annual Pollen Index (API) and mean monthly meteorological parameters

API	Meteorological parameter	January	February	March	April	May	June	July	August	September
Alder	Max. temperature	n.s.	n.s.	n.s.						
	Min. temperature	n.s.	n.s.	n.s.						
	Radiation	n.s.	n.s.	n.s.						
	Max. relative humidity	n.s.	n.s.	− 0.362*						
	Min. relative humidity	n.s.	n.s.	n.s.						
	Rainfall	n.s.	n.s.	n.s.						
	Wind force	n.s.	n.s.	n.s.						
	Max. temperature	n.s.	n.s.	n.s.						
	Min. temperature	n.s.	n.s.	n.s.						
Hazel	Radiation	n.s.	n.s.	0.389*						
	Max. relative humidity	n.s.	n.s.	− 0.436*						
	Min. relative humidity	n.s.	n.s.	− 0.425*						
	Rainfall	n.s.	n.s.	− 0.417*						
	Wind force	n.s.	n.s.	n.s.						
	Max. temperature			n.s.	n.s.					
	Min. temperature			n.s.	n.s.					
	Radiation			n.s.	n.s.					
	Max. relative humidity			n.s.	n.s.					
Birch	Min. relative humidity			n.s.	n.s.					
	Rainfall			n.s.	n.s.					
	Wind force			n.s.	n.s.					
	Max. temperature			n.s.	n.s.					
	Min. temperature			n.s.	n.s.					
	Radiation			0.361*	0.385*	n.s.				
	Max. relative humidity			− 0.463**	n.s.	n.s.				
	Min. relative humidity			− 0.422*	n.s.	n.s.				
	Rainfall			− 0.379*	− 0.444**	n.s.				
Plane	Wind force			n.s.	− 0.374*	n.s.				
	Max. temperature			n.s.	n.s.	n.s.	n.s.			
	Min. temperature			n.s.	n.s.	n.s.	n.s.			
	Radiation			0.676***	0.522**	n.s.	n.s.			
	Max. relative humidity			− 0.623***	n.s.	− 0.403*	− 0.392*			
	Min. relative humidity			− 0.624***	− 0.419*	n.s.	n.s.			
	Max. temperature			n.s.	n.s.	n.s.	n.s.			
	Min. temperature			n.s.	n.s.	n.s.	n.s.			
	Radiation			0.676***	0.522**	n.s.	n.s.			

Table 3 continued

API	Meteorological parameter	January	February	March	April	May	June	July	August	September
Grasses	Rainfall			− 0.478**	− 0.483**	n.s.	n.s.			
	Wind force			n.s.	− 0.424*	0.418*	n.s.			
	Max. temperature					n.s.	n.s.	n.s.	n.s.	
	Min. temperature					n.s.	n.s.	n.s.	n.s.	
	Radiation					n.s.	n.s.	n.s.	n.s.	
	Max. relative humidity					n.s.	n.s.	n.s.	n.s.	
	Min. relative humidity					n.s.	n.s.	n.s.	n.s.	
Mugwort	Rainfall					n.s.	n.s.	n.s.	− 0.355*	
	Wind force					n.s.	n.s.	n.s.	n.s.	
	Max. temperature					− 0.437*	− 0.437*	n.s.	n.s.	− 0.390*
	Min. temperature					n.s.	n.s.	n.s.	n.s.	n.s.
	Radiation					− 0.627***	− 0.627***	n.s.	n.s.	n.s.
	Max. relative humidity					0.601***	0.601***	n.s.	n.s.	n.s.
	Min. relative humidity					0.570**	0.570**	n.s.	n.s.	n.s.
	Rainfall					0.500**	0.500**	n.s.	− 0.355*	n.s.
	Wind force					n.s.	n.s.	n.s.	n.s.	n.s.

n.s. nonsignificant

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

and hazel pollen were the sole taxa to show a significant correlation between the season start date and wind force, for which the impact might be greater before the leafing of trees.

For all the other selected pollen taxa, significantly negative correlations were observed between start date and the maximum/minimum temperatures measured from 1 to 5 months prior to the average season start. The most extreme example is the pollen season start of mugwort, which appeared to depend on the temperature already measured on February, hence much earlier its blooming on July. In contrast, negative correlation with radiation and positive correlation with rainfall was observed with shorter lag in time prior to the average season start. For instance, low radiation and high rainfall levels on March were independently correlated with later birch pollen season onset, as well for plane and grasses on May.

Notably, no correlation could be found with any of the seven mean monthly meteorological parameters measured on April for all the tree taxa that may start blooming from this month (ash, birch and plane).

Regarding the potential impact of the weather conditions on the annual magnitude of airborne pollen concentrations (Table 3), we observed correlation patterns rather different from these found with the pollen season start. The API of alder and hazel was shown to be significantly correlated with several mean monthly meteorological parameters measured on March, which is a period comprising great proportion of the API. Hence, this suggests the direct influence of these parameters, e.g., radiation, relative humidity and rainfall, on the emission and dispersal of airborne pollen. In contrast, the weather conditions observed on January and February, i.e., during the pre-pollination period of alder and hazel, appear here to have less impact on the development of flowers and on their capacity to produce pollen. To some extent, this capacity may be further determined by intrinsic physiological and phenological factors for these trees. More strikingly, the annual amounts of airborne ash pollen appeared here to be entirely determined by non-meteorological factors because the API was shown to be non-correlated to any of the selected parameters.

For birch and plane trees, the correlation test revealed significantly positive values between their API and radiation, and significantly negative values were found with the relative humidity and rainfall parameters. Moreover, mean monthly wind force

measured on April appeared to be negatively correlated with the API of birch and plane, whereas this correlation was significantly inverted on May for plane.

With regard to grasses, the negative correlation value calculated between the API and the mean monthly rainfall measured on August was the sole significant correlation observed for this taxon. This may seem rather logical as the pollen of these herbaceous plants is dispersed in the air during a relatively long period. For instance, the potential positive effect that may induce high radiation levels on pollen dispersal during the month of June could be compensated by negative effects due to high relative humidity and/or rainfall levels during the months of July and August, hence preventing an overall impact on the API.

Finally, the results obtained for mugwort were again substantially distinct from the other taxa. Correlation values calculated on June were rather counterintuitive because they were significantly negative for maximum temperature and radiation and significantly positive for maximum/minimum relative humidity and rainfall, strengthening the notion of water availability which is crucial for this herbaceous plant during its pre-pollination period. In contrast, high rainfall levels on August, thus during the season, seem to prevent optimal pollen dispersal in the air, as it is shown by a significantly negative correlation value.

4 Discussion

The results obtained in this study indicate that seasonal variations in pollen concentrations exist, but that no general overall trend for the total pollen load can be observed. However, specific trends for the different taxa can be detected, which is in agreement with most previous European studies on the subject (Spieksma et al. 2003; Ziello et al. 2012). The fact is that this kind of study may be subject to various interpretations depending on the selected period of analysis and on the selected statistical test. For instance, we have shown here that the nonparametric Mann–Kendall test sometimes revealed a significant trend where the linearity model did not, which was never inversely the case. The discrepancies between these two statistical approaches have already been reported in the literature (Fernandez-Llamazares et al. 2014). Moreover,

several trends could here be significantly demonstrated only thanks to a large period of analysis, which was allowed by the monitoring of more than three decades in Brussels. Previously, the long-term evolution of some pollen taxa could not be statistically proven during the period 1982–1997 (Detandt and Nolard 2000). Firstly, because of the extremely variable annual pollen production cycles of some trees that were reported in that time, a phenomenon we also observed between 1997 and 2015. Secondly, because even more pronounced trends of increase in the API appeared from the years 2000s for some taxa (alder, hazel, birch and especially plane trees).

In addition to the season timing and the annual pollen index, we also analyzed the long-term trends in annual exposure duration, which indicates the annual amount of days above a particular pollen concentration threshold. This indicator has already been used in other pollen monitoring reports (Clot 2003; Lind et al. 2016), but it is important to take into account the fact that it may deliver divergent results depending on the value that is subjectively fixed for this threshold. The “low” threshold (20 pollen grains/m³) used by Clot (2003) could for instance demonstrate trends of increase for *Taxus*/Cupressaceae and Urticaceae, considered among the most abundant pollen taxa in Switzerland, whereas the use of “high” threshold (50 pollen grains/m³) could not. Furthermore, the trend significance of plant taxa like mugwort, which present very low daily pollen concentrations, relies on the selection of a threshold value within a relatively constrained range. In the Swedish study reported by Lind et al. (2016), which uses percentiles instead of absolute concentration thresholds, the 41-year trend calculated for mugwort pollen was shown to be very contrasted, ranging from highly positive (< 25 percentile) to negative (> 75 percentile) values. In our study, we decided to fix a rather strict threshold of one pollen grain/m³ that is applicable for all taxa, even for mugwort. Moreover, we added for birch and grasses an additional threshold related to the risk of developing specific allergy symptoms, which may be more relevant and concrete when interpreting the trend results (de Weger et al. 2013). These two pollen taxa are abundant in the air (birch API accounted for 9–30% total pollen API these last 10 years), and they are the main cause of pollinosis in Belgium (Blomme et al. 2013; Guilbert et al. 2016). With this indicator combined with the others, we have been able to

describe the long-term evolution of airborne pollen trends from several angles. For example, birch pollen season has become more severe, not because it has been longer or with higher peaks, but because the days of low concentration are relatively fewer. These results are likely to corroborate with many other European studies showing an overall rise of the birch pollen presence in the air these last decades (Frei and Gassner 2008; Rasmussen 2002; Spiessma et al. 2003; Ziello et al. 2012).

So far, long-term variations in ash and plane pollen concentrations in Belgium have not yet been reported. Although the exposure to pollen from the Oleaceae family is not dominant in this European region as compared to the Betulaceae family (Smith et al. 2014), the increasing trend of API we observed for ash might be of major importance in terms of allergy risk. In central Europe, concentrations of ash pollen can be as important as birch pollen concentrations (Clot 2003), and it was shown to have a considerable effect on pollinosis in some countries (Hemmer et al. 2000; Poncet et al. 2010).

Plane trees are considered as a major source of airborne allergens in the Mediterranean area, where its pollen is the second cause of pollinosis after grass pollen (Alcazar et al. 2011; Asam et al. 2015; Varela et al. 1997). In this study, a clear increasing trend of the annual plane pollen index was observed over time, especially these last 10 years, together with earlier annual peak dates. In northern France and Belgium, this tree does not seem to represent yet a great public health problem in terms of allergy, probably because the emitted pollen amounts are 1000 times less important than in the Mediterranean region (Pauli et al. 2014). Plane represents nonetheless 25% of the trees growing in Brussels streets (Brussels Regional Public Service—Brussels Mobility 2013). Besides, the severe increase in the concentration trend recently observed for plane suggests that this pollen season might reach soon the situation known in some cities of southern regions of Europe, where short but intense pollen peaks momentarily increase the allergy risk for the sensitized population (Fernández et al. 2015; Gabarra et al. 2002; Subiza et al. 1995).

There are multiple factors that may be involved in this long-term process of increase in airborne tree pollen concentration in Belgium, among them the global climate change, land cover management, tree aging, air pollution, biogeochemical factors, etc.

Although they are confounding factors, we have been able to show close correlations between several meteorological parameters and the timing or intensity of the pollen seasons. We observed for instance that temperature is a central parameter determining the onset of pollen seasons, even several months before the season start. These results are consistent with the many studies reporting the earlier onset of pollen seasons as a consequence of the warmer springs observed these recent years (Ariano et al. 2010; Clot 2003; Emberlin et al. 2006; Frei and Gassner 2008; Malkiewicz et al. 2016; Rasmussen 2002; Spieksma et al. 2003). Besides, radiation, rainfall and relative humidity were shown to have a direct short-term impact on airborne pollen concentration. This clearly illustrates the differential influence of meteorological variables that may act on the phenological stages on the one hand and on the pollen dispersal on the other (Newnham et al. 2013).

More particularly for mugwort, our correlation results showed the positive influence of temperature, several months before, on the timing of the pollen season as well as the negative influence of this same parameter, during the month of June, on the intensity of the season (Grewling et al. 2012). In addition to corroborate with our pollen trend analysis, which revealed an extended but less intense mugwort pollen season; these results are consistent with those reported for the same mugwort species in Poland, at a 1.6° difference of latitude from Brussels (Bogawski et al. 2014; Stach et al. 2007). Furthermore, the relative advance in the mugwort pollen season timing might be more particularly determined by the earlier flowering of the *Artemisia vulgaris* species, which is the most common species found in Poland but also in Belgium (Bogawski et al. 2016). In terms of season intensity, rainfall is a key factor for both the development of the herbaceous plant and its pollen dispersal. While water availability during the pre-pollination period drives the production of high pollen quantities, long and/or intense rainfall during the flowering period is negatively correlated with pollen concentration in the air (Green et al. 2004).

Nonetheless, the weather conditions are most likely not the only factors involved in the trend of decrease observed for the annual pollen index of mugwort and evenly of grasses. Indeed, in the Brussels Capital Region, open land surface has gradually disappeared to the advantage of residential buildings, therefore

directly reducing the available space for these herbaceous plants to proliferate (Brussels Institute of Statistics and Analysis 2015). Moreover, air pollution such as an elevation of atmospheric carbon dioxide concentration have been shown to affect plant's reproduction biology and growth and has direct impact on pollen production (Jablonski et al. 2002; LaDeau and Clark 2001). Such local aspects, which need to be further investigated, clearly depict the extent to which multiple factors may specifically affect the pollen season patterns and why some pollen seasons might present significantly different trends between relatively close locations (Smith and Emberlin 2006; Ziello et al. 2012).

Overall, it should though be kept in mind that the correlation tests performed in this study between pollen indicators and meteorological parameters do not take into account any trend over time. Since it is already relatively difficult to demonstrate significant trends in airborne pollen concentration for some taxa on the basis of annual data, an analysis of associations between trends in pollen concentration and trends in meteorological conditions would require the use of daily data series (unpublished work). This might for instance bring more clues on why we did not observe any significant trends for an earlier start of the alder and hazel pollen seasons together with the trend of increase in temperature on January and February, despite the evident close correlation between these parameters. Moreover, an analysis based on daily data, given the more precise time series they offer and the distinct statistical approach, might allow to bypass the need of even more long-term datasets in order to obtain statistically significant results.

5 Conclusion

Our descriptive analysis revealed a significant increase in airborne pollen from alder, hazel, ash and plane trees and a significant decrease in grass pollen in the air of Brussels between 1982 and 2015. Although the total pollen index for birch has not increased significantly, an increasing trend in the annual amount of days above the concentration threshold of 80 pollen grains/m³ was clearly observed. Moreover, the pollen season has tended to end earlier for birch, ash and plane, and the peak concentration of the pollen of plane has been appearing earlier in the year. Close

monitoring remains important as our results suggest that pollinosis due to Betulaceae trees might become more prevalent in the Belgian population and that additional pollinoses, i.e., to ash and plane pollen, might also emerge. The pollen seasons of grasses and mugwort have tended to become less severe. Furthermore, we reported a temporal shift of the grass pollen season, beginning and ending earlier, together with an advance of the annual peak date.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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