

Poaceae pollen in Galicia (N.W. Spain): characterisation and recent trends in atmospheric pollen season

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Abstract Airborne Poaceae pollen counts are greatly influenced by weather-related parameters, but may also be governed by other factors. Poaceae pollen is responsible for most allergic reactions in the pollen-sensitive population of Galicia (Spain), and it is therefore essential to determine the risk posed by airborne pollen counts. The global climate change recorded over recent years may prompt changes in the atmospheric pollen season (APS). This survey used airborne Poaceae pollen data recorded for four Galician cities since 1993, in order to characterise the APS and note any trends in its onset, length and severity. Pollen sampling was performed using Hirst-type volumetric traps; data were subjected to Spearman's correlation test and regression models, in order to detect possible correlations between different parameters and trends. The APS was calculated using ten different methods, in order to assess the influence of each on survey results. Finally, trends detected for the major weather-related parameters influencing pollen counts over the study period were compared with those recorded over the last 30 years. All four cities displayed a trend towards lower annual total Poaceae pollen counts, lower peak values and a smaller number of days on which counts exceeded 30, 50 and 100 pollen grains/m³. Moreover, the survey noted a trend towards delayed onset and shorter

duration of the APS, although differences were observed depending on the criteria used to define the first and the last day of the APS.

Keywords Poaceae · Pollen · Recent trends · Galicia · Atmospheric pollen season

Introduction

Over recent decades, allergic diseases have become more prevalent in industrialised countries. Increased prevalence may be ascribed to a variety of factors, among them an increase or change in airborne pollen distribution (Frei 1998, 2000).

The Poaceae family is the most diverse and prolific herbaceous plant family in urban areas. Its pollen is considered a major aeroallergen, causing symptoms in over 80% of pollen allergy sufferers in Europe (D'Amato et al. 2007). In Spain, 22% of the population suffers from pollen allergies, Poaceae pollen being identified as the key source: positive skin test values range from 97% in northern Spain to 48% in coastal south-eastern Spain (Subiza 2003). The most abundant pollinosis-causing genera in Galicia are *Dactylis*, *Avena*, *Arrhenatherum*, *Vulpia* and *Bromus*.

Recent studies report that pollen allergies are found in 80–90% of childhood asthmatics and 40–50% of adult onset asthmatics (Taylor et al. 2007). Grass pollen has been credited with an etiological role in localised asthma epidemics associated with weather perturbations, particularly thunderstorms and rainfall (Green et al. 2004). Different thresholds are indicated in the bibliography as triggering allergy symptoms: pollen counts of over 50 grains/m³ are reported to cause clinical symptoms in all allergy sufferers (Negrini et al. 1992), while levels of less

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than 30 grains/m³ are considered sufficient to produce nasal hypersensitivity (Rantio-Lehtimäki et al. 1991); counts of less than 10 pollen grains/m³ are reportedly enough to provoke an allergic response in 10% of patients sensitive to Poaceae pollen (Hyde 1972).

Due to the large number of species included in this family, phenological studies tend to reveal an irregular pollen curve with many peaks, as a consequence of overlapping flowering times (Férmández-González et al. 1999; Emberlin et al. 1999; Spieksma et al. 2003). Moreover, phenological behaviour may be influenced by weather conditions.

Grass development is positively influenced by soil-water availability; generally speaking, shallow root systems limit the capacity of grasses to use deeper soil-water supplies (Clary et al. 2004). Pasture ecosystems are especially sensitive to changes in temperature, rainfall (French and Sauer 1974) and water availability (Dickinson and Dodd 1976); temperature is the key parameter for pasture development in cool, rainy areas (Ram and Singh 1988).

Airborne Gramineae pollen counts are strongly influenced by the vegetation present in the area surrounding the spore-trap, while year-on-year oscillations may be attributed to a range of parameters, chief among which are the weather conditions both before and during pollination. Changes in air temperature observed in recent years could affect the atmospheric pollen season (APS), prompting an earlier onset if the weather becomes warmer. Moreover, climate change could modify water availability, the most important factor for grass development. Other major factors resulting from possible changes in land use may also influence the abundance and distribution of herbaceous vegetation.

This paper sought to analyse recent trends in the Poaceae APS, as a function of environmental—and especially weather-related—factors at four sites in Galicia (NW Spain).

Materials and methods

Pollen monitoring

Poaceae pollen data from four aerobiological monitoring stations included in the Galician Aerobiological Network were used (Fig. 1). Pollen sampling was performed using LANZONI VPPS 2000 volumetric traps located on top of several buildings at a similar height (between 10 and 20 m above ground level). Melinex tape coated with a 2% silicone solution was used as the pollen-trapping surface. The exposed tape was cut into seven pieces, which were mounted on separate glass slides. Pollen grains were counted following the model proposed by the Spanish



Fig. 1 Geographical location of study sites

Aerobiological Network (R.E.A.), based on four longitudinal transects along the slides (Galán et al. 2007); daily mean pollen counts were expressed as pollen/m³ of air. Daily mean Poaceae pollen counts from 52 annual records corresponding to the four aerobiological stations were used. The study period began in 1993 in Santiago and Ourense, 1995 in Vigo and 1999 in Lugo; in all cases, the last study year was 2007.

Ten different methods were used to define and limit the APS (Jato et al. 2006). Three of them consider the period over which a given percentage of the total annual pollen count is recorded in the atmosphere: 90% (Nilsson and Persson 1981), 95% (Andersen 1991; Torben 1991) or 98% (Galán et al. 1995). Two of them are based on the period between the first and last day with pollen counts higher or lower, respectively, than a specific level: 30 pollen/m³ (Sánchez-Mesa et al. 2003) or 50 pollen/m³ (Davies and Smith 1973). The criterion suggested by Driessen et al. (1989), who consider the first day as the date when cumulative average daily pollen counts (accumulated from 1 January) reached $\Sigma 50$, $\Sigma 75$, $\Sigma 100$ or $\Sigma 125$ pollen grains was also used. Finally, the start of the APS was selected as the date from which pollen grains are recorded on a continuous basis and identified in tables and figures as “n+n...” (Jato et al. 2002).

Geographic and phytogeographical characterisation of the studied areas

The four cities studied are located in Galicia (NW Iberian Peninsula). The boundary between the Eurosiberian and Mediterranean regions splits Galicia into two territories: Lugo, Santiago and Vigo are located in the Eurosiberian and Ourense in the Mediterranean Region. The Galician

climate is influenced by the Atlantic Ocean. There are, however, a number of climatic differences between the four cities: Ourense displays a stronger Mediterranean influence, with greater oscillations in temperature (summer-winter and day-night) and lower annual rainfall than the other cities (Table 1). Despite the climatic and biogeographical differences between the four cities, the major Poaceae species in the area surrounding traps are very similar. Lugo has a greater surface area devoted to agriculture and pastureland.

Weather-related parameters

The meteorological data used (daily mean, maximum and minimum temperature, sunlight hours and rainfall) were provided by the Spanish Meteorological Agency (AEMET) from weather stations located closer than 1 km to the spore-traps. From them, a total of 490 variables were calculated:

- Monthly and 15-day average daily temperatures (maximum, minimum and mean) and sunlight hours from January to August
- Monthly and 15-day sum of daily temperatures (maximum, minimum and mean), rainfall and number of rainy days from January to August
- The above parameters were calculated for periods of 2, 3, 4 and 5 months (January + February, February + March, March + April, January + February + March; February + March + April; March + April + May; April + May + June; January to June; January to May.....) from both the same year and the previous year.
- Finally, annual and seasonal percentages of normal precipitation (PNP) from the same and the previous year were used. For each period, PNP was expressed as a percentage of the long-term average for 1977–2006.

Statistical treatment

Spearman's rank correlations test was used to determine possible correlations between Poaceae pollen counts and weather-related variables. Linear regression models were developed in order to detect possible trends in major Poaceae pollen behaviour characteristics over recent years. In both cases, the SPSS 15.0 statistical software package was used.

Results

Annual pollen

The average annual total Poaceae pollen values were highest in Lugo (5,735 pollen grains). The lowest average value was recorded in Santiago, with a total of 3,621 pollen grains. In 33% of the years studied, annual Poaceae pollen counts did not exceed 3,000 pollen grains; in Ourense, Vigo and Lugo, this percentage dropped to 7%, 8% and 11% respectively.

The average annual maximum daily mean pollen count was also highest in Lugo (470 pollen/m³), the absolute maximum for the study set as a whole being 835 pollen/m³ recorded in 1999. The lowest value was recorded in Santiago (257 pollen/m³), which also recorded the absolute minimum value of 68 pollen grains/m³ in 2006. Intermediate values were found for Vigo (mean and maximum values of 327 pollen/m³ and 509 pollen/m³, respectively) and Ourense (287 pollen/m³ and 535 pollen/m³).

Daily mean Poaceae pollen counts were also highest in Lugo; values of 30, 50 and 100 pollen grains/m³ were recorded on more days than elsewhere (average 37, 18 and 6 days, respectively); the lowest values were again found for Santiago (average 29, 8 and 3 days, respectively). The

Table 1 Biogeographical and climatic characteristics of study sites

Biogeographic characterisation					
Lugo	Eurosiberian region, Cántabro-Atlántica Province, Galaico-Portugués Sector, Lucense Subsector				
Santiago	Eurosiberian region Cántabro-Atlántica Province, Galaico-Portugués Sector, Compostelano Subsector				
Ourense	Mediterranean region, Carpetano-Iberico-Leonesa Province, Orensano-Sanabriense Sector, Orensano Subsector				
Vigo	Eurosiberian region, Cántabro-Atlántica Province, Galaico-Portugués Sector, Miñense Subsector				
Climatic characterisation					
	Average annual temperature (°C)	Annual maximum temperature (°C)	Annual minimum temperature average (°C)	Annual rainfall (mm)	Geographic location
Lugo	11.5	16.8	6.3	1,084	43°0'N, 7°53'W
Santiago	13.4	18	8.8	1,913	42°53'N, 8°32'W
Ourense	14.8	20.9	8.6	873	42°20'N, 7°52'W
Vigo	14.1	18	10.2	1,683	42°14'N, 8°44'W

reference values were exceeded on 37, 14 and 4 days in Ourense and on 34, 12 and 4 days in Vigo.

The curve for average daily mean pollen counts recorded in all years at each site displays oscillations resulting from the successive flowering of the major species in this pollen type (Fig. 2). June and July were the months in which the largest proportion of the annual Poaceae pollen count was recorded (93% of the total in Lugo, compared with the lowest percentage of 77% in Vigo).

Atmospheric pollen season

Depending on the city and on the defining criterion used, the APS extended on average from early March or mid-March to mid-September. On the basis of the minimum value achieved by the standard deviation, those criteria considering the onset of the APS as the day when daily mean pollen concentration reached 30 pollen/m³ (Sánchez-Mesa et al. 2003) or 50 pollen/m³ (Davies and Smith 1973) and those that consider the onset as the day when 90% (Nilsson and Persson 1981) or 95% of the annual pollen is captured (Andersen 1991; Torben 1991) were the best-fitting criteria in all four study cities (Table 2).

Using the Sánchez-Mesa et al. (2003) criterion, the APS tended to begin earlier in Vigo (mid-May) than in Lugo, Santiago and Ourense (late May). The most marked difference between the earliest and latest onset in the same city was recorded for Vigo (63 days), differences being considerably smaller in Lugo (20 days), Santiago (21 days) and Ourense (29 days). The maximum difference in APS onset date between cities in a given year was found for 1995 (51 days difference). The mean APS

length ranged between 49 days (Lugo and Santiago) and 80 days (Vigo).

Statistical survey

A trend towards lower annual total Poaceae pollen counts was observed in all four cities. The trend was significant ($p < 0.01$) in Lugo and Santiago, whereas in Ourense and Vigo it was a more gentle slope and the trend was not significant (Fig. 3). The same tendency was observed in Santiago even if the 1996 data were eliminated; this year showed a total annual pollen value exceptionally low that could be considered as anomalous. Similar declining trends were noted for the number of days when counts exceeded 30, 50 and 100 pollen grains/m³ (Fig. 4) and for peak pollen counts (Fig. 5).

In order to identify the parameters most influencing observed differences in annual Poaceae pollen counts, correlation tests were applied to the weather-related and pollen-related parameters listed above and annual Poaceae pollen counts (Table 3).

The rainfall-related variables displaying the strongest correlation with annual Poaceae pollen counts (positive correlation, $p < 0.01$) were percentage of normal precipitation (PNP) for the previous year, number of rainy days in the same year, and between February and June and April to July in Lugo. In Santiago, a significant positive correlation was recorded between annual pollen counts and Spring PNP. No significant positive correlation ($p < 0.01$) was obtained for these parameters in Ourense and Vigo, either in the same year or in the previous year.

Few temperature-related variables displayed a significant correlation with annual pollen counts. A negative correlation

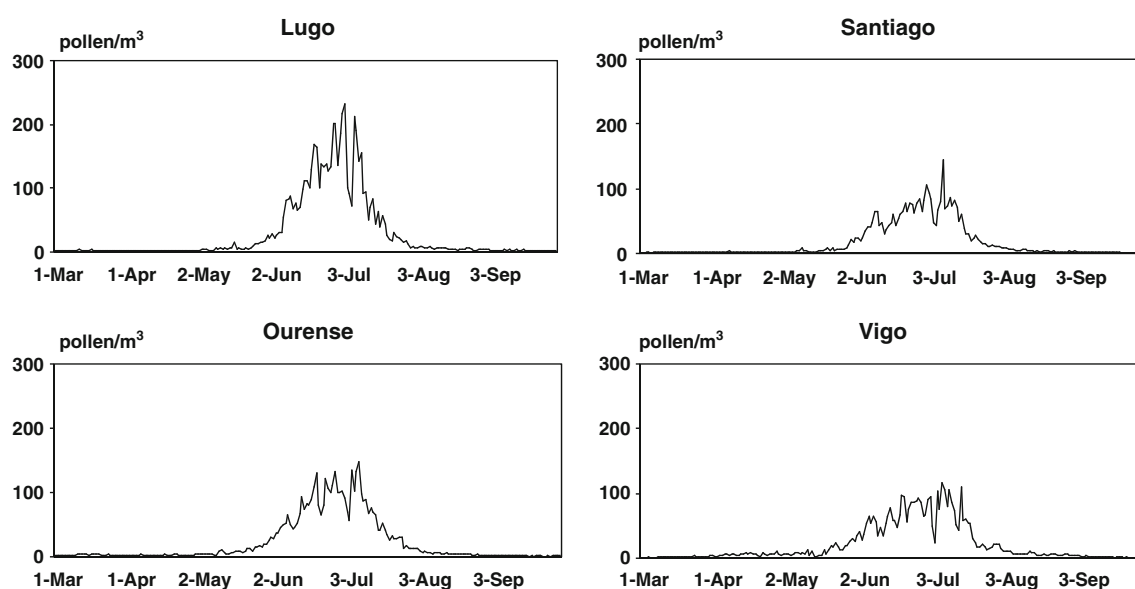


Fig. 2 Average daily mean Poaceae pollen counts

Table 2 Average of the first, last day and length of the atmospheric pollen season calculated with the different criteria

	1st day	SD	Last day	SD	Length	SD	1st day	SD	Last day	SD	Length	SD
Lugo						Santiago						
$\Sigma 50$	29 Mar	21.7	4 Sep	5.94	160	17.9	27 Mar	23.7	29 Aug	7.11	156	22.2
$\Sigma 75$	13 Apr	18	25 Aug	5.94	134	22.2	12 Apr	24.7	19 Aug	7.66	129	31.1
$\Sigma 100$	29 Apr	14.5	15 Aug	6.42	109	27	23 Apr	23.3	10 Aug	7.83	109	37.6
$\Sigma 125$	8 May	12	9 Aug	6.63	93	29.4	3 May	21.2	6 Aug	7.48	95	41.6
1st day>30	29 May	4.75	16 Jul	7.4	48	34.4	28 May	5.08	15 Jul	5.57	48	28.7
1st day>50	1 Jun	4.28	12 Jul	6.75	41	40.9	2 Jun	5.86	10 Jul	6.26	38	38.9
90%	29 May	2.26	23 Jul	1.71	54	8.48	10 May	13.9	31 Jul	3.29	82	22.6
95%	10 May	6.87	9 Aug	2.8	91	13.3	13 Apr	17	20 Aug	4.36	129	18.1
98%	26 Mar	17.5	2 Sep	2.58	160	8.32	14 Mar	21.7	11 Sep	3.81	181	11.4
n+n...	5 Apr	29.8	15 Sep	8.34	163	26.9	1 Apr	28.1	11 Sep	8.1	162	23.6
Ourense						Vigo						
$\Sigma 50$	7 Mar	22.5	6 Sep	6.57	183	13.6	18 Mar	17.6	14 Sep	3.74	180	10.1
$\Sigma 75$	17 Mar	22.2	25 Aug	6.36	161	16.8	27 Mar	16	4 Sep	4.29	161	12.5
$\Sigma 100$	28 Mar	24.6	17 Aug	6.12	142	21.4	3 Apr	14.4	27 Aug	4.58	146	14.9
$\Sigma 125$	8 Apr	22.5	10 Aug	5.76	125	25.4	10 Apr	15.1	27 Aug	6	133	19.1
1st day>30	26 May	6.24	20 Jul	3.03	56	20.3	12 May	13.4	26 Jul	5.08	75	28.5
1st day>50	31 May	5.9	16 Jul	3.88	46	26.8	20 May	10	16 Jul	4.47	57	30.2
90%	5 May	14.7	26 Jul	3.35	82	28.4	24 Apr	13	6 Aug	6.08	104	22.5
95%	2 Apr	19.2	13 Aug	4.97	133	18.3	5 Apr	11.8	26 Aug	3.36	143	11.5
98%	3 Mar	21.1	8 Sep	6.62	189	10.7	15 Mar	13.1	19 Sep	4.08	188	7.44
n+n...	21 Mar	52.9	21 Sep	5.27	184	27.2	10 Mar	50.1	1 Oct	6.84	205	22.4

was noted between annual pollen counts and average maximum temperature over the first fortnight in June in Lugo and Santiago. A similarly negative correlation ($p < 0.05$) was noted with mean and maximum June temperatures, in all

cities except Vigo, where results were not statistically significant.

A significant correlation was not detected between sunlight hours and annual pollen in every city.

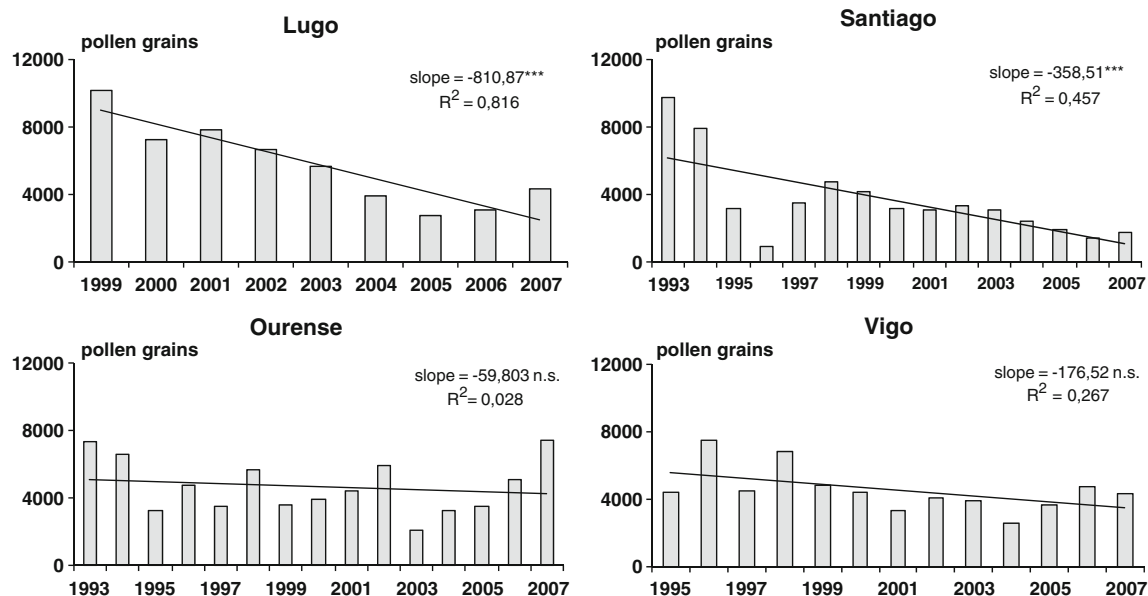


Fig. 3 Annual Poaceae pollen trend: slope and adjusted R^2 are shown (*** $p < 0.01$; ** $p < 0.05$)

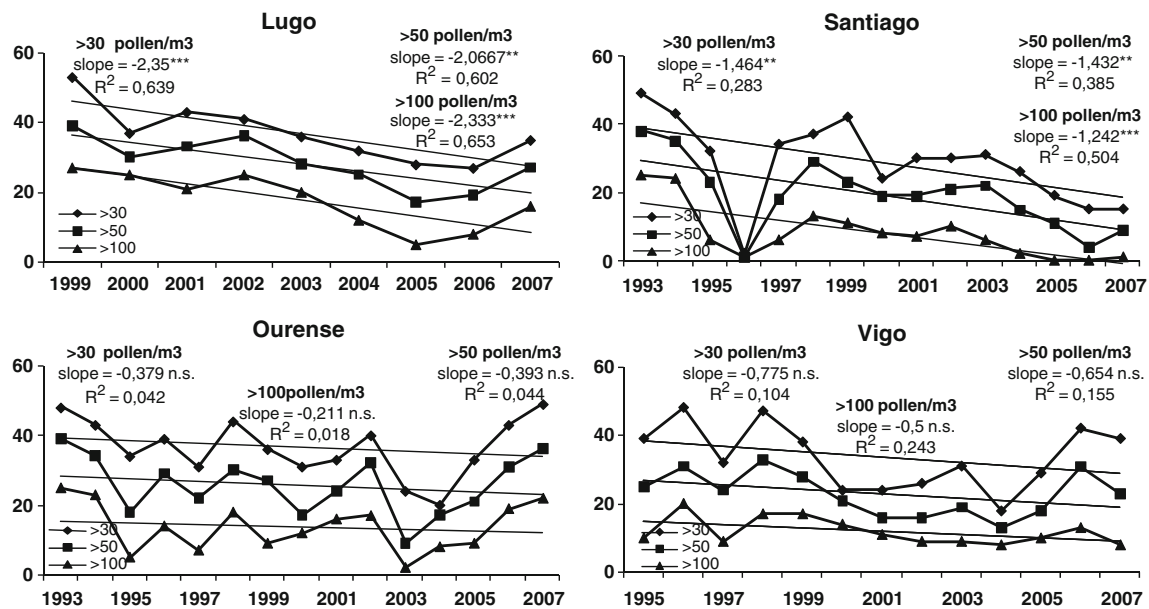


Fig. 4 Trend for number of days with daily mean pollen counts exceeding 30, 50 and 100 pollen/m³. Slope and adjusted R^2 are shown (*** $p < 0,01$; ** $p < 0,05$)

A stronger positive correlation was recorded between July and August pollen counts and the annual pollen counts at all sites, particularly in Lugo, Santiago and Ourense.

When the tendency in monthly pollen was analysed, a trend towards an increase in June pollen count and a strong positive correlation between mean maximum temperature in June and percentage of Poaceae pollen captured in the same

month were observed in all study cities (adjusted $R^2 = 0.962$ in Lugo, 0.780 in Ourense and 0.758 in Vigo in each case, $p < 0.01$. In Santiago $R^2 = 0.622$, $p < 0.05$).

The observed trend in the onset date and length of the APS differed according to the criteria used to define it (Table 4). In Lugo, a trend towards earlier onset was observed using the 98%, 95% and 90% criteria, although the trend only achieved statistical significance ($p < 0.05$) for

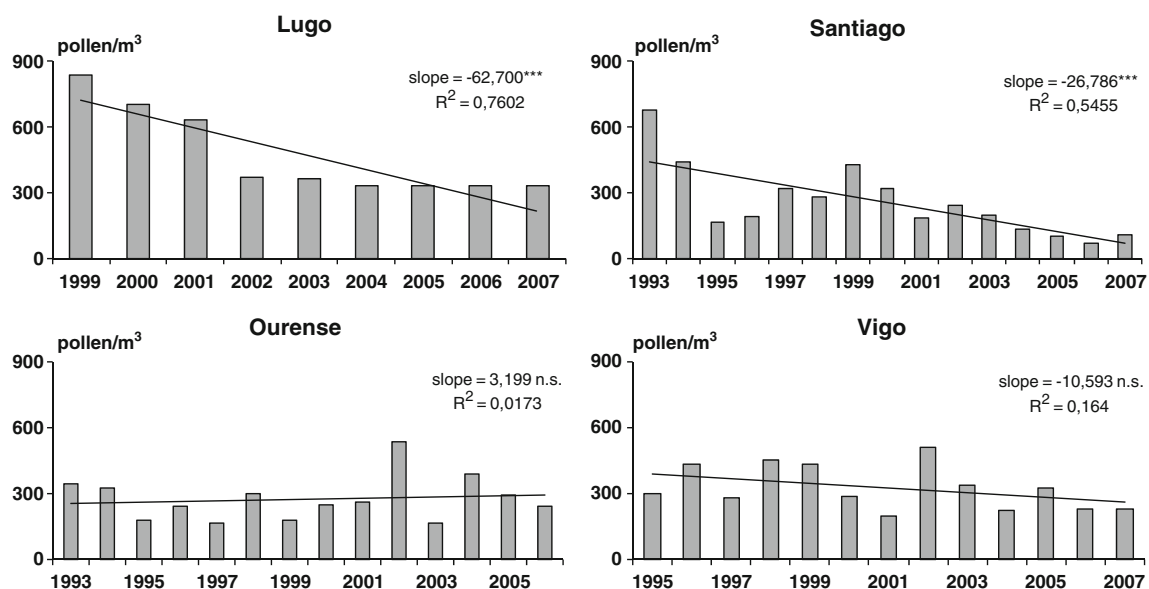


Fig. 5 Trend for peak daily pollen counts: slope and adjusted R^2 are shown (*** $p < 0,01$; ** $p < 0,05$)

Table 3 Correlation coefficient for annual pollen versus rainfall, temperature, and recorded pollen in previous periods ($***p<0.01$)

Annual pollen-rainfall, temperature, sun and pollen correlations				
Metorol. parameter	Variable	R^2	Variable	R^2
Lugo			Santiago	
Rainfall (mm)	Previous annual PNP	0.905***	Spring PNP	0.754***
Rainfall (days number)	Year	0.867***	Jul+Aug	-0.655***
	Feb–Jun	0.845***	Mar 2nd fortnight	-0.767***
	Apr–Jul	0.800***		
Maximum T ^a	Jun 1st fortnight mean	-0.800***	Jun 1st fortnight mean	-0.754***
Pollen	Jul 1st fortnight sum	0.933***	Jul 1st fortnight sum	0.954***
	Aug 1st fortnight sum	0.833***	Jul 2nd fortnight sum	0.836***
	Jul sum	0.833***	Aug 1st fortnight sum	0.687***
	Aug sum	0.833***	Aug 2nd fortnight sum	0.643***
			Jul sum	0.957***
Ourense			Vigo	
Rainfall (days number)	1st fortnight Aug	-0.695***		
Maximum T ^a	Apr 1st fortnight sum	-0.646***		
Pollen	Jul 1st fortnight sum	0.725***	Jul 1st fortnight sum	0.730***
	Jul 2nd fortnight sum	0.696***		
	Aug 1st fortnight sum	0.772***		
	Aug 2nd fortnight sum	0.843***		
	Jul sum	0.739***		
	Aug sum	0.700***		

the 95% criterion. The other criteria suggested a non-significant tendency towards delayed onset. Santiago showed a clear trend towards delayed onset using most APS-defining criteria, with the exception of 1st day>30

pollen/m³ and 50 pollen/m³. A strongly significant trend ($p<0.01$) was obtained using the $\Sigma 50$, $\Sigma 75$, $\Sigma 100$ and $\Sigma 125$ criteria. The same trend was observed in Ourense, although was only significant with the 98% criterion

Table 4 Trend regression models for atmospheric pollen season onset vs. length

APS criteria	$\Sigma 50$	$\Sigma 75$	$\Sigma 100$	$\Sigma 125$	1st day>30	1st day>50	90%	95%	98%	n+n...
Lugo										
Onset trend	+2.78 n.s.	+3.43 n.s.	+2.68 n.s.	+2.82 n.s.	+1.20 n.s.	+0.77 n.s.	-0.33 n.s.	-2.15**	-3.12 n.s.	+3.33 n.s.
Length trend	-5.88 n.s.	-7.38**	-7.22**	-6.93**	-2.78 n.s.	-1.53 n.s.	-0.10 n.s.	+2.72 n.s.	+2.88 n.s.	-9.53 n.s.
Santiago										
Onset trend	+3.26***	+3.93***	+3.81***	+3.78***	-0.13 n.s.	-0.31 n.s.	+0.54 n.s.	+0.39 n.s.	+2.10**	+1.16 n.s.
Length trend	-4.38**	-5.31**	-5.30**	-5.21**	-0.46 n.s.	-0.48 n.s.	+0.13 n.s.	+0.26 n.s.	-1.66 n.s.	-1.80 n.s.
Ourense										
Onset trend	+1.69 n.s.	+1.95 n.s.	+2.26 n.s.	+2.53 n.s.	-0.72 n.s.	-0.83 n.s.	+1.33 n.s.	+1.83 n.s.	+1.70**	+3.48 n.s.
Length trend	-2.26 n.s.	-2.50 n.s.	-2.76 n.s.	-2.86 n.s.	0.36 n.s.	0.39 n.s.	-1.58 n.s.	-2.23 n.s.	-1.09 n.s.	-3.87 n.s.
Vigo										
Onset trend	+1.62 n.s.	+1.92 n.s.	+1.81**	+2.16**	+2.30 n.s.	+1.21 n.s.	+1.16 n.s.	+1.13 n.s.	+0.64 n.s.	+1.84 n.s.
Length trend	-1.12 n.s.	-2.03 n.s.	-2.14 n.s.	-2.93 n.s.	-2.54 n.s.	-1.81 n.s.	-0.91 n.s.	-0.98 n.s.	+0.38 n.s.	-1.86 n.s.

Slope and adjusted R^2 are shown ($***p<0.01$; $**p<0.05$)

($p < 0.05$). Finally, a tendency towards delayed onset was observed with all criteria in Vigo, but only with $\Sigma 100$ and $\Sigma 125$ was significant ($p < 0.05$).

A tendency towards shorter APS length was observed using most criteria in all cities; however, level of significance varied depending on the defining criteria. The most significant results were obtained in Lugo and Santiago; no statistically significant trend was discerned in Ourense or Vigo (Table 4).

Spearman's correlation test was performed in order to identify the major variables likely to influence the length of the APS (Table 5). A negative correlation was observed with maximum June temperature in Lugo and Santiago, and with maximum temperature in the second fortnight of June in Vigo. The adjusted R^2 value and significance of this correlation varied depending on the criteria used to define the atmospheric pollen season. In Ourense, the strongest and most significant correlation was with rainy days during the second fortnight in May, which seems to have a positive influence on APS length.

Finally, a regression analysis was performed to chart recent trends in major weather-related variables in comparison to those observed for the same variables over the last 30 years (1977–2007) in Santiago, Ourense and Vigo (Table 6). Weather data from Lugo for that period were not available. A significant rising trend was recorded for annual average temperature in the three cities over the last 30 years. Similar results were obtained with monthly maximum temperatures from January to June. The rainfall variables behaviour was not uniform. Annual, winter and autumn rainfall displayed a significant negative trend over the last 30 years in Vigo; no significant tendency was recorded in Santiago and Ourense for the same period and parameters. Finally, the percentage of normal precipitation (PNP) showed a similar tendency to that of rainfall, with a significant decline in annual, spring,

winter, and autumn PNP in Vigo over the last 30 years. In Santiago, a trend towards increasing summer PNP was noted for the same period.

An apparent trend towards rising temperatures was detected but it was not significant. A significant negative trend for annual and summer rainfall in Lugo and for annual and spring rainfall in Ourense was noted. Annual PNP displayed a significant decline in Lugo and Ourense while spring PNP did so in Ourense. Elsewhere trends, though always negative, were not statistically significant.

Discussion

Poaceae pollen is the most prevalent airborne pollen in Galicia (Aira et al. 2005). It is a risk factor for patients with respiratory diseases and the major cause of pollinosis in this area (Arenas et al. 1996). In Lugo, Ourense and Vigo, daily mean pollen counts exceeded 30 pollen grains/ m^3 on more days than in Santiago. This level is widely considered sufficient to trigger respiratory symptoms (Rantio-Lehtimäki 1991).

Poaceae pollen counts in Galicia varied by city and year, the highest counts being recorded in Lugo in 1999. Of all the stations in the Spanish Aerobiological Network, peak Poaceae pollen counts in Lugo are exceeded only by those located in Extremadura in eastern Spain and Ciudad Real in central Spain (cf. Rea 1995–2004; Fernández-González 1999). The onset of the APS is usually delayed with respect to more southerly Spanish cities, and both mean pollen counts and monthly counts tend to be highest in June and July. From all the studied cities, Vigo tended to begin the APS around 10–15 days earlier.

Poaceae was the most prevalent pollen type in the total annual pollen count in all cities and years except for 2006

Table 5 Correlation coefficient, for pollen-season length versus weather-related parameters

APS criteria	Test	$\Sigma 50$	$\Sigma 75$	$\Sigma 100$	$\Sigma 125$	1st day > 30	1st day > 50	90%	95%	98%	n+n...
Lugo											
June Max. T ^a average	R^2	-.751**	-.790**	-.723**	-.698**	-.782**	-.689**	-.237	.363	-.134	-.840***
Santiago											
June Max. T ^a average	R^2	-.549**	-.639**	-.550**	-.562**	-.335	-.479	.020	-.689	.004	-.367
Ourense											
May 2nd fortnight (rainy days n°)	R^2	.684***	.672***	.666***	.642***	-.070	0.448	.422	.367	.478	.534**
Vigo											
June 2nd fortnight Max. T ^a sum	R^2	-.468	-.594**	-.531	-.747***	-.374	-.590**	-.724***	-.742***	-.637**	-.566**

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

Table 6 Trend regression adjusted R^2 values observed with the weather-related parameters observed from 1977 to 2007 and from the study period

Meteorological trends

Lugo			Santiago		Ourense		Vigo	
Variable	R^2		Variable	R^2	Variable	R^2	Variable	R^2
1977–2007	Meteorological data not available		Annual mean T ^a	0.104***	Annual mean T ^a	0.061***	Annual mean T ^a	0.059***
			Jan max T ^a avg	0.097***	Jan max T ^a avg	0.074***	Jan max T ^a avg	0.102***
			Feb max T ^a avg	0.111***	Mar max T ^a avg	0.106**	Feb max T ^a avg	0.082***
			Mar max T ^a avg	0.164***	Apr max T ^a avg	0.123**	Mar max T ^a avg	0.105**
			Apr max T ^a avg	0.116**	May max T ^a avg	0.137***	May max T ^a avg	0.098**
			May max T ^a avg	0.167***	Jun max T ^a avg	0.134***	Annual rainfall	−33.19***
			Jun max T ^a avg	0.151***			Winter rainfall	−17.48***
			Summer PNP	5.30**			Autum rainfall	−11.18**
							Annual PNP	−2.80***
							Spring PNP	−2.10**
							Autum PNP	−4.22**
1993–2007	Annual rainfall	−61.55**	Any significant trend		Annual rainfall	−55.84**	Any significant trend	
	Summer rainfall	−17.09**			Spring rainfall	−10.04**		
	Annual PNP	−6.699**			Annual PNP	−5.82***		
					Spring PNP	−5.37**		

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

in Santiago, accounting for 10% of total annual pollen every year (Aira et al. 2005).

According to all models assessed by the IPCC, increases in global mean surface temperature are likely to continue throughout the twenty-first century (IPCC 2007), the rate of increase varying according to the geographical area. Temperature trends are expected to display regional differences, and their influence on phenological events will not be uniform. Changes in climatic conditions affecting atmospheric pollen season are likely to be more evident in early-spring tree species. A number of European areas have reported an earlier onset in species such as alder, hazel, birch or oak (García-Mozo et al., 2006; Frei and Gassner 2008; Emberlin et al. 2002), and it will be even earlier if the weather becomes warmer. The evidence is less clear, however, for late-spring species (Emberlin et al. 2002). A trend towards higher daily mean pollen concentrations has also been signalled for birch by Frei and Gassner (2008). For Poaceae, a tendency towards earlier and more severe grass pollen seasons in north London has been noted in recent years (Emberlin and Smith 2006). The influence of climate change on annual Poaceae pollen counts is not evident (Spieksma et al. 2003), although a declining trend is reported for yearly Poaceae pollen counts in Leiden by Jäger et al. (1991) and in London and Derby by Emberlin et al. (1993, 1999). Although the low number of years does not allow to produce results that are sufficiently robust, a general trend towards falling annual grass pollen counts was detected in all four Galician cities ($p < 0.01$ in Lugo and Santiago). The statistical results could have been

influenced by the decline of the pollen counts in the last 5 years in all the cities included in the investigation. The lowest annual Poaceae pollen counts were registered from 2004 to 2007 in Lugo and Santiago (exception to 1996 in the last city), from 2003 to 2005 in Ourense and 2001, 2004 and 2005 in Vigo.

Changes in rainfall patterns are less marked than in temperature, due largely to the complexity of rainfall distribution over space and time (Meehl et al. 2007). Although model simulations suggest a global increase in mean rainfall, a substantial decline (of up to 20%) is likely in the Mediterranean region. Rainfall is expected to decrease over most of the Iberian Peninsula, particularly in summer and spring, although season's patterns are likely to vary (Rio González 2005).

Poaceae development is strongly influenced by both temperature and rainfall. Water availability is a major determinant of growth; the key factor in drought resistance is root depth, which varies significantly among species. Other factors, particularly related to weather conditions, affect pollen dispersal and transport during the flowering period and thus prompt annual variations in pollen count. Even pollen release and dispersal may be negatively influenced by rainfall; higher rainfall over the months prior to pollen season onset, when grasses start their physiological growth, results in increased pollen production (Ong et al. 1995; Green et al. 2004). Grass pollen season patterns are governed by environmental factors, and studies comparing airborne pollen counts in different climates report differences in the importance of weather-related parameters

(Galán et al. 1995). The low number of years considered in the statistical analysis could bring us not wholly stable results; consequently, greater importance should be attached to those results displaying higher adjusted- R^2 values and greater statistical significance ($p < 0.01$). Even so it is difficult to produce an accurate interpretation of the correlation between meteorological parameters and annual pollen in Galicia which appear to be positively affected by rainfall, particularly spring rainfall in the case of Lugo and Santiago. In all study cities, the years with the lowest annual pollen count (especially 2004 to 2007) matched with the lowest rainfall years, as much annual as winter and spring precipitation.

Drought is a protracted period of deficient precipitation resulting in extensive damage to crops. Several indexes can be used to evaluate drought periods. This study used the PNP, which divides actual accumulated precipitation over a given period of time by average precipitation over the same period for a certain area, the result being expressed as a percentage. Historical average precipitation for a certain period (normal precipitation) is obtained from average rainfall values over not less than 30 years (here, from 1977 to 2007). The most notable correlation between annual Poaceae pollen counts and meteorological variables was recorded for annual PNP for the previous year in Lugo, with high adjusted R^2 values and strong statistical significance ($+0.905$, $p < 0.01$). Other rainfall parameters also appear to exert a positive influence on annual Poaceae pollen counts. This highlights the crucial role of water availability for seed development and thus for grass growth and flowering the following year. The number of pre-seasonal rainy days correlated positively with annual pollen counts, especially in Lugo.

Only Vigo showed a significant trend towards a declining rainfall and PNP (annual, winter and autumn) over the 30-year reference period. However, an evident decline was noted considering only the study period, especially in Lugo and Ourense, both the most inland and driest cities. Correlations recorded between annual pollen counts and rainfall parameters, and the observed trends in both rainfall and PNP, may account—at least in part—for the decline in grass pollen counts over recent years, which are likely to increase over the coming years, especially in the south and inland areas of Galicia, if the tendency towards increasing drought is maintained. However, other non-meteorological parameters could also affect the pollen counts.

The significant trend towards increasing temperatures over the months prior to the onset of the pollen season, which appeared to be constant over the recent years, may well lead to even earlier onsets. Nevertheless, the delay observed in some years and sites in this survey may be due more to reduced water availability than to variations in

temperature. The advance of flowering in the various species may be prompted not only by high temperatures (Sparks et al. 2000), but also by increased water availability (Yuan et al. 2007). In Gramineae, León Ruíz (2008) reports that the driest years display shorter phenophase duration.

The use of different methods to define and limit the APS gave rise to major differences in the resulting length. Further research is required into a number of factors, such as pollen transport possibilities and phenological considerations, in order to select the most adequate criterion for defining the APS. This is of particular importance in studies of climate change (Jato et al. 2006). The availability of more data in the future will also increase the stability of the regression models obtained in this survey.

Correlations noted between annual total pollen and monthly pollen counts in July and August, together with the negative correlation between pollen counts and June temperature or the negative one between maximum temperature of June and the length of APS, may be indicative of an earlier and shorter flowering period in years with higher June temperatures, leading to a shorter pollen season and thus to lower pollen counts in July and August. By contrast, rainy and/or cool springs would favour grass development, prolong the flowering period and thus lengthen the atmospheric pollen season.

Weather conditions are not, in themselves, sufficient to account for the changes observed in the Poaceae APS; other factors need be taken into account to explain year-on-year changes and trends in pollen counts. Emberlin (1997) reported a marked decrease in the severity of grass pollen seasons in North London from the 1960s to the early 1970s with a continued decline through to the mid-1980s when the trend levelled off. This author signals as one of the causes the changes in land use and agricultural practices taking place in the sixties and early seventies.

Land use changes modify the proportion of tree, scrub and pasture formations and the amount of cropland. Galicia has seen major changes in land use over the last few decades. Chief among these is a considerable reduction in arable land (a decline of almost 22% over the last 30 years in the area around Ourense). A larger amount of land is now covered by trees and scrub (which have increased by 12% and 7%, respectively, around Ourense). Urban land use has doubled, although in percentage terms the increase from 1.5% to 3.22% is less significant (López Quintas 2007). The same changes were also observed in the surroundings of the cities.

Finally, forest fires can also cause changes in land use, removing existing vegetation and favouring a new ecological re-colonization. Some Poaceae species play a pioneering role in the re-colonization of burnt land. The reduction in tree cover also favours an increased presence of Poaceae species. Thus, forest fires may well have some impact on airborne

grass-pollen counts, not only by clearing vegetation but also by favouring recolonization of affected lands; *Agrostis*, *Avena*, *Arrhenatherum*, *Holcus*, *Festuca*, *Anthoxanthum* are among the most frequently-cited pioneer species in land recolonization following forest fires in Galicia (Dalda 1978; Casal et al. 1984). Recolonisation may take place from rhizomes that persist in the soil or by the growth of seeds whose germination and growth is enhanced by the minerals added to the soil as a result of the fire. The frequency and intensity of forest fires vary considerably and both human factors and summer weather conditions—particularly in July and August in Galicia—may also influence the affected land.

A study has been made of the land affected by forest fires from 1993 to 2007 in the area around the aerobiological traps, using data provided by the Galician Regional Council. The total surface area comprised: 1,215 km² in Lugo, 814 km² in Santiago, 469 km² in Ourense and 386 km² in Vigo. In Ourense, as much as 4% of land was affected in 2005. Of the four cities studied, Ourense displays the strongest Mediterranean influence, in terms of both climate and phytogeography; this leads to a greater fire risk. An increase in July–September temperatures was noted, particularly from 2000 onwards, with average maximum temperatures exceeding 30°C in 2003, 2005, 2006 and 2007, accompanied by low rainfall levels in 2001, 2003 and 2005. Even so, no significant correlation was noted in any of the four cities between amount of burnt land and annual pollen counts the following year. However, this may account, in part, for the absence of correlation between total annual pollen and weather-related parameters, particularly in Ourense and Vigo where forest fires are more common.

Conclusions

The greatest risk posed by Poaceae for pollen allergy sufferers in Galicia lasts from mid-May to mid- or late July; during this period, daily mean pollen counts may exceed 30 pollen grains/m³. The highest pollen counts tended to be recorded in June and July in all four study sites.

In the four cities studied, a general trend was observed towards lower annual grass pollen counts, lower annual peak values and a lower number of days on which pollen counts exceeded 30, 50 and 100 pollen grains/m³. Annual total pollen counts in Galicia appear to be affected more by rainfall than temperature, and especially by spring rainfall in Lugo and Santiago.

Despite the trend towards increasing temperatures in the months prior to pollen season onset, the delay observed in the onset of the APS may be due more to reduced water availability than to rising temperatures.

The criteria selected to define and limit the APS should be taken into account when interpreting results, especially when pollen is considered as an indicator of climate change. Generally shorter and later Poaceae pollen seasons were observed.

Weather related factors alone are insufficient to account for the Poaceae APS trends observed. Others factors such as land use and forest fires must be taken into account.

New data that will be recorded over the coming years will show whether the results obtained in this study will be confirmed.

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