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Influence of precipitation and temperature on airborne pollen concentration in Santiago de Compostela (Spain)

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This paper presents data of airborne pollen concentration of *Pinus*, *Platanus*, *Quercus*, *Betula*, *Poaceae* and *Castanea*, the most abundant pollen types, during the last eight years, in Santiago de Compostela (NW Iberian Peninsula). We determined their respective principal pollen release periods and analysed statistically the influence of the main meteorological parameters on their pollen concentration, obtaining a negative correlation with precipitation and a positive correlation with temperature, in the majority of the cases, during these years. A detailed study of accumulated pollen values, in relation to accumulated average temperatures and the precipitation distribution, enabled us to establish a relationship between these parameters and the principal pollination period of each of these taxa.

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There are basically two kinds of factors related to pollen production and release among plant species: biologic and climatic. Although pollen productivity is an intrinsic character of a plant, the maturing process of pollen grains inside the anthers, as well as the opening of the anthers, is related to climatic conditions (Bassani et al. 1994, Frenguelli et al. 1994, Tormo et al. 1996). The relationship between both factors has been cited in numerous aerobiological studies that point to precipitation and air temperature as the parameters that have the greatest influence on the release of pollen grains and the time that they remain in the air (Frenguelli et al. 1991, Caramiello et al. 1994, Dahl & Strandhede 1996).

In this paper we used the data of the six most abundant taxa in the atmosphere of Santiago de Compostela during 1993–2000, e.g. the anemophilous tree taxa *Pinus*, *Platanus*, *Betula* and *Quercus*, the amphiphilic pollinated trees of *Castanea*, and *Poaceae*. The daily average values of pollen concentration of each taxon during its principal pollen release period (PPP) were correlated for each individual year and for the eight-year total, with the precipitation and air temperature values, in order to ascertain their influence in Santiago de Compostela. Likewise, we calculated the ranges of accumulated average temperature (AAT), counted from January 1st onwards and every 10 days before the onset of the PPP, required to trigger the pollination process of each taxon and the influence of precipitation during the principal pollination periods.

MATERIAL AND METHODS

The city of Santiago de Compostela (Fig. 1) is located in the northwest corner of the Iberian Peninsula (UTM 29TNH3647), 40 km from the Atlantic coast, within the Atlantic Province of the

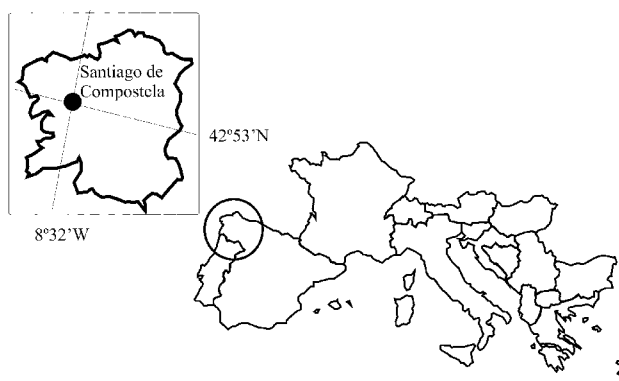


Fig. 1. Sampling site: Santiago de Compostela.

Euro-Siberian Region (Izco 1987). The vegetation associated with this zone includes forests of *Quercus robur* along with different coniferous species, such as *Pinus pinaster* and *P. radiata*, and the ornamental flora in the urban centre (mainly Cupressaceae, Taxaceae and Taxodiaceae).

The city has an oceanic and humid climate, with fairly constant precipitation throughout the year, around 1,288 mm annually, with relatively dry periods during July and August. Its annual average temperature is 12.9°C, with absolute maximum of 33°C in July and absolute minimum of –0.4°C in January (Carballeira et al. 1983). The University of Santiago Astronomical Observatory (situated in a neighbourhood of the pollen trap) supplied the meteorological data in this study.

Aerobiological samples were collected with a Hirst volumetric pollen trap (Hirst 1952), Lanzoni VPPS-2000 model, situated 27 m above ground level in the south of the city. This system, which has a constant air intake (10 litres/minute), enables weekly sampling using a silicone-soaked Melinex tape, from which seven fractions are obtained corresponding to daily samples. We followed the Spanish

Aerobiological Network's proposal in order to determine the pollen count, expressing the results as No. of pollen grains $\times m^{-3}$ of air (Domínguez et al. 1991).

We followed the proposal of Nilsson & Persson (1981) in order to calculate the PPP of the different taxa, eliminating 5% of the pollen concentration at the beginning and end of each year. In relation to the resulting periods, we applied non-parametric statistics due to the characteristics of the samples (pollen counts and meteorological data).

The Spearman rank correlation test was used with the help of the *Statistica* computer programme in order to establish correlations between pollen data with the meteorological data. The values of accumulated average temperature (AAT) were calculated retrospectively (Alba & Díaz de la Guardia 1998) by taking into account daily average temperature from January 1st, and from every ten days

onwards, until the starting day of the pollination season. Thresholds of temperature between 0–9°C, with a step of 1°C, were used in order to establish the value above which daily temperatures would be effective. In each case, the mean value (mean), the standard deviation (SD) and the coefficient SD/mean were calculated for the eight years, selecting as temperature and starting date of accumulating temperature, those that minimize the coefficient.

RESULTS

The annual sum of daily pollen concentrations in the city of Santiago during the last eight years was, on average, more than 15,000 grains, with minimum values in 1996 (4,759

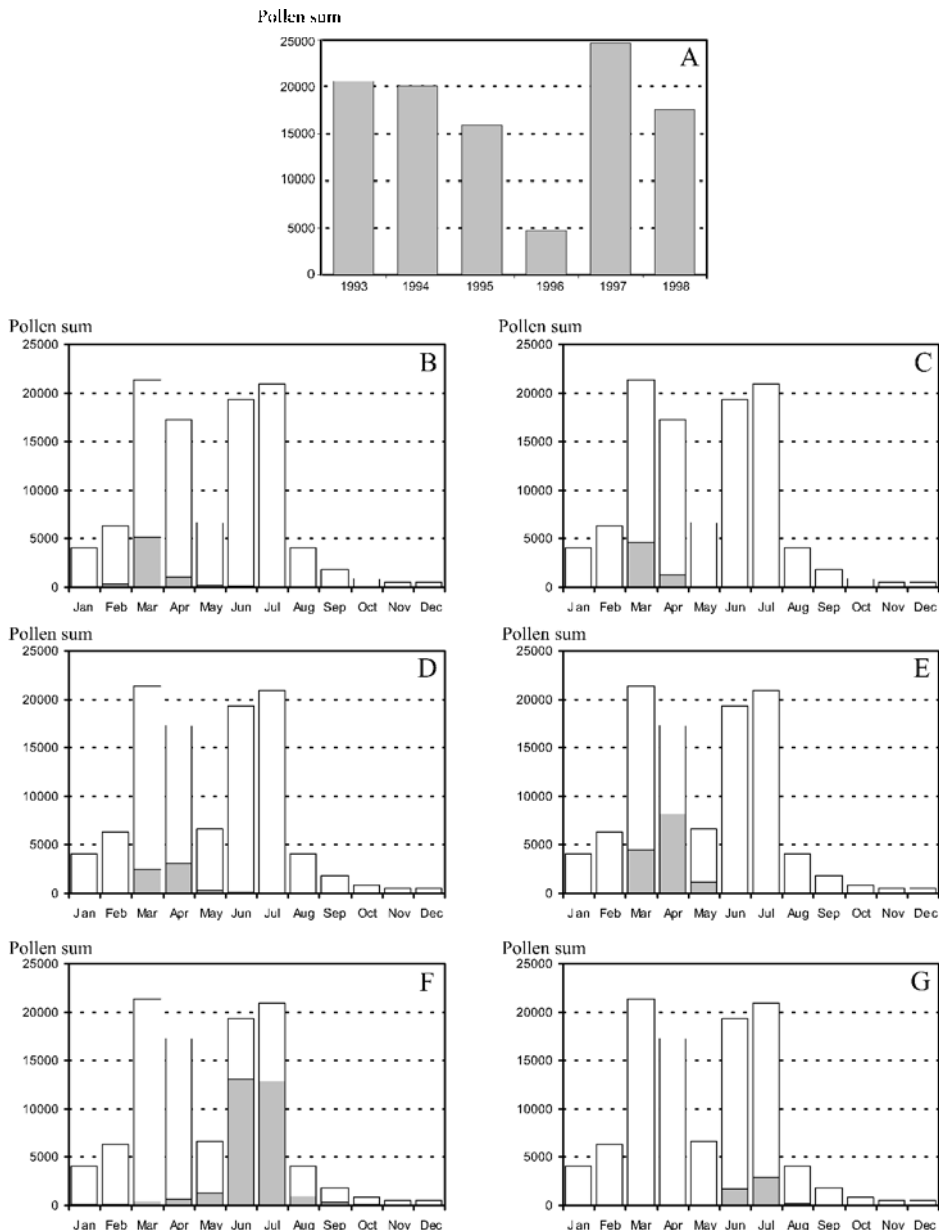


Fig. 2. Pollen sums (No. of pollen) in Santiago de Compostela: (A) All investigated pollen taxa; (B) *Pinus*; (C) *Platanus*; (D) *Quercus*; (E) *Betula*; (F) *Poaceae*; (G) *Castanea*. B-G. Comparison to mean (1993–2000) of the total monthly pollen sum.

grains) and maximum in 1997 (24,655 grains). Two phases of greater abundance are observed during each year, one in March–April with a high representation of *Betula* (with an average representation of 40% in this period), *Pinus* (15%), *Platanus* (12%) and *Quercus* pollen (11%), and another in June–July with a predominance of Poaceae (59% being the average representation in these two months) and *Castanea* (16%) (Fig. 2). These six taxa represent between 57 and 71% of the total annual pollen identified.

The correlation between the PPP concentrations of the different taxa and the precipitation and average temperature data in that period (PPP) was highly significant (99%) for the total study period (1993–2000), in all taxa with the exception of *Castanea*, being positive for temperature and negative for precipitation. For each year and taxon in which the correlation was significant, the influence of temperature was positive, except in 1993 and 1997 with *Pinus*, while precipitation had a negative influence on the pollen concentration of all of the taxa regardless of the year (Table I).

In chronological order, *Pinus* was the taxon with the earliest flowering. Its PPP began in mid-February (1998–2000) or March (1993–1997) with duration between 35 and 102 days and total annual values that varied between 173 and 2019 grains. The AAT required to trigger the onset of flowering from January 1st on average was $601.6 \pm 120.1^\circ\text{C}$ (Table II), with the lowest value (401.5°C in 1999) coinciding with precipitation of moderate intensity (Fig. 3). The AAT calculated with threshold lower than 5°C showed a coefficient of variation high and very similar in all cases (0.20), which indicates that the sum of temperatures in this taxon is not very appropriate as a predictor of the onset of the pollen season.

For its part, the PPP of *Platanus* was concentrated in March and April and was shorter than that of *Pinus*, between 12 and 51 days, with total annual pollen between 187 and 2445 grains and the AAT-over 1°C of $743.0 \pm 73.4^\circ\text{C}$ (Table II). The SD/mean coefficient obtained using threshold of 0, 1, 2 or 3°C was the same, being higher if we consider any other temperature as threshold. The years with the maximum concentration of this pollen type (1997 and

Table II. Mean values of average accumulation temperature (AAT), starting date and temperature threshold that showed the lowest SD/mean ratio in each taxon for the period 1993–2000.

	AAT ($^\circ\text{C}$)	SD	Date	Threshold ($^\circ\text{C}$)	SD/Mean
<i>Pinus</i>	601.6	120.1	Jan 1st	0	0.20
<i>Platanus</i>	743.0	73.4	Jan 1st	1	0.10
<i>Quercus</i>	406.3	20.5	Jan 20th	4	0.05
<i>Betula</i>	507.9	37.1	Jan 10th	4	0.07
Poaceae	1445.8	275.6	Jan 1st	0	0.19
<i>Castanea</i>	1724.6	41.9	Jan 10th	2	0.02

1998 with 2455 and 1779 total annual pollen grains respectively) coincided with very short pollination periods (15 and 12 days respectively) and an absence of precipitation (Fig. 4).

During these years *Quercus* had a very low atmospheric pollen concentration until the second fortnight of March or beginning of April, with its PPP lasting between 37 and 75 days with minimum total annual values of 179 pollen grains (1996) and maximum of 2152 pollen grains (1995), and an AAT-over 4°C from January 20th of $406.3 \pm 20.5^\circ\text{C}$ (Table II). The best coefficients were obtained with temperature threshold lower than 5°C and considering the end of dormancy between January 10th and January 20th. The two years of greatest pollen values (1995 and 1997) coincided with the absence of precipitation during the first 20 days of the PPP (Fig. 5).

Betula pollen had total annual values of between 966 and 7381 grains, mainly collected from March to May, with a PPP of between 28 and 61 days and an AAT-over 4°C from January 10th of $507.9 \pm 37.1^\circ\text{C}$. As *Quercus*, the best coefficients were obtained with temperature threshold lower than 5°C , considering the end of dormancy on January 10th. The year of greatest abundance (1997) coincided with the driest PPP of the study period, with only 13 mm of precipitation on 3 days (Fig. 6).

The two most abundant pollen types during the summer months were Poaceae and *Castanea*. The PPP of Poaceae lasted from April/May to July/August, with a duration of

Table I. Correlations between the PPP pollen concentrations and meteorological parameters for each year and the whole period (1993–2000). (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.1$ and (N.S.) p not significant.

	1993	1994	1995	1996	1997	1998	1999	2000	1993–2000
Precipitation									
<i>Pinus</i>	−0.213**	−0.273N.S.	−0.102N.S.	−0.058N.S.	−0.300**	−0.337***	−0.254**	−0.224N.S.	−0.409***
<i>Platanus</i>	−0.304**	−0.541***	—	−0.440*	—	—	−0.609***	−0.550***	−0.562***
<i>Quercus</i>	−0.340***	−0.107N.S.	−0.483***	−0.120N.S.	−0.361**	−0.468***	−0.371***	−0.386***	−0.405***
<i>Betula</i>	−0.317**	−0.558***	−0.599***	−0.335*	−0.478***	−0.325***	+0.292N.S.	−0.202N.S.	−0.363***
Poaceae	−0.256**	−0.340***	−0.276***	−0.425***	−0.394***	−0.590***	−0.431***	−0.247*	−0.343***
<i>Castanea</i>	−0.119N.S.	−0.445**	+0.120N.S.	−0.347**	−0.125N.S.	−0.364**	−0.372**	−0.315*	−0.142**
Average temperature									
<i>Pinus</i>	−0.216**	+0.736***	+0.532***	+0.388***	−0.273*	+0.344***	+0.054N.S.	+0.131N.S.	+0.223***
<i>Platanus</i>	−0.178N.S.	+0.430**	+0.190N.S.	+0.826***	−0.034N.S.	+0.0680**	+0.613***	+0.165N.S.	+0.456***
<i>Quercus</i>	−0.156N.S.	+0.052N.S.	+0.527***	−0.096N.S.	+0.225N.S.	+0.570***	−0.040N.S.	−0.173N.S.	+0.157***
<i>Betula</i>	+0.182N.S.	+0.257N.S.	+0.731***	+0.457***	−0.212N.S.	+0.413***	+0.142N.S.	+0.154N.S.	+0.349***
Poaceae	+0.320***	+0.295**	+0.456***	+0.615***	+0.640***	+0.542***	+0.414***	+0.216*	+0.486***
<i>Castanea</i>	−0.198N.S.	+0.609***	+0.163N.S.	+0.306*	+0.253*	+0.168N.S.	+0.547***	−0.009N.S.	+0.042N.S.

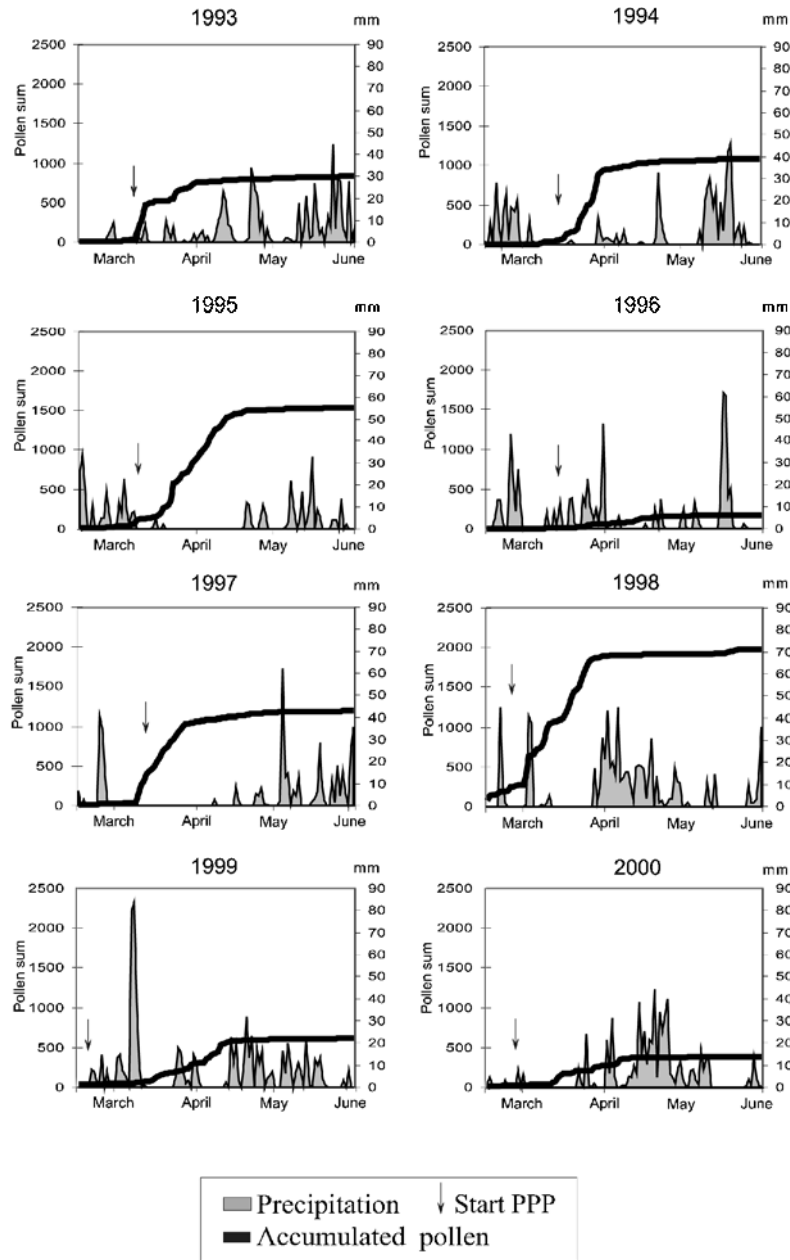


Fig. 3. Accumulated *Pinus* pollen (No of pollen) and precipitations during the years of study (1993–2000).

between 59 and 113 days and total annual values of between 951 and 9835 pollen grains, reaching a AAT range from January 1st of $1445.8 \pm 275.6^\circ\text{C}$. Temperature threshold of 0, 1 or 2°C keeps a SD/mean coefficient of 0.19, but it is higher if we consider higher thresholds. In 1993 and 1994 its pollen concentration increased sharply during the third week in June, with average daily concentrations that, on several days, exceeded 400 and 600 grains $\times \text{m}^{-3}$ respectively, while the increase was gradual in the other years, reaching total accumulated concentrations that did not surpass 50% of the previous years (Fig. 7). *Castanea* was the taxon with the latest pollination, since its PPP lasted from mid-June to July/August, with a duration of between 29 and 60 days,

reaching total values of between 255 and 1344 pollen grains (Fig. 8) with an AAT-over 2°C from January 10th of $1724.6 \pm 41.9^\circ\text{C}$ (Table II). In this genus the differences in the coefficient of variation (SD/mean) are very low during January 1st to March 1st, so according to the flowering of this tree it is better to consider March 1st as the onset of heat accumulation.

DISCUSSION

An analysis of the correlations between pollen concentration and the meteorological parameters for each of the years under study shows that *Betula* and Poaceae were constantly

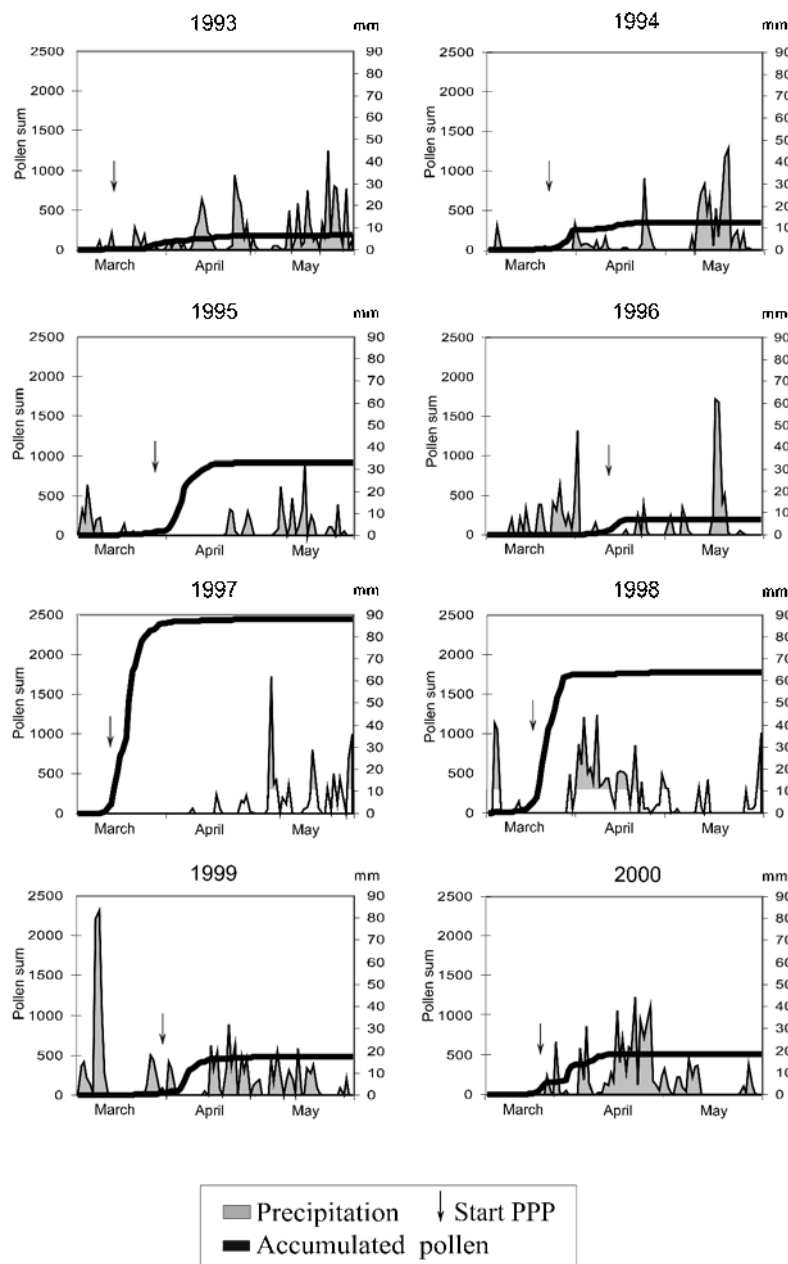


Fig. 4. Accumulated *Platanus* pollen (No of pollen) and precipitations during the years of study (1993–2000).

influenced by precipitation and *Poaceae* and *Pinus* by temperature, although in the latter case the correlation sign differed according to the year.

Precipitation cleans the atmosphere of pollen, so that both its intensity and annual distribution can be related to the duration and intensity of the PPP. The wettest March months of the entire study period were in 1996 (196 mm on 18 days) and 1999 (320 mm on 18 days), with less precipitation in April; in 1996 March coincided with the onset of *Pinus* pollination, resulting in the minimum pollen concentration of the six years analysed.

On the other hand, the wettest April months were in 1998 (419 mm on 28 days) and 2000 (439 mm on 28 days) with the

pollen curve levelling off due to the constant precipitation in this month. Therefore, the limited concentration of *Pinus* pollen in 1996 can be related to the continuous precipitation recorded during the period that is biologically favourable for this tree's pollination. However, the cleaning effect caused by the precipitation from mid-March to mid-April, 1993, explains, at least partly, why the pollen concentration that year was practically half that of 1995.

The same pattern was observed for the other spring-flowering taxa (*Platanus*, *Quercus*, *Betula*). *Platanus* has a brief but intense PPP concentrated in March–April; in the years in which these months had spells of several dry days

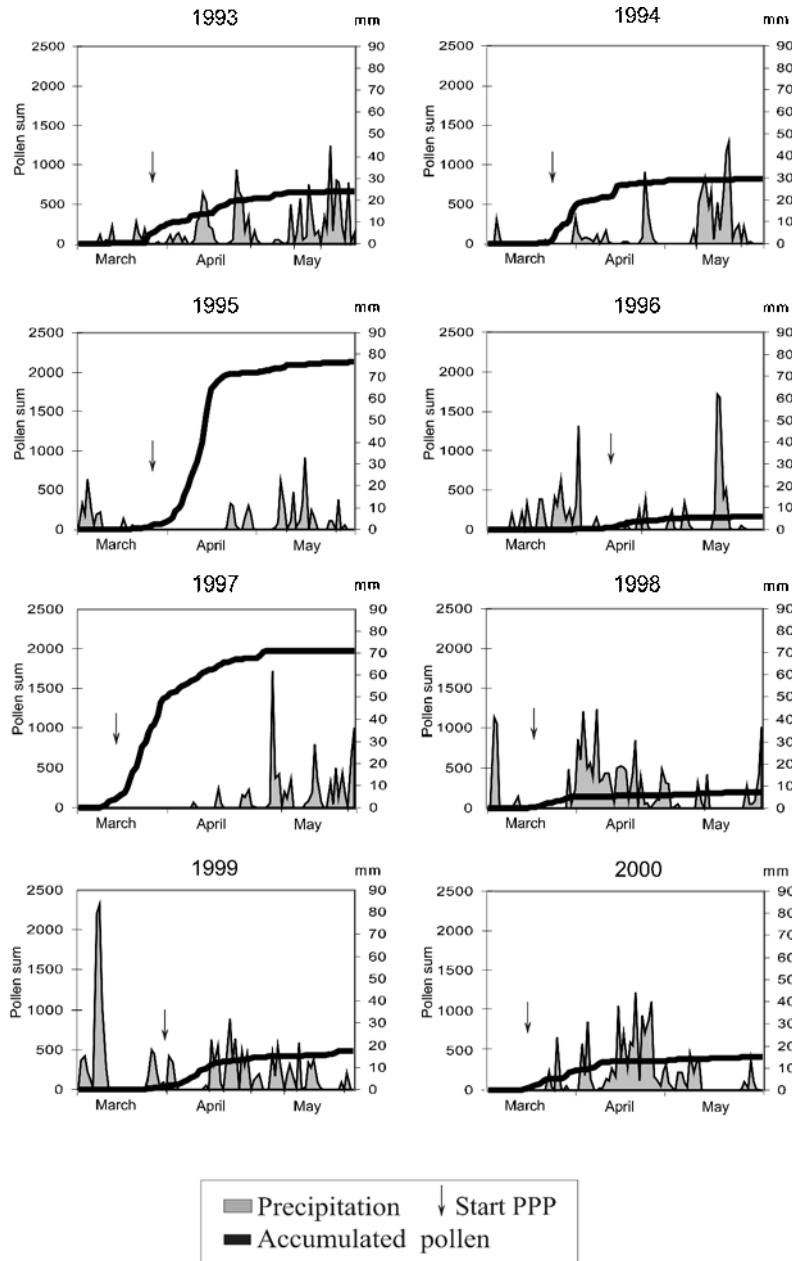


Fig. 5. Accumulated *Quercus* pollen (No of pollen) and precipitations during the years of study (1993–2000).

(1997 and especially 1998) there were peaks of average daily concentrations of $478 \text{ grains} \times \text{m}^{-3}$, while there were smaller total annual pollen concentrations in the years with continuous precipitation (mainly 1993 and 1996).

The small concentrations of *Quercus* pollen in 1996 and 1998 coincided with precipitation during the second fortnight of March and the first fortnight of April, which corresponds to this tree's flowering period. For its part, the greatest concentrations of *Betula* pollen were recorded during the first fortnight of April. In 1993, 1994 and 2000 a gradual increase in the accumulated curve was observed. Although in 1995, 1997 and 1999 the evolution of

the pollen concentrations at the onset of the PPP was very similar, coinciding in 1995 and 1997 with zero precipitation, in these years the annual total was very different, which indicates that other factors should be considered.

In relation to the summer-flowering taxa, we observed that the influence of precipitation during the period determined their pollen concentration. The years of less *Castanea* pollen in the atmosphere, 1995 and 1996, coincided in the first case with considerable precipitation in July (109 mm on 13 days), with no relation being found between the limited values of 1996 and the precipitation recorded during its PPP. In June and July of the last

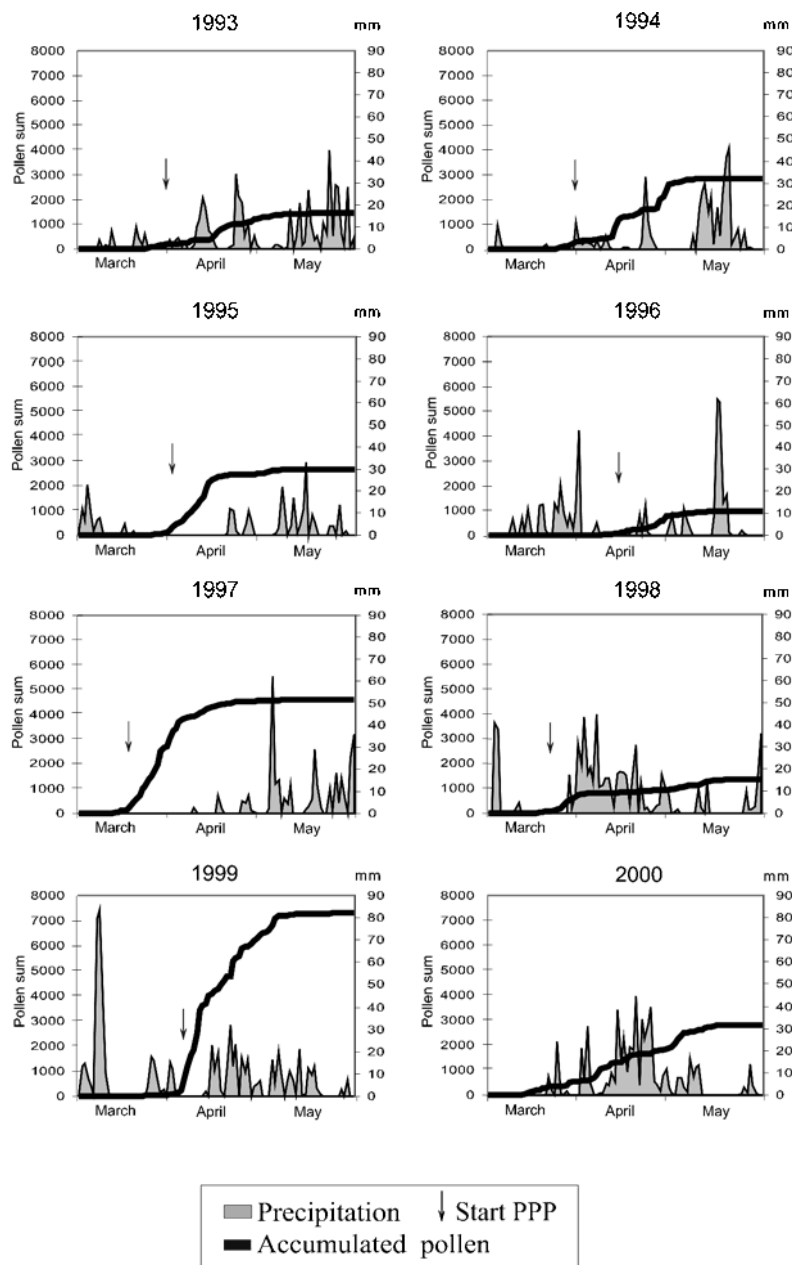


Fig. 6. Accumulated *Betula* pollen (No of pollen) and precipitations during the years of study (1993–2000).

two years (1999–2000), the maximum concentration was registered, coinciding with less precipitation in relation to previous years.

Although it is not possible to determine an exact date for the beginning of the PPP of a specific taxon, the ranges of AAT can be used to predict the onset of the pollination phase and the time it will remain in the air (Latorre 1999, Norris-Hill 1998). Applying this standard to our data, we observed that in the studied species, the dormancy period ends in the beginning of January, at the moment in which the plant starts the heat accumulation (Corden et al. 2000). In the same way, the variation coefficients (SD/mean) showed similar results when the temperature threshold is

lower than 5°C, so, is preferable to use the AAT without any threshold (Clot 2001). With temperature thresholds above 5–6°C the ratio SD/mean increases sharply, that is in accord with the temperature registered in January and February (rarely above 10°C) in this geographic area.

For *Betula* the best coefficient is obtained with AAT from January 10th, about fifteen days before that in other northern localities (Laaidi 2001), in which the onset of PPP also occurs fifteen days later. Nevertheless, the onset of pollination period occurs when the plant accumulates a temperature much higher than that found by Clot (2001) or Corden et al. (2000). The total annual concentration of *Betula* pollen recorded in 1995 was 42% less than that of

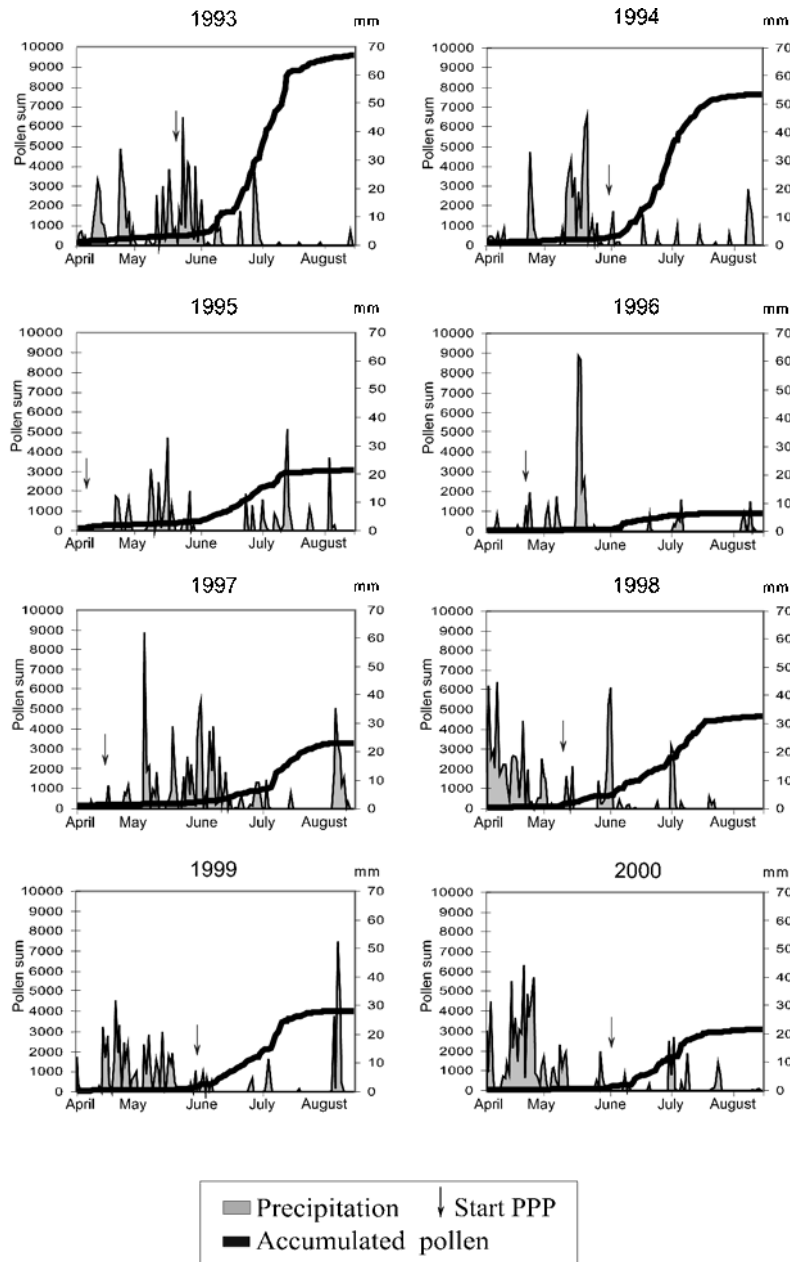


Fig. 7. Accumulated Poaceae pollen (No of pollen) and precipitations during the years of study (1993–2000).

1997; the absence of precipitation during the PPP in both years seems to indicate that this difference in the annual total could be associated with the moment in which the AAT required for the onset of the PPP was attained, resulting in a difference of 12 days earlier in 1997, during which 2682 grains of this taxon were recorded, which mark the difference between both years. A biannual cycle was observed in the period of study, with high pollen concentrations in 1995, 1997 and 1999 alternating with low concentrations in 1996, 1998 and 2000, as was mentioned by Emberlin et al. (1993) and Spieksma et al. (1995).

The results obtained with *Quercus* and *Platanus* indicate

that the optimum temperature threshold is 4 and 1°C, respectively, though the differences obtained if we used temperatures over 0–5°C are minimum, according with results obtained by González-Minero et al. (1999). In other south-localities of Spain, where the annual average temperature is higher, a threshold of 11°C is considered appropriate (García-Mozo et al. 2000).

The results obtained with *Pinus* are unsuitable because the variation coefficient obtained is high enough in all cases (whether if we use a temperature threshold or not), that makes us to think that the sum of temperatures is not a good predictor in this species.

In the case of *Castanea*, the differences observed in the

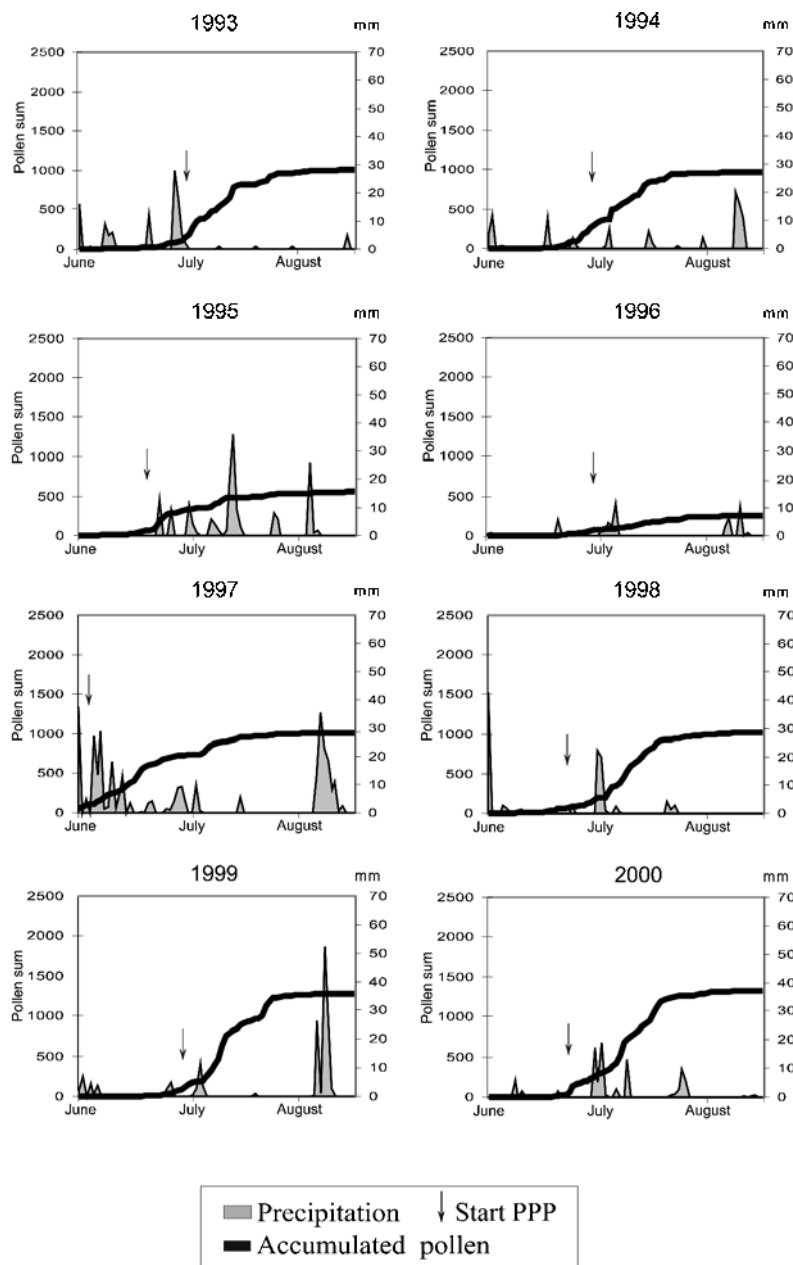


Fig. 8. Accumulated *Castanea* pollen (No of pollen) and precipitations during the years of study (1993–2000).

ratio SD/mean are low from January 1st or March 1st that is in relation with the process of flowering of this tree in Galicia. Along with Poaceae the difference obtained using temperature thresholds are not significant, due to the summer flowering of these taxa, on which the importance of chilling hours is lower.

Meteorological factors are not the only cause of the differences observed in the severity of the pollen seasons analysed. It is well known that some taxa, especially trees, undergo alternating cycles in their pollen production. The large-scale mobilization of reserves in order to increase pollen and fruit production would reduce the production of

the following year. Specifically, in the case of *Quercus* and *Betula*, biannual alternation with the odd asynchronous intermediate period has been cited, although its cause is unknown (Nilsson & Persson 1981, Jäger et al. 1991, Spieksma et al. 1995, Corden & Millington 1999). In this study, based on the data of eight years, it is not possible to establish rigorously any periodicity; however, we observed that *Pinus* and *Platanus* follow a similar frequency every two years, with high values in 1994–1995, 1997–1998, 1999–2000 and lower concentrations in 1993 and 1996. No rhythmicity was observed in the summer-flowering species for the eight years studied.

The influence of meteorological factors generally explains the differences observed in the duration and intensity of the pollen seasons during the years studied, with the exception of 1996, whose limited pollen levels are apparently not explained by the meteorological differences recorded.

CONCLUSIONS

The most abundant pollen types in Santiago de Compostela in the last eight years were five tree taxa (*Pinus*, *Betula*, *Platanus*, *Quercus* and *Castanea*) that represented on average 44% of the total atmospheric pollen concentration and the Poaceae pollen with a 30%.

In general we observed that the influence of precipitation during the principal pollination period determined the annual pollen concentration in the atmosphere, obtaining a negative correlation with precipitation and a positive one with temperature, in the majority of the cases.

The AAT used to predict the onset of the pollination phase can be calculate from the beginning of January, specially in spring-flowering trees. In the case of *Pinus*, new parameters must be analyzed in order to improve these results. In the summer-flowering taxa studied (*Castanea* and Poaceae), the results are similar with AAT from January 1st or March 1st, so we can think that in these species the influence of chilling hours is lower.

The ratio SD/mean using different temperature thresholds is very similar with temperature over 0°C to 5°C, so we propose calculating the AAT directly, simplifying the analysis. Nevertheless, a more detailed study of each taxon, using any other phenologic index, is necessary to obtain the best conclusions.

Although a period of eight years is probably not sufficient to detect cycles in the pollination, in the case of *Betula* a biannual alternation from 1995 has been observed and *Pinus* and *Platanus* have showed maximum values every two years.

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