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Models for predicting the onset of pollination and daily pollen concentrations of *Betula* sp.

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Abstract

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This paper analyses *Betula* pollen levels and hourly variation in two localities in the NW Iberian Peninsula (Santiago de Compostela and Ourense) from 1993 to 2001, with the objective of evaluating regional differences.

It also describes models for predicting the onset of the pollen season and pollen concentrations, with mean and maximum temperature, thermal range and hours of sunshine as prediction parameters. Prediction capacity was assessed using the aerobiological data of 2002.

Key words: Betula sp., meteorological parameters, NW Iberian Peninsula, prediction.

Introduction

Birch pollen is one of the main causes of spring allergies, mainly in north and central Europe (D'Amato et al. 1991; D'Amato and Spieksma 1992; Spieksma et al. 1995; Wüthrich et al. 1995). In the NW Iberian Peninsula between 1% (Belmonte et al. 1998) and 24% (Ferreiro et al. 1998) of the human population is sensitive to this pollen. In the localities of this study, allergy occurrence has been found between 19% (Dopazo 2002) and 13% (Arenas et al. 1996), indicating a clear relationship between respiratory pathology and periods with the greatest concentrations of atmospheric pollen. Predicting the onset of the pollen season, as well as average daily concentrations, several days in advance, is of great importance to allergic patients. It enables them to take appropriate measures in order to minimize the symptoms. On the other hand, knowing the time of day when the maximum concentrations are expected, helps to organise daily activities, avoiding being outdoors when the allergen's concentration is highest.

Meteorological factors strongly influence pollen concentrations. The thermal conditions during the period prior to flowering control the onset of the pollen season. Precipitation and relative humidity may delay the pollination by hindering pollen dispersion, even when the thermal sum has been attained (Clot 2001; Corden et al. 2000; Latalowa et al. 2002). On the other hand, other meteorological parameters, especially temperature, precipitation, wind direction and speed are known as factors which strongly influence pollen release and dispersion. This explains to a large degree the variations in inter- and intra-daily pollen concentrations.

The pollen data of Santiago de Compostela and Ourense were used, since it comprises the longest series available in our geographical area, and also reveals the variation within the NW Iberian Peninsula. Precipitation and temperature are the meteorological variables most frequently used to predict pollen concentration (Clot 2001; Dahl and Strandhede 1986; Laaidi 2001; Latolowa et al. 2002). In the localities studied, both parameters strongly influence atmospheric pollen load, as shown in previous papers (Dopazo 2001; Méndez 2000).

The objective of this paper is predicting the onset of the pollen season, as well as daily levels and diurnal variations in these geographical areas.

Material and Methods

Figure 1 shows the geographical location of the two cities. The specific influence of the Atlantic Ocean establishes climatologic and biogeographical differences in both localities. Due to its proximity to the sea, Santiago de Compostela (42°53'N 8°32'W) has an oceanic climate, while Ourense (42°N 7°51'W), situated approximately 100 km inland, is more continental. The former belongs to the Euro-Siberian region (Cantabrian-Atlantic Province, Galician-Portuguese Sector, Compostela Sub-Sector), while Ourense is included in the north-western corner of the Mediterranean Region (Carpeto-Iberian-León Province, Ourense-Sanabria Sector, Ourense Sub-Sector; Izco 1987).

In Santiago de Compostela the vegetation consists of deciduous forests of *Quercus robur*, which is the most characteristic taxon. In Ourense, situated in the valley of the River Miño, the forests are dominated by the presence of *Quercus pyrenaica*, along with *Quercus suber*, and due to the Atlantic influence, there is also an abundance of *Quercus robur*. The Mediterranean influence is indicated by the taxa present in its serial substitution stages, with a predominance of *Cytisus multiflorus*, along with *Cytisus striatus*, *Cytisus scoparius*, *Genista polygaliphylla* and *Pteridium aquilinum*.

The presence of *Betula* in both locations is associated with humid terrain, in river valleys, where *Betula pendula* is predominant; it has also been recently introduced into city gardens as an ornamental tree.

The most significant meteorological factor is the precipitation pattern of Santiago de Compostela, since it includes intensive rainfall from the coast, making it one of the rainiest localities in Galicia. It receives an average of 1,288 mm per year, although annual values around 2,000 mm have been recorded in the last five years. The rainy season covers most of the year except July and August, during which only occasional light rainfall occurs. In Ourense, however, rainfall does not exceed an average of

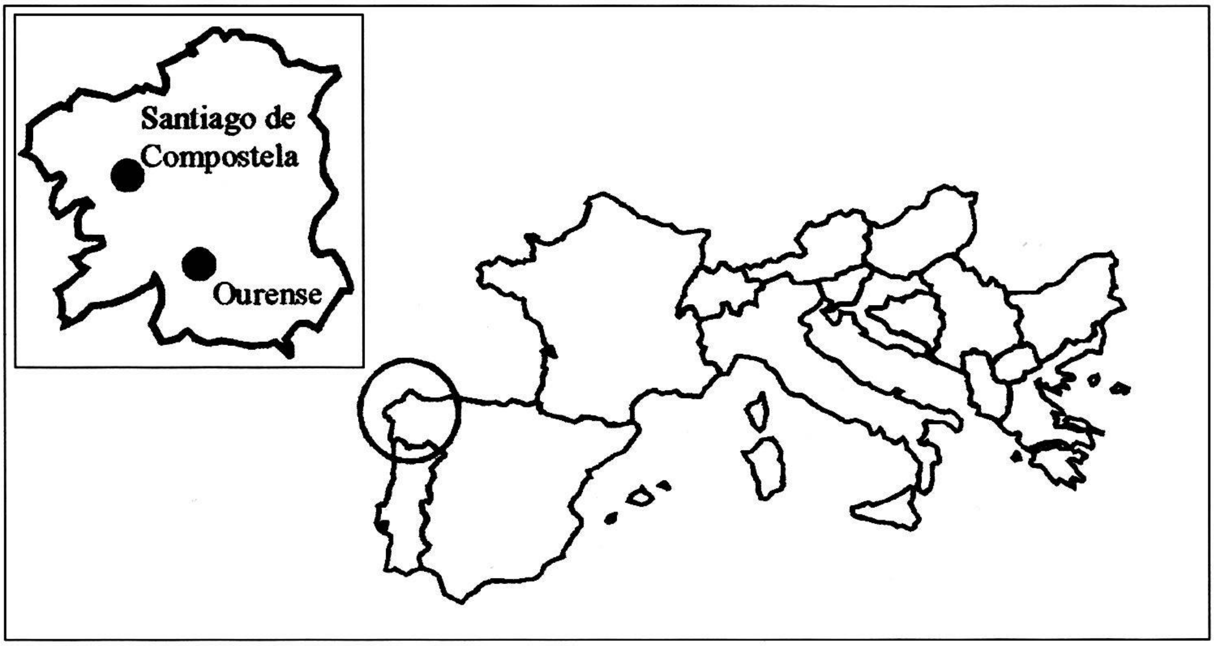


Fig. 1. Geographical situation.

800 mm annually, with a well-defined dry season during the summer months. The parameter that best defines this locality is thermal range, with minimum temperatures of −8.6 °C and maximums of 42.2 °C, and an average of 23 days per year with sub-zero temperatures.

The sampling period began on January 1st, 1993, and continued until now. Data from 1993 to 2001 were used to obtain an individual model in each locality, and the data of 2002 served to check the models. Aerobiological control was carried out by Hirst pollen traps (Hirst 1952), Lanzoni VPPS-2000 model, 25 m above ground level in obstacle-free areas, guaranteeing free air circulation. The traps operate independently for a week, sucking in a constant air volume of 10 litres/minute. The instructions of the Spanish Aerobiology Network (Domínguez et al. 1991) were followed to prepare the samples and count the pollen.

Four different methods were followed to define the principal pollination period (P.P.P.). The pollen season was considered the period covering 90% of total annual pollen (Nilsson and Persson 1981) or 95% (Torben 1991) or 98% (Galán et al. 1995) and finally the criterion of Jato et al. (2002), which establishes the onset of the pollen season as the day when 1 pollen grain m-3 is collected continuously (followed by no more than 2 consecutive days without pollen). From the four approaches we selected the method with the smallest standard deviation (SD) during the sampling years.

To determine the thermal sum initiating the onset of pollination, we used mean and maximum daily temperatures, calculating their sum, establishing the onset date as January 1st and trying different time periods with 10-day intervals. We chose January 1st as the first onset date since during the first days of this month with increasing temperature a change of tendency is observed. The sum was calculated by including mean and maximum daily temperatures or the same values minus threshold values between 0 and 9 °C, at intervals of 1 °C initially and of 0.5 °C with temperatures yielding the smallest SD/mean quotient (negative values were counted as 0). We selected as the best

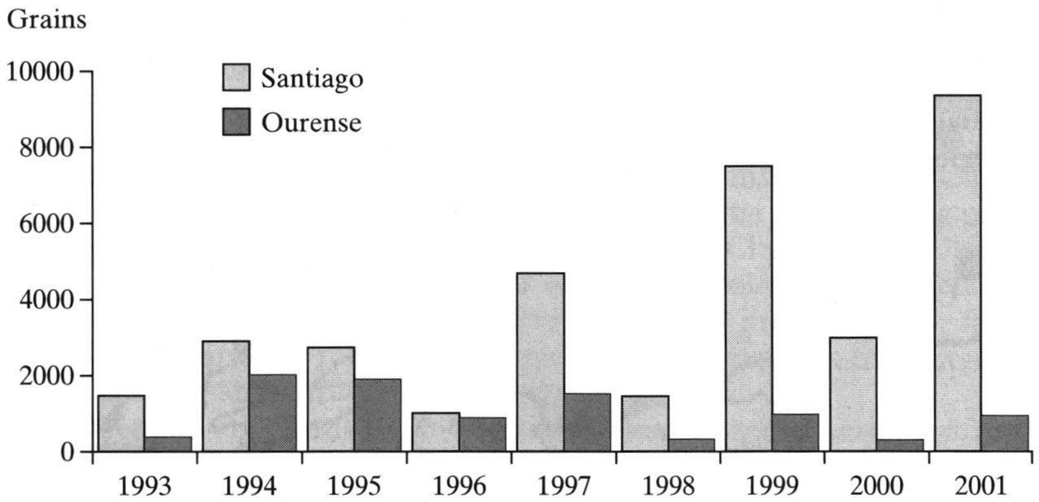


Fig. 2. Annual pollen of *Betula* in Santiago de Compostela and Ourense.

parameter and temperature the one with the smallest relationship between standard deviation and the mean (SD/mean).

The data were processed statistically to obtain a model for predicting the mean daily pollen concentration. First this was done independently for each locality and then jointly for both locations. Scheffé's test was carried out to exclude significant differences among the sampling years. The daily pollen concentrations were then correlated to the corresponding meteorological data by Spearman's correlation test, in order to ascertain which parameters influence primarily the atmospheric pollen levels. Finally, a linear regression analysis was carried out to establish a model for predicting daily pollen concentrations, using one or more meteorological parameters as prediction variables for pollen concentration.

Diurnal behaviour was determined according to the method of Galán et al. (1995), which designs an ideal day with the P.P.P. data. By calculating the daily mean and eliminating the days with a precipitation record as well as those with a value below the mean. The selected days are used to calculate the mean 3 hours-period, including the previous and subsequent hour.

Results

The aerobiological yields between 1993–2001 were averaged to obtain the annual total percentage of *Betula* pollen for each locality: 21% in Santiago (3,722 grains) and 5% in Ourense (972 grains), with a large variations between among years. In both localities there was a biennial alternation beginning with 1996, which was more pronounced in Santiago (Fig. 2). The daily maxima during the entire period wer 1,186 grains m^{-3} (14-4-1994) in Santiago and 254 m^{-3} (28-4-1994) in Ourense, with daily concentrations greater than 30 grains m^{-3} during an average of 21 days in Santiago and 9 in Ourense.

The onset of the P.P.P. calculated with the four methods was very similar in both localities (Tab. 1), while the end in Santiago de Compostela ocurred one or two weeks

Tab. 1. Onset, end and duration of the P.P.P. depending of the method employed.

	Santiago			Ourense		
	Onset	End	Duration	Onset	End	Duration
PPP-90%	28-Mar (±9.5)	05-May (±10.0)	37±14.9	26-Mar (±9.2)	30-Apr (±10.4)	36±12.7
PPP-95%	26-Mar (±9.3)	12-May (±18.5)	47±23.9	24-Mar (±9.5)	09-May (±11.7)	46±14.5
PPP-98%	**21-Mar (±8.3)**	10-Jun (±59.5)	80±63.1	**21-Mar (±8.4)**	18-May (±13.5)	58±14.1
PPP-2d	20-Mar (±8.5)	18-May (±10.3)	59±13.7	19-Mar (±10.0)	07-May (±13.2)	49±12.4

Tab. 2. SD/mean indexes for the accumulated temperatures: TMA (mean temperature), TAA (maximum temperature) and Th (threshold temperature).

		TMA					TAA				
	Th	1 Jan	10 Jan	20 Jan	30 Jan	9 Feb	1 Jan	10 Jan	20 Jan	30 Jan	9 Feb
Santiago	**0°C**	**0.109**	0.126	0.152	0.164	0.195	**0.090**	0.104	0.124	0.141	0.167
	1°C	**0.112**	0.129	0.156	0.167	0.197	**0.091**	0.105	0.125	0.141	0.167
	2°C	**0.115**	0.134	0.161	0.172	0.200	**0.092**	0.106	0.126	0.142	0.166
	3°C	**0.119**	0.140	0.168	0.178	0.206	**0.094**	0.108	0.128	0.144	0.166
	4°C	**0.125**	0.148	0.177	0.186	0.212	**0.096**	0.111	0.130	0.146	0.167
	5°C	**0.132**	0.159	0.189	0.197	0.221	**0.099**	0.115	0.133	0.149	0.168
Ourense	**0°C**	0.141	**0.128**	0.140	0.137	0.158	0.092	**0.088**	0.099	0.117	0.152
	1°C	0.149	**0.133**	0.146	0.138	0.156	0.093	**0.087**	0.097	0.115	0.149
	2°C	0.159	**0.141**	0.153	0.142	0.155	0.093	**0.087**	0.095	0.112	0.146
	3°C	0.172	0.152	0.164	**0.147**	0.154	0.094	**0.087**	0.094	0.109	0.142
	4°C	0.188	0.167	0.180	**0.155**	0.156	0.095	**0.087**	0.092	0.106	0.138
	5°C	0.207	0.187	0.201	0.171	**0.162**	0.097	**0.088**	0.091	0.103	0.133

later. To calculate the temperature sum accumulated at the beginning of pollination, the pollen season was defined as the period in which 98% of total annual pollen is collected (Galán et al. 1995). This approach resulted in the least standard deviation during the years and produced the same date for the onset of the pollen season in both localities.

Table 2 shows a summary of the SD/mean indexes obtained for the accumulated temperatures (mean – as TMA – and maximum temperature – as TAA). The results obtained by subtracting threshold temperatures (Th) greater than 6 °C and those obtained with the onset of accumulation on dates later than February 10th were omitted, since they were less significant. The SD/mean index was lower when working with maximum temperature in both localities and also more homogeneous, regardless of the

Tab. 3. Thermal sum obtained with the smallest SD/Mean indexes (cf. Table 2). TMA and TAA expressed in °C.

Th = 0°C	Santiago (starting from Jan. 1st)		Ourense (starting from Jan. 10th)	
	TMA	TAA	TMA	TAA
1993	858	1239.5	631.2	1121.8
1994	808.8	1131.2	635.6	1016.6
1995	879	1175.6	773.1	1189.2
1996	668.4	954.5	822.2	1287.3
1997	789.5	1122.1	667.1	1054.5
1998	816.4	1150.7	817.8	1222.1
1999	914.1	1294.3	734.8	1238
2000	756.3	1112.9	584.4	1008.8
2001	978.1	1291.5	810.2	1156.8
Average	**829.8**	**1163.6**	**719.6**	**1143.9**

threshold temperature employed (0–5 °C). In Santiago de Compostela the best result was obtained beginning temperature accumulation on January 1st, while in Ourense the same held for January 10th. The index for accumulated mean temperature in Santiago was also similar, regardless of the threshold temperature and was lower using the temperature data from January 1st through the onset of pollination. The results were less homogeneous in the case of Ourense. The date of January 10th produced best results when threshold temperatures less than 2 °C were used; however, for temperatures above this threshold, the dates of January 30th or February 9th had smaller coefficients.

Table 3 shows the thermal sum obtained for the different years and the average over the entire sampling period. We selected the ones with the smallest SD/Mean, i.e. for Santiago the sum of TMA and TAA without threshold starting from January 1st, and for Ourense the sum of TMA and TAA without threshold starting from January 10th.

Validation of TMA and TAA as indexes for predicting the onset of the pollen season was carried out with the aerobiological data of 2002. In Santiago de Compostela there was a margin of 3–5 days, which was reduced to 2–3 days in Ourense, when compared to average TMA or TAA of the years 1993 to 2001 (Tab. 4). In view of these results, the beginning of the pollination phase can be calculated starting from January 1st for Santiago and from January 10th for Ourense, without using threshold temperatures. The pollen season begins when the accumulated mean temperatures reach 830 °C in Santiago and 720 °C in Ourense, and/or the accumulated maximum temperatures reach 1,164 °C in Santiago and 1,144 °C as indicated in Table 3.

The models for predicting pollen concentrations were sought by using the meteorological parameter that had the highest correlation with pollen levels. This parameter was defined by applying Spearman's correlation test (Tab. 5) to the date of the pollen season defined by the criterion of Galán et al. (1995). Maximum temperature, hours of sunshine and thermal range were the variables that produced the highest correlation coefficients, with 99% significance in most cases (represented in bold).

The prediction capacity of each meteorological parameter and/or their combination was included into the linear regressions. Non-homogeneous results from applying

Tab. 4. Prediction of the onset of the pollen season taking into account the TMA and TAA as indexes.

	Start PPP				
Year 2002	Real	TMA prediction	TAA prediction	Th	Start
Santiago	Mar. 26	Mar. 21 (5 days)	Mar. 23 (3 days)	0	Jan. 1
Ourense	Mar. 23	Mar. 20 (3 days)		0	Jan. 10
			Mar. 21 (2 days)	1, 2 or 3	Jan. 10

Tab. 5. Spearman correlation's test between *Betula* pollen and meteorologial parameters.

		1993	1994	1995	1996	1997	1998	1999	2000	2001	93–2001
Santiago	Rainfall	**−0.47**	**−0.58**	**−0.62**	**−0.41**	**−0.56**	**0.19**	−0.11	**0.29**	−0.34	**−0.07**
	Humidity	**−0.54**	**−0.64**	**−0.80**	**−0.30**	**−0.58**	−0.07	**−0.40**	0.04	−0.34	**−0.26**
	Max T	0.26	**0.34**	**0.64**	**0.44**	**0.36**	**−0.30**	0.00	**0.39**	**0.47**	**−0.11**
	Min T	**−0.33**	−0.05	0.09	0.03	**−0.43**	**−0.52**	−0.31	**−0.55**	0.16	**−0.44**
	Mean T	−0.00	0.21	**0.53**	**0.33**	−0.00	**−0.43**	−0.18	**−0.52**	**0.50**	**−0.26**
	Max T–Min T	**0.53**	**0.57**	**0.71**	0.29	**0.55**	0.04	0.25	0.03	0.36	**0.19**
	Sunshine	**0.47**	**0.58**	**0.68**	**0.38**	**0.55**	−0.03	0.29	−0.21	**0.55**	**0.13**
Ourense	Rainfall	−0.20	−0.25	**−0.47**	**−0.42**	**−0.63**	**−0.33**	−0.06	**−0.38**	**−0.66**	**−0.46**
	Humidity	**−0.31**	−0.24	**−0.54**	−0.27	−0.27	**0.48**	0.13	**−0.49**	**−0.59**	**−0.23**
	Max T	0.16	**0.61**	**0.43**	**0.66**	**0.39**	**−0.59**	0.08	0.18	**0.47**	**0.30**
	Min T	−0.27	0.13	**−0.43**	−0.11	**−0.49**	**−0.47**	0.04	**−0.43**	−0.26	**−0.38**
	Mean T	−0.01	**0.47**	−0.06	**0.51**	−0.01	**−0.56**	0.10	−0.15	0.23	**0.04**
	Max T–Min T	**0.28**	**0.49**	**0.69**	**0.56**	**0.51**	**−0.40**	0.11	**0.48**	**0.57**	**0.49**
	Sunshine	0.20	**0.47**	**0.47**	**0.41**	**0.59**	0.25	0.16	**0.32**	**0.54**	**0.47**

Schefée's test with different meteorological variables led us to consider the data from an entire sampling period as a single population, which produced a single model for each sampling locality. Despite the correlation between pollen concentration and meteorological parameters demonstrated by the correlation test, the percentage of variability in pollen concentrations which are explained by the model, was relatively low. As a consequence the previous day's pollen concentration were included. Table 6 shows the equations that best explained the data variability.

The model obtained for Santiago de Compostela, which includes hours of sunshine as the prediction meteorological variable, explains 76% of data variability, while in Ourense the best results were obtained with thermal range, which explains 68% of data variability. Figure 3 shows pollen concentrations over the pollination period, relating real values and those predicted according to the above equations.

Figure 4 represents the diurnal variation of *Betula* pollen computed from average data over the years. It shows that in Santiago highest atmospheric concentration is reached after noon and high values last until late in the evening. This model proved fairly homogeneous throughout the years, with the exception of 1996, when the record-

Tab. 6. Regression equations obtained to predict the severity of the *Betula* pollen season in Santiago de Compostela and Ourense.

	Equation	F	Adjusted R^2	p
Santiago	ln*Betula* = −0.053 + 0.198 Ln (Hours sunshine) + 0.861 Ln (*Betula* + 1)	1190.8	0.76	<0.000
Ourense	ln*Betula* = −1.417 + 0.724 Ln (Tmax–Tmin) + 0.725 Ln (*Betula* +1)	557.79	0.68	<0.000

ed concentrations were very low in relation to the mean. 1996 is therefore considered to be not representative of birch's behaviour in Santiago. In Ourense there occur high birch pollen concentrations during the early hours of the afternoon, which are maintained until after midnight; this graph mainly represents *Betula* behaviour during the last three years. It was not found homogeneous at the beginning of the study period.

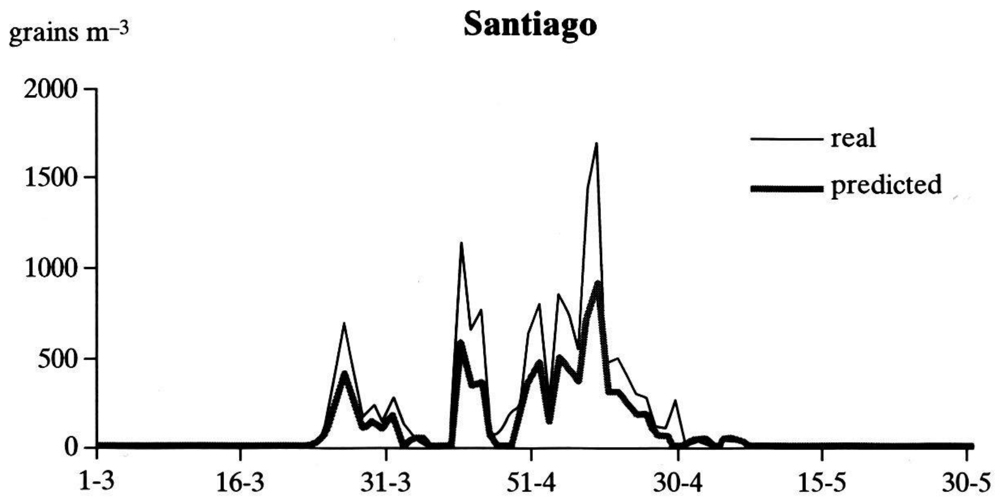
Discussion

The concentration of *Betula* pollen is clearly higher in Santiago de Compostela than in Ourense, representing the highest values in the Iberian Peninsula (Jato et al. 1999). This may be due not only to the city's biogeographical position but also – to an important degree – to the frequent ornamental use of this taxon here. *Betula* pollen thus attain values similar or even higher than in other places in northern or central Europe where they represent the main etiological agent of spring allergies (Corden et al. 2000; Dahl and Strandhede 1996; Hallsdóttir 1999; Latalowa 2002; Spieksma et al. 1995).

In both cities there is a variation in annual total, resulting in biennial cycles, as in other European localities (Corden et al. 2002; Dahl and Strandhede 1996; Emberlin et al. 1993; Latalowa et al. 2002; Spieksma et al. 1995). Only for Island, Hallsdóttir (1999) suggests a triennial cycle. Physiological factors seem to be mainly involved in these dynamics (Dahl and Strandhede 1996), although other external factors, such as meteorological and even biological parameters, may play an important role in pollen production (Jato et al. 2002).

In the two localities studied, the pollen season began around March 25th, approximately a month earlier than in places further north (Corden et al. 2002; Hallsdóttir 1999; Latalowa et al. 2002), with pollen remaining in the atmosphere during a longer period (an average of 50 days). It was also observed that the years of highest pollen concentrations coincided with hot periods at the onset of flowering, favouring the release of pollen from the anthers, which also meant that the duration of P.P.P. tended to be shorter. On the other hand, with rainy weather or days without sunshine, pollen release is slower and the pollen season lasts longer. The same behaviour was reported by Corden et al. (2000), Clot (2001) and Latalowa et al. (2002). The greater variability in the duration of the pollen season in Santiago was probably due to the larger collection of transported pollen and/or re-flotation recorded at the end of the pollen season, when the meteorological conditions favour both mechanisms (Hjelmroos, 1992).

The influence of temperature on the onset of the pollen season has been used as a prediction variable by different authors (Bricchi et al. 1995; Clot 2001; Corden et al.



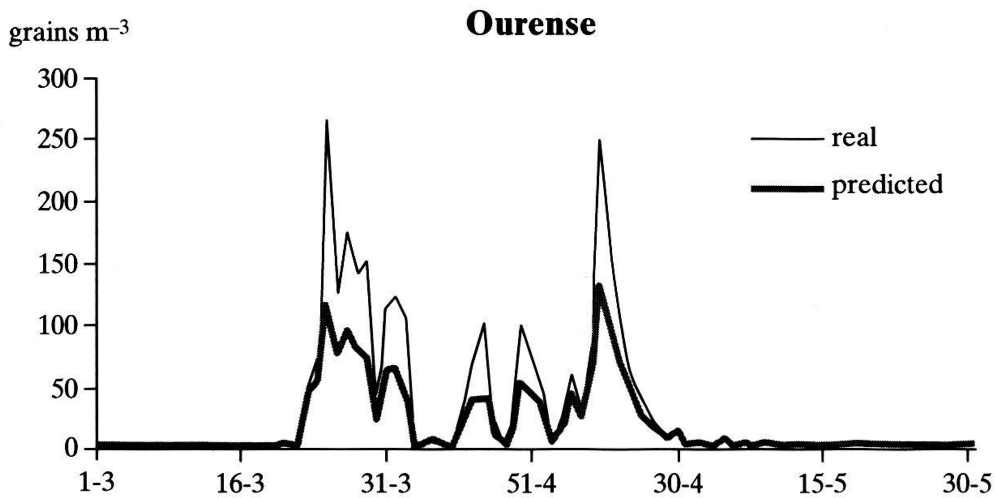
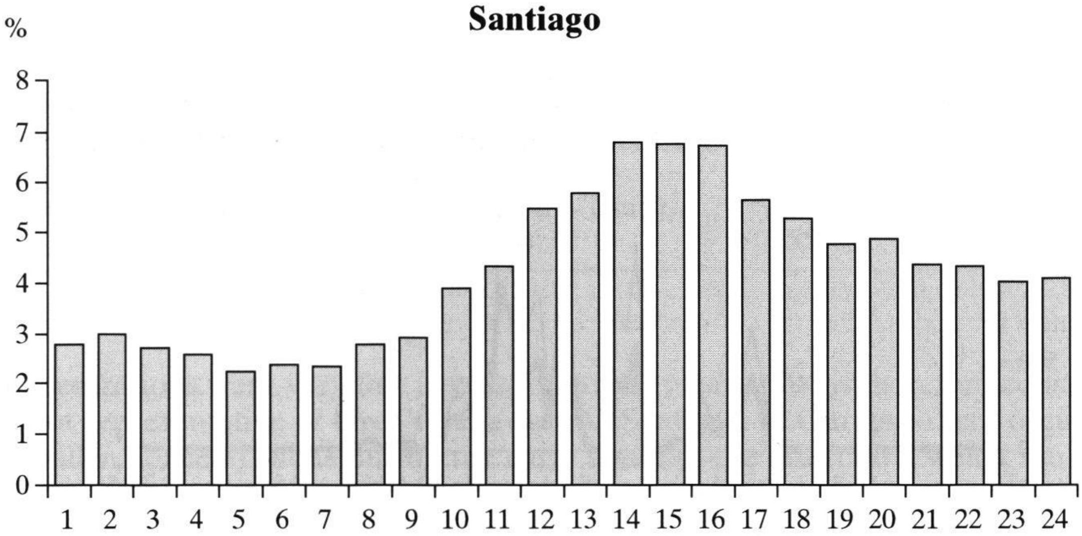


Fig. 3. Distribution of *Betula* pollen in 2002 (thin line) and predicted distribution (thick line).

2002; Latalowa et al. 2002; Norris-Hill 1998; Spieksma et al. 1989). Some authors have established equivalences between the temperature and activity accumulated by the tree (Larsson 1993), obtaining satisfactory results, especially with arboreal taxa that flower in late spring.

Spieksma et al. (1989) suggest that the temperatures during the 40 days prior to pollination are decisive with for the onset date. However, for Santiago de Compostela and Ourense our results point to longer decisive periods of time. In Santiago de Compostela the best result was obtained by accumulating the temperature from January 1st, while the date for Ourense was January 10th. Ourense's more continental climate (drier, colder and with lower absolute minimum temperatures compared to Santiago, whose proximity to the sea makes its temperatures milder) justifies the delay observed in Ourense as to the date marking the start of heat accumulation required to produce flowers.



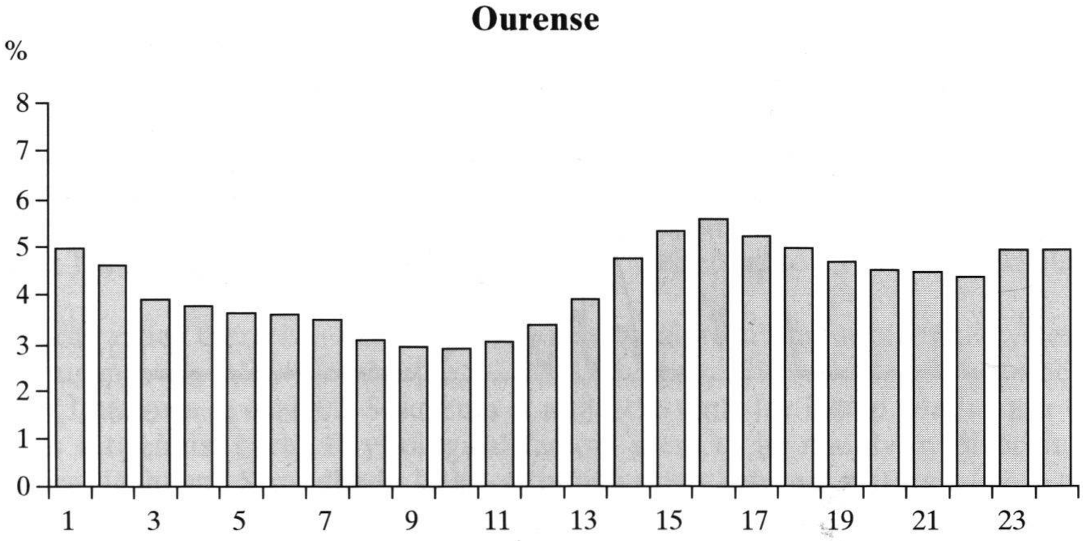


Fig. 4 Intradiurnal distribution of *Betula* pollen in both localities from 1993 to 2001 (without 1998).

Other European regions likewise show later dates for the beginning of heat accumulation. In Switzerland, Clot (2001) indicates February 1st, while Ruffaldi and Greffier (1991) suggest March 1st for France. The temperature sums found by these authors necessary for the onset of the pollen release are around 270 °C. This value is lower than that obtained in this study, which is due to the fact that in our case the onset date coincided with the first days of the year. Clot points out that once the above temperature sum is attained, an increase in atmospheric pollen will take place when the temperature is higher than 10 °C. Latalowa et al. (2002) predict the severity of the pollen season on the basis of threshold values of 5 °C, considering also the meteorological factors of specific periods during the year prior to flowering and those of the current season. In this study best results were obtained by abolishing threshold temperatures and calculating heat accumulation with each day's mean and maximum temperatures.

Using the mean value calculated by adding mean (830 °C in Santiago and 720°C in Ourense) or maximum temperatures (1,164 °C and 1,144 °C, respectively) to predict the onset of pollination, for 2002 a difference of 2–3 days between the observed and predicted date in Ourense and 3–5 days in Santiago de Compostela was obtained. This result is similar to that of Laaidi (2001), who totalled a maximum error of 2 days for Burgundy (France). The importance of the result lies in the application of preventative measures for the local allergic population.

Of all the tested prediction models, with different meteorological parameters, the percentage of variability was always low. Therefore the pollen concentration of the previous day was included, as the meteorological parameters per se only seem to be one of the numerous factors involved in the process of pollen release and dispersion. Thus, inclusion of other variables in the prediction models increases their accuracy. The equations in this study explain 76% (Santiago) and 68% (Ourense) of the variability of pollen concentration.

Determination of the time of the day when the maximum pollen concentrations are recorded, yielded similar results to previous studies in the same localities (Aira et al. 1998; Dopazo 2001; Méndez 2000). Nevertheless, it should be noted that the model bases on the mean values of the years under study and cannot be considered to accurately reflect each day's pollen evolution. The prediction is generally more accurate for Santiago de Compostela than for Ourense. Other models for the *Betula* taxon indicate a similar pollen behaviour with minimum values in the early morning and during the first hours of the day (Corden et al. 2002), although with shift towards the hours of maximum concentration. Norris-Hill and Emberlin (1991) found 6 pm as the time of maximum concentration in London, while in Sweden it is at noon or in the early afternoon (Berggren et al. 1995), and in Switzerland, Clot (2001) reported concentration maxima before midnight. There is no methodical uniformity to determine hourly behavior in the above studies, which means that some of these differences may be due to the method used. On the other hand, other causes may influence the model. In particular, the localisation of the pollen trap in relation to the pollen source can have a notable effect on the quantity of pollen collected.

The future inclusion of more aerobiological data as well as the possible use of non-meteorological parameters, such as phenological events, should be taken into account to generate new prediction models with even a greater prediction capacities.

Résumé

Dans cet article nous analysons les niveaux polliniques et la variation horaire de Betula dans deux localités du Nord-Ouest de la Péninsule Ibérique (Saint-Jacques de Compostelle et Ourense) de 1993 jusqu'en 2001, afin d'évaluer les différences régionales.

Nous décrivons également des modèles de prédiction du début de la saison pollinique et des concentrations polliniques, en tenant compte des températures moyennes et maximales, de l'oscillation thermique et des heures d'ensoleillement comme variables de prédiction. Nous évaluons la capacité de prédiction de ces modèles en les comparant aux données aérobiologiques de l'année 2002.

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