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Effect of air temperature on forecasting the start of the *Betula* pollen season at two contrasting sites in the south of Europe (1995–2001)

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Abstract In order to survive periods of adverse cold climatic conditions, plant requirements are satisfied by means of physiological adaptations to prevent cells from freezing. Thus, the growth of woody plants in temperate regions slows down and they enter into a physiological state called dormancy. In order to identify the chilling and heat requirements to overcome the dormancy period of *Betula* in the south of Europe, a comparative study was carried out with aerobiological pollen data of a 7-year (1995–2001) period in Vigo (Spain) and Perugia (Italy). To satisfy chilling requirements, base temperatures of 7 °C and 5.75 °C showed a lower standard variation coefficient: 3.94% and 2.36% in Perugia and Vigo respectively. In the case of heat accumulation, the sum of mean temperatures in Perugia and the sum of maximum temperatures in Vigo were the parameters that showed a minor coefficient of variation (11.13% and 14.51% respectively).

Keywords *Betula* · Dormancy · Forecast · Italy · Spain · Pollen · Aerobiology

Introduction

The physiological behaviour of woody plants with winter–spring flowering is subject to constant variations due to the action of different bioclimatic parameters. Before flowering, temperature plays a particularly important role in the maturation of reproductive organs and it is the primary factor influencing the growth and development of plants and pollen production. During the flowering period, secondary factors such as sunshine, rainfall and relative humidity determine the opening of anthers and the release of pollen grains. Airborne pollen is greatly

influenced by meteorological conditions and it is dispersed by a tertiary factor, the wind, which results in the scattering of pollen in the atmosphere (Laaidi 2001). Rainfall is of great importance in this process, above all because the mechanical action of rain brings a large part of the airborne pollen content down to the ground (Ybert 1980; Rajeriason 1983). In this way, the driest periods during the pollination period correspond with the moments of highest pollen concentration.

There are favourable and non-favourable periods, generally seasonal phases, which exert different kinds of influence on the life cycles of plants. Plant requirements, in order to survive periods of adverse cold climatic conditions, are satisfied by means of physiological adaptations to prevent cells from freezing. Thus, the growth of woody plants in temperate regions slows down and they enter into a physiological state called dormancy. The end of the dormancy phase, and the start of the growth of male inflorescences in the majority of woody plants, may require two conditions. First, a period of low temperatures or rest, defined as the period in which buds remain dormant as a result of growth-arresting physiological conditions in the bud itself. The rest must be followed by relatively warm temperatures under which the buds remain dormant because of unfavourable environmental conditions, a stage called quiescence. Budburst takes place when the buds are exposed to forcing temperatures for a prolonged period (Kramer 1994).

In recent years, a number of different indices have been referenced in order to determine chilling and heat requirements. The period of rest is usually determined by the number of chilling units or chilling hours (Aron 1983). The heat requirements for overcoming the dormancy period are frequently measured as degree-hours, where one degree-hour is equivalent to 1 h when the air temperature is 1 °C above a lower threshold temperature. Degree-days are calculated as the total degree-hours for a day, divided by 24 (Snyder et al. 1999).

Different models predicting the dates of budburst or flowering have been described. Some of them consider only the heat requirements (Cannell and Smith 1983), and

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others also consider the action of chilling (Landsberg 1974; Hänninen 1990; Kramer 1994; Murray et al. 1989; Sarvas 1974). Phenological data have usually been used to calculate chilling and heat requirements, and to predict the onset of different phenological phases (Kramer 1994; Snyder et al. 1999; Spano et al. 1999; Wielgolaski 1999). On the assumption that atmospheric pollen indicates the time of pollination, aeropalynological data are also employed to determine the onset of the pollen season (Frenguelli and Bricchi 1998; Garcia-Mozo et al. 2000; Jato et al. 2000; Rodríguez-Rajo et al. 2000; Galán et al. 2001; Fornaciari et al. 2000; Laaidi 2001).

In all cases, the aim is to find predictive models that enable us to ascertain the onset and severity of the pollen season. Knowing the onset of the pollen season is of particular importance to people allergic to a given pollen, who can then start anti-allergic treatment several days before the beginning of pollination, thereby optimising its effectiveness. Birch pollen is well known as the major tree allergen in central and northern Europe (D'Amato and Spieksma 1992), while in the south of Europe it also has an important effect on human health, accounting for 13% of allergy prevalence in some places (Arenas et al. 1996). Therefore, the objectives of this study are to ascertain the influence that a climatic parameter such as temperature exerts on the onset of the pollination of *Betula*, in order to identify the start of the dormancy period, its duration and the consequent temperature requirements. Furthermore, it is important to ascertain the base temperatures required to overcome this vegetative period in order to identify if there is a relationship between base temperature variation and the climatic area. In this regard, we chose two areas, one in Spain (Vigo) and another in Italy (Perugia), since they have different temperature patterns, ranging from mild in the case of Vigo to cold in that of Perugia.

Materials and methods

The monitoring station in central Italy is Perugia, which is located approximately 90 km inland on the west-facing slopes of the Apennines, 493 m above sea level, overlooking the valley of the Tiber river to the south-west and Lake Trasimeno to the north-west (Fig. 1). Perugia has a sub-Mediterranean climate, with a mean annual maximum temperature of 17.1 °C, a mean annual minimum temperature of 9.2 °C and 877 mm annual precipitation. The city of



Fig. 1 Location of the localities studied

Vigo is situated at sea level on the shore of the Vigo estuary (Fig. 1). It has a temperate maritime climate, but in this case the mean annual maximum temperature is 18.8 °C, the mean annual minimum temperature is 11 °C and the total annual precipitation is 1,412 mm.

This study was based on the monitoring of atmospheric pollen concentrations from 1995 to 2001. Sampling at the two stations was carried out by means of a 7-day Lanzoni pollen trap (Hirst 1952) placed about 15 m above ground level, in the case of Perugia on the roof of the Faculty of Agricultural Science and in that of Vigo on the terrace of the town hall. The standard sampling procedures proposed by Dominguez et al. (1992) were used to obtain pollen counts. Pollen data are expressed as pollen/m³. The meteorological data were recorded in Perugia by the Faculty of Agricultural Science's Institute of Ecology, while in Vigo they were supplied by the Spanish National Institute of Meteorology. Meteorological stations are located in the pollen sampling site.

To obtain the pollination period, we took into account the period that includes 95% of the annual *Betula* pollen, eliminating the initial period till the 5-day running mean exceeded 2.5% (Andersen 1991) because, with this method, the flowering start dates showed a lower standard deviation than when Mullenders' (1974) method was used (Table 1).

In order to calculate the freezing requirement, we used the model proposed by Aron (1983) based on the accumulation of chilling hours between 0 and 7.2 °C. It considers the maximum and minimum temperatures and the length of the chilling period:

Table 1 Onset of *Betula* pollen season calculated according 2.5% (Andersen 1991) and 1% methods (Mullenders 1974). CS standard deviation coefficient as a percentage

Vigo			Year	Perugia		
Start 2.5%	Start 1%	Start 2.5%		Start 2.5%	Start 1%	Start 2.5%
28 Mar	84	86	1994–95	94	93	04 Apr
05 Apr	93	95	1995–96	94	93	03 Apr
13 Mar	70	73	1996–97	77	76	18 Mar
17 Mar	75	78	1997–98	89	89	30 Mar
15 Mar	76	82	1998–99	91	91	1 Apr
12 Mar	67	71	1999–00	90	84	30 Mar
10 Apr	97	100	2000–01	79	78	20 Mar
	11.43	10.88	SD	6.92	7.06	
	14.23	13.01	CS	7.89	8.19	

$$N = 801 + 0.2523 B + 7.57 B^2 \times 10^{-4} - 6.51 B^4 \\ \times 10^{-10} - 11.44 T_{i,\min} - 3.32 T_{i,\max}$$

where N = number of chilling hours during the period,

$$B = 24 D(7.2 - T_{\min}) / (T_{\max} - T_{\min})$$

where $T_{i,\min}$ and $T_{i,\max}$ are the average minimum and maximum temperatures during the study period respectively, and D is the length of the study period in days. In this study the value 7.2 in the B formula has been substituted by the different base temperatures (12, 11, 10, 9, 8, 7, 6.75, 6.5, 6.25, 6, 5.75, 5.5, 5.25, 5 and 4 °C) in order to identify if there is a relationship between base temperature variation and the climatic area. We began calculating the accumulation of chilling hours (CH) from the moment of the year when the mean and minimum temperatures dropped below the base temperature under consideration in Perugia and Vigo respectively.

The heat accumulation required to trigger pollination was expressed by the summation of daily mean and maximum temperatures and the sum of the range between the minimum and maximum temperatures; finally, growth degree days (GDD) were calculated according to the equation proposed by Rickman et al. (1983):

$$T_n = \sum [(T_{i,\max} + T_{i,\min}) \times 0.5] - T_b$$

where T_n is the sum of °C for n days, and $T_{i,\max}$ and $T_{i,\min}$ are daily maximum and minimum temperatures (°C) of Day i , and T_b is the base temperature.

In order to estimate the most significant base temperature for *Betula* pollination, we calculated the aforementioned heat sums with different base temperatures (4, 4.5, 5, 5.5, 6 and 6.5 °C). The beginning of the study period was the first day when the mean temperature reached the minimum values and started to follow a positive trend (on average, from the end of January to the beginning of February). Only temperatures above or equal to 0 °C were taken into account to calculate cumulative sums. Negative temperatures were considered as 0 °C.

In the statistical approach, the chill and heat accumulation were calculated using different experimental data sets, and the amount of variation was calculated as the standard deviation coefficient (SD) and standard deviation coefficient as a percentage (CS %).

Results

In Vigo and Perugia, *Betula* began its pollination period between the third week of March and the first week of April. Figure 2 shows the evolution of the average temperature from November up to the moment when flowering started, as well as the heat and chill periods in both localities. There are important temperature differences. Birch pollen is usually released earlier into the atmosphere of Vigo, the city with the coldest temperature, several days later the corresponding phenomenon occurs in Perugia. The length of the main pollen season is usually longer in Vigo and in both cities it oscillates between 30 and 70 days, with the exception of 1995 in Perugia, when it amounted to 90 days.

In order to express the chilling accumulation as chilling hours, which provides us with a relationship between recorded temperatures and the effective temperature for the developing catkin, we took into account the time when the mean or minimum temperatures dropped below the base temperature under consideration. This condition generally occurs during November and the chill was overcome in the first fortnight of January in Vigo and in the second in Perugia. The values were different in the

Table 2 Chilling units (CH) calculated according to the Aron method (1983)

Year	Chilling units for a base temperature of:																
	12 °C	11 °C	10 °C	9 °C	8 °C	7.5 °C	7.25 °C	7 °C	6.75 °C	6.5 °C	6.25 °C	6 °C	5.75 °C	5.5 °C	5.25 °C	5 °C	4 °C
Perugia																	
1994–95				748	1,123	1,132	1,111	1,078	1,038	992	1,046	1,008	989	952	916	881	767
1995–96				229	1,072	1,128	1,109	1,067	1,010	946	862	804	755	718	694	685	738
1996–97				38	1,033	907	1,021	1,096	1,140	1,154	1,147	1,125	1,090	1,048	1,000	951	780
1997–98					690	1,046	1,116	1,136	1,118	1,074	1,015	948	881	820	768	729	7007
1998–99				193	740	912	985	1,041	1,094	1,126	1,150	1,167	1,177	1,181	1,180	1,175	1,117
1999–00			286	744	1,023	1,102	1,129	1,149	1,162	1,168	1,171	1,166	1,158	1,146	1,131	1,114	1,031
2000–01				585	1,021	1,116	1,140	1,151	1,152	1,142	1,125	1,102	1,079	1,048	1,024	990	858
CS (%)				72.8	17.8	9.5	5.5	3.9	5.3	7.9	10.2	12.8	15.1	17.1	18.7	19.6	132.0
Vigo																	
1994–95	1,001	841	698	626	627	652	649	657	667	676	683	686	685	652	654	656	673
1995–96	940	741	626	624	636	655	665	675	680	682	678	667	647	616	572	512	628
1996–97	1,025	1,054	889	746	654	641	642	646	652	650	650	654	652	654	656	659	663
1997–98	966	780	649	620	662	650	661	671	640	643	648	654	659	666	672	678	677
1998–99	677	1,028	1,112	1,044	915	848	817	788	761	738	718	701	688	679	728	717	699
1999–00	736	1,063	1,091	977	827	762	735	711	692	678	668	662	660	662	667	668	694
2000–01		631	1,072	1,068	893	802	763	729	703	683	670	664	664	669	679	691	724
CS (%)	16.5	19.7	24.9	25.4	17.2	12.1	9.6	7.1	5.8	4.5	3.5	2.6	2.4	3.1	7.0	10.1	4.5

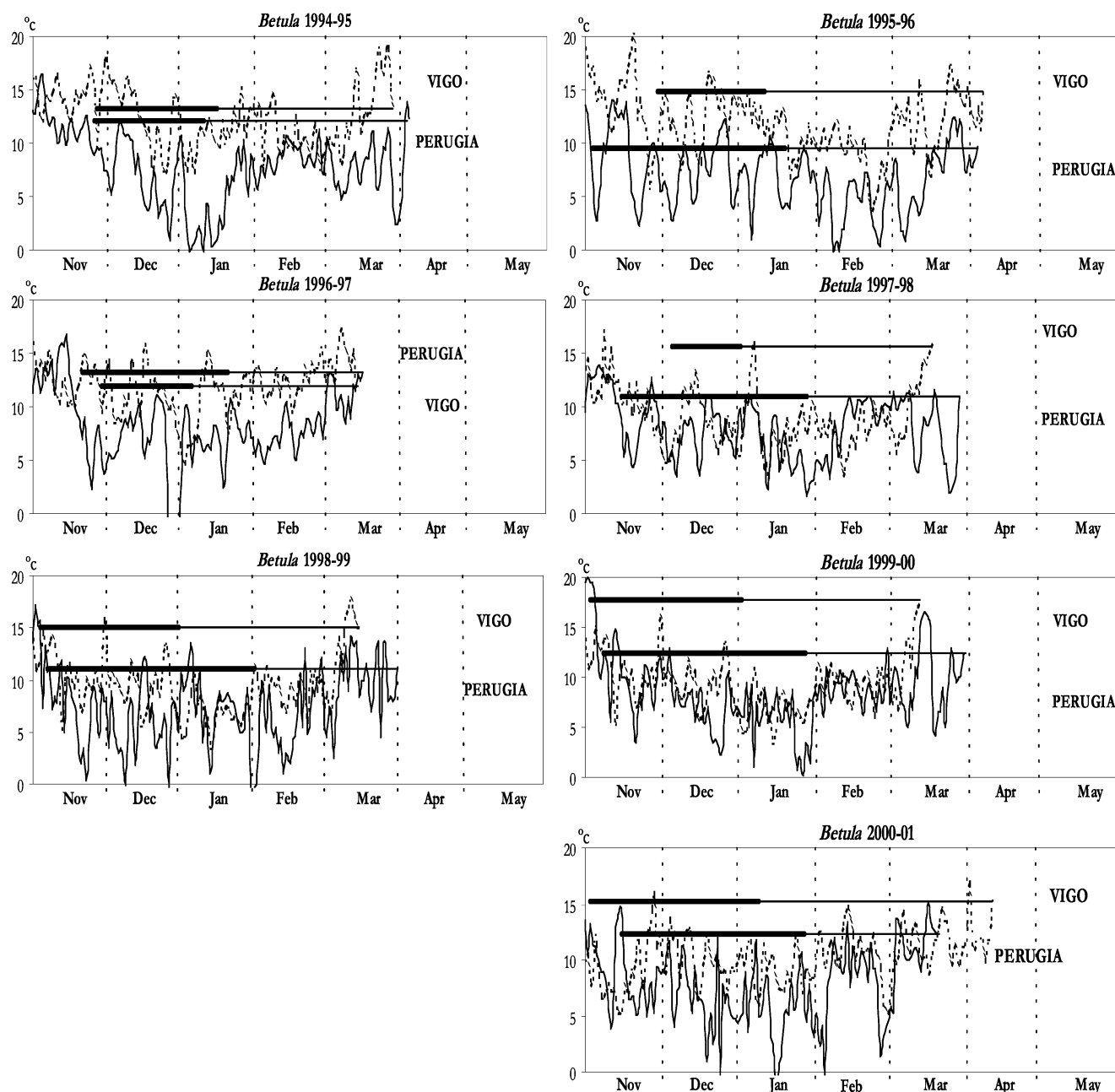


Fig. 2 Variation of daily mean temperature from November to the start of pollination in Vigo and Perugia. Chilling period, Heat requirements, Pollen season

two cities, probably because of the cold climatic conditions in Perugia and the temperate ones in Vigo. The chilling requirement was lower in Vigo than in Perugia, with an average accumulation of 665 and 1,103 chilling hours respectively, showing a very low coefficient of standard deviation with the 5.75 °C base temperature in Vigo and 7 °C in Perugia (Tables 2, 3).

The heat accumulation from January until the start of flowering, calculated according to the different methods used and expressed as GDD, is shown in Table 4. The sum of mean temperatures in Perugia and the sum of maximum temperatures in Vigo were the parameters that

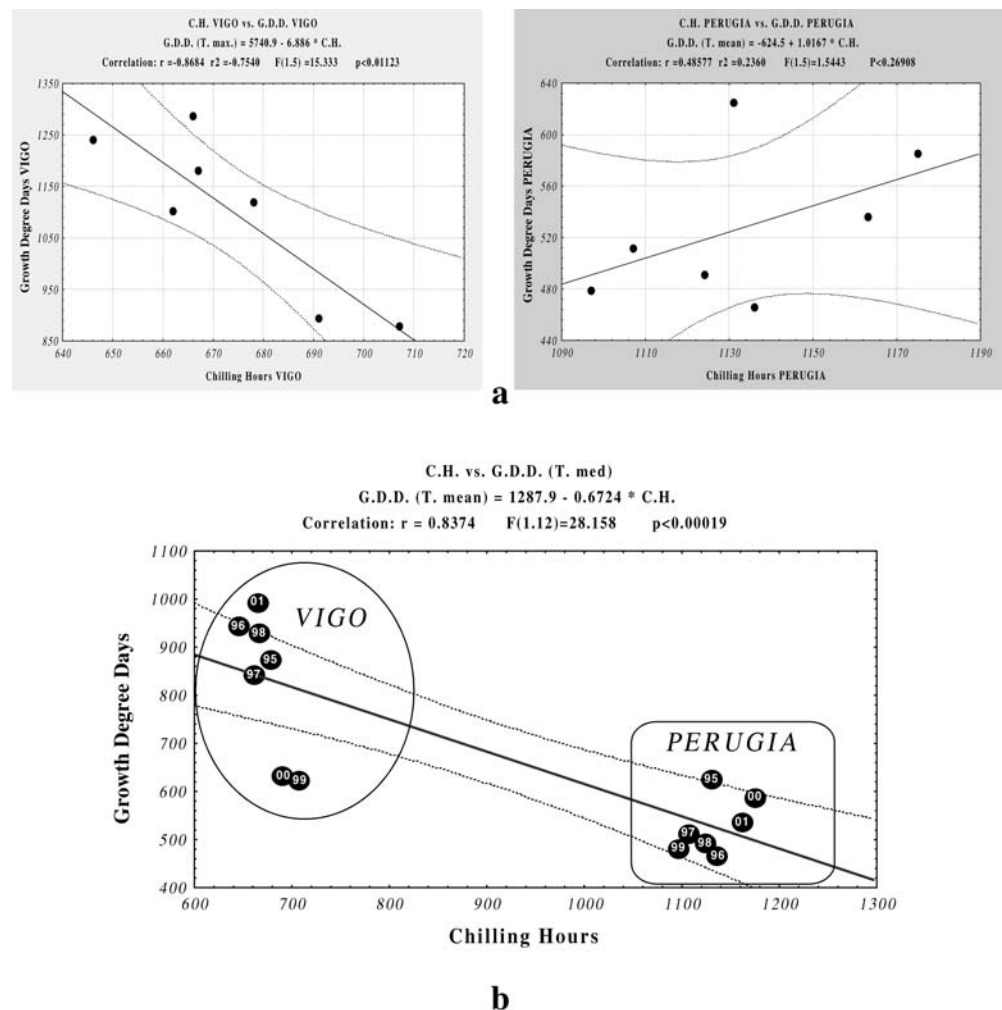
showed a minor coefficient of variation (11.13% and 14.51% respectively). To make the model more accurate we tested different threshold temperatures, but in any case the results improved. Perugia needed 528 GDD (mean temperature) to trigger flowering (Table 4), while Vigo required, 1,101 GDD (maximum temperature).

We applied the Scheffé test (Table 5) with the aim of checking the differences between the temperatures recorded during the years under study. There are two groups of years that showed different temperature patterns. The first includes 1995–1998 and the second 1999–2001. The same table shows the differences

Table 3 Dates of the starting and ending of chilling accumulation (*cu*) calculated by using the base temperature with the lowest coefficient of standard variation (*cs*, see Table 2)

Year	Vigo (5.75 °C)				Perugia (7 °C)			
	Start	End	Length (days)	Cu	Start	End	Length (days)	Cu
1994–95	27 Nov	15 Jan	50	685	14 Nov	10 Jan	58	1,078
1995–96	26 Nov	10 Jan	46	647	04 Nov	18 Jan	76	1,067
1996–97	07 Dec	05 Jan	30	652	20 Nov	19 Jan	61	1,096
1997–98	06 Dec	01 Jan	27	659	16 Nov	28 Jan	74	1,136
1998–99	05 Nov	01 Jan	58	688	05 Nov	30 Jan	87	1,041
1999–00	04 Nov	01 Jan	59	660	06 Nov	27 Jan	83	1,149
2000–01	03 Nov	08 Jan	67	664	01 Nov	14 Jan	75	1,151
Average			48	665			73	1,103
SD			15.03	15.73			10.63	43.44
CS (%)			31.21	2.36			14.47	3.94

Fig. 3a, b Equations of the linear regression model to predict heat requirements by using chilling units. **a** Vigo and Perugia, **b** both areas



between maximum and minimum temperatures in the two groups of years. Finally, for all the Vigo and Perugia data, we applied Spearman's correlation test (Table 6) in order to verify the correlation between the different phenological phases studied (length of chilling, length of period of forcing temperatures, number of GDD, chilling hours and start of the pollen season). The correlation was positive and significant between the length of the chilling period

and the number of chilling units accumulated, and was significant and negative between the heat requirements and the length of the period and number of chilling units.

The graphics of the linear regression models obtained are presented in Fig. 3. The models enable us to predict the values that are necessary to complete the heat requirement, depending on the chilling requirement during the rest period and also the moment when heat

Table 4 Heat requirements calculated by using different parameters and base temperatures. *GDD* Growth degree days

Year	Heat requirement (GDD)									
	T_{Max}	T_{Mean}	$T_{Max} - T_{Mean}$	Rickman 4 °C	T_{Mean} 4 °C	T_{Mean} 4.5 °C	T_{Mean} 5 °C	T_{Mean} 5.5 °C	T_{Mean} 6 °C	T_{Mean} 6.5 °C
Perugia										
1994–95	890	625	530	307	307	270	234	200	168	137
1995–96	703	466	475	196	196	167	141	118	96	76
1996–97	724	511	424	276	276	247	219	191	165	140
1997–98	718	491	443	257	252	226	201	178	156	135
1998–99	955	479	967	248	256	230	206	184	163	143
1999–00	1,074	586	1,013	315	333	303	273	244	215	186
2000–01	882	536	686	299	296	269	242	218	195	173
Average	849	528	648	271	274	244	216	190	165	141
SD	140.63	58.76	248.99	41.79	44.88	43.23	41.21	39.00	36.94	35.13
CS (%)	16.56	11.13	38.41	15.42	16.40	17.69	19.04	20.51	22.36	24.84
Vigo										
1994–95	1,120	872	457	563	828	792	755	719	682	646
1995–96	1,241	944	598	552	893	850	806	763	719	676
1996–97	1,103	842	525	535	831	797	763	729	695	661
1997–98	1,181	928	524	585	877	839	801	763	725	687
1998–99	879	622	515	291	583	546	509	472	435	398
1999–00	894	631	530	218	606	570	534	498	462	427
2000–01	1,287	992	752	549	915	868	822	775	729	682
Average	1,101	833	557	585	790	752	713	674	635	597
SD	159.68	149.45	95.16	149.95	137.57	135.23	133.00	130.88	128.89	126.82
CS (%)	14.51	17.94	17.07	31.87	17.40	17.99	18.66	19.42	20.29	21.25

Table 5 Temperature average during the dormancy period and values of the Scheffé test coefficients during the years studied in Vigo (shared area) and Perugia

Scheffé test	1995	1996	1997	1998	1999	2000	2001
Perugia T_{Max}	10.1	10.2	10.5	10.2	14.1	15	11.2
Perugia T_{Min}	5.1	5.3	5.1	5.5	0.1	1	2.6
Vigo T_{Max}	15.7	15.2	14.3	14.8	12.6	12.5	12.3
Vigo T_{Min}	9.7	9.7	8.5	9.8	5.8	5.6	6.5
Perugia	11.401	10.767	11.656	11.692	15.444	16.517	13.931
Vigo	15.347	14.752	14.774	15.241	12.444	12.399	12.989
1995		0.950	1.000	0.999	0.000*	0.000*	0.000*
1996	0.793		0.788	0.751	0.000*	0.000*	0.000*
1997	0.833	1.000		1.000	0.000*	0.000*	0.003*
1998	1.000	0.924	0.943		0.000*	0.000*	0.003*
1999	0.000*	0.000*	0.000*	0.000*		0.598	0.170
2000	0.000*	0.000*	0.000*	0.000*	1.000		0.000*
2001	0.000*	0.000*	0.000*	0.000*	0.861	0.822	

* 99.9% significance

Table 6 Coefficients of Spearman's correlation test. CH chilling hours, GDD Growth degree days

Parameter	r^2
Length CH and CH	0.670**
Length CH and GDD (T_{Mean})	-0.714**
Length CH and GDD ($T_{Rickman}$)	-0.615*
CH and GDD (T_{Max})	-0.701**
CH and GDD (T_{Mean})	-0.771**
CH and GDD ($T_{Rickman}$)	-0.534*

* 95% significance

** 99.9% significance

Table 7 Equation of the linear regression model to predict heat requirements of *Betula* by using chilling units of both areas (without Vigo 1999 and 2000). For 1994–2001 GDD (T_{mean}) = $1,300.7 - 0.6824 \times CH$

Parameter		
r	0.882	
r^2	0.778	
$Adj. r^2$	0.756	
F	35.073	
ld	1.10	
P	0.000	
SE_{est}	91,271	
Intercept		T_{Mean}
β	–	-0.8821
$SE \beta$	–	0.1490
B	1,300.696	-0.682
$SE B$	111.593	0.115
$t (10)$	11.655	-5.922
P	0.0000	0.0001

accumulation is sufficient to trigger pollination. The model takes account of the two localities together and also each one individually.

Discussion

Other studies centred on *Quercus* and *Alnus* have been carried out in the same area (Rodríguez-Rajo et al. 2000; Jato et al. 2000), and a statistically significant correlation was found between the start of the pollination period and

the addition of the temperatures recorded during the days before flowering. Different authors point out the influence of temperature on pollination (Frenguelli et al. 1991; Richardson et al. 1974; Spieksma et al. 1989; Norris-Hill 1998), but a more extensive knowledge of the chilling and heat requirements is needed to predict the start of flowering in *Betula*.

In both areas where this study was carried out, *Betula* is represented by the species *Betula alba*. Usually its flowering occurs earlier in Vigo, which has warmer temperatures than Perugia. Climatic differences between the two areas, different chilling and heat requirements genetically conditioned in each zone and also the diverse origin of the populations studied may explain the differences observed in the start of pollination.

In Perugia (the locality with lower winter temperatures) the number of chilling hours obtained was higher than in Vigo, because in colder areas the plant needs to protect itself from adverse environmental conditions during a more extensive period. Chilling units and the length of this period are usually larger in such areas (Richardson et al. 1974; Aron 1983; Landsberg 1974). Different base temperatures were tried in order to determine which were the most effective for satisfying the chilling requirements. Base temperatures of 7 °C and 5.75 °C have a lower standard variation coefficient: 3.94% and 2.36% in Perugia and Vigo respectively. A base temperature higher than 7 °C (Table 2) produces an increase in the standard variation coefficient, and even in the case of Perugia it is impossible to overcome chilling up to a 9 °C base temperature. In this way, many authors claim that chilling-effective temperatures lie in the range 0–7 °C (Lamb 1948; Aron 1983; Richardson et al. 1974). Several additional environmental factors may govern the effectiveness of the chilling temperatures: the influence of the sea, the proximity of cities and height above sea level (Aron 1983).

Heat requirements were calculated from the day after the end of the chilling period to the first day of the main pollen season, using different methods (Table 4). In each of them, we looked for possible improvements by applying several threshold temperatures. The mean temperature in Perugia and the maximum temperature in

Vigo showed the lowest standard deviation. However, the results obtained in Vigo when the mean temperature and the difference between maximum and minimum temperatures were used were also low. The results did not improve when several threshold temperatures were used. In a previous study centred on *Quercus*, threshold temperatures of 5.5 °C in Vigo and 4.5 °C in Ourense (a locality near Vigo) showed the lowest coefficient of standard deviation (Rodríguez-Rajo 2000), and threshold temperatures of 11 °C and 12.5 °C in *Quercus* and *Olea* respectively were noted in the south of Spain (García-Mozo et al. 2000; Galán et al. 2001). In the Zurich area, the method using accumulated temperatures to forecast the beginning of the birch pollen season is not useful, but in this case the location of the trap as well as microclimatic elements may influence the results (Peeters 1998). Clot (2001) pointed out that a cumulated threshold of 270 °C is necessary before the release of birch pollen, and the pollen concentration increases in the air when the daily average temperature is higher than 10 °C.

It is necessary to point out that differences in the meteorological conditions of the years studied may produce certain deviations in the proposed models. More specifically, if the behaviour of the temperatures during the rest and quiescence period shows large differences during any of the years studied, the coefficient of standard deviation can increase and make the model not significant. We carried out the Scheffé test to check the existence of significant differences between the temperatures recorded from November (onset of dormancy) to March (onset of pollination) and we found significant differences among the years (Table 5). This may explain the difference in the sum of temperatures between the years that raise the coefficient of standard deviation obtained. The maximum temperatures were approximately 10 °C in Perugia and 14–15 °C in Vigo from 1995 to 1998. From 1999 to 2001 the temperature pattern was different: in Perugia the thermal oscillation was higher and in Vigo temperatures were lower than in the previous years.

The results obtained by applying Spearman's coefficient test reinforce the evidence for a correlation between the length of the rest periods and the accumulated chill, and also between the chilling and heat requirements that have been pointed out by different authors (Richardson et al. 1974; Aron 1983; Frenguelli 1997; Hänninen 1990; Jato et al. 2000). Likewise, Myking (1997) in a study centred on two ecotypes of *Betula* indicates a decrease of heat accumulation when the length of the chilling period increases. Previous studies carried out in Perugia (Frenguelli and Bricchi 1998) showed that an unusually short, warm winter means that many trees bloom early in the season, but a long winter delays the dates of pollination by 1 month, and the heat requirements are satisfied at lower values. When the temperature of the dormancy period is high, the heat requirement for beginning pollination is higher; on the other hand, if the temperature is low, the heat requirement is smaller.

Figure 3 shows the linear regression models obtained to predict the flowering heat requirement as a function of the accumulated chilling in the two localities. When the data of each locality are considered independently (Fig. 3a), only the Vigo model is significant ($r^2 = -0.754$). When both localities are considered together (Fig. 3b), the linear regression model obtained explains the high percentage of heat requirement variability ($r^2 = 0.83$; 99.9% significant level). This graph reinforces the assertion that the areas with colder temperatures have higher chilling and lower heat requirements that have been previously determined (Jato et al. 2000). The colder the temperatures in the region, the lower the heat requirement was found to be: at one end of the regression line we have the points corresponding to the values reached during the years of study in Vigo, and at the other end those of Perugia.

Finally, because the temperature behaves differently from year to year, it is possible to improve the result of the prediction if we look for the best-suited model. Taking into account the minimum temperature in Vigo during the period of heat accumulation, the values reached in 1999 and 2000 were the lowest in any of the years studied. We can consider these years anomalous (Table 4), because the points in the regression line of Fig. 3b are not near the scatter plot. The general model previously presented was improved when in the case of Vigo, these years, were removed. The equation of this new linear regression is presented in Table 7 and is the general model proposed to predict the heat requirement for triggering flowering. In this case, the value of r^2 increases to 0.778% (99.9% significant level).

Conclusions

These data show that the differences that appear in relation to the start of the pollen season for different species of winter–spring flowering trees in the temperate zone may be explained by the air temperature during the period preceding the pollen season. In both areas the pollen season starts in March or April. The period of chilling accumulation ranges from November to January. Perugia needed twice as many chilling hours as Vigo to overcome its requirements, and base temperatures of 7 °C and 5.75 °C result in the lowest standard deviation coefficients. The period of heat accumulation for triggering flowering in *Betula* takes place from February to March, and Vigo needed twice as many growth degree days as Perugia to get through the dormancy period.

The heat requirement and the length of the chilling accumulation differ according to the climatic conditions of the areas where the plants live. Generally the heat accumulation period is significantly reduced as the length of chilling increases. In colder areas these requirements are larger because the trees need to be protected for longer.

In the context of a possible global climatic warming, the studies focused on the quantification of the temper-

ature requirements necessary to overcome the dormancy period arouse particular interest. A knowledge of chilling temperatures in different areas can help us to explain the natural distribution of plants, as well as changes that could now be taking place.

There are some aspects that need further investigation to identify markers that indicate the end of dormancy for other arboreal plants and determine how the winter temperature could be increased without affecting the dormancy of the trees.

New studies over more years should be carried out with the aim of attaining greater statistical significance, and parallel phenological research will be necessary in order to increase our knowledge of this phenomenon.

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