

Chilling and heat requirements for the prediction of the beginning of the pollen season of *Alnus glutinosa* (L.) Gaertner in Ponferrada (León, Spain)

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Abstract

Winter-flowering trees such as the alder (*Alnus glutinosa* (L.) Gaertner) can survive periods of adverse climatic conditions, entering a period of dormancy in the early fall. The end of dormancy and the start of the pollen season require a period of low temperatures followed by another of warm temperatures. These requirements were studied from 1995 to 2002, in order to develop a model to predict the onset of the alder pollen season in Ponferrada (Spain). Chilling accumulation took place from late October to late December or early January. The best result was obtained with a threshold temperature of 6.5 °C and an average of 848 chilling hours (CH). Heat requirements were calculated at maximum temperature, an average 143 growth degree days (GDD) were needed, with a threshold temperature of 0 °C. In order to validate models, predicted values were compared with real values for 2002–2003, 2003–2004 and 2004–2005, years not used in developing the models. Predictions for the pollen-season start-date differed only slightly from observed dates: in 2002–2003 predicted and observed dates were the same, in 2003–2004 there was a difference of 7 days and in 2004–2005 a difference of 3 days.

1. Introduction

Over recent years, numerous studies have demonstrated the importance of temperature for the onset of flowering in trees that bloom in winter or early spring (Frenguelli et al., 1989; Alba and Díaz de la Guardia, 1998; Fornaciari et al., 1998; Chuine et al., 1999; Rodríguez Rajo et al., 2003).

Most winter-flowering trees, including the alder, have to survive periods of adverse climatic conditions, entering a period of dormancy; the onset of male-inflorescences growth requires a period of low temperatures followed by another of

relatively warm temperatures (Faust, 1989; Jato et al., 2000). Knowledge of these requirements enables the onset of pollination to be predicted.

Recently, a number of forecasting studies have been carried out to predict the pollen season start for *Alnus*, *Artemisia*, *Betula*, Poaceae, *Populus*, *Quercus* and *Ulmus* (Spijksma et al., 1989; Andersen, 1991; Frenguelli et al., 1991; García-Mozo et al., 2000; Rodríguez-Rajo et al., 2003).

Alder was selected for this study not only because it is widespread in Ponferrada, but also because alder pollen is one of the eight major allergenic airborne pollen types in the area

(Valencia-Barrera et al., 1999; Vega-Maray et al., 2002); various authors have reported that between 9 and 20% of hay fever sufferers in north-western Spain are allergic to *Alnus* pollen (Arenas et al., 1996; Rodríguez-Rajo et al., 2004). *Alnus* pollinosis is thus relatively important, even though its allergens are present in the air over a relatively short period of time. Alder pollen also displays cross reactivity with pollen grains of other genera belonging to the Betulaceae and Fagaceae families (Mathiesen et al., 1991; Subiza et al., 1998).

The only alder species found in Ponferrada is *Alnus glutinosa*, which – together with *Betula alba* L. *Salix atrocinerea* Brot and *Frangula alnus* Miller – forms part of the riparian forest (Rivas Martínez, 1987). Its distribution area lies at the boundary of the Eurosiberian and Mediterranean regions (Rodríguez-Rajo et al., 2004).

The aim of this study was to determine the chilling required for *Alnus* to break dormancy and heat accumulated to the flowering season start, with a view to timing the onset of pollination and charting the pollen season in this Mediterranean region.

2. Material and methods

The city of Ponferrada is located in the north-western Iberian Peninsula (latitude 42°33' N, longitude 6°35' W), at 541 m above sea level. The city's climate is Mediterranean with Oceanic influence, mean annual temperature is 13.1 °C and total annual rainfall is 597 mm (from 1939 to 1970) (Rivas-Martínez, 1987).

The Meteorological data were supplied by the Ponferrada regional weather station, located 1 km from the pollen sampler.

2.1. Aerobiological survey

To determine the start of the *Alnus glutinosa* pollen season, airborne pollen counts were monitored from 1995 to 2002 using Lanzoni® VPPS-2000 seven-day-recording volumetric spore trap sampler. Samples were prepared and counted using the method developed by the Spanish Aerobiology Network (Domínguez, 1992). The pollination period was calculated as 95% of

the annual *Alnus* total pollen-production season; the first days, producing up to 2.5% of total production, were removed from the calculations as well as the final days (from 97.5 to 100% of total production) (Andersen, 1991).

2.2. Predicting start of pollen season

The chilling and heat requirements required to break dormancy were estimated in order to predict the date of onset of the *Alnus* pollen season. Chilling requirements were determined using the thermal time model developed by Aron (1983), which has been used with good results by other authors for these taxa in other areas of Spain (Rodríguez-Rajo et al., 2004). This method calculates cumulative chilling hours (from 0 °C to 7.2 °C) with reference to maximum and minimum temperatures and the length of the chilling period:

$$CH = 801 + 0.2523B + 7.57B^2 \times 10^{-4} - 6.51B^4 \times 10^{-10} - 11.44 Ti_{\min} - 3.32 Ti_{\max}$$

CH = number of Chilling Hours during the period.

$$B = 24D[(A - Ti_{\min})/(Ti_{\max} - Ti_{\min})].$$

where $Ti_{\max}$ and $Ti_{\min}$ are average maximum and minimum temperatures, respectively, over the period considered, and D is the number of the days of which the period consist. The letter A in the B formula, representing base temperatures, was given various values (8, 7.5, 7, 6.5 and 6 °C) in order to ascertain which base temperature was most effective for chilling accumulation.

Calculation of cumulative chilling hours (CH) started in October or November, when local mean temperatures fell below 12.5 °C – the point below which winter-flowering woody plants begin to satisfy their chilling requirement (Richardson et al., 1974) – and ended when a change in temperature trend was recorded.

The heat requirement was calculated as a function of the sum of the difference between the daily maximum temperature and the threshold temperatures (0, 1, 2, 3 and 4 °C) from the end of the chilling period to the beginning of the pollen season. The heat requirement was expressed in growth degree days (GDD °C) (Faust, 1989).

The lowest coefficient of variation was used to identify the most adequate threshold temperature in both cases.

For validation of the date obtained by these forecasting methods for the start of the pollen season, three periods were used: 2002–2003; 2003–2004 and 2004–2005.

3. Results

The mean pollination period for *Alnus* began between the second fortnight of December and the second fortnight of January, and generally ended in the second fortnight of February (Table 1). The mean duration of the main pollination period (MPP) was 49 days.

The chilling accumulation period started in late October or the first fortnight of November and latest until December or January (Figure 1). The best result was obtained with a threshold temperature of 6.5 °C, which showed the smallest coefficient of variation (15.0%) and an average of 926 CH (Table 2). Higher-than-average CH values were recorded in 1998–1999 and 1999–2000 due to low temperatures during the chilling period. The duration of chilling accumulation ranged between 45 days in 1995–1996 and 81 days in 1998–1999 (Table 2).

Once chilling requirements were reached, heat accumulation was calculated. Heat accumulation started early in 1996–1997 (11 December in 1996) and the latest start was recorded in 1998–1999 (13 January in 1999). The lowest coefficient of variation (50.1%) was obtained with a threshold temperature of 0 °C and an average of 112 GDD (Table 3).

The length of the heat requirement period ranged between 3 days in 2000–2001 and 17 days in 1999–2000. In general, the heat requirement

was satisfied within in a short period of time (Figure 1). Lower-than-average values were recorded in 1998–1999 and 2000–2001. Those years differing from the mean in terms of chilling (1998–1999 and 1999–2000) and heat (1998–1999 and 2000–2001) requirements were eliminated on the grounds that they might be considered anomalous, altering the general model. This yielded better results, lowering the coefficient of variation for the chilling requirement from 15.0 to 3.7%, and for the heat requirement from 50.1 to 14.9%. The average obtained after these changes was 848 CH and 143 GDD (Table 4).

Finally, pollen-season start dates were predicted for 2002–2003, 2003–2004 and 2004–2005. Results obtained for chilling (848 CH) and heat (143 GDD) requirements were used to validate models. Dates predicted were 23 December for 2002–2003; 24 December for 2003–2004 and 20 January for 2004–2005.

Predicted MPP start dates were then compared with real dates: 23 December in 2002–2003 (as predicted), 31 December in 2003–2004 (seven days later than predicted) and 23 January in 2004–2005 (three days later than predicted).

4. Discussion

A number of authors report a correlation between the start-date of the *Alnus glutinosa* pollen season and temperatures over the preceding period (Spieksma et al., 1989; Andersen, 1991; Larsson, 1993); chilling and heat requirements were therefore analyzed in order to chart pollination behaviour in this species.

Alnus glutinosa pollen appears at the start of the year, as with all winter taxa. The periodicity of this pollen type in Ponferrada was very similar to

Table 1. *Alnus* Main Pollination Period (MPP), as defined by Andersen (1991), for the years 1995–2002

	Start dates of MPP	Final dates of MPP	Days of MPP	PPP (grains of pollen)
1995–96	31-12-95	06-03-96	67	662
1996–97	25-12-96	21-02-97	59	811
1997–98	04-01-98	23-02-98	51	304
1998–99	17-01-99	27-02-99	42	1979
1999–00	17-01-00	22-02-00	37	2140
2000–01	19-12-00	12-02-01	56	1340
2001–02	25-01-02	23-02-02	30	1928

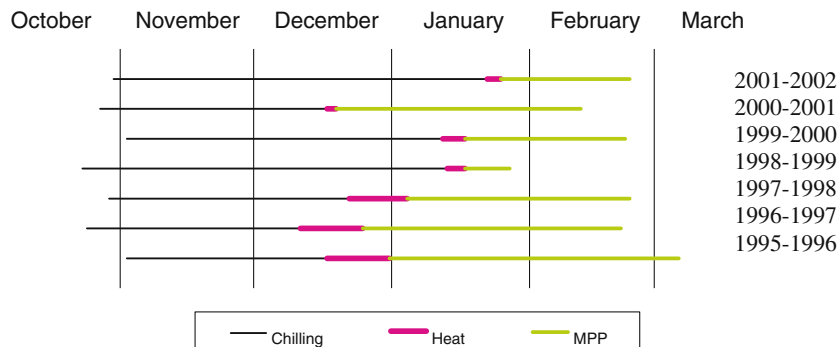


Figure 1. Chilling hours, growth degree days and pollination period for *Alnus* in Ponferrada over the study period 1995–2002.

that reported for areas of north-western Spain including León, Santiago de Compostela, Vigo and Ourense (Vega-Maray et al., 1998; Jato et al., 2000; Rodríguez-Rajo et al., 2004).

In Northern Europe, e.g. Leiden or Heldmond (Holand), the pollen season starts later (February) and last longer, until April. This is due to differences in weather conditions, since temperatures in Holland are generally lower than in Ponferrada, and the dormancy phase last longer (Spieksma et al., 1989; Frenguelli et al., 1991).

Mean duration of the pollen season (49 days) was similar to that recorded for nearby cities such as Ourense and Santiago de Compostela (53 days) (Rodríguez-Rajo et al., 2004).

Values obtained for chilling units (848 CH) were also similar to those recorded elsewhere in Spain, e.g. Santiago de Compostela (748 CH) and Ourense (816 CH) and in Italy (Perugia

(952 CH). All these locations have very similar mean annual temperatures (Santiago de Compostela 12.9 °C; Ourense 14 °C, Perugia 13.2 °C and Ponferrada 13.1 °C) (Jato et al., 2000; Rodríguez-Rajo et al., 2004). By contrast, considerably different values are reported for Vigo (460 CH) and Copenhagen (Denmark) (1550 CH) (Andersen, 1991). Vigo has a higher mean temperature (17 °C) than Ponferrada, so fewer cumulative chilling hours are required to break dormancy, while in Copenhagen (Denmark) the mean temperature is lower, and thus more chilling hours need to be accumulated.

The best results were obtained with a threshold temperature of 6.5 °C, compared to 5.5 °C in Santiago de Compostela and Ourense (Rodríguez-Rajo et al., 2004). This difference may suggest that species adapt to local climate conditions (Chuine and Cour, 1999; García-Mozo et al., 2002).

Table 2. Chilling hours (CH) for *Alnus* in Ponferrada over the study period, using different threshold temperatures

Periods	Threshold temperatures (°C)					Beginning CH	Final dates	Days
	8	7.5	7	6.5	6			
1995–96	982	930	878	830	787	02-11-95	16-12-95	45
1996–97	1006	955	903	853	808	24-10-96	10-12-96	47
1997–98	1077	1017	947	877	812	29-10-97	21-12-97	53
1998–99	232	645	918	1079	1153	23-10-98	12-01-99	81
1999–00	973	1090	1151	1167	1150	02-11-99	31-12-99	60
2000–01	997	930	864	804	753	27-10-00	16-12-00	50
2001–02	12	380	664	876	1026	30-10-01	10-01-02	72
Mean	754	849	904	926	927			
Maximum	1077	1090	1151	1167	1153			
Minimum	12	380	664	804	753			
Standard deviation	437.5	249.1	143.1	139.0	177.0			
Coef. Std. Var. %	58.0	29.3	15.8	15.0	19.1			

Table 3. Heat requirement (HR) for *Alnus* in Ponferrada over the study period, using different threshold temperatures

Periods	Threshold temperatures (°C)					Beginning HR	Final dates	Days
	4	3	2	1	0			
1995–96	110	125	140	155	170	17-12-95	31-12-95	15
1996–97	89	104	119	134	149	11-12-96	25-12-96	15
1997–98	88	102	116	130	144	22-12-97	04-01-98	14
1998–99	19	24	29	34	39	13-01-99	17-01-99	5
1999–00	43	60	77	94	111	01-01-00	17-01-00	17
2000–01	17	20	23	26	29	17-12-00	19-12-01	3
2001–02	80	95	110	125	140	11-01-02	25-01-02	15
Mean	64	76	88	100	112			
Maximum	110	125	140	155	170			
Minimum	17	30	23	26	29			
Standard deviation	37.1	41.5	46.1	51.0	56.0			
Coef. Std. Var %.	58.3	54.9	52.6	51.2	50.1			

The heat accumulation phase started once the chilling requirement had been met, and lasted for only a short time. Similar findings are reported for Perugia, Santiago de Compostela and Ourense (Jato et al., 2000; Rodríguez-Rajo et al., 2004). The mean heat requirement for Ponferrada (143 GDD) was higher than that recorded elsewhere (59 GDD in Vigo, 42 GDD in Perugia and 50 GDD in Santiago de Compostela) (Jato et al., 2000), probably because heat accumulation was calculated using different threshold temperatures.

Values obtained here for heat requirements differ from those reported for other taxa (Galán et al., 2001; García-Mozo et al., 2002), perhaps because, as Chuine and Cour (1999), Bewley et al. (2000), Jato et al. (2000) and García-Mozo et al. (2002) have suggested, this requirement is either genetically conditioned or governed by local climate differences.

The results bear out the strong correlation between chilling and heat accumulation in prompting the onset of flowering, reported by a

number of authors (Andersen, 1991; Jato et al., 2002; Iglesias et al., 2003; Rodríguez-Rajo et al., 2004). When developing general models, certain findings in anomalous years need to be taken into account:

- The persistence of low temperatures delays heat accumulation, while a slight increase in temperature will satisfy heat accumulation requirement in a matter of days (Aron, 1983; Myking, 1997). In 1998–1999, for example, temperatures were low, and more chilling hours were required, but a few days were sufficient to meet heat requirement. For that reason, results for 1998–1999 were excluded from the final model.
- Warm temperatures during the chilling period not only signify the absence of chilling, but will reverse some of the effects of previous exposure to chilling temperatures, the negative effect of high temperatures increases steeply between 19 and 21 °C (Aron, 1983). In 2004–2005, chilling accumulation began later

Table 4. Chilling and heat requirements of *Alnus*, eliminating anomalous periods 1998–1999, 1999–2000 (for chilling) and 1998–1999, 2000–2001 (for heat)

	Chilling Requirement					Heat Requirement				
	Threshold temperatures (°C)					Threshold temperatures (°C)				
	8	7.5	7	6.5	6	4	3	2	1	0
Mean	815	842	851	848	837	82	97	112	128	143
Standard deviation	450.0	261.0	109.4	31.3	108.0	24.5	23.6	22.8	22.0	21.3
Coef. Std. Var %.	55.2	31.0	12.9	3.7	12.9	29.9	24.3	20.3	17.3	14.9

than in other years, due to around to weeks of high temperatures (nearly 19°C) in November; this prompted a suspension of chilling accumulation, which started anew in December.

- Other year-on-year differences in the pollen-season start date may be due to high temperatures during the freezing period and low temperatures during heat accumulation (Jato et al., 2000).

The models developed here to predict the start of the *Alnus* pollen season are suitable, since validation yielded results similar to those reported for areas such as Ourense (3 days) and Santiago de Compostela (6 days) (Rodríguez-Rajo et al., 2004). Difference between modeled and real values were small.

5. Conclusions

The *Alnus* pollen season in Ponferrada started between the second fortnight of December and the second fortnight of January and continued until late February or early March.

Lower temperatures prolonged the pollen season. The chilling requirement was shorter in years when *Alnus* flowered earlier. Results demonstrated proved the vegetative effect of high temperatures and the persistence of lower temperatures during chilling.

In general, the heat accumulation period started in the second fortnight of December and ended on January, and was very short; an average of 143 heat units were required, with a threshold temperature of 0 °C.

Chilling and heat accumulation requirements differ as a function of local climate conditions, areas with similar mean annual temperatures displaying similar requirements. Further research is required to determine more precisely the influence of temperature on the length of the chilling and heat accumulation periods, and thus on the onset of flowering.

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