

The use of the pheno-climatic model for forecasting the pollination of some arboreal taxa

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Abstract

Air temperature is one of the most frequent parameters for the application of pheno-climatic models which can give information for the forecasting of the beginning of pollination of various species. For the present study 12 years of aerobiological monitoring data concerning the pollination of hazel, alder, elm, poplar, and willow have been employed to forecast the beginning of their pollination assuming that the beginning of pollination of one species corresponds to a specific moment of phenological development for another species with later pollination. The difference expressed in days between the pollination of two winter taxa with successive flowering is very variable. If this interval is expressed in terms of heat (summation of mean daily temperature above a certain threshold) the differences are smaller. The delay between the pollination of alder and elm varies between 3 and 21 days depending on the climatic trend, but during this period elm on average accumulates 26 degree-days (base temperature 4°C) with a lesser variability. In this way we can begin to calculate the heat requirement for elm from the beginning of alder flowering. This application can be used for other couples obtaining statistical values which are more significant than those obtained with the phenological model, with the exception of willow. The results indicate that for the majority of the species with winter flowering there is a linear relation between the flowering dates and air temperature. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Weather conditions directly influence pollination by determining the time of flowering onset, the abundance of vegetation and by controlling the amount of pollen daily discharged into the air. While for the winter and early spring plants the greatest influence on the time of flowering is determined by the temperature, for late spring and early summer there is the influence of temperature and the photoperiod at the same time, and finally for the late summer species the onset of pollination depends above all on the photoperiod (Edmonds, 1979).

The time of onset of pollination of winter and early spring flowering plants in temperate zones is very variable and to forecast the beginning of pollination it is

necessary to consider when the plant has satisfied the chilling requirement to overcome dormancy and when it begins to accumulate heat (Frenguelli et al., 1992).

Therefore for these plants the use of the phenological model to forecast the beginning of the pollination is not always applicable (Bricchi et al., 1995). The use of the pheno-climatic model is more appropriate because it considers the air temperature as one of the environmental parameters which principally influence pollination (Puppi, 1989). The variations which are observed from year to year can be accounted for by linear correlation of the temperature in the preceding period and the accumulated heat (Maracchi, 1977).

The use of this model is based on the application of a linear correlation which links the air temperature to the speed of the development of the plant (Marletto et al., 1992). Assuming that the beginning of pollination of one species corresponds to a specific moment of phenological development for another species with later

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Table 1

Beginning of the main pollination period (in days) of studied taxa from the 1 January

	<i>Corylus</i>	<i>Alnus</i>	<i>Ulmus</i>	<i>Populus</i>	<i>Salix</i>
1984	1	37	21	19	11
1985	23	15	16	10	23
1986	11	36	18	6	13
1987	25	15	20	13	7
1988	6	26	6	25	17
1989	25	20	6	12	20
1990	1	32	11	9	5
1991	11	43	3	78	6
1992	25	12	12	8	13
1993	24	18	10	24	23
1994	4	26	5	20	19
1995	26	15	3	11	21
Mean	15	25	11	14	15
Min	1	12	3	6	5
Max	26	43	21	25	23
S.D.	10.4	10.4	6.5	9.1	6.6
Coef. vs. %	68.6	42.1	17.0	47.7	13.3

The numbers in italics indicate the difference in days with the pollination of the following taxon.

pollination, we have applied the pheno-climatic model to 12 years of aerobiological monitoring data to obtain information about the beginning of pollination of some arboreal winter species.

2. Material and methods

Pollen grains were monitored by means of a 7-day volumetric Hirst-type pollen trap (Lanzoni, Bologna) located in Perugia, Central Italy, on a rooftop at 20 m above ground level. Description of the trap and the methods used for the preparation and scanning of the slides are explained in a previous paper (Frenguelli et al., 1981).

The pollination of five taxa with winter flowering was studied: hazel (*Corylus*), alder (*Alnus*), elm (*Ulmus*), poplar (*Populus*) and willow (*Salix*). For each taxon, over a 12-year period (1984–1995) of pollen monitoring, the dates of the beginning of the main period of pollination were calculated using the method of Lejoly-Gabriel (1978).

The heat accumulation to induce pollination is expressed as growth degree days (GDD°C), obtained by the summation of daily mean temperatures above 4, 5, 6°C which represent the thresholds above which the temperature became effective for growth (Faust, 1989).

For the hazel, heat accumulation began on 15 December and continued until pollination; this date, in the studied area, represents, on average, the moment at which the chilling requirement to overcome the dormancy is fulfilled and the hazel begins to accumulate heat for floral bud growth (Frenguelli et al., 1992, 1994). For the other taxa the heat accumulation began

with the pollination of the previous taxon and continued until their pollination.

For the calculation of the chilling requirement we have used the model proposed by Aron (1983), that is based on the accumulation of chilling hours between 0 and 7.2°C. In the present paper we have calculated the chilling hours accumulated from 1 November, when the mean temperature normally begins to decrease under 10°C, and 15 December.

3. Results

The dates of the beginning of pollination are reported in Table 1. The values of the dates vary considerably from year to year, for all the taxa examined,

Table 2

Correlation of the start dates of the main pollination period between the taxa, over a 12-year period

Correlated taxa	r Coefficient	Mean warning days
<i>Corylus/Alnus</i>	0.001 n.s.	22
<i>Corylus/Ulmus</i>	0.064 n.s.	33
<i>Corylus/Populus</i>	0.001 n.s.	46
<i>Corylus/Salix</i>	0.003 n.s.	61
<i>Alnus/Ulmus</i>	0.643*	11
<i>Alnus/Populus</i>	0.118 n.s.	24
<i>Alnus/Salix</i>	0.036 n.s.	39
<i>Ulmus/Populus</i>	0.722**	13
<i>Ulmus/Salix</i>	0.147 n.s.	28
<i>Populus/Salix</i>	0.781 **	15

n.s., not significant.

* $P < 0.05$.

** $P < 0.01$.

Table 3
Accumulated GDD°C (base 4, 5 and 6°C)

Year	<i>Corylus</i> (°C)			<i>Alnus</i> (°C)			<i>Ulmus</i> (°C)			<i>Populus</i> (°C)			<i>Salix</i> (°C)		
	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
1984	78	61	45	62	39	22	10	4	0	24	14	7	50	38	29
1985	57	43	32	49	35	22	21	15	11	43	34	25	77	59	44
1986	63	43	28	36	22	10	38	25	16	27	22	16	45	33	22
1987	45	29	19	38	27	16	45	31	20	8	5	3	8	6	3
1988	89	67	45	87	64	45	27	21	14	40	25	13	53	38	26
1989	53	26	11	75	56	39	21	16	11	55	43	32	137	117	97
1990	86	74	62	66	46	31	34	25	17	66	58	48	41	36	31
1991	65	46	31	55	38	26	25	22	19	51	44	36	55	49	43
1992	61	35	18	28	21	13	42	31	20	18	13	10	74	61	48
1993	80	55	32	62	46	33	15	9	4	51	39	27	133	112	94
1994	57	41	28	75	54	38	18	13	8	39	28	18	151	131	113
1995	64	45	31	53	37	24	17	14	10	54	43	32	76	56	38
Mean	67	47	32	57	40	27	26	19	13	40	31	22	75	61	49
Min	45	26	11	28	21	10	10	4	0	8	5	3	8	6	3
Max	89	74	62	87	64	45	45	31	20	66	58	48	151	131	113
S.D.	13.7	14.7	13.7	17.6	13.5	10.9	11.3	8.4	6.4	17.3	15.6	13.4	43.7	38.5	34.0
Coef. vs. %	20.7	31.2	43.2	30.8	33.3	41.0	43.2	44.8	51.1	43.5	50.8	60.1	58.3	62.8	69.4

These values are from 15 December for *Corylus*, and for each other taxon, from the beginning of pollination of the previous taxon and its pollination.

with differences of 20–40 days between the earliest and latest dates. Both 1987 and 1993 were years with very late pollination, while in 1994 the plants pollinated early. This trend did not however occur in all the examined years, because in the same year, flowering could occur early in some plants and late in others.

In 1984 *Corylus* and *Alnus* pollinated early while *Ulmus*, *Populus* and *Salix* delayed for about 10 days before flowering. The same occurred in 1991 for *Corylus* and *Salix* which pollinated early while the other taxa pollinated slightly later than the average. The delay of *Alnus* in relation to *Corylus* was only 12 days in 1992, and 43 days in 1991, but between *Alnus* and *Ulmus* there was a delay of 12 days in 1992 and only 3 days in 1991. In this way, if we apply the phenological forecasting model, which is based on the number of average days of delay (mean warning days) between two successive flowerings (Table 2), only the pairs

Ulmus/Populus and *Populus/Salix* have highly significant regression coefficients.

Table 3 shows the heat accumulation, expressed as GDD°C and calculated with base temperatures of 4, 5 and 6°C. Even in this case, the values vary, but with statistically lesser differences. For example, if the delay between the pollination of *Ulmus* and *Populus* varies between 6 and 25 days (Table 1) depending on the climatic trend, during this period *Populus*, on average, accumulates about 40 GDD°C (base 4°) from the pollination of *Ulmus*, showing a relatively low coefficient of variation. The delay between the pollination of alder and elm varies between 3 and 21 days, but during this period elm on average accumulates 26 degree-days (base temperature 4°C) with a lesser variability. In this way we can begin to calculate the heat requirement for *Populus* from the beginning of *Ulmus* flowering.

Table 4
Correlation of the GDD°C accumulated between the taxa and forecasting model

Correlated taxa	<i>r</i> Coefficient	Mean GDD°C accumulated	Forecasting model
<i>Corylus/Alnus</i>	0.816**	25 (base 6°)	$y = 25.696 + 0.994x$
<i>Corylus/Ulmus</i>	0.782**	37 (base 6°)	$y = 40.654 + 0.897x$
<i>Alnus/Ulmus</i>	0.857***	25 (base 4°)	$y = 58.030 + 0.728x$
<i>Alnus/Populus</i>	0.880***	66 (base 4°)	$y = 52.118 + 1.101x$
<i>Alnus/Salix</i>	0.710**	141 (base 4°)	$y = 69.451 + 1.563x$
<i>Ulmus/Populus</i>	0.905***	23 (base 6°)	$y = -1.566 + 1.345x$
<i>Populus/Salix</i>	0.708**	75 (base 4°)	$y = 28.305 + 1.246x$

Calculated over a 12-year period.

** $P < 0.01$.

*** $P < 0.001$.

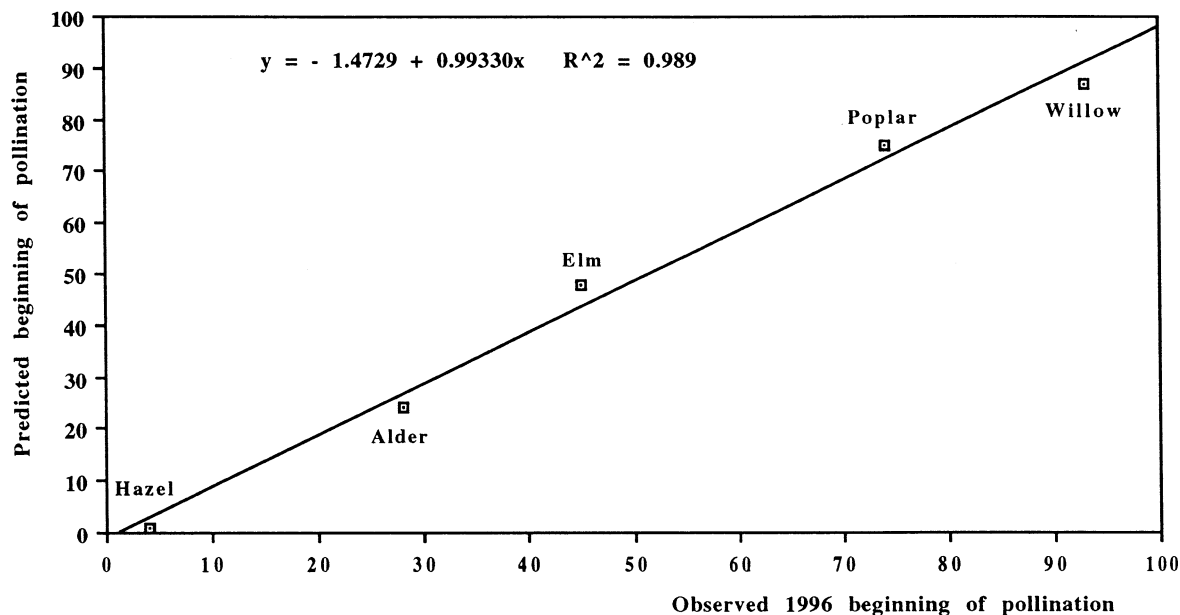


Fig. 1. Predicted versus observed 1996 onset of pollination for different species.

The same calculation can be made for the other couples, obtaining in each case, values which are statistically more significant. Only for *Salix* the model is less significant than for other plants.

When the heat requirements for pollination are correlated, as in Table 4, there are very significant coefficients for all the pairs, this enables the elaboration of a forecasting model which, starting with the heat requirement of the first species, leads to a significant indication of the beginning of pollination for the next species. The differences registered using the three different base tem-

peratures, were not highly significant, and in Table 4 the highest coefficients are given. This model was applied to forecast the beginning of pollination for the taxa examined in 1996. Fig. 1 shows the comparison between the observed dates and those predicted, which demonstrates that the model is extremely accurate especially when the base temperature of 4°C is used.

Fig. 2 shows the correlation between the heat requirements of two taxa (*Ulmus* and *Populus*) in which it is possible to see that if more heat is required for the flowering of *Ulmus* in a given year, *Populus* also re-

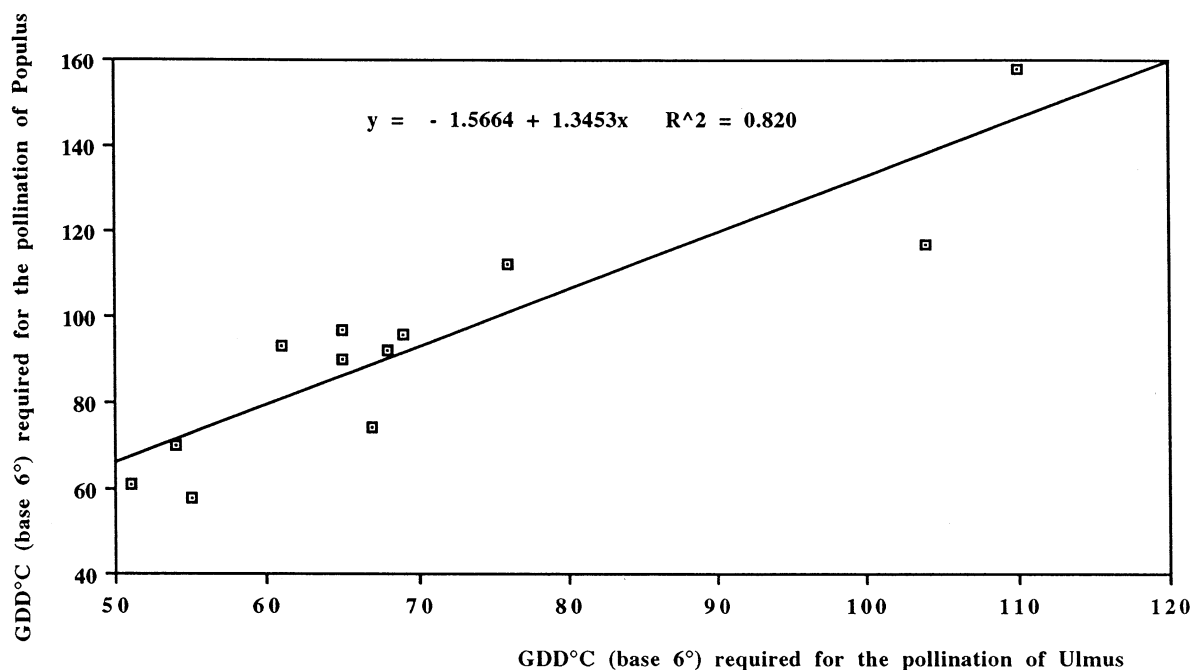


Fig. 2. Relationship between the GDD°C (base 6°) required for the pollination of *Ulmus* and *Populus*.

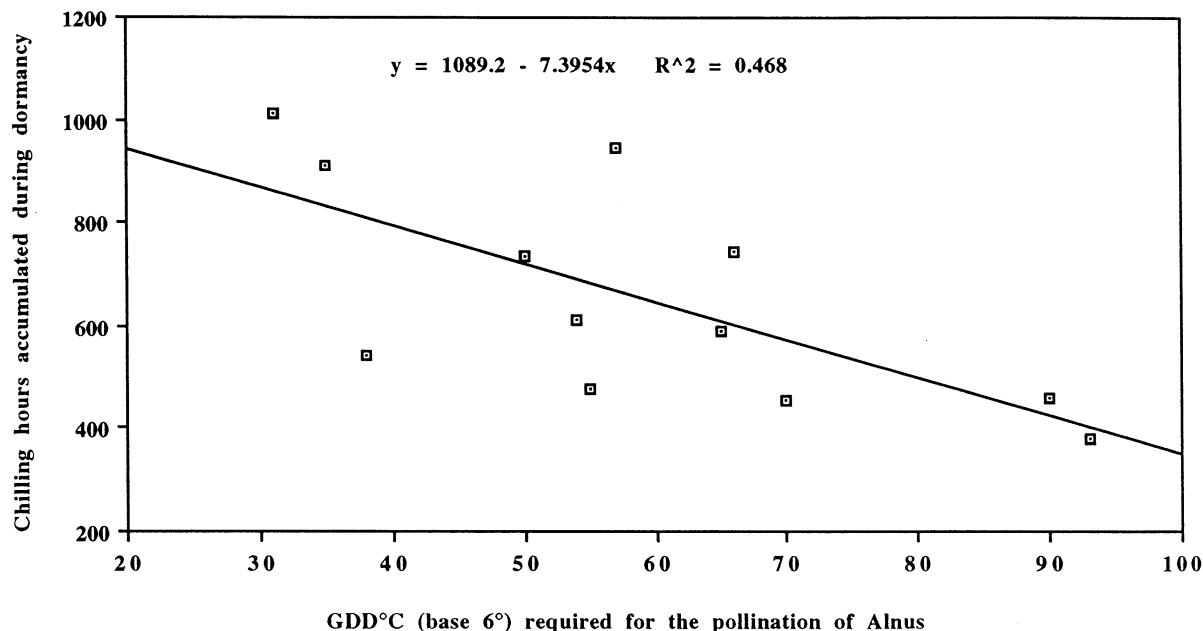


Fig. 3. Relationship between the chilling-hours accumulated during dormancy and the heat (GDD°C, base 6°) required for *Alnus* pollination.

quires a larger quantity than the average. This larger heat requirement, valid for all the examined couples, seems to be linked to the temperature trend in the dormancy period. When the quantity of cold is calculated, expressed as chilling hours accumulated during autumn, we can note, for example, in *Alnus* (Fig. 3), that the more the plant has accumulated cold, the less will the quantity of heat be which the plant must then accumulate for pollination.

4. Discussion

In a previous paper (Bricchi et al., 1995) we found many taxa correlated in pairs and able to give significant indication both for medium and long-term forecasts. But when we apply this model to winter pollinating plants the results are not very significant. These taxa show high year to year variability in the date of pollination onset, with ranges sometimes higher than 40 days. For these taxa the severity and duration of the autumn and winter determines, to a great extent, the onset of their pollination. Following an unusually short, warm winter many trees bloom early in the season, but an unusually long winter will postpone the dates of pollination for more than a month. In our study we have found a high coefficient of regression only for *Ulmus/Populus* and *Populus/Salix*. Therefore the phenological model is valid for a medium-term forecast and not for every taxa.

The results have shown relationships between phenological behaviours of the studied species and the thermal patterns in the years. Therefore for the realization

of a flowering forecasting model we have applied the pheno-climatic model. The use of this model assumes the potential applicability of the linear approach which links the speed of growth of the flower to the air temperature with a simple linear correlation. We can assume that the product between the duration in days of a phenological phase and the heat expressed as degree-days remains more or less constant. Winter species which are suitable for models with degree-days are the majority and can be used as leading species to indicate the beginning of pollination of a later species. The results indicate that for many pairs of species there is a linear relation between the flowering dates and air temperature above a certain threshold and only for *Salix* the model is not highly statistically significant.

The severity and duration of the winter, control to a great extent the beginning of tree pollination. This study shows that there is a significant relationship between the heat requirement in the five taxa to reach the pollination. If a taxon with an early flowering needs a heat requirement higher than the average value, also the taxa with later flowering will need a higher value of heat. This figure could be explained with the pattern of temperature in the preceding months, when the trees accumulate the chilling hours to overcome the dormancy. If the winter is relatively warm, the plant needs more heat to pollinate; vice versa if the winter is cold and long, the heat requirement is fulfilled early at lower values of GDD°C.

This statement must however, be better checked with further data and with a more detailed calculation of the chilling requirement; above all the moment must be defined when the cold accumulation ends and heat

accumulation begins and it will be necessary to extend these models to other taxa with winter pollination.

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