



Regional variations in the pollen season of *Betula* in Burgundy: two models for predicting the start of the pollination

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Abstract

Today, 10% of the French population suffer from pollen allergy, a world-wide rising ailment since the end of the last century. To prevent the appearance of the symptoms, physicians need precise and early information on the pollination date of the main allergenic species. This was carried out in Burgundy on birch (*Betula*), which is responsible for frequent pollinoses in March–April. Two of the tested methods were both successful and complementary: the sum of temperatures and the multiple regression. The first one is very precise but only allows forecasting five days in advance: this is enough for people suffering from rhinitis or conjunctivitis, who must start a preventive treatment one or two days before pollination is effective. But for asthmatic patients, the treatment must one or two weeks in advance; the second method, although a little less precise, is interesting because forecasting can be done at least two weeks in advance. The results, from 1995 to 1998, were used prospectively in 1999.

1. Introduction

Nowadays, about 20% of the French population are allergic, and half of them suffer from pollen allergy, that is to say pollinosis. This represents a total of 6 to 7 million individuals (D'Amato et al., 1991; Guérin, 1993). To relieve them or, better, to prevent symptoms, physicians need accurate information about the pollination period of the main anemophilous species. At the present time, pollen counts collected on all the sites of the National Network of Aerobiological monitoring (Réseau National de Surveillance Aérobiologique, R.N.S.A.) are spread as an allergopollinic report which only gives the raw data of the major first four taxa. Furthermore, there is a 9 day delay, which cannot be cut down, between the start of the weekly pollen gathering, the analysis and the publishing of the results. Physicians, however, must receive this information early enough to implement an effective preventive treatment. Such an aim needs that observations be completed by forecasting.

2. Materials and methods

The airborne pollen was sampled by a volumetric Hirst trap (Hirst, 1952), which is now the most commonly used aerobiologic measurement instrument in Europe.

The sampler is calibrate to handle a flow of 10 litres of air per minute, which roughly corresponds to human breathing. Pollen grains are impacted on a cylindrical drum covered by a melinex film coated with a uniform layer of sticky substance, and rotated by a 7-day clockwork at a speed of 2 mm/hr (Mandrioli, 1990; Mandrioli, 1994; Rantio-Lehtimäki, 1991).

Four traps were used in this study, located (Figure 1) in the Burgundy region (France) in Côte-d'Or (Montbard, Dijon) and Saône-et-Loire (Chalon-sur-Saône, Mâcon). Studied years were 1995 to 1998.

The methodology employed is common for this type of sampling. Every week, the ribbon strip is removed and cut into seven equal segments corresponding to the seven days of the week. Each segment

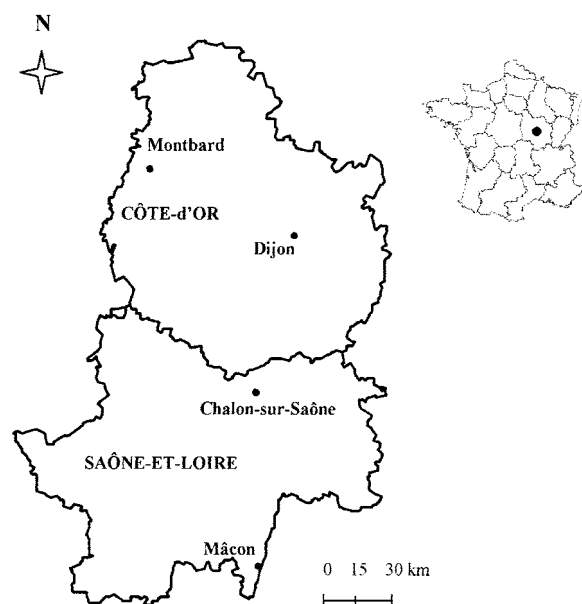


Figure 1. Situation of the four Burgundian pollen traps.

is mounted between two slides which adhere by means of a solution of gelatine, glycerol, phenol and distilled water. Then it is examined by light microscopy following the method of K  p  l   and Penttinen (1981). The results are expressed as the number of pollen grains per cubic meter of air.

Meteorological data were recorded by M  t  o-France less than two kilometres away from each sampling site.

Pollination takes place after the growth and development period of the plant, both phenomena depending on environmental conditions and being interlinked, since the plant always grows between two developmental stages. Under natural conditions, development essentially depends on temperature, other environmental factors (edaphic and climatic) being less important. The action and cumulative effect of temperature on the development could be assimilated to a linear, exponential or sigmoid relation, which allows to estimate it by methods such as the sum of temperatures or the sum of Q_{10} .¹ The growth also advances according to the temperature context, but other environmental factors act on it (soil and radiation in particular) and many of them are difficult to integrate in a forecast model. Nevertheless, it is always possible to find a linear or exponential adjustment of the temperature action curve by statistical methods. But the best adjustment, found for a given site, may

not necessarily apply to another site characterized by another scale of thermal variation.

Yet, whatever the method chosen for forecasting the pollination period of a plant, temperature is generally used (Niqueux and Arnaud, 1967; Ashcroft et al., 1977; Lejoly-Gabriel, 1978; Niqueux and Arnaud, 1981; Richardson and Anderson, 1986; T  rnevik, 1982; Linvill, 1990; Andersen, 1991; Frenguelli et al., 1991; Sutra et al., 1992; Larsson, 1993; Lafont and Perret, 1995), rarely radiation (Maurain, 1933; Thornthwaite, 1952 quoted by Durand, 1967) or sometimes several meteorological factors like temperature, wind and rainfall put together (P. Mandrioli et al., 1993).

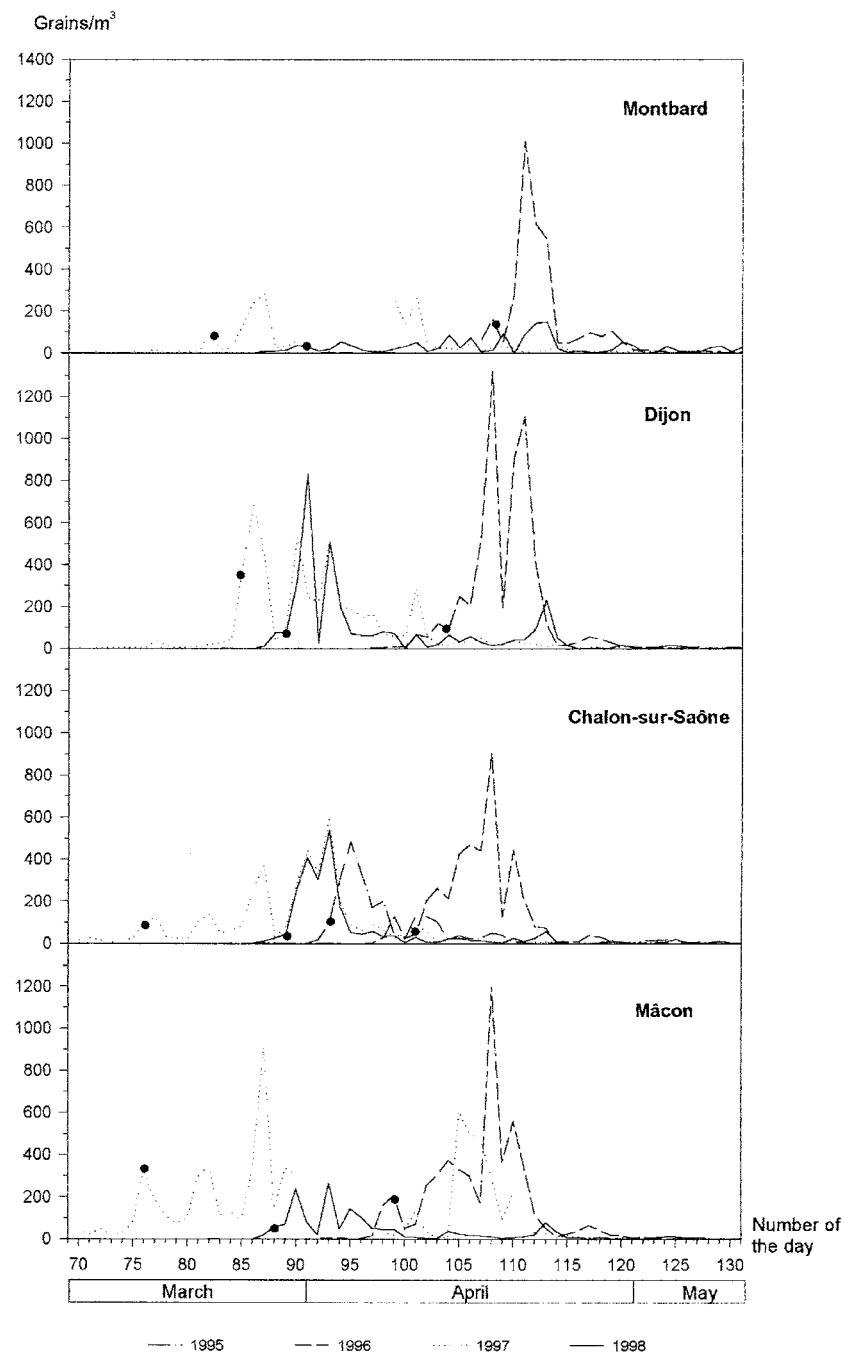
The choice of *Betula* is justified because in the East-Center of France it is in second place in the list of all the pollinic allergens after *Poaceae*, but also because its pollination period reveals a great variability from one year to the other (Laaidi et al., 1998).

For birch, the Starting Date of the Pollen season (SDP) from one year to the other can vary by 18 and 25 days for a given site and, for a given year the variability between sites ranges from 2 to 9 days (Figure 2). In this way, birch pollination is quite variable in space and time, so it is of prime importance to forecast it. But before forecasting the onset of Birch pollination, it should first be estimated on a number of available years. Our estimation was based on a graphical method where drawing the pollination curves of a taxa with the daily cumulated pollen percentages on Y-axis and the date of observation on X-axis. Then it can be observed that the curve is sigmoid with two bends (Pathirane, 1975; Lejoly-Gabriel, 1978). These two points correspond to the start and the end of the main pollination period. Lejoly-Gabriel developed an arithmetic method to determine these two dates: for the onset of the Pollen season, two conditions must be fulfilled, and the SDP occurs when:

- the pollen concentration of the day reaches at least 1% of the total annual catch.
- the total accumulated until this day is equal to 5% of the annual catch.

3. Results and discussion

The forecast models we tested were numerous and all did not give significant results: for instance, the sum of radiation, which is based on energy received by the plant and seemed physiologically more appropriated,



On each curve, SDP is mentioned by a point ●

Figure 2. Variability of the birch SDP according to the site and the year.

Table 1. Forecasting the birch SDP (Sum of temperatures method) with different parameters for each trap

	Calculation parameters			Predicted SDP					
	Start of T°C sum	Threshold (°C)	Sum of T°C	1995	1996	1997	1998	μ	σ
Montbard				18/04	24/03	31/03			
	14/02	2	327.3	(+1)	(+1)	(0)	0.67	0.58	
Dijon				15/04	25/03	30/03			
	05/01	0	440.1	(+2)	(-1)	(0)	0.33	1.53	
Chalon/S.				03/04	10/04	18/03	30/03		
	24/02	5	210.5	(0)	(0)	(+1)	(0)	0.25	0.50
Mâcon				08/04	17/03	30/03			
	24/02	5	232.5	(0)	(0)	(1)	0.33	0.58	

Predicted SDP:

Bold type number = day of the month.

Number in brackets = distance apart the predicted date and the observed date.

did not give the expected results, maybe because of the lack of available data; the sum of Q_{10} was also proved not very reliable. On the contrary, two methods gave interesting results: the sum of temperatures and the multiple regression.

3.1 The sum of temperatures

This method was inspired by Lejoly-Gabriel's works (1978): in its original formulation it consists of adding the daily average air temperatures from a predefined date, specifically April 1st, above a reference temperature or 0°C threshold until the temperature sum reaches 279.8°C. This sum of temperatures should correspond to the starting date of the pollen season forecasted by the model. But, applied to the Burgundy region, these parameters didn't give good results (up to 16 days later), probably because the chosen date to start the sum of temperatures was too late. This method was first devised at Louvain (Belgium), and so it seemed necessary to adapt it to French, and especially Burgundian, phytoclimatic conditions.

In order to estimate the date used for cumulating the sum of daily temperatures, we tested every 10-day period between November 1st and March 1st (or February 29 for the leap year 1996). We have also tested the starting dates every five days (from November 1st to March 6th) in order to find more precise results. This was not the case and the use of 10-day periods remained our basic procedure.

We also considered the thresholds above which daily temperatures would be efficient. These thresholds were chosen from 0 to 9°C, with a

step of 1°C. So we found for each site 130 date-threshold combinations. For each combination, we calculated the mean μ and the standard deviation σ of the sum of temperatures, for all the years. Then, the best starting date and threshold are those which minimize the ratio σ/μ . The results are given in Table 1. These parameters allowed us to evaluate the SDP and to calculate the error about the real SDP. It was also possible, using the same method, to determine a sum, a starting date and a threshold for all the Burgundian cities (Table 2).

Calculations made with parameters common to the four cities gave errors between 0 and 7 days. On the contrary, using specific parameters for each site, since they have their own climate characteristics, results were better adjusted: the distance between real and predicted SDP never exceeded 2 days, and more often than not it remained between ± 1 day. This points out the importance of a sufficiently dense network of traps, in order to obtain precise forecasts.

3.2 The multiple regression

It is aimed at establishing a relation between the predicted variable ($Y = \text{SDP}$) and several explanatory variables, according to the following equation:

$$Y = b + a_1X_1 + a_2X_2 + \dots + a_kX_k$$

We first established simple correlations between the dependent variable Y and each of the explanatory variables. Y is the SDP day rank. The explanatory variables have been chosen according to studies real-

Table 2. Forecasting the birch SDP (Sum of temperatures method) with common parameters for the four traps

Calculation parameters				Predicted SDP					
	Start of T°C sum	Threshold (°C)	Sum of T°C	1995	1996	1997	1998	μ	σ
Montbard					15/04 (-2)	23/03 (0)	30/03 (-1)	-1.00	1.00
Dijon	14/02	0	320.1		13/04 (0)	21/03 (-5)	30/03 (0)	-1.67	2.89
Chalon/S.				03/04 (0)	14/04 (+4)	24/03 (+7)	31/03 (+1)	3.00	3.16
Mâcon					10/04 (+2)	18/03 (+1)	27/03 (-2)	0.33	2.08

Predicted SDP:

Bold type number = day of the month.

Number in brackets = distance apart the predicted date and the observed date.

ised by Lejoly-Gabriel (1978) and by Sutra et al. (1992):

– Raw meteorological parameters, that is to say precipitation and the average 10-day minimum and maximum temperatures. The periods of ten days taken into account range from the beginning of November to the end of February, that is to say two weeks to one and a half month before SDP, depending on the sites and years. Because of the small size of samples at each site (3 or 4 years of pollen counts), it turned out to be necessary to consider the thirteen available observations as thirteen independent data, and so to establish only one regression equation for all the sites. Sunshine, radiation and soil temperatures (–10 and –20 cm) could not be retained as descriptive variables insofar as we only have these data for two sites, Dijon and Mâcon.

– Agrometeorological parameters of Cold and Warm Action defined from minimum and maximum temperatures and Q_{10} coefficient.

Simple correlations between Y and the explanatory variables were calculated according to the Spearman rank order correlation. This was chosen rather than the Pearson correlation because the population under consideration is not normally distributed. Table 3 summarizes the values of ρ (correlation coefficient), p (probability of being wrong when concluding that there is a relationship between both variables) and n (number of sample) for the variables which are correlated with Y, and which will be integrated into the regression model. Eight explanatory variables were

Table 3. Selected variables for the regression equation

Variables	ρ	p	n
Tmax _{19–28/02}	–0.975	<0.001	13
Tmin _{19–28/02}	–0.916	<0.001	13
Tmin _{01–10/11}	–0.694	0.008	13
Tmax _{01–10/11}	–0.694	0.008	13
Tmax _{11–20/11}	0.639	0.018	13
Pmm _{30/01–08/02}	0.598	0.029	13
Tmin _{21–30/11}	0.590	0.033	13
Pmm _{11–20/11}	–0.548	0.049	13

used because it is necessary to have fewer explanatory variables than observations.

The regression equation found can be written as following:

$$Y = 110.893 + 1.891 * \text{Tmin}_{21-30/11} - 2.240 * \text{Tmax}_{19-28/02}$$

Correlation coefficients were calculated between the independent variables in order to verify if the two variables retained for the model were definitely uncorrelated. The obtained correlation was not significant ($\rho = -0.505$ $p = 0.074$). On the other hand, Normality and Constant Variance Tests were significant ($p = 0.808$ et 0.964 respectively). The Power of performed test was equal to 1 ($\alpha = 0.05$).

The regression equation obtained only integrates temperature, and not precipitation, maybe because in Burgundy, even if rainfall differs from one year

Table 4. Birch SDP calculating by the multiple regression method

	1995	1996	1997	1998	μ	σ
Montbard		104	80	90		
		(-4)	(-2)	(0)	-2.00	2.00
Dijon		103	81	89		
		(-1)	(-4)	(0)	-1.67	2.08
Chalon/S.	94	103	80	85		
	(+1)	(+2)	(+4)	(-4)	0.75	3.40
Mâcon		103	80	88		
		(+4)	(+4)	(0)	2.67	2.31

Bold type number = running number of day (from January 1st upwards).

Number in brackets = distance between the predicted date and the observed date.

to the other, water requirements of plants are satisfied. On the contrary, differences are pronounced for temperature (November more or less cold during the plant dormancy, February more or less mild before pollination).

The maximum temperature of the last 10-day period of February was the most representative variable, which shows the effect of high temperature during the month before pollination on the forwardness of Birch pollination. Minimum temperature from November 21st to 30th had a positive coefficient, which means that increasing temperature delays pollination: this points out how much cold is important during the dormancy of birch. In order to test the regression equation, SDP were calculated for the years 1995 to 1998 and for each site. Results (Bold type numbers) and error to real SDP (numbers into brackets) are given in Table 4.

The maximum error reached four days, which can be considered as relatively low, especially as only one equation was established for the four towns. So this method can well predict SDP, even if errors are a little larger than with the method of the sum of temperatures.

3.3 Using these two methods for 1999

In 1999, the above methods were tested for Dijon and Chalon-sur-Saône.

With the method of the temperature summation, the distance between predicted and real SDP was small: in Dijon, the forecasting was particularly accurate since the difference was equal to zero, in Chalon-sur-Saône the predicted date came only just two days before the actual date.

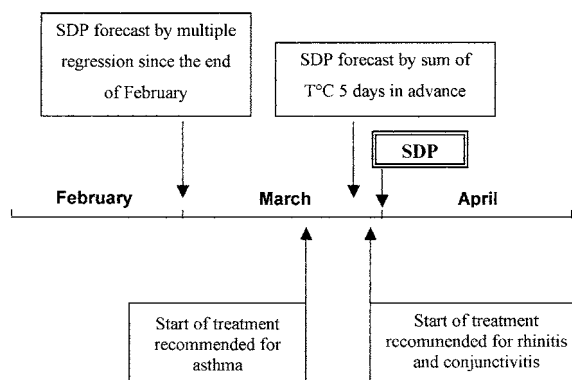


Figure 3. Complementary nature of the SDP forecasting methods.

With the regression, SDP was predicted for March 23rd in Dijon and Chalon-sur-Saône, that is to say 7 to 9 days before the actual SDP.

Regression, even if less precise, allows to supply forecasting as early as the end of February. This is of particular interest for asthmatic patients, because they need to begin an antiallergenic treatment one or two weeks before pollination. Nevertheless, regression does not integrate the meteorological data of March, and so needs to be completed by the method of the sum of temperatures. This last method give results five days in advance when using predicted temperature (Météo-France), which is more than enough for allergic patients with rhinitis or conjunctivitis, who only need to begin their treatment one or two days in advance (Figure 3). The association of both methods allows to give allergic patients early and accurate information, so that they can begin their treatment in good time.

SDP is certainly the most interesting parameter to forecast for allergic patients; but predicting the length of the pollination period and the total pollen amount can also be helpful, in order to estimate the potential severity of pollinosis.

3.4 Attempted at predicting the duration and the abundance of the pollen season of birch

Some authors suggested that meteorological conditions before pollination could influence, not only its earliness but also its quantitative importance. In that way, Andersen (1980) showed that the blooming intensity of birch and alder in Denmark depends on the precipitation of April of the previous year, whereas that of oak and beech would rather depend on the average temperature of the previous year. Working

on oak in California, Fairley and Batcheler (1986) observed a high correlation between the quantities of pollen trapped and the sum of precipitation of the previous year. Lejoly-Gabriel (1978) established a regression between pollen quantities, average relative humidity of November and December and average soil temperature at fifty centimetres, for the same months. Comparing the pollinic seasons of London and Liverpool, Davies and Smith (1973) observed that high pollen concentrations correspond to sums of temperatures rapidly increasing, in connection with an earlier and longer pollen season. We also searched for correlation between:

- birch pollen quantities released during the season, and various meteorological parameters and SDP;
- duration of the main pollen season, various meteorological parameters and SDP.

Concerning the pollen quantities produced, no correlation could be found either with SDP or meteorological factors.

Concerning the duration of the pollen season, some correlations could be found with monthly meteorological factors, which have then been integrated into a multiple regression model. This one finally included two variables, minimum relative humidity of October ($H_{min_{oct}}$) and maximum temperature of February ($T_{max_{feb}}$):

$$Y(\text{duration}) = 41.046 - 0.555 * H_{min_{oct}} + 1.830 * T_{max_{feb}}$$

$H_{min_{oct}}$ being negative, the pollination season should be shorter when October is very damp. Conversely, $T_{max_{feb}}$ is positive; so, high temperature during February seems to induce a longer pollination period. In addition, it could be seen in the regression equation of SDP according to meteorological factors that maximum temperature of the last 10-day period of February also played a part, this time with a negative coefficient: so, high maximum temperatures during February, and particularly during the last 10-day period, is expected to induce an earlier and longer season.

The equation was tested on available years, and its error with actual duration varied from 0 to 6 days. In 1999, we forecasted in this way a duration of 15 days for both sites still in operation (Dijon and Chalon-sur-Saône), and it has proven to be 14 days in either case.

4. Conclusions

The most precise method for predicting the onset of pollination for birch was the sum of temperatures, for which maximum error did not exceed two days. It enables, using predicted temperatures from Météo-France, to forecast five days in advance. It is also possible to use the multiple regression which integrated minimum temperature from November 21st to 30th and maximum temperature from February 19th to 28th. Even if a little rougher estimate is achieved (maximum error reaching 4 days), it allows forecasts right from the end of February, i.e., from two weeks to one and a half month before pollination. Actually, these two methods complement each other: regression should be first used, then results can be refined as they go along by the sum of temperatures, using the temperatures predicted by Météo-France when going up to the necessary sum, and finally the measured temperatures to verify the forecasts.

We have also been able to approximately forecast the duration of the main pollen season, using a multiple regression taking into account minimum relative humidity of October and maximum temperature of February. But pollen quantities could not be estimated: indeed, they depend not only on meteorological conditions before pollination, but also and maybe mostly on those prevailing during pollination (pollen wash-out by rainfall, stopping of pollen grains release in the event of frost). For grasses (*Poaceae*), Davies and Smith (1973) recommended the use of average temperature of the air in April-May and pollen concentration of May to forecast the total pollen season. Of course, this method cannot be applied to birch, whose pollination is shorter.

It should be noted that the methods developed on the years 1995 to 1998 and verified in 1999, even if giving promising results, should be tested again on several years to obtain a better statistical validity. They also can be applied to other pollen types and sites, after being adapted to local phytoclimatic conditions. This will be achieved in the future years for Ragweed, whose pollen grains seem to be becoming more and more important in Burgundy (Laaidi and Laaidi, 1999).

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Note

¹ Q_{10} corresponds to the ratio between the growth speed of a plant at a T temperature and the one which would be observed at a temperature of T+10 °C.

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List of abbreviations

- SDP: Starting Date of the Pollen season
 σ : Standard deviation
 μ : mean
 T°C: Temperature
 Tmax: maximum temperature
 Tmin: minimum temperature
 Pmm: precipitation
 ρ : correlation coefficient
 p : the p value is the probability of being wrong in concluding that there is a true association between the variables
 n : number of samplers