

Mohamed Laaidi · Michel Thibaudon ·
Jean-Pierre Besancenot

Two statistical approaches to forecasting the start and duration of the pollen season of *Ambrosia* in the area of Lyon (France)

Received: 5 June 2002 / Revised: 13 January 2003 / Accepted: 9 April 2003 / Published online: 29 May 2003
© ISB 2003

Abstract The aim of the present study was to forecast the start and duration of the pollen season of *Ambrosia* from meteorological data, in order to provide early information to allergists and allergic people. We used the airborne pollen data from Lyon (France), sampled using a Hirst trap from 1987 to 1999, and the meteorological data for the same period: air temperature (minimal, maximal, and average), rainfall, relative humidity, sunshine duration and soil temperature. Two forecasting models were used, one summing the temperatures and the other making use of a multiple regression on 10-day or monthly meteorological parameters. The start of the pollen season was predicted with both methods, results being more accurate with the regression (the errors between the predicted and the observed SDP ranging from 0 to 3 days). The duration of the pollen season was predicted by a regression model, errors ranging from 0 to 7 days. The models were later tested with satisfactory results from 2 additional years (2000 and 2001). Such forecasting models are helpful for allergic people, who have to begin their anti-allergic treatment before the start of the pollen season and not when the symptoms have appeared, since a preventive treatment is more efficient than a curative one. The regression allows predictions to be made 3–5 weeks in advance and so it is of particular interest. The forecasts will be broadcast on the Internet.

Keywords *Ambrosia* · Pollen · Forecast · Meteorology

Introduction

Allergies to *Ambrosia* pollen (a plant that belongs to the Asteraceae family) were first described by Dr. M. Wyman (“autumnal cattarrh”) in the United States during the second half of the 19th century (Déchamp 1995). The potent allergenicity of this pollen is now well-established in Canada and in the United States (Durand and Comtois 1989; Frenz et al. 1995; Frenz 1999). In Europe, only *Ambrosia maritima* L. and *Xanthium* are native. The introduction of two North American species, *A. artemisiifolia* L. and *A. trifida* L., occurred in Lyon in 1930 and then again during the Second World War, probably as contaminants in cereal sacks (Touraine 1984), even if some rare occurrences were found as early as 1875 in some French regions such as the Loire valley or the Rhône valley (Coste 1937). *Ambrosia* distribution can be related to climate; in Canada it grows in cold temperate latitudes, particularly in south-eastern Saskatchewan, southern Manitoba, southern Ontario and Quebec; while it is very rare in British Columbia and Alberta (Basset and Terasmae 1962), the Laurentides being the northernmost region where it is found, in the Montreal region the plant is endemic (Banken and Comtois 1992). In the United States, it grows in the climates of the eastern side of the continent at medium latitude, the climate of the subtropical part of Florida and Texas, and it seems to avoid all the Pacific coast, the plant being rare in the western states where the altitude is highest and also in the southernmost tip of Florida and northern Maine (Anonymous 1987). In Asia, *Ambrosia* seems to prefer the climates of the eastern sides of the continent at medium latitude (Déchamp 1997). In Europe its distribution covers the area of continental climate at medium latitude and it started its expansion from Hungary, Croatia and Italy (D’Amato et al. 1998; Déchamp and Deviller 1990), the most ragweed-polluted countries being Hungary (Járai-Komlódi and Juhász 1993), Croatia and certain parts of France. In France, it is especially found in the Rhône-Alpes region (Déchamp and Cour 1987) and Burgundy (Laaidi and Laaidi 1999) but also in the surrounding areas of

M. Laaidi (✉) · J.-P. Besancenot
Climat et Santé, Centre d’Épidémiologie de Population,
Faculté de Médecine, BP 87900, 21079 Dijon Cedex, France
e-mail: mohamed.laaidi@u-bourgogne.fr
Fax: +33-3-80393300

M. Thibaudon
Réseau National de Surveillance Aérobiologique (RNSA),
La Croix Bayard, 69930 Saint-Clément-les-Places, France

Clermont-Ferrand, Saint-Etienne, Grenoble, Annecy and Monluçon (Thibaudon 1992; Mathern 2002). *Ambrosia* pollen has also been found in Bulgaria in increasing amounts since 1991 (Yankova et al. 2000), in Austria (Vienna), where a change in the diurnal peaks, occurring in the 80s, suggested that the sources were becoming closer (Jäger 2000), and in Switzerland (Leuschner et al. 1990), where the pollen can be transported long-distances from France or Italy or, more recently, locally produced (Clot et al. 2002; Peeters 2000). *Ambrosia* has also been growing in certain parts of the Czech Republic from the 1880s (Rybníček and Jäger 2001) and now the pollen traps are recording various amounts of pollen, depending on the site, the highest being in Brno (Rybníček et al. 2000). In Slovenia, *A. artemisiifolia* was introduced at the end of the second world war and it is now well established in the lowlands (Kofol Seliger et al. 1998), and it is also found in the south-west of the Slovak Republic (Makovcová et al. 1998). *Ambrosia* has even been appearing in Sweden since 1996 (Dahl et al. 1999). In Poland, gravimetric traps have recorded ragweed pollen in very low concentrations, probably brought in from the Ukraine, the Czech Republic, Slovakia and Hungary (Stepalska et al. 2002). Studies of prick-tests or RAST (radioallergosorbent test) reactions to ragweed allergens in pollen-allergic European patients, done in the late 1990s, showed high positive values (Rybníček and Jäger 2001): more than 80% in Hungary, nearly 70% in Northern Italy, 30%–40% in the Rhône area (France), about 35% in Prague and 19%–25% (Rybníček et al. 2000) in Brno (Czech Republic) and about 25%–30% in Vienna (Austria) where both ragweed pollen counts and allergenic sensitization have been increasing since the 1980s (Jäger 2000). In the Southern part of European Russia, ragweed is considered the most important allergen, even before house dust (Ado and Ostroumov 1968). *Ambrosia* pollen and allergy are also documented in Australia, where Bass et al. (2000) revealed 34% of prick-tests were positive among a sample of volunteers, and it represents the second most important pollen allergen in Japan after *Cryptomeria* (Sado and Takeshita 1990).

In the area of Lyon (France), where this study took place, the *Ambrosia* pollinosis prevalence in the general population was estimated to be 2.1% in 1993 (Déchamp 1995). The pathology is characterized by rhinitis (89% of the patients) often associated with conjunctivitis (71%) and asthma (43%), sometimes also with urticaria or eczema. The two ragweed species found in the Rhône valley (*A. artemisiifolia* L. and *A. trifida* L., Guérin 1993) are annual herbaceous plants, monoecious (male and female flowers produced on the same plant) and pollinated by the wind. Only *A. artemisiifolia* is abundant, while *A. trifida* is rarer (Raynaud 1984). The thousands of male flowers on each plant result in the release of approximately 2.5×10^9 pollen grains (Bouillène and Bouillène 1930). The pollen grain is tricolporate, echinate, slightly prolate, with an average diameter of 25 μ m (Kumer 1990; Guérin 1993). It releases a complex mixture of proteins that have been shown to be some of

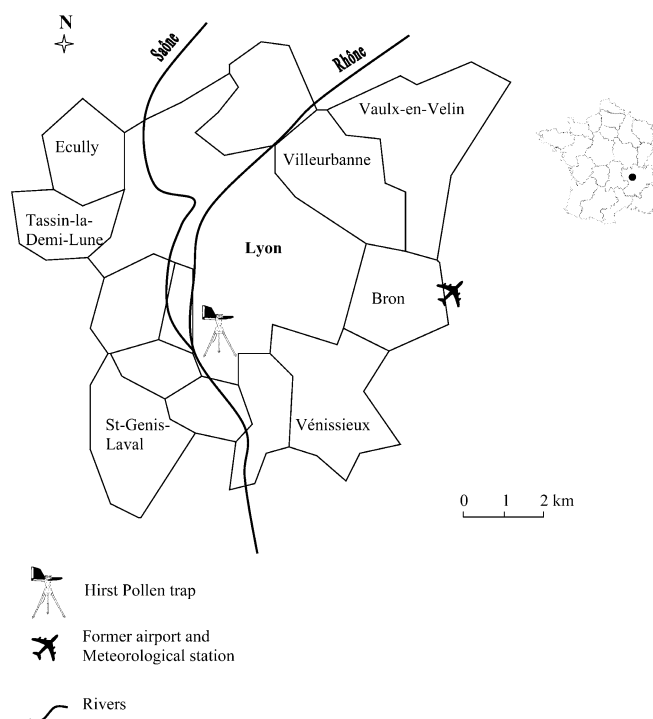


Fig. 1 Geographical situation of the pollen sampling site of Lyon (France)

the most powerful allergens known, comprising 22 allergens as defined by reactivity with human IgE, and six major allergens making up to 12% of the extracted proteins (Bagarozzi and Travis 1998). Allergens are present in entire pollen grains, but also in aerosol submicronic fractions below 5 μ m and present during seasonal periods of ragweed pollination (Solomon et al. 1983). They are also produced before and after the pollen season, coming from various parts of the plant, especially the inflorescence (Agarwal et al. 1984).

The strong allergenicity and the increase of *Ambrosia* pollen in Europe, especially in France, encouraged us to develop methods of forecasting the appearance of pollination for use by allergists and allergic people. The aim of such forecasts was to predict the start of the pollen season (and also its duration) from meteorological data early enough to allow patients to take preventive treatment.

Material and methods

Pollen data

The air was sampled by a Lanzoni volumetric Hirst-type trap (Hirst 1952), VPPS 2000, located on the flat roof of a building in the city of Lyon, France (Fig. 1), 25 m above ground level. It was calibrated to handle a flow of 10 l air/min, which roughly corresponds to a human breathing rhythm, and it was at all times oriented into the wind by a wind vane. Pollen grains were impacted on a cylindrical drum covered by a plastic strip coated with a uniform layer of adhesive (vaseline, paraffin oil and toluene), and rotated by a 7-day clockwork at a speed of 2 mm/h (Mandrioli 1990). Guérin (1993) determined that a roof-top trap would be representative of a 30-km

radius. Every week, the strip was removed and cut into seven equal segments corresponding to the 7 days of the week. Those segments were mounted between slide and cover glass using a mixture of gelatine, glycerin, phenol, distilled water and basic fuchsin. Then, they were examined by light microscopy following the method described by K  pyl   and Penttinen (1981), which consists of reading 12 traverses. The results were expressed as the number of pollen grains per cubic meter of air. The pollen data were recorded continuously from 1987, the years 1987–1999 being used to construct the forecast models and the subsequent years 2000 and 2001 to validate these models. The study focused on Ragweed pollen (*Ambrosia*) which is highly allergenic in this region.

Meteorological data

Meteorological data were recorded by the national meteorological office (M  t  o-France) at the meteorological station of Lyon-Bron. We used the average daily air temperature for the method of summing temperatures and the 10-day average data (rainfall, minimal, maximal and average air temperature, minimal and maximal relative humidity, insolation – which corresponds to the sunshine duration – and temperature 10 cm or 20 cm under ground) for the multiple regression.

Determination of the main pollen season

The main pollen season was determined by its beginning (SDP, Starting Date of the Pollen season) and its end (EPS, End of the Pollen Season), the difference between SDP and EPS corresponding to the duration of the main pollen season (DMPS = EPS – SDP). Before establishing a method of predicting SDP, the start had to be precisely defined, and calculated for the years available. The calculated SDP could then be used to adjust a forecasting model, which would allow prediction of the SDP in the following years. Many different methods of determining the main pollen season can be found in the literature, depending on the aim of the investigation (Mullenders et al. 1972; Lejoly-Gabriel 1978; Nilsson and Persson 1981; Driessen et al. 1989; Frenguelli et al. 1991; El-Ghazali et al. 1993; Spieksma and Nikkels 1998). Graphically, the pollination curve of a plant, plotted from accumulated daily percentages of pollen on the y-axis and the date of observation on the x-axis, looks like a sigmoid with two bends (Pathirane 1975; Lejoly-Gabriel 1978). The two inflection points correspond to the onset and the end of the main pollination period, and can arithmetically be determined (Lejoly-Gabriel 1978). We used the graphical method, which showed that, for the years available, the onset corresponds to 2% of the annual pollen sum. This accumulated percentage of 2% is lower than those determined by some other authors, who used a value of 5%. However, ragweed begins its pollination very rapidly, and the clinical threshold that causes the symptoms of allergy can be as low for this pollen type as 1–3 grains/m³ for hypersensitive patients, and 10–50 grains/m³ for the majority of patients (Solomon 1984; Comtois and Gagnon 1988; Banken and Comtois 1992); the value of 2% therefore ensured that we did not miss the time corresponding to the appearance of symptoms. The EPS was also determined graphically at the second bend of the curve, and corresponds to 95% of the annual sum.

Forecasting methods

Forecasting methods were developed on the basis of data from the years 1987 to 1999, and then tested on 2000 and 2001. Many authors have forecast the SDP of various plants, using meteorological parameters; regardless of the procedure, temperature was the most frequently used parameter (Lejoly-Gabriel 1978; Niqueux and Arnaud 1981; T  rnevik 1982; Richardson and Anderson 1986; Linvill 1990; Andersen 1991; Frenguelli et al. 1991; Sutra et al. 1992; Larsson 1993; Ant  para et al. 1995; Recio et al. 1997; Gonz  lez Minero et al. 1999; Garc  a-Mozo et al. 2000; Orlandi et al. 2002). On rare occasions, radiation or evapotranspiration

(Durand 1967), or sometimes several meteorological factors like temperature, wind and rainfall (Mandrioli et al. 1993; Fornaciari et al. 1998; Laaidi 2001a, b) were used. Among the methods used in these papers, some of them did not seem suitable for ragweed pollination prediction. The method using chill units (CU) and growing degree hours (GDH) is based on the hypothesis that plants react continuously to their environmental variations, and so it uses hourly temperatures (Richardson and Anderson 1986; Linvill 1990; Orlandi et al. 2002). Meteorological data available in France are only 3-hourly, and some tests carried out in our country with this method proved to be rather inconclusive (Sutra et al. 1992). Such considerations led us to reject this method. The model of T  rnevik (1982), based on daily average temperatures, requires parameters to be determined that are dependent on the species and on the phenological stage of the plant. The complexity of this model made it inappropriate for routine use, compared with the easy method of temperature sums. Other methods are based on the approximation of the increasing stage of the plants development curve as a function of temperature: a linear approximation for the temperature sums, an exponential approximation for the Q_{10} ¹ coefficient sums. According to Durand (1969), the Q_{10} coefficient sums are more appropriate for cool climates and for plants that bloom in winter or spring, while the temperature sums are more suitable for plants flowering in summer, such as ragweed. Some authors used solar radiation or evapotranspiration instead of temperature, because they correspond better to the energy the plant really gets (Durand 1967). However, according to Durand (1969) those two factors mostly influence the plant growth in dry organic matter, while temperature works both on the growth and on the development of the plant, in particular the development of anthers and pollen grains. In fact the method based on solar radiation gave quite bad results. All those considerations led us to focus on two methods: temperature sums and multiple regression, the latter being of particular interest because it combines different meteorological parameters and brings out the most informative one(s).

Temperature sums

The method of summing temperatures consists of cumulatively summing the daily average temperatures from a statistically determined date, above a thermal threshold and to the SDP, calculated as previously described. Several dates were tested to determine an appropriate date for starting the sum of temperatures calculation. These ranged from the beginning of April to the end of July, by steps of 10 days. The earliest starting date was chosen as 1 April because ragweed, which is an annual species, begins to germinate around this date in the studied area (Bertrand and Maupas 1996). The latest starting date was chosen at the end of July, since ragweed begins its pollination in August (4 August at the earliest). Different thermal thresholds, above which daily temperature is effective, were also tested, from 0 to 15   C, by steps of 1   C. The result was 208 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. The best starting date and the more appropriate threshold are those that minimize the ratio σ/μ , which corresponds to the coefficient of variation.

Multiple regression

The multiple regression method attempts to predict the SDP from 10-day average meteorological data. The regression is a forward stepwise regression, using the SigmaStat software. The analysis used the mean rainfall, temperature, relative humidity, insolation and soil temperature for 10-day periods from April 01–10 to 20–29 July, as independent variables influencing the SDP. To assess the amount of interdependence of the variables, Spearman's rank

¹ Q_{10} is an agrometeorological coefficient that corresponds to the ratio between the growth rate of a plant at a particular temperature (T ,   C), and that which would be observed at temperature $T + 10$

correlation coefficient was used, because data were not normally distributed. The multiple regression methods were also used in order to predict the duration of the main pollen season (DMPS). A χ^2 -test (Bravais-Pearson) was performed in order to characterize, for the whole distribution, the difference between the observed SDP (or observed DMPS) and the predicted ones for each value of the distribution. This was used to choose the best regression equations.

Finally, for both methods (temperature sums and regression) and for the years 1987–1999, we calculated the real SDP (or the real DMPS) after the pollen season in order to compare them to the predicted values. We also tested the methods on 2 additional years, 2000 and 2001. In each case, we calculated the error (in days), that is to say the discrepancy between the predicted and the observed SDP (or DMPS).

Results

Using the criteria previously determined, the ragweed SDP ranged from 4 to 22 August and the EPS from 11 to 26 September, therefore the duration of the main pollen season ranged from 24 to 47 days. The time of ragweed pollination is thus quite variable. In particular, the SDP presented an inter-annual variability of 18 days, reflecting the variability in the appearance of pollinosis; it is therefore of prime importance to forecast it.

Forecasting the SDP from the years 1987–1999

Temperature sums

With this method, the ratio σ/μ was minimal (0.056) for a threshold of 6 °C and with summing starting on 11 April, resulting in a sum of 2,239.3 °C (using temperatures above the threshold of 6 °C). The errors ranged from 0 to 8 days. In order to minimize those errors, we tested earlier starting dates from the 1 March. But results were not improved; on the contrary the maximal error reached 9 days.

Multiple regression

With this method, equations were first drawn-up using meteorological data from April to July, as for the method of summing temperatures. Among the meteorological parameters initially considered, rainfall, maximal temperature and temperature 10 cm under ground were finally rejected by the models because they were not significant. With the regression equations obtained, errors ranged from 0 to 7 days. In order to improve the forecast, we tried using earlier meteorological data, from March to July. The equations obtained allowed a real improvement. Five of them were retained and for each of them the χ^2 -test indicated that the model had a probability of 99% of correctly describing the SDP distribution. These equations are as follows:

$$\begin{aligned} \text{SDP} = & 165.33 - 0.0015 \times \text{Insol}_{2-11 \text{ Mar}} \\ & + 0.0011 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} - 1.38 \times T_{21-30 \text{ May}}^{\min} \\ & + 0.62 \times H_{22-31 \text{ Mar}}^{\max} + 0.23 \times H_{21-30 \text{ Apr}}^{\max} \end{aligned} \quad (1)$$

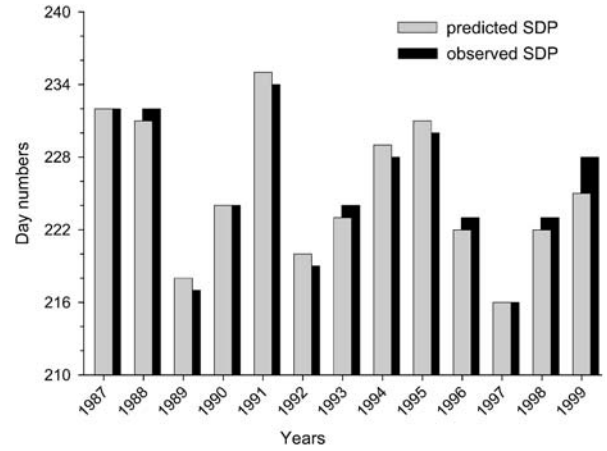


Fig. 2 Comparison between predicted and observed starting date of the pollen season (SDP) of *Ambrosia* in Lyon by the first regression equation ($\text{SDP} = 165.33 - 0.0015 \times \text{Insol}_{2-11 \text{ Mar}} + 0.0011 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} - 1.38 \times T_{21-30 \text{ May}}^{\min} + 0.62 \times H_{22-31 \text{ Mar}}^{\max} + 0.23 \times H_{21-30 \text{ Apr}}^{\max}$). The observed SDP ranged from day 216 (4 August) to day 234 (22 August)

$$\begin{aligned} \text{SDP} = & 173.25 - 0.0016 \times \text{Insol}_{2-11 \text{ Mar}} \\ & + 0.0015 \times T_{30 \text{ Jun}-9 \text{ Jul}}^{\min} - 1.09 \times T_{21-30 \text{ May}}^{\min} \\ & + 0.71 \times H_{22-31 \text{ Mar}}^{\max} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{SDP} = & 187.30 + 0.0013 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} \\ & - 1.65 \times H_{22-31 \text{ Mar}}^{\min} \\ & + 0.43 \times H_{21-30 \text{ Apr}}^{\max} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{SDP} = & 178.53 - 0.0016 \times \text{Insol}_{2-11 \text{ Mar}} \\ & + 0.0015 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} \\ & + 0.70 \times H_{22-31 \text{ Mar}}^{\max} \\ & - 0.97 \times T_{21-30 \text{ May}}^{\text{mean}} \end{aligned} \quad (4)$$

$$\begin{aligned} \text{SDP} = & 193.44 - 0.0017 \times \text{Insol}_{2-11 \text{ Mar}} \\ & + 0.0016 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} \\ & - 0.97 \times T_{20 \text{ cm}}_{21-30 \text{ May}} \\ & + 0.53 \times H_{22-31 \text{ Mar}}^{\max} \end{aligned} \quad (5)$$

Where Mar = March, Apr = April, Jun = June, Jul = July, Insol = insolation (or sunshine duration), $T_{\min}$ = minimal temperature, T_{mean} = average temperature, $T_{20 \text{ cm}}$ = temperature 20 cm under ground, $H_{\min}$ = minimal relative humidity, $H_{\max}$ = maximal relative humidity.

Thus, errors ranged only from 0 to 3 days, the Eq. 1 (Fig. 2) being a priori the most effective (error from 0 to 1 day). But all five equations gave good results, so it seems interesting to test all of them in subsequent years, and to send the forecasts to allergists as an estimation range. A regression model was also tested using monthly meteorological data, but the results were worse, with errors ranging from 0 to 7 days.

Forecasting the DMPS from the years 1987-1999

Regression equations were established in order to predict the duration of the main pollen season, using meteorological data for 10-day periods from April to July, then earlier periods from March to July, and lastly monthly data from March to July. Three 10-day-period equations based on the meteorological data from March to July and one using monthly data were the most effective. The χ^2 -test indicated that the models had a probability of 95%–99% of correctly describing the DMPS distribution. These equations are as follows:

$$\text{DMPS} = 165.14 - 0.57 \times H_{\min_{2-11 \text{ Mar}}} - 1.15 \times H_{\max_{22-31 \text{ Mar}}} \quad (6)$$

$$\text{DMPS} = 253.76 - 1.02 \times H_{\max_{2-11 \text{ Mar}}} - 1.41 \times H_{\max_{22-31 \text{ Mar}}} \quad (7)$$

$$\text{DMPS} = 74.26 - 0.0029 \times \text{Insol}_{30 \text{ Jun}-9 \text{ Jul}} - 0.51 \times H_{\min_{11-20 \text{ May}}} \quad (8)$$

$$\text{DMPS} = 221.25 - 0.62 \times H_{\min_{\text{May}}} - 1.74 \times H_{\max_{\text{Mar}}} \quad (9)$$

Among the 10-day meteorological parameters initially considered, rainfall, minimal, maximal and average temperature and temperature 10 cm or 20 cm under ground were finally rejected by the models because they were not significant. With the first three equations, errors ranged from 0 to 7 days, and with the last one, errors ranged from 0 to 5 days (Fig. 3). We also tried to predict the magnitude of the pollen season, using the same regression method as for the duration of the pollen season. However, the model results were poor in comparison with the real quantities (the χ^2 -test indicated that the models had only a 1% probability of correctly describing the magnitudes).

Application of the forecast methods on the years 2000 and 2001

The forecasting methods developed on the basis of 1987–1999 were tested in 2000 and 2001 in real time.

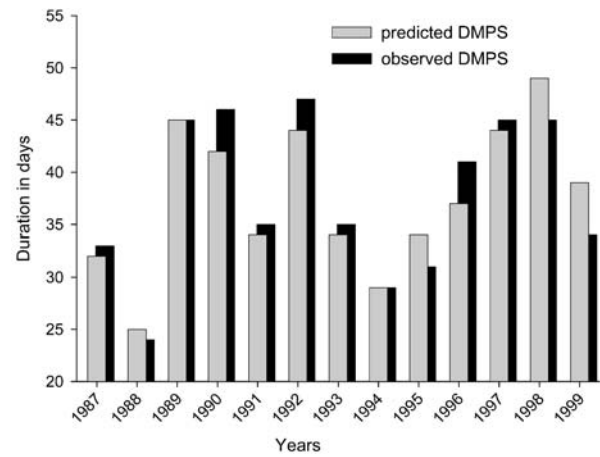


Fig. 3 Comparison between predicted and observed duration of the main pollen season (DMPS) of *Ambrosia* in Lyon by the regression equation on the monthly meteorological data ($\text{DMPS} = 221.25 - 0.62 \times H_{\min_{\text{May}}} - 1.74 \times H_{\max_{\text{Mar}}}$)

Predicting the SDP in 2000 and 2001

In 2000 and 2001, the SDP was predicted by multiple regression, and by the method of summing temperatures. For this last method, we used the observed temperature and then, when approaching the necessary thermal sum, we used the temperature predicted 5 days in advance by the national meteorological office (Météo-France). In 2000, the predicted SDP was 9 August when the temperature sum was used and between 12 and 14 August with the multiple regression method. In 2001, the corresponding dates were 11 August with the temperature sum method and between the 8 and 15 August with the multiple regression method. The real SDP was then calculated after the end of the pollen season and for both years it appeared to be 10 August. The prediction made before the start of the pollen season was therefore very precise when the temperature sums method was used, the error being only 1 day. With the regression method the errors were a little bigger: 2–4 days in 2000, and 2–5 days in 2001 (Table 1).

Table 1 Forecasting the starting date of the pollen season (SDP) for *Ambrosia* by five multiple regression equations (the number in the first column of the table refers to the number of the SDP equation in the text)

Regression equation	Errors (number of days) between predicted and observed SDP 1987–1999	Predicted SDP		Errors (number of days) between predicted and observed SDP	
		2000	2001	2000	2001
1	0–1	12/08	13/08	+2	+3
2	0–2	14/08	14/08	+4	+4
3	0–2	14/08	08/08	+4	–2
4	0–2	14/08	14/08	+4	+4
5	0–3	12/08	15/08	+2	+5

Table 2 Forecasting the duration of the main pollen season (DMPS) for *Ambrosia* in Lyon by four multiple regression equations (the number in the first column of the table refers to the DMPS equation number in the text)

Regression equation	Errors (number of days) between predicted and observed DMPS 1987–1999	Predicted DMPS		Errors (number of days) between predicted and observed DMPS	
		2000	2001	2000	2001
1	1–7	40	27	0	–9
2	0–7	38	30	–2	–6
3	0–7	38	36	–2	0
4	1–5	44	30	+4	–6

Predicting the DMPS in 2000 and 2001

The DMPS was predicted by four multiple regression equations. In 2000, the first three equations, which used 10-day period meteorological data, estimated the DMPS to be between 38 and 40 days, 0–2 days different from the real duration. With the fourth equation, which used monthly meteorological data, we predicted a duration of 44 days, an error of 4 days. In 2001, predicted results differed by 0–9 days from the actual DMPS of 36 days (Table 2).

Discussion

The SDP forecast using the summing of temperatures generated errors ranging from 0 to 8 days for the years 1987 to 1999 that were used to develop the method. In 2000 and 2001, the forecast was particularly precise since the error did not exceed 1 day. With the regression equations, the forecast errors ranged from 0 to 3 days for the years 1987–1999, and they ranged between 2 and 5 days when the method was tested on 2000 and 2001.

In order to explain the errors found in our forecast models, we can first ask whether the years used are representative for the climate of Lyon. The monthly values of the meteorological parameters used in the different regression equations were therefore compared to the climatological standard normal values of the 1960–1990 period by a χ^2 -test (risk threshold 0.05): this was only applicable to temperatures (minimal, maximal and average) and insolation, because the normal values of the relative humidity were not available. The values that most often differed from the climatic normal values were those of temperature, mainly minimal but also maximal, for January and December. However, those 2 months were not included in the regression equations, ragweed being then only a seed. During the germination, the growth and the development of ragweed from March to June, the meteorological data differed little from the normal values. However, in some years the meteorological means of these 4 months could differ from the normal, particularly insolation, the duration of which could differ from –4 to +5 days from the normal insolation. The long period used to establish the regression equations, i.e. 13 years, therefore allowed us to integrate years that were representative of the climate of Lyon but also years that

showed some discrepancies from the normal: the diversity of meteorological situations encountered allowed us to think that our models are reliable enough, in normal as in non-normal years. However, in 2001 the minimal temperature of March was particularly high, 5.5 °C above the normal, which could partly explain why the errors were a little bit higher in this particular year. It is therefore obvious that the models will have to be refined in the future, taking into account the most recent years.

Other meteorological factors as well as temperature, can act on the growth and development of ragweed, but in all our regression equations insolation, relative humidity and temperature emerged as the main factors. This points to the fact that different parameters contribute towards the development of ragweed and so condition its blossoming and the beginning of its pollination. A study by Deen (1998) showed that the phenological development of common ragweed occurred over a wide temperature range, and that the rate of development increased with temperature. In fact temperature, especially the minimal temperature, often plays a part in our equations with a negative coefficient, which indicates that an increase in temperature leads to an earlier SDP. The same study showed the role of irradiance on ragweed development, but only when combined with the additional stress of low temperatures. The effects of these parameters were measured in growth cabinets, while our equations were established for plants growing outside in natural conditions, but it suggests the role played by solar radiation, which most of the time moves in parallel with insolation, in ragweed development. In addition, this result showed the effect of combined parameters on plant development. Experiments in a controlled chamber have also demonstrated the role played by parameters in combination, in this case relative humidity and temperature, but this time in the opening of ragweed flowers, i.e. just before pollination (Bianchi et al. 1959): the extension of anthers was slowed or prevented by holding them at reduced temperatures, while the opening of pollen sacs was retarded or stopped by high humidity. The effect of temperature on the extension of anthers may be due to its influence on the rate of water uptake and so to the enlargement of the cells of the stalk-like filaments on which they are borne. As regards the role of relative humidity, it acts on the mechanism involved in dehiscence, which consists in a desiccation of the anther sac walls resulting in the deformation of individual cells in

the wall tissues by changing water tensions. But neither the amount of light nor the water could induce significant changes. Our regression equations also integrated several meteorological parameters to forecast the start of ragweed pollination, but those parameters related to a period of time long before blossoming. Among these parameters, relative humidity plays a part in each equation for predicting SDP or DMPS. It always has a positive coefficient, while temperature (minimal, average or under ground) always has a negative coefficient, so an increase in the relative humidity implies a later SDP, while an increase in temperature implies an earlier SDP. Wind conditions (speed or direction) were not used in our forecast models, because this parameter acts on pollen release (Davies and Smith 1973; Reddi and Reddi 1985), when pollination has already started, but it does not act on the growth or development of the plant.

The errors found in the forecasting methods could arise from the difference between the temperature measured at the meteorological station and that to which the plant is actually submitted, which depends on the site, the exposure, and the altitude (Bonhomme 2000). As regards the method of summing temperatures, it is based on the accumulation of heat, which determines the growth and the development rates of plants depending on the amount of time they are exposed to temperatures between lower and upper thresholds. This accumulation of heat is called "physiological time" and it is measured by the degree days. But as Mandrioli et al. (2000) pointed out, the choice of a correct temperature sum depends on lots of parameters that influence the reproductive physiology of a plant, such as height, exposure, soil type or structure and availability of water. Such parameters can introduce unknown factors into the predictions. However, our results were quite satisfactory, particularly with the temperature sums.

The two methods (summing the temperatures and multiple regression) can complement each other. The regression equations enabled the prediction of the SDP from the 9 July (the latest meteorological parameter used in each equation is the insolation from 30 June to 9 July), so 26–44 days in advance if referring to the observed SDP from 1987 to 2001. This early forecast allows allergic patients to take preventive anti-allergic treatments, which are more effective than curative treatments. In fact, the average SDP occurs on 13 August, but it remains very variable with a deviation from –9 to +9 days around the mean. A forecast is therefore necessary in order to avoid either a too late treatment, which is less effective, or a too early one, which is stressful for the allergic people and expensive in terms of health economy. An early forecast is of particular importance for people suffering from asthma, who have to take preventive treatments a few days to 3 or 4 weeks before the beginning of ragweed pollination (Michel and Bousquet 1997). For rhinitis or conjunctivitis, the preventive treatment can be taken only 1 or 2 days in advance so, in that case, the method of summing temperatures gives a sufficiently early forecast. As was illustrated by a forecasting study on birch (Laaidi

2001b), the complementarity between the two methods is interesting: the regression, even if sometimes less precise, allows early forecasts to be made, and it can be refined by using the temperature sums, which integrate the thermal data of the days preceding the pollination and allow more precise but later forecast. However, both methods should be tested for several additional years, in order to improve the established models if necessary.

A former study, based on weekly data from a Cour trap, attempted to make predictions about ragweed in the area of Lyon (France). It used 14 years of pollen data to estimate that the first allergic symptoms would appear in week 31, 32, 33 or 34, and that the fortnight of the pollen peak would occur, in the majority of cases, 3 or 4 weeks later (Déchamp et al. 1997). This considerable inaccuracy is probably due to the weekly time step inherent to the Cour trap, which prevents meteorological data being used for making predictions. This led us to establish the present forecast models, based on daily pollen counts and meteorological data.

The forecast equations for calculating the duration of the main pollen season (DMPS) can also be useful for allergic people because they allow information on the duration of ragweed pollination, and therefore on the duration of the anti-allergic treatment, so that patients do not stop treatments too early.

The forecast regression equations failed to predict the total quantities of pollen. It is probably not essential in allergology practice to predict the amount of pollen accurately, but it is generally necessary to estimate them roughly and to know if they will be greater than those of the previous year, which will allow an estimation to be made of the severity of the pollinosis to come. Other studies used meteorological data to predict not the seasonal quantities but the daily ragweed pollen concentrations (Raynor and Hayes 1970; Comtois and Sherknies 1992). Stark et al. (1997) succeeded in predicting the ragweed pollen levels 1 day in advance, using a Poisson regression. Such predictions should also be interesting in the future and could complete our information for allergic patients.

In conclusion, the SDP and DMPS forecasts gave satisfactory results, for the previous years on which the models were established as well as on the test years 2000 and 2001. They should now be used each year to inform the allergists, but also directly the allergy sufferers because of the important auto-medication linked to this pathology. Forecasts will be provided on the web site (<http://www.rnsa.asso.fr>) of the French network of pollen traps (RNSA, Réseau National de Surveillance Aérobiologique).

References

- Ado A, Ostroumov A (1968) Allergie aux pollens d'ambrosies dans la région de Krasnodar. *Rev Fr Allergol Immunol Clin* 8:29

- Agarwal MK, Swanson MC, Reed Ch E, Yunginger JW (1984) Airborne ragweed allergens: association with various particle sizes and short ragweed plant parts. *J Allergy Clin Immunol* 74:687–693
- Andersen TB (1991) A model to predict the beginning of the pollen season. *Grana* 30:269–275
- Antépara I, Fernández JC, Gamboa P, Jauregui I, Miguel F (1995) Pollen allergy in the Bilbao area (European Atlantic seaboard climate): pollination forecasting methods. *Clin Exp Allergy* 25:133–140
- Anonymous (1987) Advice from your allergist. *Ann Allergy* 59:2–3
- Bagarozzi DA, Travis J (1998) Ragweed pollen proteolytic enzymes: possible roles in allergies and asthma. *Phytochemistry* 47:593–598
- Banken R, Comtois P (1992) Concentration du pollen de l'herbe à poux et prévalence de la rhinite allergique dans deux municipalités des Laurentides. *Allergie Immunol* 24:91–94
- Bass DJ, Delpech V, Beard J, Bass P, Walls RS (2000) Ragweed in Australia. *Aerobiologia* 16:107–111
- Basset JJ, Terasmae J (1962) Ragweeds, *Ambrosia* species, in Canada and their history in postglacial time. *Can J Bot* 40:141–150
- Bertrand P, Maupas M (1996) L'ambrosie à feuilles d'armoise, envahissante et allergisante. *Phytoma* 484:25–26
- Bianchi D, Schwemmin D, Wagner W (1959) Pollen release in the common ragweed (*Ambrosia artemisiifolia*). *Bot Gaz* 120:235–243
- Bonhomme R (2000) Bases and limits to using 'degree.day' units. *Eur J Agron* 13:1–10
- Bouillène M, Bouillène R (1930) Recherches expérimentales sur l'agent toxique du pollen d'*Ambrosia* div. Sp. (Compositacées). *Bull Sci Acad R Belg* 16:1052–1073
- Clot B, Schneiter D, Tercier P, Gehrig R, Annie G, Thibaudon M (2002) Pollen d'ambrosie en Suisse: production locale ou transport? *Allerg Immunol* 34:126–128
- Comtois P, Gagnon L (1988) Concentration pollinique et fréquence des symptômes de pollinose: une méthode pour déterminer les seuils cliniques. *Rev Fr Allergol Immunol Clin* 28:279–286
- Comtois P, Sherknies D (1992) Le pollen de l'ambrosie (*Ambrosia artemisiifolia* L.): prévisions et prévention. *Allerg Immunol* 24:22–26
- Coste H (1937) Flore descriptive et illustrée de la France, de la Corse et des contrées limitrophes. 2nd edn, vol 2. Librairie des Sciences et des Arts, Paris, p 482
- Dahl A, Strandhede SO, Wihl JA (1999) Ragweed – an allergy risk in Sweden? *Aerobiologia* 15:293–297
- D'Amato G, Spiekma FTH, Liccardi G, Jäger S, Russo M, Kontou-Fili K, Nikkels H, Wüthrich B, Bonini S (1998) Pollen-related allergy in Europe. *Allergy* 53:567–578
- Davies RR, Smith LP (1973) Weather and the grass pollen content of the air. *Clin Allergy* 3:95–108
- Déchamp C (1995) L'ambrosie, un nouveau fléau. Verso, Ahun
- Déchamp C (1997) Climats et continents de l'ambrosie. *Clim Santé* 17:43–56
- Déchamp C, Cour P (1987) Pollen counts of ragweed and mugwort (Cour collector) in 1984 measured at 12 meteorological centers in the Rhône basin and surrounding regions. In: Boehm G, Leuschner RM (eds) *Advances in aerobiology*, Proceedings of the 3rd International Conference on Aerobiology. *Experientia Suppl* (Basel) 51:119–124
- Déchamp C, Deviller P (1990) Ragweed, a potential plague in Europe. *Allergy Clin Immunol* 2:78–81
- Déchamp C, Rimet ML, Méon H, Deviller P (1997) Parameters of ragweed pollination in the Lyon's area (France) from 14 years of pollen counts. *Aerobiologia* 13:275–279
- Deen W (1998) Influence of temperature, photoperiod, and irradiance on the phenological development of common ragweed (*Ambrosia artemisiifolia*). *Weed Sci* 46:555–560
- Driessen MNBM, Van Herpen RMA, Moelands RPM, Spiekma FTH (1989) Prediction of the start of the grass pollen season for the western part of The Netherlands. *Grana* 28:37–44
- Durand R (1967) Action de la température et du rayonnement sur la croissance. *Ann Physiol Vég* 9:5–27
- Durand R (1969) Signification et portée des sommes de températures. *Bull Tech Informat Ministère Agric Dév Rural* 238:185–190
- Durand L, Comtois P (1989) A comparative study between the Cour and the Burkard samplers. In: Comtois P (ed) *Aerobiology, health, environment, a symposium*. Université Montréal, Montréal, pp 93–101
- El-Ghazali G, El-Ghazali PK, Larsson KA, Nilsson S (1993) Comparison of airborne pollen grains in Huddinge and Stockholm, Sweden. *Aerobiologia* 9:53–67
- Fornaciari M, Pieroni L, Ciuchi P, Romano B (1998) A regression model for the start of the pollen season in *Olea europaea*. *Grana* 37:110–113
- Frenguelli G, Spiekma FTHM, Bricchi E, Romano B, Mincigrucci G, Nikkels AH, Dankaart W, Ferranti F (1991) The influence of air temperature on starting dates of the pollen season of *Alnus* and *Populus*. *Grana* 30:196–200
- Frenz DA (1999) Volumetric ragweed pollen data for eight cities in the continental United States. *Ann Allergy Asthma Immunol* 82:41–46
- Frenz DA, Palmer MA, Hokanson JM, Scamernhorn RT (1995) Seasonal characteristics of ragweed pollen dispersal in the United States. *Ann Allergy Asthma Immunol* 75:417–422
- García-Mozo H, Galán C, Gómez-Casero MT, Domínguez E (2000) A comparative study of different temperature accumulation methods for predicting the start of the *Quercus* pollen season in Cordoba (South West Spain). *Grana* 39:194–199
- Gonzales Minero FJ, Morales J, Tomas C, Candau P (1999) Relationship between air temperature and the start of pollen emission in some arboreal taxa in southwestern Spain. *Grana* 38:306–310
- Guérin B (1993) Pollen et allergies. Allergbio, Varennes-en-Argonne
- Hirst JM (1952) An automatic volumetric spore trap. *Ann Appl Biol* 39:257–265
- Jäger S (2000) Ragweed (*Ambrosia*) sensitization rates correlate with the amount of inhaled airborne pollen. A 14-year study in Vienna, Austria. *Aerobiologia* 16:149–153
- Járai-Komlódi M, Juhász M (1993) *Ambrosia elatior* (L.) in Hungary (1989–1990). *Aerobiologia* 9:75–78
- Käpylä M, Penttinen A (1981) An evaluation of the microscopical counting methods of the tape in Hirst-Burkard pollen and spore trap. *Grana* 20:131–141
- Kofol Seliger A, Macarol Hiti M, Berger T (1998) Ragweed in Slovenia. Ragweed in Europe. In: Satellite symposium proceedings. 6th International congress on aerobiology, Perugia, Italy. ALK-Abelló, Hørsholm, pp 39–41
- Kumer E (1990) Size and shape of allergenic pollen grains. In: Falagiani P (ed) *Pollinosis*. CRC, Boca Raton, Fla, pp 53–65
- Laaidi K, Laaidi M (1999) Airborne pollen of *Ambrosia* Burgundy (France) 1996–1997. *Aerobiologia* 15:65–69
- Laaidi M (2001a) Forecasting the start of the pollen season of Poaceae: evaluation of some methods based on meteorological factors. *Int J Biometeorol* 45:1–7
- Laaidi M (2001b) Regional variations in the pollen season of *Betula* in Burgundy: two models for predicting the start of the pollination. *Aerobiologia* 17:247–254
- Larsson KA (1993) Prediction of pollen season with a cumulated activity method. *Grana* 32:111–114
- Lejoly-Gabriel M (1978) Recherches écologiques sur la pluie pollinique en Belgique. *Acta Geogr Lovan* 13:1–278
- Leuschner RM, Boehm G, Mari R (1990) L'ambrosie progresse-t-elle? *Bull Soc Bot Fr* 137:144–145
- Linville DE (1990) Calculating chilling hours and chill units from daily maximum and minimum temperature observations. *HortScience* 25:14–16
- Makovcová S, Zlinská J, Mikoláš V, Salát D, Krio M (1998) Ragweed in Slovak Republic. Ragweed in Europe. In: Satellite symposium proceedings. 6th International congress on aerobiology, Perugia, Italy. ALK-Abelló, Hørsholm, pp 27–28

- Mandrioli P (1990) Aerobiology – Pollen sampling, influence of climate, pollen sources, and pollen calendar. In: Falagiani P (ed) Pollinosis. CRC, Boca Raton, Fla, pp 39–52
- Mandrioli P, Marletto V, Sirotti M, Puppi G, Zanotti A (1993) A forecast model for hazel (*Corylus*) and chestnut (*Castanea*) pollen emission. *Allerg Immunol* 25:141–144
- Mandrioli P, Ariatti A, De Nuntis P (2000) Annual trends of thermal summations in pollen forecasts. Second European symposium on aerobiology, Vienna (Austria), p 25
- Matheron G (2002) Ambrosie et étude de sa dissémination. *Allerg Immunol* 34:129–130
- Michel FB, Bousquet J (1997) Les allergies. Hachette Paris
- Mullenders W, Dirickx M, Van der Haegen D, Bastin-Servais Y, Desair-Coremans M (1972) La pluie pollinique à Louvain-Heverlee en 1971. *Louv Méd* 91:159–176
- Nilsson S, Persson S (1981) Tree pollen spectra in the Stockholm region (Sweden), 1973–1980. *Grana* 20:179–182
- Niqueux M, Arnaud R (1981) Peut-on prévoir la date d'épiaison des variétés de graminées? *Fourrages* 88:39–56
- Orlandi F, Fornaciari M, Romano B (2002) The use of phenological data to calculate chilling units in *Olea europaea* L. in relation to the onset of reproduction. *Int J Biometeorol* 46:2–8
- Pathirane L (1975) Graphical determination of the main pollen season. *Pollen Spores* 17:609–610
- Peeters AG (2000) Ambrosia sp pollen in Switzerland. *Aerobiologia* 16:295–297
- Raynaud J (1984) Les Ambrosia françaises: botanique, origine et extension de certaines espèces. *Allerg Immunol* 16:277–278
- Raynor G, Hayes J (1970) Experimental prediction of daily ragweed concentration. *Ann Allergy* 28:580–585
- Recio M, Cabezudo B, Del Mar Trigo M, Toro FJ (1997) Accumulative air temperature as a predicting parameter for daily airborne olive pollen (*Olea europaea* L.) during the pre-peak period in Malaga (Western Mediterranean area). *Grana* 36:44–48
- Reddi CS, Reddi NS (1985) Relation of pollen release to pollen concentrations in air. *Grana* 24:109–113
- Richardson EA, Anderson JL (1986) The omnidata biophenometer (TA45 - p): a chill unit and growing degree hour accumulator. *Acta Horti* 184:95–99
- Rybníček O, Jäger S (2001) Ambrosia (ragweed) in Europe. *Allergy Clin Immunol Int* 13:60–66
- Rybníček O, Novotná B, Rybníková E, Rybníček K (2000) Ragweed in the Czech Republic. *Aerobiologia* 16:287–290
- Sado M, Takeshita R (1990) The seasonal variation of airborne pollen grains that cause sugi-pollinosis in Japan in the last three years. In: Hjelmroos et al. (eds) Proceedings of the 4th International Conference on Aerobiology. Scandinavian University Press, Oslo-Stockholm, p 59
- Solomon WR (1984) Aerobiology of pollinosis. *J Allergy Clin Immunol* 74:449–461
- Solomon WR, Burge HA, Muilenberg ML (1983) Allergen carriage by atmospheric aerosol. I. Ragweed pollen determinants in smaller micron fractions. *J Allergy Clin Immunol* 72:443
- Spiekma FTH, Nikkels AH (1998) Airborne grass pollen in Leiden, The Netherlands: annual variations and trends in quantities and season start over 26 years. *Aerobiologia* 14:347–358
- Stark PC, Ryan LM, McDonald JL, Burge HA (1997) Using meteorological data to predict daily ragweed pollen levels. *Aerobiologia* 13:177–184
- Stepalska D, Szczepanek K, Myszkowska D (2002) Variation in *Ambrosia* pollen concentration in southern and central Poland in 1982–1999. *Aerobiologia* 18:13–22
- Sutra JP, Desroziers M, Ceron JP, Frayssinet P, Martin E, Merlier C, Perarnaud V, Traulle MP, Veyssière JM, Hoff M, Burnichon A, Julien P, Ruffaldi P, Bourgeois E, Chambaud R, Marguier S (1992) Climat et prévention des pollinoses: la prévision statistique de la date initiale de pollinisation du bouleau en France. *Clim Santé* 7:53–84
- Thibaudon M (1992) *Ambrosia* en France; quelques données aéropolliniques pour les années 1987 à 1990. *Allerg Immunol* 24:9–16
- Törnevik H (1982) An aerobiological model for operational forecast of pollen concentration in the air. SMHI (Swedish Meteorological and Hydrological Institute) Reports. *Rapp Meteorol Klimatol* 38:1–38
- Touraine R (1984) La pollinose à *Ambrosia*. *Allerg Immunol* 16:275–276
- Yankova R, Zlatev V, Baltadjieva D, Mustakov T, Mustakov B (2000) Quantitative dynamics of *Ambrosia* pollen grains in Bulgaria. *Aerobiologia* 16:299–301