



Seasonal variations in the atmospheric *Betula* pollen count in Gdańsk (southern Baltic coast) in relation to meteorological parameters

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Abstract

Seven years of observations of the patterns and fluctuations in atmospheric *Betula* pollen concentration with respect to meteorological variables enable the most important factors shaping the pollen season of birches in the Gdańsk area (northern Poland) to be defined. The correlation factors for different aspects of the pollen season and particular meteorological variables are presented. A biennial cyclic rhythm is observed in the annual pollen sums. The starting date of the *Betula* pollen season is a rather stable parameter for those years which represent the average, most typical, meteorological conditions as recorded for the area.

1. Introduction

Atmospheric birch pollen is of special aerobiological interest in northern and central Europe as one of the most common causes of spring-time pollen allergy (Vik et al., 1991; Spieksma et al., 1995). In the Gdańsk area the *Betula* pollen counts attain high values. Although its allergenic role has not been systematically investigated in this area, one can assume that the *Betula* pollinosis problem is a rather serious one. A forecast of the starting date of the birch pollen season and the annual concentration level, as well as a prediction of the daily pollen count some days in advance, would be of importance for people suffering from this pollen allergy.

Long-term observations from sampling stations located in various parts of Europe show both similarities and differences in the *Betula* pollen season in the same year; rather large year-to-year variations in starting dates and in total pollen quantities are reported individually for each station (Spieksma et al., 1995). These data point to the importance of local evaluation of the aerobiological data. On the other hand, observations of the long-distance transported birch pollen,

which in some areas cause allergic symptoms before the start of the local flowering of *Betula* trees (Hjelmroos, 1991, 1992; Wallin et al., 1991; Hjelmroos and van Hage-Hamsten, 1993; Hicks et al., 1994) suggest that the pollen forecast should not only be regarded as informative locally, but is also of importance for more distant areas. According to these authors it is of clinical importance to inform patients of the possibility of an early start to the pollen season due to the transport of pollen from other regions.

The aim of this study is to delimit the major meteorological parameters influencing seasonal variation in the atmospheric *Betula* pollen count in Gdańsk, as a basis for future forecast modelling.

2. Materials and methods

The city of Gdańsk is part of a large urban agglomeration extending as a narrow strip along Gdańsk Bay (southern Baltic coast), for a distance of about 50 km. The most characteristic feature of this agglomeration is the presence of large green areas, including patches of strongly anthropogenically transformed forests,

both along the sea shore and at the landward side of the western border of the urbanized area. Two *Betula* species, *B. pendula* and *B. pubescens* are sub-constituents of these forests. *B. pendula* is also commonly grown as an ornamental tree in the town, along some streets and in parks. Single *B. pendula* trees are present in the near vicinity of the sampling station. The aerobiological investigation was carried out by means of a Seven-Day Volumetric Spore Trap (BURKARD LTD, UK) situated about 30 m above ground level, on the flat top of a tower, in a moderately dense built-up quarter. Most of the buildings are 3–4 stories high.

Gdańsk is situated in a region of cool temperate climate, strongly modified by the influence of Atlantic air masses and by the immediate vicinity of the Baltic Sea. The climate is characterised by a great variability in weather conditions on both the seasonal and annual scale.

There are three meteorological stations located in Gdańsk. However none of them is in the immediate vicinity of the aerobiological sampling site. These stations represent different meteorological conditions in districts of Gdańsk which are far from each other. In this paper the meteorological conditions during the period January 1993–August 2000 are characterized on the basis of the data from the station located in Świbno, which is representative for air masses entering the Gdańsk region mainly from the south, north and the east. The data analysed in this paper concern mainly those periods of the year that are the most important for the *Betula* pollen season. For the same reason some data on 1993, the year preceding the first year of aerobiological sampling, was included in the analysis.

Regular aerobiological sampling by means of a Burkard trap started in 1994. Pollen was counted on the tape across twelve transverse traverses. The daily pollen concentration values were calculated according to the method presented by K  p  l   and Penttinen (1981). The data are stored in the aerobiological database in the Department of Plant Ecology at the University of Gda  nsk.

The beginning of the pollen season in particular years was established as the date when the cumulative pollen sum reaches 5% of the total annual pollen count, while the end of the season is shown by the date when the sum reaches 95%. To describe the main features of the pollen season, graphs illustrating the stages when the cumulative pollen sum attains values of 5–25%, 25–50%, 50%, 50–75%, and 75–95% of

the total annual pollen count (Figure 1) are shown. Complementary information is given by the elements “a” and “b” in this figure (starting at the date for 1% and ending at the date for 99% respectively of the annual pollen sum), which illustrates the presence of small amounts of pollen, mainly secondary, before and after the season.

The relationships between aerobiological data and meteorological parameters have been studied at the seasonal level so all data were averaged at the monthly and seasonal scale. The basic statistical measure used is the correlation coefficient between aerobiological and climatic factors. The statistical significance of the estimated coefficients was tested by verification of the null hypothesis on the lack of correlation (correlation coefficient equals 0) against an alternative hypothesis (correlation coefficient differs from 0). The multi-linear regression technique was applied to describe the total seasonal concentration of the *Betula* pollen (*TC*) or the length of the *Betula* pollen season (*LS*) and the starting date of the season (*SD*) as the function of seasonal or monthly climatic parameters. The statistical significance of all coefficients determining the linear regression was tested by means of analysis of variance and the Student t-test.

3. Results

3.1. Aerobiological records

3.1.1. Starting dates and annual pollen sums

The mean starting date of the *Betula* pollen season in Gda  nsk calculated for the period 1994–2000 is 21st April (the 111th day from 1st January). Although the year-to-year variation in starting dates is rather large, with a difference of 18 days between the earliest (1999) and the latest date (1997), it appears that the most typical start of the *Betula* pollen season in this area (4 out of 7 occurrences) takes place at around 21st–23rd April (Figure 1).

The annual sums of atmospheric *Betula* pollen (Figure 2) for the period 1994–2000 show a clear two-year cyclic rhythm. The high annual sums (1994, 1996, 1998, 2000) rise distinctly during this period, but the increase in the low year sums (1995, 1997, 1999) is not as evident because of the very specific features of the 1997 pollen season.

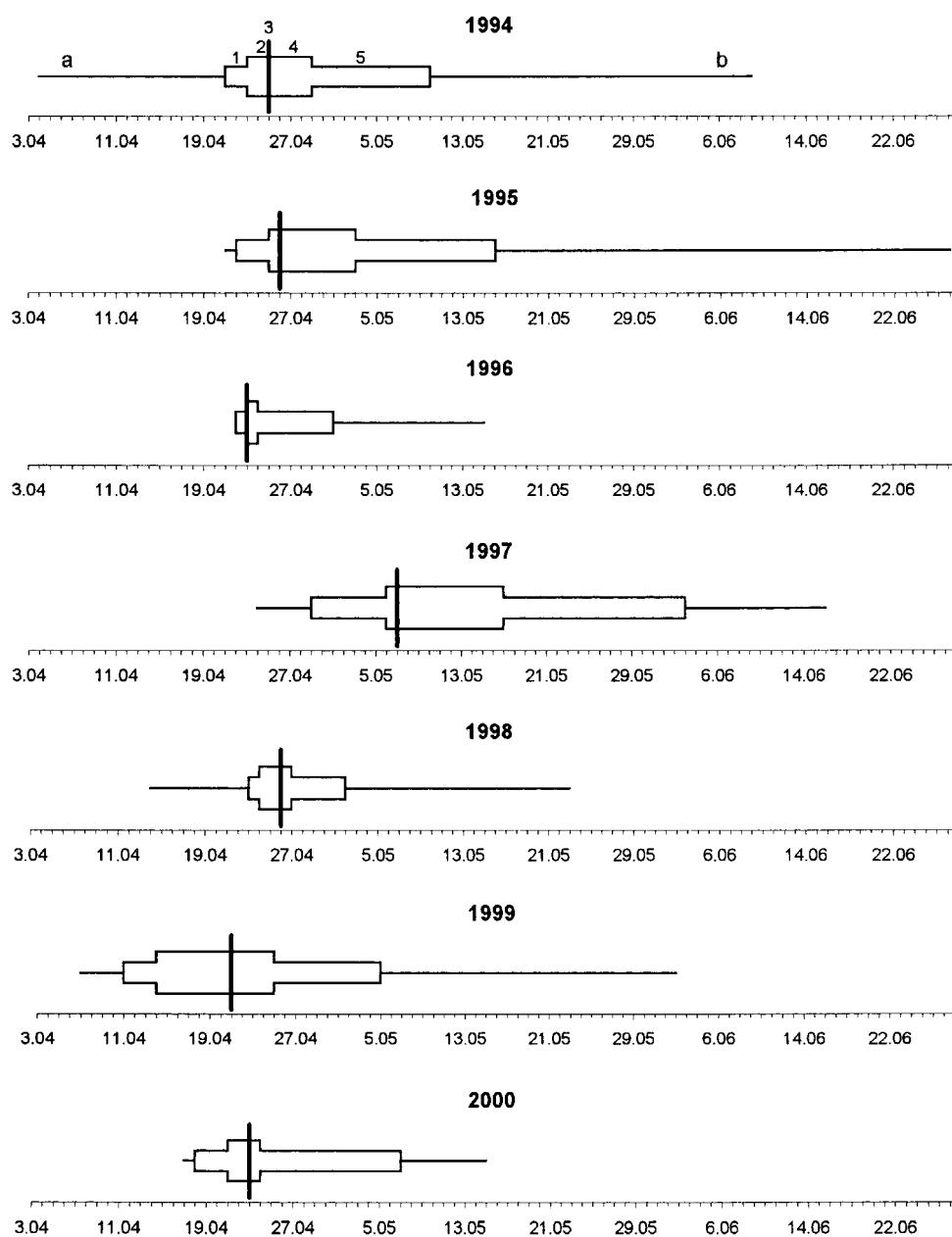


Figure 1. The starting dates and dynamics of the *Betula* pollen seasons 1994–2000; following stages of the pollen season: (1) 5–25%, (2) 25–50%, (3) 50%, (4) 50–75% and (5) 75–95% of the total annual pollen count; element (a) – starts at the date for 1%, element (b) – ends at the date for 99% of the annual pollen sum.

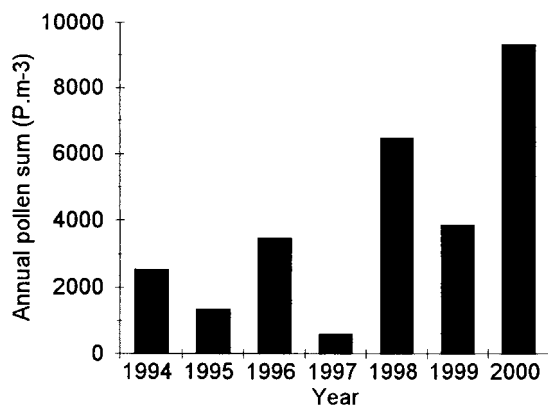


Figure 2. The annual *Betula* pollen counts for the period 1994–2000.

3.1.2. Dynamics of the *Betula* pollen seasons

The length of the *Betula* pollen season varied considerably from 9 days in 1996 and 1998 to 24 days in 1995 and 1999 and even 35 days in the very atypical year of 1997 (Figure 1). The season tends to be shorter in the years of high annual sums and longer in the years with smaller quantities of atmospheric birch pollen. The maximum daily values also differ from year to year, being only 125 P. m³/day in 1997, but 2200 P. m³/day in 2000.

The dynamics of particular pollen seasons are well described by the graphs (Figure 1) illustrating the four consecutive stages in which the cumulative pollen sums attain the designated levels of the annual total. The birch season usually starts very rapidly and, even in the first days, attains a pollen concentration level which can cause allergic symptoms. In most cases the first stage takes 1–3 days, while 50% of the total pollen sum is reached after 4–5 days from the beginning of the season. Exceptional cases were recorded in 1996 when 50% of the annual total was reached after only one day of the pollen season, whereas in 1999 it was not until after 10 days. In the years of observation the third stage lasted 1–4 days and longer only in exceptional cases, which means that 75% of the total pollen sum appears after a relatively short period. The last stage is clearly the longest and the season ends more gradually than it starts. Some pollen grains appearing before the season could be the result of long-distance transport.

3.2. The main meteorological features of the period 1993–2000

The mean air temperature of the period under analysis was higher than the climatological normal (according

to the World Meteorological Organization (WMO) climatological normals calculated for the period 1961–1990) in the range of 0.4 °C. From January to September long-term monthly mean air temperatures were usually higher than normal while from October to December they were below normal. Mean monthly air temperature minima ranged from –8.8 °C in February 1996 to 15.9 °C in July 1999, and mean monthly air temperature maxima were between –2.5 °C in January 1996 and 24.4 °C in July 1994. As is typical for this area, January was the coldest month of the year and July the hottest (Figure 3).

The mean annual precipitation sum for the period January 1993–August 2000 was 534.5 mm, i.e., nearly 12 mm less than the long-term annual mean. However, almost all individual months from the first quarter of the year were wetter than normal. April and May were characterized by great variability in the amount of precipitation. The summers were generally drier than normal, in the range of 3 to 12 mm. However, in some months heavy precipitation occurred and monthly precipitation totals exceeded 110 mm (in June 1996, July 1997 and August 1995).

The relative humidity was characterized by an annual rhythm with the maximum in January (88%) and in December (89%) and minimum in May (76%).

Total cloudiness varied from 4.5 octants in May and July to 6.2 octants in November. Total sunshine duration varied significantly from month to month and from year to year. The lowest sunshine duration was recorded in 1996 (1380 hours per year) and the highest in 1997 (1689 hours per year). From March to September long-term monthly sunshine duration exceeds 100 hours. May was characterized by the greatest number of hours with sunshine (nearly 239 hours on average) but the July value was only 6 hours less. In May 1993 and May 2000, as well as in July 1994, monthly sunshine duration exceeded 300 hours.

The period 1993–2000 was characterized by the domination of a westerly zonal circulation in the southern Baltic region. The tendency towards an intensification of the westerly circulation observed from the mid 70s still continued. The mean monthly wind speed registered in Świbno during the daytime ranged from 3.0 m s^{–1} in August 1997 to 7.0 m s^{–1} in January 1993.

A comparison of the main meteorological variables (mean temperature and precipitation) during the most important period with respect to the *Betula* pollen season, i.e., the first 160 days of the year, is shown in Figures 4 and 5, which present deviations

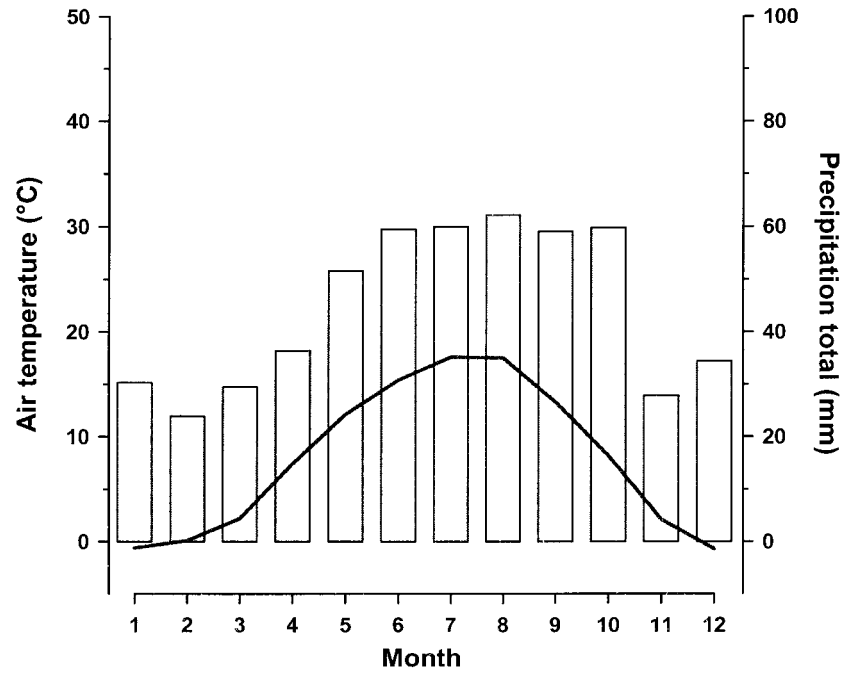


Figure 3. Annual variability in air temperature (curve) and precipitation (bars) at Gdańsk-Świbno station, 1993–2000.

of the mean values for the period 1994–2000 from the mean decadal temperature and precipitation. The warmest beginning of the year (January–February) was recorded in 1994 and 1998 and the coldest in 1996. The most atypical year was 1996, when for the whole period temperatures and precipitation were below the mean. The warmest Marches were those of 1997, 1999 and 2000, while 1996 was relatively cold. April was exceptionally cold and wet in 1997 when the mean monthly temperature was 4.5 °C and minimum daily temperatures below −4 °C were observed. April was clearly warmer than the mean in 1999 and 2000, and May was distinctly warmer than the mean in 1998 and 2000.

3.3. *Betula* pollen season in relation to meteorological parameters

The relationships between the different aspects of the *Betula* pollen season and the individual meteorological variables were statistically correlated by computing the correlation coefficients.

The first analysis concerns the relationship between the annual *Betula* pollen sum and the meteorological conditions during the period April–August of the preceding year. During this period the formation of flowers and pollen, which will be shed

in the next year, takes place (Chałupka and Krawiarz, 1979). Therefore, it is thought that the meteorological conditions during this period should be of importance for pollen production, i.e., for the potential level of the annual pollen sum in the following year (Spieksma et al., 1995). In this case the following variables were taken into consideration: temperature, precipitation, relative humidity and sunshine duration, each of them separately for each month from April to August. A high positive correlation was obtained for June temperature (T_{N-1}^{June} , 0.82) and a slightly lower one for precipitation in April (R_{N-1}^{April} , 0.74) and July (R_{N-1}^{July} , 0.55) and for relative humidity in April (H_{N-1}^{April} , 0.55) and July (H_{N-1}^{July} , 0.50). The liner regression model fitted to the data is as follows:

$$TC_N = 1736.5T_{N-1}^{June} + 18.7R_{N-1}^{April} + 58.9R_{N-1}^{July} + 226.3H_{N-1}^{April} - 243.2H_{N-1}^{July} - 25568.8 \quad (1)$$

The *R-square* value is 0.83 which confirms a very good linear relationship between the total seasonal concentration of *Betula* pollen in a given season (N) and the climatic conditions during spring and summer of the previous year ($N-1$). Adjusted *R-square* equals

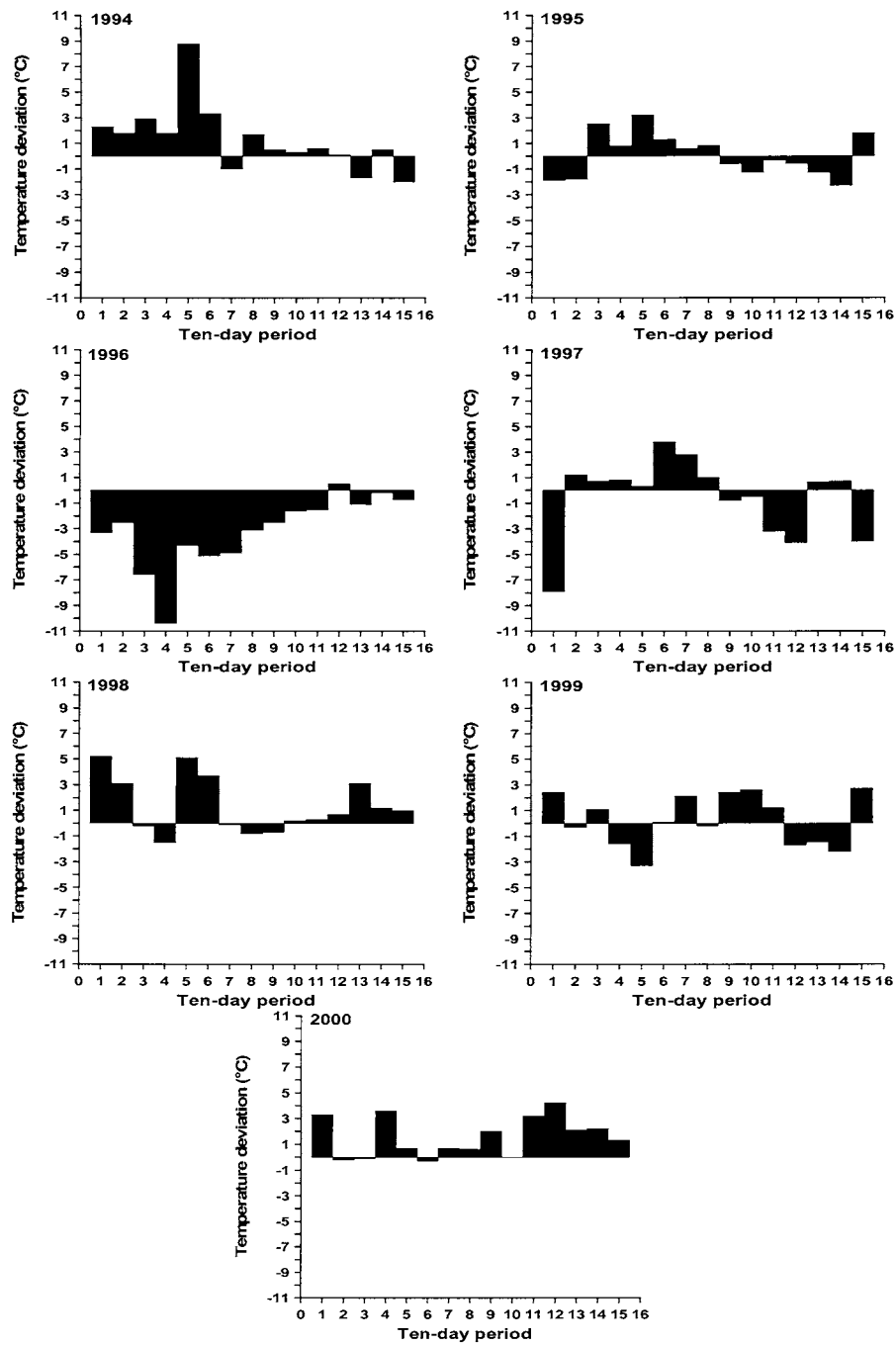


Figure 4. Temperature deviations in the first 160 days of the year (1994–2000).

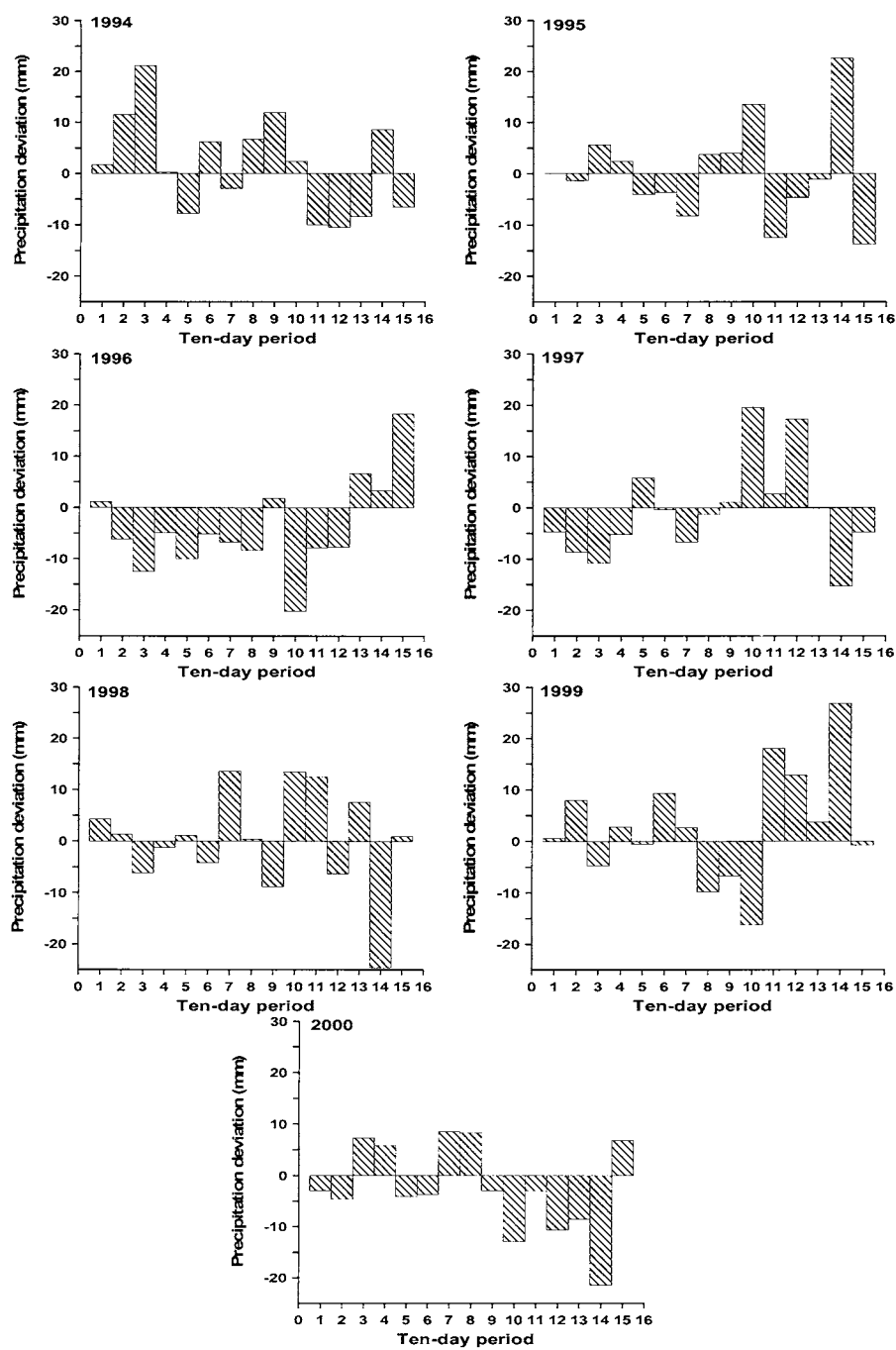


Figure 5. Precipitation deviations in the first 160 days of the year (1994–2000).

−0.006 which means that the information on climate conditions in a current year is not sufficient for estimating the total seasonal concentration of *Betula* pollen in the following year. *P-values* for *t* statistics of all regression coefficients are in the range 0.6–0.9. This means that the significance of influence of each of the climate variables listed above is of a significance level not lower than 0.6–0.9. Such significant limitations are due to the limited amount of data available (only 7 seasons) and will be statistically reliable after the 10 next years or so of observations.

Meteorological conditions during the pollen season modify the potential annual pollen sum that could be expected from the abundance of flowers and pollen set in the preceding year. In order to find the most important weather variables of the current season, which are responsible for the level of the annual pollen sum, analysis involved temperature, precipitation, relative humidity, sunshine and wind speed during the pollen season of the individual years. The results show a high positive correlation with thermal conditions i.e., with mean seasonal air temperature (T_N^{mean} , 0.70) and mean seasonal minimum (T_N^{min} , 0.62) and maximum air temperature (T_N^{max} , 0.73). A negative correlation was calculated for mean seasonal wind speed (FF_N , −0.73) and the seasonal precipitation sum (R_N , −0.65). The linear regression model fitted to the data is as follows:

$$TC_N = -14014.8T_N^{mean} + 7188.8T_N^{min} + 6474.8T_N^{max} + 43.1R_N - 4306.1FF_N + 23319 \quad (2)$$

As in the case of the earlier correlation the *R-square* value is 0.83 which confirms a very good linear relationship between total seasonal concentration of *Betula* pollen and climatic conditions in a given season. The adjusted *R-square* is also small and negative (−0.005) which indicates that the total seasonal concentration of birch pollen in a given year is not completely predetermined by climate conditions during the actual season. *P-values* for *t* statistics of thermal coefficients are in the range of 0.27–0.34 while for precipitation (R_N) and wind speed (FF_N) they are 0.69–0.89. This confirms the stronger influence of thermal conditions on total concentration of *Betula* pollen than that of the other parameters.

If climate conditions of neither the year prior to pollen emission nor during the emission season determine total seasonal concentration of *Betula* pollen in a given year then this value should depend on

both characteristics together. To determine such a relationship two of the dominant elements of the previous year i.e., mean air temperature in June (T_{N-1}^{June}) and precipitation in April (R_{N-1}^{April}) and three for the current year i.e., mean air temperature (T_N^{mean}), mean value of maximum air temperature (T_N^{max}) and mean wind speed (FF_N) were considered. The relationship of these is as follows:

$$TC_N = 75.10R_{N-1}^{April} + 711.75T_{N-1}^{June} + 1298.76T_N^{mean} - 828.86T_N^{max} - 1229.77FF_N - 5621.52 \quad (3)$$

In this case the *R-square* value is 0.999 which confirms a very good linear relationship between the total seasonal concentration of *Betula* pollen in a current season (*N*) and the climate conditions during spring and summer of the previous year (*N*−1) as well as during the given season (*N*). Adjusted *R-square* equals 0.999 which means that the information on climate conditions in the previous and the current year is sufficient for estimating the total seasonal concentration of *Betula* pollen in a given year. The standard error of the linear estimation is 56.2. *P-values* for *t* statistics of all coefficients are lower than 0.001. This indicates that all the climate elements included in the regression contribute to the total seasonal concentration of *Betula* pollen at a significance level greater than or equal to 0.001. The null hypothesis that all coefficients in equation (3) are simultaneously equal to 0.0 can be refuted at each level of significance greater than 0.013. However, it should be kept in mind that due to the limited amount of data, all these results have limited statistical value.

The length (i.e., number of days) of individual pollen seasons was compared with the following meteorological variables for those seasons: temperature, precipitation, relative humidity, sunshine duration and wind speed. On the basis of the correlation coefficients obtained for individual factors, the *Betula* pollen season tends to be longer, mainly due to the higher wind speed (0.64). The negative correlation with temperature (−0.46) means that in good thermal conditions birches shed all their pollen in a short time. The equation describing the duration of the season (*LS*) as a function of climate condition during this season is as follows:

$$LS_N = 19.12T_N^{mean} - 13.60T_N^{max} - 0.33R_N + 14.43FF_N + 0.26H_N - 44.66 \quad (4)$$

In this case *R-square* equals 0.96 but adjusted *R-square* equals 0.74. The standard error of estimation is 4.7 days. This confirms a strong dependence of the duration of a season on the climate conditions during that season. A higher mean temperature tends to prolong the season but, simultaneously, a higher mean maximum temperature tends to shorten it. Because mean maximum temperature is greater in 45% of the cases than mean temperature, so the thermal impact on the length of the season is minimised and eventually tends to make the season shorter ($T^{mean}=11.0^{\circ}\text{C}$, $T^{max}=16.0^{\circ}\text{C}$). Precipitation tends to shorten the season (even in the range of 28 days), however in the case of a lack of precipitation there is no influence. Wind speed is responsible for prolonging the duration of the season. The typical contribution from wind speed is in the range of 64 days and it varies between 40 and 84 days. Relative humidity also tends to prolong the length of the season; its mean contribution is in the range of 20 days.

Statistics were also used to find the correlation level between meteorological factors and the starting date of the *Betula* pollen season (*SD*) in the Gdańsk area. According to earlier published data (Spieksma et al., 1995), the start of the *Betula* pollen season is clearly dependent upon the meteorological conditions in approximately four decades preceding flowering. Therefore, the analysis involved the following variables, calculated for the last two decades of March and the first two decades of April: sum of mean temperatures, sum of mean daily temperatures $>5^{\circ}\text{C}$, sum of precipitation, sunshine duration and mean value for relative humidity. The analysis indicates a very high positive or negative correlation for each of these variables. A negative correlation, which indicates an influence on the earlier starting dates, was obtained for the sum of daily mean temperatures (T_N^{40} , -0.68), daily mean temperature greater than 5°C ($T_N^{40\geq 5}$, -0.79), and for mean relative humidity (H_N^{40} , -0.79). While a positive correlation was obtained for the sum of sunshine duration (U_N^{40} , 0.53) and the sum of precipitation (R_N^{40} , 0.52). The linear regression is as follows:

$$\begin{aligned} SD_N = & -21.64T_N^{40} + 22.96T_N^{40\geq 5} \\ & + 2.81R_N^{40} - 9.57U_N^{40} \\ & - 123.92H_N^{40} + 12664.6 \end{aligned} \quad (5)$$

The *R-square* value is 0.97 which confirms a very good linear relationship between the starting

date of the *Betula* season in a given year (*N*) and climate conditions during the preceding 40 day period. Adjusted *R-square* equals 0.60 which indicates that the beginning of the season depends fairly well on climate conditions as in the 40-day period close to the start. The mean standard error equals 27 days. *P-values* for *t* statistics of all regression coefficients are around 0.015, only in the case of precipitation they are 0.06. The total influence of thermal conditions seems to be negative, which should be interpreted to mean that a warm period prior to the pollen season tends to start *Betula* flowering earlier. This same effect occurs in the case of sunny weather. Rainy weather tends to delay the starting date.

4. Discussion and conclusions

Throughout the years monitored, the *Betula* pollen season shows great variation with respect to the total pollen sum, the number of days in the season, its dynamics and the maximum daily pollen concentration values.

The pollen data from Gdańsk show clear fluctuations in the annual sums of daily pollen concentration. The same phenomenon is observed at other European stations (e.g., Spieksma et al., 1995) and appears to be a synchronous, alternating cyclic rhythm. A two-year cycle in which a low annual birch pollen sum is followed by a high one has been reported by many authors (e.g., Nilsson and Persson, 1981; Emberlin et al., 1993). The cause of this biennial rhythm and its synchronicity over large areas is not clear. However, some authors suggest that it is physiological factors that are mostly involved: the high pollen production usually results in high fruit production, which takes a lot energy, inhibiting the development of new flowers and pollen for the next year (Chałupka and Krawiarz, 1979; Hicks et al., 1994). The high fruit production also inhibits other processes, for example the vegetative growth of the tree (Chałupka and Krawiarz, 1979; Zarzycki, 1979). This biennial rhythm in pollen production is of importance for predicting the severity of the pollen season in the next year. On the other hand, it is clear that the annual *Betula* pollen sum is dependent on both the weather conditions during the formation of flowers in the year preceding the pollination period (in Gdańsk mainly temperatures in June and precipitation in April), and on the thermal conditions during the pollen season. Pollen data from Gdańsk suggest that in recent years the annual pollen

totals, in the sequence of years with high sums and low ones, are rising. However, the observation period is too short to allow more general conclusions on a possible climatically driven trend with respect to this aspect of the *Betula* pollen season in Gdańsk, such as that discussed, for example, by Spieksma et al. (1995) and Emberlin et al. (1997) on the basis of aerobiological records or by Hicks (1999) on the basis of pollen deposition values at northern tree limits.

One of the most important problems in forecasting the pollen season of any taxon is predicting its starting date (Frenguelli et al., 1991; Marletto et al., 1992; Puls and Bock, 1993; Emberlin et al., 1994; Bricchi et al., 1995; Norris-Hill, 1998). Although the first appearance of *Betula* pollen differs from year to year, the start of the pollen season in the period 1994–2000 seems to be a relatively stable parameter if we exclude those years which are characterised by unusual meteorological conditions in the short period before the season. Such a conclusion is based on pollen data from those years that are the most typical with respect to the average spring meteorological features in the last seven years (Figures 4 and 5). As has been reported by other authors (Spieksma et al., 1989), thermal conditions during the period of about 40 days before the *Betula* pollen season are decisive for the starting date at a very high statistic level. However, comparing “by eye” the data included in Figures 1 and 4, it seems that an even shorter time period should be taken into consideration in order to gain more precise results. This will be analysed at a further stage of investigations.

The data presented in this paper are a first step towards forecasting the *Betula* pollen season in the Gdańsk region, showing the relationship between different aspects of pollen appearance and specific meteorological variables. In recent years more and more papers dealing with this problem have appeared. Modelling of pollen forecasts for different allergenic taxa is also starting to be more common, as shown by the programme of the Second European Aero-biological Conference, Vienna, 2000. However, it should be taken into consideration, that for forecasting purposes it is necessary to produce specific data for each particular area. The most important points behind this statement are: the geographical distribution of those species identified in aerobiological material only at a higher taxonomic level and their specific ecological requirements at different locations within their geographical range.

With respect to the first of these two problems, the genus *Betula* is relatively slightly differentiated in Europe; the most important and widely distributed species are *B. pendula* and *B. pubescens*, while the dwarf-shrub *B. nana* occupies large areas mostly in Scandinavia and shrub birch *B. humilis* occurs in the north-east. The hybrid of *B. pubescens* and *B. nana* (*B. tortuosa*) is common on the northern fringes of Europe (Hultén and Fries, 1986). All these taxa have specific ecological requirements with respect to those environmental factors which regulate their most important physiological processes, including those connected with flowering and pollen production. The second of the two problems mentioned above involves the fact that, in various parts of the geographical range of any one species, plants are exposed and then adapt to different climate conditions, concerning both the range of individual factors (e.g., temperature) and combinations of factors (e.g., temperature and relative humidity); the day length, so different in the northern and southern areas of Europe, should be mentioned as a factor which plays an important role in the formation of flowers and production of the *Betula* pollen (Chalupka and Krawiarz, 1979). Therefore, from the theoretical point of view, the relevance of forecast models produced for one area, to another area is limited.

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