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Aerobiologia 13 (1997) 91–97

Aerobiologia
International Journal of Aerobiology

The influence of ambient temperature on the abundance of Poaceae pollen

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Received 24 April 1996; received in revised form 12 February 1997; accepted 26 February 1997

Abstract

The sampling of pollen concentrations over six seasons in north London has revealed the importance of temperature in influencing the start, severity, daily and diurnal variation of Poaceae pollen seasons. Using accumulated degree days above 6°C and rainfall amount as predictors, models have been developed which account for 96% of the variation in the starting date and 91% of the variation in the severity of the Poaceae pollen season. Maximum daily temperature is an important influence on the daily pollen count although this relationship is not linear and maximum daily temperatures within the range 21.1–25°C are associated with the highest daily pollen concentrations. Likewise, when the two-hourly variation of pollen concentration is examined, temperatures within 2–4.9°C above the normal diurnal range, rather than in excess of 5.0°C, are found to be associated with the highest two-hourly concentrations. Occasional night-time maxima of pollen concentration have also been recorded and these are examined in relation to the possibility of temperature inversions, although few conclusive results have emerged. © 1997 Elsevier Science Ireland Ltd.

Keywords: Aerobiology; Pollen; Temperature; Prediction; London

1. Introduction

Much previous work in aerobiology has concentrated on establishing the role of meteorological conditions in pollen concentrations: for example, McDonald (1962), Dingle and Gatz (1966), and Norris-Hill and Emberlin (1993) have analysed the washout of pollen by raindrops; McDonald (1979) and McDonald (1980) studied the influence of wind direction on the pollen spectrum of a coastal area; Spieksma (1983) the influence of temperature inversions on night-time pollen counts; and Steel (1983) the role of convection currents. These studies have all contributed to the understanding of meteorological controls on pollen production and dispersal, and have aided in the construction of pollen dispersal models and pollen forecasting systems. Other authors have examined the role of temperature in influencing pollen counts (for example, Emberlin et al., 1993; Galan et al., 1995; Liem, 1980; Davies and Smith, 1973) and have concluded that the parameter of temperature is undoubtedly important in influencing both pollen season timing and abundance. This paper intends to supplement these previous studies and elucidate the rôle of temperature in influencing Poaceae pollen concentrations with particular emphasis paid to the ways in which variations in temperature can promote high Poaceae pollen counts both on a daily and diurnal basis as these episodes are of importance to hayfever sufferers sensitised to Poaceae pollen and have also been associated with an increased incidence of childhood asthma (Hill et al., 1979). Although this paper examines just one pollen taxa, it has relevance to the analysis and forecasting of other pollen types as long as the phenological differences between Poaceae and other taxa are considered.

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PII S0393-5965(97)00011-5

2. Materials and methods

The sampling of pollen concentrations for this study was conducted in a densely built area within London with a Burkard volumetric pollen sampler (Hirst, 1952) located on the open roof of a six-storey building. This sampler monitors two-hourly records of pollen abundance per cubic meter of air. Data from 1987 to 1992 are available for use in this study, although only daily, rather than two-hourly, records of pollen concentration are available for 1992, and so the latter stages of analysis use results from 1987 to 1991 only. The study area is described in detail in Emberlin and Norris-Hill (1991) but essentially comprises few local pollen sources, particularly for Poaceae pollen as most grasslands are intensely managed and are mown at frequent intervals. Although there are a small number of derelict areas with uncut grasses, the majority of the Poaceae pollen is believed to originate from outside of the study area (Davies and Smith, 1973). Hourly records of the meteorological parameters of temperature, humidity, sunshine, rainfall, cloud cover, wind speed and wind direction, and daily records of maximum and minimum temperature, hours of sunshine, rainfall amount, and synoptic situation were obtained from the London Weather Centre of the Meteorological Office in the south of the sampling area, 4 km from the sampling site.

3. Results and discussion

For the purpose of this analysis of the influence of temperature on Poaceae pollen concentrations, the study will focus on several different aspects of pollen seasons. Specifically, this paper will examine the influence of temperature on the start of the season, on pollen formation, on seasonal abundance, on pollen release, pollen dispersal, and on the occurrence of high night-time pollen counts.

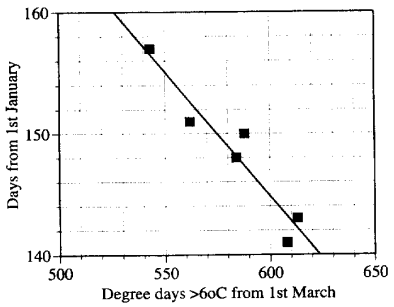


Fig. 1. Forecasting the start of the Poaceae pollen season using degree days above 6°C as a predictor variable.

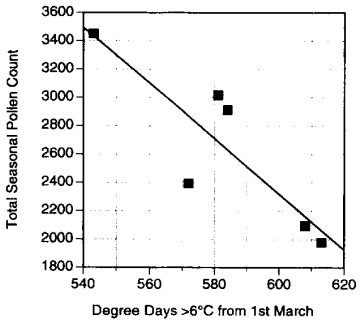


Fig. 2. Seasonal pollen abundance 1987–1992 plotted against accumulated average daily temperature above 6°C from 1st March.

3.1. The influence of ambient temperature during the pollen formative period

The first aspect of the influence of temperature on pollen seasons to be considered here is the way in which variations in temperature can influence the start date of the Poaceae pollen season as several authors have noted that warm, dry weather during the period that pollen is forming within the anthers of a plant result in increased pollen concentrations during the pollen season (Davies and Smith, 1973).

The start dates of the Poaceae pollen seasons in London from 1987 to 1992 (in days from 1st January and defined as the day on which the accumulated count from 1st January reaches 2.5% of the total sum of the daily counts, Nilsson and Persson, 1981) are displayed in Fig. 1 and are analysed with respect to daily average, maximum and minimum, and accumulated temperatures for March, April and May through a stepwise multiple regression procedure as these are the parameters suggested by Davies and Smith (1973) to determine the start of the Poaceae pollen season. The results from this analysis suggest that the accumulated average daily temperature above 6°C from 1st March each year can account for 96.1% of the variation in the start of the Poaceae pollen season alone and the very close relationship between these two parameters is displayed in Fig. 1. Thus degree days above 6°C, recorded from 1st March, might productively be used as a predictor of the start of the Poaceae pollen season in the form,

$$\text{Start} = 278.18 - 0.2225T$$

where Start is the start date of Poaceae pollen season (in days from 1st January), T is the accumulated average daily temperature above 6°C from 1st March, where $r^2 = 0.961$, which is significant at 95% level. The determination of the parameter of degree days above 6°C from 1st March as being the best predictor of the start of the Poaceae pollen season is in contrast to the

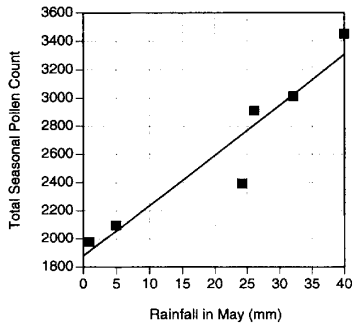


Fig. 3. Seasonal pollen abundance 1987–1992 plotted against total rainfall during the month of May (in mm).

findings of Davies and Smith (1973) who found that the best predictors of the start of a pollen season were temperature and rainfall during the months of April and May. The additional variation in the start date accounted for in this research might be attributed to the use of 6°C as a threshold, below which temperatures are not considered to influence the development of grasses. The use of 5.6°C or 6°C has become standard in much botanical work as a threshold above which the effective growing season of plants commences (Sutra, 1992) since Taylor (1972) described the stem growth of grasses as a linear process with a minimum temperature of 5.6°C.

The London data also demonstrate the influence of meteorological conditions during the months preceding the start of the season on the abundance of Poaceae pollen. The abundance, or severity, of the Poaceae pollen season varied considerably between 1987 and 1992. A stepwise multiple regression procedure indicated that the parameters which account for the greatest variation in seasonal pollen abundance are degree days above 6°C from 1st March and rainfall in May. The equation,

$$Cs = -60.086 + 40.78R + 3.14T$$

where Cs is the estimated pollen sum for June and July, R is the total rainfall for May (in mm), T the accumulated average daily temperature above 6°C from 1st March.

This forecasts the pollen sum with a coefficient of determination of $r^2 = 0.910$, significant at the 95% level. The bivarate relationships between the pollen season abundance and the accumulated average daily temperature above 6°C from 1st March, and the total rainfall in May are shown in a graphical form as Fig. 2 and Fig. 3, and these relationships are surprisingly close, as the recorded pollen totals are also partly dependent on the meteorological conditions during the pollen season.

However, these results highlight the way in which although the relationship between accumulated temperature and pollen season abundance initially appears to be negative (Fig. 2), when this variable is entered into a multiple regression equation the beta coefficient is positive. This anomaly may arise due to the strong negative relationship between the two independent variables of rainfall in May and accumulated average daily temperature above 6°C from 1st March ($r^2 = 0.862$, significant at the 95% level). The initial negative relationship between accumulated temperatures and pollen season severity might arise due to the extreme springtime weather during the years of pollen sampling: the mean monthly temperature for May in 1987, 1989, and 1990 was up to 3.9°C above the thirty year average, whilst rainfall in May was below average from 1988 to 1990 (as little as 8% of the 30-year average in 1990). The dearth of water available to grasses may have increased the importance of rainfall amount as a predictor of pollen season severity, so that when this variable is entered into the multiple regression equation it supercedes the variable of temperature in importance. Whether or not this relationships exists in years with more typical weather conditions remains to be seen.

Table 1
Analysis of variance test between daily Poaceae pollen concentrations (logged and standardized) recorded under different categories of maximum daily temperature

Group	Temperature range	Mean pollen	N	Group					
				1	2	3	4	5	6
1	min.–15.0°C	0.5813	42						
2	15.1–17.0°C	0.7127	39						
3	17.1–19.0°C	0.8193	51	*					
4	19.1–21.0°C	1.1324	32	*	*	*			
5	21.1–25.0°C	1.2628	38	*	*	*	*		
6	25.1°C–max.	1.1198	27	*	*	*			

*Denotes groups significantly different at the 95% confidence level.
F-ratio: 18.1129; F-probability: 0.0000.

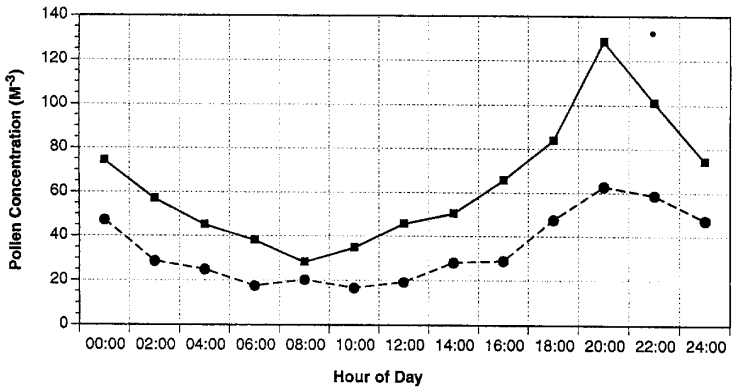


Fig. 4. Diurnal variation of pollen concentration. The solid line represents the average two-hourly concentration on days with a maximum temperature above 21.1°C, whilst the dashed line represents the average two-hourly concentration on days with a maximum temperature below 21°C. Note that wet days have been excluded from the analysis.

3.2. The influence of ambient temperature during the pollen season

As there is no direct correlation between airborne pollen concentrations and the release of pollen (Subba Reddi and Reddi, 1985), the data collected in London may only be used to illuminate the influence of temperature on the patterns of dispersal that occur once pollen is released from the anther of a plant. An examination of the results of the analyses of variance between the daily pollen counts recorded under different categories of the meteorological variables reveals clear patterns of variation and, although the analyses are not shown due to limitations of space (see also Norris-Hill, unpublished Ph.D. thesis, University of North London, 1992). Table 1 however illustrates the relationship between maximum daily temperature and the daily pollen count. Strong positive correlations exist between daily Poaceae pollen concentrations and the maximum daily temperature, even when the influence of other meteorological variables have been eliminated, and this variable is the first to be entered into stepwise multiple regression equation.

Table 1 demonstrates that the highest maximum daily temperatures do not necessarily result in the highest pollen counts, as extremely high temperatures (above 25°C) record lower average pollen counts than do temperatures in the range 21.1–25.0°C, although these two groups are not significantly different. There are two possible reasons for this result which does not fit with the assumed linear relationship between temperature and pollen concentration. The first possible explanation is that pollen production on days of extreme temperatures may be limited despite the potential for pollen dispersal, a factor also noted by Liem (1980) who found that temperatures of around 20°C proved the most favourable for pollen production. A further possible explanation for this result is that, in London, the highest temperatures are likely to occur through July and into August, the time when the pollen count is declining at the end of its natural season.

3.3. The influence of ambient temperature on the diurnal variation of pollen

A further way in which ambient temperature influences the abundance of Poaceae pollen may be examined through the analysis of diurnal variations in pollen abundance. Fig. 4 illustrates the marked diurnal variation of Poaceae pollen on dry days, and also differentiates between days with a maximum daily temperature above and below 21°C. A visual examination of Fig. 4 reveals how although temperatures above 21°C do in fact produce higher concentrations of pollen, these extremes of temperature do not alter the regular pattern of pollen abundance, with low concentrations recorded between 02:00 and 14:00 h and high concentrations recorded between 16:00 and 24:00 h. The data suggest that although high temperatures may increase the amount of pollen in the air, they do not prolong convection. However minor changes in the duration of convection may occur that are not detectable with a time-resolution of 2 h.

Temperature exhibits a regular pattern of diurnal variation and so, for a statistical analysis of the influence of ambient temperature on the diurnal variation of Poaceae pollen, a curve of the average variation through the day has been calculated and the deviation of each two-hourly value from this curve used instead of the actual value in the analysis. An analysis of variance statistic has then been calculated between the pollen counts recorded under different categories of temperature to elucidate the relationship between temperature and the abundance of Poaceae pollen through the day. Table 2 displays the results of this analysis and shows that the diurnal variation of Poaceae pollen is

Table 2
Analysis of variance test between two-hourly Poaceae pollen concentrations (logged and standardized) recorded under six different categories of the variation of temperature from the diurnal norm (see text for explanation)

Group	Temp.	Difference	Mean pollen	*N*	Group					
					1	2	3	4	5	6
1	>5.0°C	Below norm	1.2300	19						
2	2.0–4.9°C	Below	1.4868	442	*					
3	0.0–1.9°C	Below	1.8440	868	*	*				
4	0.0–1.9°C	Above	2.1563	771	*	*	*			
5	2.0–4.9°C	Above	2.2412	507	*	*	*			
6	>5.0°C	Above norm	1.9583	53	*	*				

*Denotes groups significantly different at the 95% confidence level.
F-ratio: 98.7748; *F*-probability: 0.0000.

closely related to temperature although the relationship is, once again, not linear as the mean count recorded under temperatures more than 5°C above the normal diurnal variation is lower than that recorded under temperatures within 5°C of the normal variation.

3.4. The influence of temperature inversions

The analysis of diurnal variations in Poaceae pollen abundance reveal the occurrence of high concentrations of pollen recorded at night, at times much later than the normal late afternoon or early evening peak. These night-time peaks in pollen abundance occurred only infrequently during the five Poaceae pollen seasons monitored for diurnal variation during this study, with a total of 15 nights recording peaks in concentration between 02:00 and 08:00 h. The meteorological conditions recorded during these nights may therefore be examined to determine the factors contributing to their formation, in particular the occurrence of temperature inversions. Because detailed the temperature profiles necessary to identify temperature inversions are not available in London, the atmospheric stability has been estimated using the system devised by Pasquil (1962) and illustrated in Table 3. This estimates night-time stability as a function of wind speed and cloud cover and derives six stability categories ranging from 'very unstable' (A) through 'neutral' (D) to 'moderately stable' (F).

An analysis of variance statistic is calculated to test for significant differences between the pollen counts recorded under each of the stability categories that may occur overnight, i.e. categories 'D', 'E', and 'F', irrespective of whether or not a peak in concentration was recorded (Table 4). The highest pollen counts are recorded under conditions of stability (Pasquil's categories 'E' and 'F'), a difference from the other stability categories significant at the 95% confidence level.

These results are in general agreement with the idea proposed by Steel (1983) and Spieksma and den Tonkelaar (1986); that high nocturnal pollen concentrations result from ground level temperature inversions. Although the presence of inversion layers cannot be proven in this study, they form under conditions of extreme stability such as frequently occur overnight (Sumner, 1988). Stability is usually characterised by a lack of vertical movement in the atmosphere and frequently low wind velocities (Pasquil, 1962). Many authors have suggested that the top of an inversion layer can trap pollution (for example Oke, 1987) and therefore at the same time this will also limit pollen dispersal. It is hypothesised that any pollen remaining in the air overnight is unable to be dispersed upwards but is concentrated close to ground level where it is recorded

Table 3
Stability categories (after Pasquil, 1962)

Wind speed at 10 m (m/sec)	Insolation			Night	
	Strong	Moderate	Slight	>4/8 cloud	<3/8 cloud
<2	A	A/B	B	—	—
2–3	A/B	B	C	E	F
3–5	B	B/C	C	D	E
5–6	C	C/D	D	D	D
>6	C	D	D	D	D

Key: A, very unstable; B, unstable; C, neutral; D, slightly stable; E, stable; F, very stable.

Table 4
Analysis of variance test for significant differences in Poaceae pollen concentrations (logged and standardized) recorded under night-time stability categories (Pasquils's categories 'D', 'E' and 'F')

Pasquil category	Mean pollen count
D	0.7801
E	1.0049
F	1.1327

F-ratio: 24.5622; *F*-probability: 0.0010.

in abundance by the Burkard sampler. The height of the pollen sampler relative to the top of the inversion layer will be of significance in determining the frequency and abundance of high night-time pollen concentrations although most authors suggest that temperature inversions usually form to several hundred meters, a height well above the position of the pollen sampler. The rarity of high night-time pollen concentrations is thought likely to reflect the infrequency of temperature inversions in an urban area (where increased turbulence may be sufficient to breakdown any layers of stable air) and the need for these to be combined with times of pollen release, for unless pollen is becoming suspended at ground level then the effects of capping or concentration will be minimal. Some species of Poaceae have been reported to flower at night and in the very early morning, for example Dowding (1987) and Takahashi et al. (1993) recorded the overnight anthesis of *Dactylis glomerata* and *Poa pratensis*, and this suggests the possibility that more pollen than was previously assumed is being released at night and that this may coincide with extreme stability or a temperature inversion. However as the majority of pollen is dispersed during daylight hours (even if anthesis occurs earlier) this coincidence of pollen release or reentrainment and temperature inversion are likely to be rare. If pollen dispersal does become limited by the capping effect of stable layers of air, then a reduction in the pollen count will gradually occur as the grains begin to sediment out of the air. However further dilution of pollen may occur as the stable conditions forming overnight generally disintegrate in the morning when insolation on the urban surface results in convection and turbulence (instability). Most authors generally agree that overnight stability, and an inversion if formed, usually disappear by 10:00 h (for example, Schmidt, 1973). However, the nocturnal peaks in the pollen count in London start to decline as early as 04:00 h, and a diurnal minima is frequently recorded at 06:00 to 08:00 h suggesting that the fall-out of pollen from the atmosphere may well be of importance in reducing the count. However, this early collapse of night-time temperature stability may come about because stability layers forming at ground level in an urban area are frequently weakly developed (Oke, 1987) and so will be rapidly broken down by solar induced convection.

4. Conclusions

The meteorological variable of temperature has, in its various forms, proven to be extremely important in influencing many aspects of the Poaceae pollen season in north London. In the form of degree days above 6°C it determines the start of the pollen season and hence may then also be used to forecast this start. Forecasting the start of pollen seasons is of extreme importance to both sufferers of allergic rhinitis and those concerned with the monitoring and reporting of pollen counts. If informed of the likely start date of the Poaceae pollen season, hayfever sufferers will be able to plan ahead their use of anti-histamine remedies and even be able to start taking them before the onset of the pollen season. Likewise, pollen counters would also be able to plan when to start the daily monitoring and reporting of pollen counts. A forecast of the likely severity of a pollen season would also be of use to hayfever sufferers and, once again, this may be predicted with some accuracy through the use of accumulated degree days above 6°C together with rainfall amount.

Temperature is also important in determining the day-to-day and diurnal variations of pollen counts, although it is a less reliable predictor of these variations than it is of the start and severity of a season. Other meteorological parameters such as relative humidity, sunshine hours, and wind direction appear to influence both the daily and diurnal variation of pollen concentration in combination with temperature. Temperature inversions or very stable atmospheric conditions may result in increased pollen counts at times other than the typical late afternoon or early evening peak in pollen concentration, and so this factor must be given consideration also when attempting to forecast high pollen counts. A further factor when considering the influence of temperature on the incidence of allergic respiratory diseases is that some authors have suggested that temperature, independent of the pollen count, can influence the severity with which hayfever, as well as asthma, is suffered (Tromp, 1980).

Acknowledgements

The author is grateful to the Pollen Research Unit, Worcester College of Higher Education, for supplying the daily pollen counts from 1992.

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