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Atmospheric Poaceae pollen frequencies and associations with meteorological parameters in Brisbane, Australia: a 5-year record, 1994–1999

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Abstract Grass pollen is an important risk factor for allergic rhinitis and asthma in Australia and is the most prevalent pollen component of the aerospora of Brisbane, accounting for 71.6% of the annual airborne pollen load. A 5-year (June 1994–May 1999) monitoring program shows the grass pollen season to occur during the summer and autumn months (December–April), however the timing of onset and intensity of the season vary from year to year. During the pollen season, Poaceae counts exceeding 30 grains m^{-3} were recorded on 244 days and coincided with maximum temperatures of 28.1 ± 2.0 °C. In this study, statistical associations between atmospheric grass pollen loads and several weather parameters, including maximum temperature, minimum temperature and precipitation, were investigated. Spearman's correlation analysis demonstrated that daily grass pollen counts were positively associated ($P < 0.0001$) with maximum and minimum temperature during each sampling year. Precipitation, although considered a less important daily factor ($P < 0.05$), was observed to remove pollen grains from the atmosphere during significant periods of rainfall.

This study provides the first insight into the influence of meteorological variables, in particular temperature, on atmospheric Poaceae pollen counts in Brisbane. An awareness of these associations is critical for the prevention and management of allergy and asthma for atopic individuals within this region.

Keywords Aerobiology · Poaceae · Pollen season · Correlation · Rainfall · Temperature

Introduction

Grasses, belonging to the family Poaceae (Gramineae), are the most prolific and diverse family of herbaceous plants that occur in urban areas of Brisbane. Anemophilous Poaceae pollen is a well-established airborne allergen and is generally considered a risk factor for patients with respiratory disease in southeastern Australia (Wright and Derrick 1975; Hill et al. 1979; Abramson et al. 1996). Understanding pollen dispersal, particularly that of Poaceae, is becoming increasingly important in Australia as the seasonal prevalence of pollen-related asthma and hay fever is rising with up to 10% of adults and 30% of children diagnosed with clinical respiratory disease (Australian Bureau of Statistics 1997). In Brisbane, grass pollen is more related to the incidence of hay fever than to exacerbations of asthma (Derrick 1973; Wright and Derrick 1975), even though grass pollen accounts for approximately 71% of the total annual atmospheric pollen count (Green et al. 2002). However, recent reports have suggested an etiological role for grass pollen in localized epidemics of asthma that are associated with weather perturbations, particularly thunderstorms and rainfall (Grote et al. 2001; Marks et al. 2001). Thus, identifying the factors that influence Poaceae pollen dispersal and its concentration in the atmosphere is of significance in providing a predictive model that may be used by clinicians for warning patients who suffer pollen-related asthma and hay fever.

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Statistical models that predict the start dates, duration and intensity of grass pollen seasons have been established for European regions (Subiza et al. 1992; Emberlin et al. 1993; Gonzalez Minero et al. 1998). Parameters identified as influencing flowering phenology as well as the seasonal and daily distribution of airborne grass pollen include maximum temperature, minimum temperature, rainfall, humidity and wind speed. The effect of temperature and precipitation is of special interest as grasses prevalent in Brisbane are adapted to rainfall concentrated in summer, by contrast to grasses of southern Australia that experience a winter rainfall regime. The influence of meteorological parameters on the atmospheric concentrations of grass pollen in Australia has been established for southern regions (Smart et al. 1979; Ong et al. 1995), but to date there have been no studies that have explored these relationships in tropical and subtropical regions of Australia and indeed elsewhere in the Southern Hemisphere.

This is the first study to investigate the associations between meteorological parameters and the incidence of atmospheric grass pollen in a subtropical environment in the Southern Hemisphere and it follows our preliminary investigation of the airborne pollen content of Brisbane (Green et al. 2002). The study describes the quantitative and temporal distribution of Poaceae pollen seasons with statistical reference to meteorological parameters, on the basis of 5 years of pollen measurements, June 1994–May 1999.

Materials and methods

Airborne Poaceae pollen was collected over a 5-year period (June 1994–May 1999) in the city of Brisbane (27°29'S 153°8'E), southeastern Queensland, Australia. The trapping site was at an elevation of 12.5 m above sea level, in the suburb of Rocklea, 7 km southeast of the central business district on a Queensland Department of Primary Industries research farm. Brisbane experiences a subtropical climate (average yearly mean temperature 25.9 °C) with a summer rainfall regime (average yearly rainfall 1,114.6 mm) (Bureau of Meteorology 1983). Vegetation of the trapping site and the surroundings includes open and riparian *Eucalyptus* woodland with an understorey of Poaceae and herbaceous species. Grasses represented include *Capillipedium* spp., *Chloris gayana*, *Cynodon dactylon*, *Eleusine tristachya*, *Lolium temulentum*, *Sorghum halepense*, *Avena fatua*, *Dactylis glomerata* and *Paspalum notatum* (Moss 1965; Rutherford et al. 1997; Green et al. 2002). The nearby urban and industrial areas include grassed and wooded areas of both endemic and exotic species.

Aerobiological data were collected using a 7-day Burkard volumetric spore and pollen trap (Burkard Manufacturing Co. Ltd.,

Rickmansworth, Hertfordshire, UK), which was elevated 2 m above ground level and operated almost continuously at the Rocklea site between June 1994 and May 1999 (Green et al. 2002). The pollen data corresponded to the mean daily values expressed as the number of pollen grains per cubic meter of air. Meteorological data were obtained from the Australian Bureau of Meteorology's weather station at Brisbane airport, which is situated 10 km northeast of the sampling site and includes daily readings of maximum temperature, minimum temperature and total rainfall.

Data corresponding to 5 years (June 1994–May 1999) of pollen monitoring and meteorological records were studied. The characteristics of each Poaceae pollen season were documented graphically and evaluated statistically. To calculate the period of the Poaceae pollen season, the criteria developed by Nilsson and Persson (Nilsson and Persson 1981) were used where the date when 5% of the total Poaceae pollen count for that year had accumulated corresponded to the beginning of the season and 95% of the total accumulated Poaceae pollen count corresponded to the end of the season. Daily counts were classified into three categories (1–10 low, 11–30 moderate and >30 grains m⁻³ abundant), an airborne grass pollen standard that has been used by Rantio-Lehtimäki and others (Rantio-Lehtimäki et al. 1991). Variations between pollen count categories were determined by single-factor analysis of variance, using Analyse-It for Microsoft Excel (Analyse-It Software Ltd., Leeds, UK). Associations between the mean daily Poaceae pollen counts and meteorological values were calculated using Spearman's (non-parametric) correlation analysis for the entire study period and by season, and calculations were performed using Stata (Stata 1999).

Results

Pollen of the Poaceae was recorded throughout the entire year in air samples collected from the Rocklea trapping site at Brisbane (June 1994–May 1999) and accounts for 71.6% of the total airborne pollen spectrum (Green et al. 2002). The main grass anthesis period was during the summer and autumn months (October–May), while highest frequencies occurred during December–February (Table 1, Fig. 2). Start dates of the Poaceae season varied between October 4 (1995–1996) and 17 December (1994–1995). The intensity and timing of peak concentrations also varied each year; the earliest peak date was recorded on 5 December (1996–1997) and the latest on 1 April (1994–1995), whereas the peak counts fluctuated between 63 and 164 grains m⁻³. The end dates varied from 6 March (1995–1996) to 17 May (1994–1995, 1997–1998). The mean duration of the grass season was 157 days, and it ranged between 103 days in 1995–1996 to 178 days in 1998–1999 (Table 1). Counts exceeded 30 grains m⁻³ on 244 days, and were within the ranges 11–30 grains m⁻³ on 290 days and 1–10 grains m⁻³ on 718 days (Table 1).

Table 1 Seasonal distribution of pollen from Poaceae in Brisbane, June to May, 1994–1999. The seasonal dates where the accumulated sum since the beginning of the year reaches 5% and 95%, and the peak pollen count and date, seasonal duration and daily count categories are shown in each case

Parameter	1994–1995	1995–1996	1996–1997	1997–1998	1998–1999
5% date	17/12	25/11	26/10	22/11	4/10
Peak day	1/4	25/12	5/12	8/3	18/2
Peak count (grains m ⁻³)	127.4	164.1	157.4	70.7	63.1
95% date	17/5	6/3	18/4	17/5	30/3
Season duration (days)	152	103	175	177	178
count >30 (days)	50	73	52	28	41
count 11–30 (days)	23	37	77	82	71
count 1–10 (days)	196	118	133	123	148

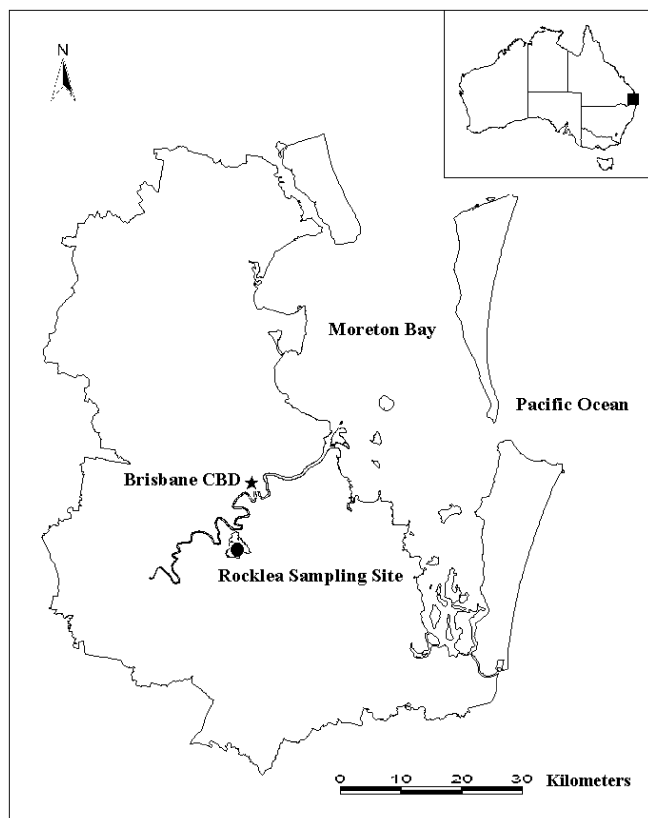


Fig. 1 Map of Brisbane, southeastern Queensland. ★ Central Business District (CBD), Brisbane; • locality of the Rocklea sampling site

The highest frequencies of Poaceae pollen were recorded during the period of highest average monthly maximum ($>27^{\circ}\text{C}$) and minimum ($>19^{\circ}\text{C}$) temperatures and highest rainfall ($>5\text{ mm}$) (Fig. 2). Total rainfall and the average daily maximum and minimum temperature measurements from 1 June to the start of the season as well as during the season were calculated for each individual study year (Table 2). Yearly total pollen frequencies varied; higher frequencies were recorded when the average seasonal rainfall was low (1994–1995, 1995–1996 and 1996–1997), whereas lower frequencies were recorded in seasons of higher average rainfall

(1997–1998 and 1998–1999; Table 2). Cumulative rainfall prior to the season did not seem to influence the intensity and length of the season, but later seasons corresponded to lower levels of pre-seasonal precipitation (Table 2). The prior and seasonal maximum and minimum temperature parameters did not display significant patterns that linked them to the length and intensity of the grass season. In the case of the starting date there was a sustained pattern of contrast between the mean maximum temperature prior to the start of the season.

During the grass pollen season, pollen counts greater than 30 grains m^{-3} occurred when daily maximum temperatures were $28.1 \pm 2.0^{\circ}\text{C}$, whereas lower counts ($1\text{--}30\text{ grains m}^{-3}$) occurred when maximum temperatures were $26.2 \pm 3.3^{\circ}\text{C}$ (Table 3). Analysis of variance conducted on the individual pollen-count categories showed that maximum-temperature data sets were significantly different ($P = 0.001$). There was also a significant difference ($P = 0.004$) between the minimum temperature pollen count categories (Table 3), however there was no apparent variation in precipitation measurements between the categories ($P = 0.745$).

The daily and seasonal Poaceae pollen count data for each individual sampling year (June–May) demonstrated both inter- and intra-seasonal variations (Fig. 3). Grass pollen incidence fluctuated widely on a daily basis (Fig. 3). Daily concentrations often exceeded 50 grains m^{-3} , and, in some years (1995–1996 and 1996–1997), daily counts exceeded 100 grains m^{-3} . Each season had multiple peaks, which may coincide with the different flowering periods and phenological patterns of various Poaceae species. Daily maximum temperatures greater than 30°C , recorded over each individual sampling period, coincided with the lowest daily Poaceae pollen counts ($<10\text{ grains m}^{-3}$), whereas daily ($>1\text{ mm}$) and prolonged ($>5\text{ days}$) periods of rainfall also appeared to decrease the daily pollen counts ($<10\text{ grains m}^{-3}$, Fig. 3).

Non-parametric correlation analysis indicated strong positive associations ($P < 0.0001$) between daily Poaceae seasonal pollen counts and temperature parameters, during the sampling years 1996–1997 and 1998–1999 for maximum temperature and during 1995–1996 and 1996–1997 for minimum temperature (Table 4). However, positive associations between rainfall measurements and

Table 2 Pre-seasonal and seasonal meteorological data with start date, length and the total number of pollen grains of the Poaceae season. Precipitation A rainfall between 1 June and starting date of season; B rainfall recorded during the season. *Mean T_{max} prior*; mean maximum temperature between 1 June and starting date of

the season; *Mean T_{max}* mean maximum temperature during the season; *Mean T_{min} prior* mean minimum temperature between 1 June and starting date of the season; *Mean T_{min}* Mean minimum temperature during the season

Year	Precipitation		Mean T_{max} prior	Mean T_{max}	Mean T_{min} prior	Mean T_{min}	Starting date from 1 June (days)	Length (weeks)	Intensity (grains m^{-3})
	A (mm)	B (mm)							
1994–1995	183.2	504.4	23.8	27.6	12.0	18.9	200	21.7	3476
1995–1996	343.8	598.1	23.2	28.6	12.2	20.2	178	14.7	6404
1996–1997	167.4	484.2	22.5	27.9	10.9	18.7	148	25.0	4670
1997–1998	336.4	641.2	22.9	28.6	12.1	19.8	175	25.2	2854
1998–1999	269.7	964.1	22.0	27.6	12.1	18.9	126	25.4	3347

Fig. 2 Average monthly Poaceae pollen count ($\pm$ SD) based on 5 sampling years (June 1994–May 1999) of daily pollen counts (grains m^{-3})

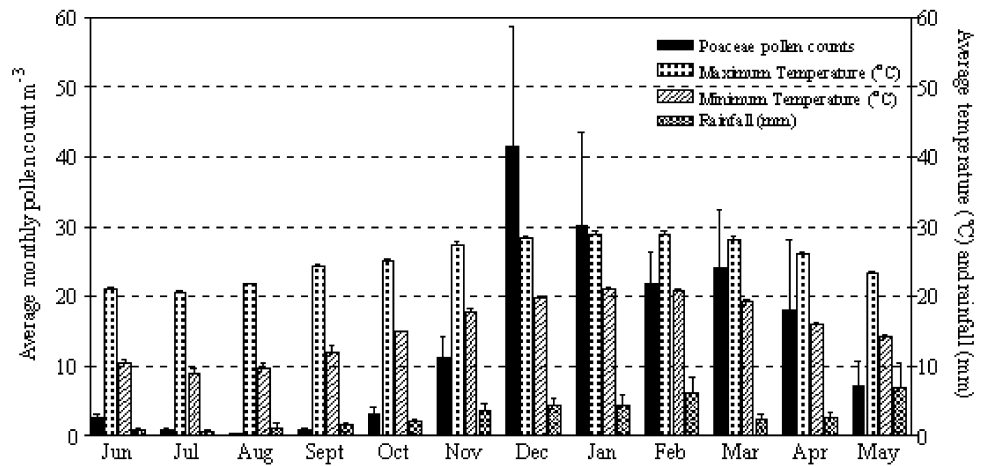


Table 3 Average daily meteorological parameters $\pm$ SD including maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation recorded during two pollen count categories each season

Pollen counts	Weather parameters		
	T_{max} ($^{\circ}\text{C}$)	T_{min} ($^{\circ}\text{C}$)	Precipitation (mm)
1–30 grains m^{-3}			
1994–1995	25.7 $\pm$ 3.8	15.3 $\pm$ 5.6	1.2 $\pm$ 4.3
1995–1996	25.9 $\pm$ 3.2	15.9 $\pm$ 4.2	2.2 $\pm$ 6.3
1996–1997	26.2 $\pm$ 2.9	16.3 $\pm$ 3.9	2.7 $\pm$ 7.2
1997–1998	27.2 $\pm$ 3.2	18.2 $\pm$ 4.0	4.1 $\pm$ 11.1
1998–1999	25.9 $\pm$ 2.7	16.7 $\pm$ 3.1	3.6 $\pm$ 9.4
Mean	26.2 $\pm$ 3.3	16.5 $\pm$ 4.5	2.8 $\pm$ 8.1
>30 grains m^{-3}			
1994–1995	27.3 $\pm$ 2.2	17.5 $\pm$ 2.7	1.6 $\pm$ 5.6
1995–1996	28.4 $\pm$ 1.9	20.1 $\pm$ 2.1	7.6 $\pm$ 20.4
1996–1997	27.8 $\pm$ 1.7	19.1 $\pm$ 2.1	1.7 $\pm$ 5.1
1997–1998	29.1 $\pm$ 2.6	18.9 $\pm$ 3.2	0.7 $\pm$ 2.0
1998–1999	28.4 $\pm$ 1.7	19.7 $\pm$ 2.3	4.5 $\pm$ 18.0
Mean	28.1 $\pm$ 2.0	19.2 $\pm$ 2.6	3.8 $\pm$ 14.0

Table 4 Spearman's correlation coefficients (r_s) between meteorological parameters and Poaceae yearly ($n = 365$) and total pollen counts ($n = 1826$)

Poaceae season	r_s		
	T_{max}	T_{min}	Precipitation
1994–1995	0.4186**	0.4030**	0.0957
1995–1996	0.6983**	0.7435**	0.1716*
1996–1997	0.7466**	0.7001**	0.1047*
1997–1998	0.7074**	0.6822**	0.1129*
1998–1999	0.8139**	0.6979**	0.0583
1994–1999	0.6825**	0.6467**	0.1120**

* 95% significance; ** 99% significance

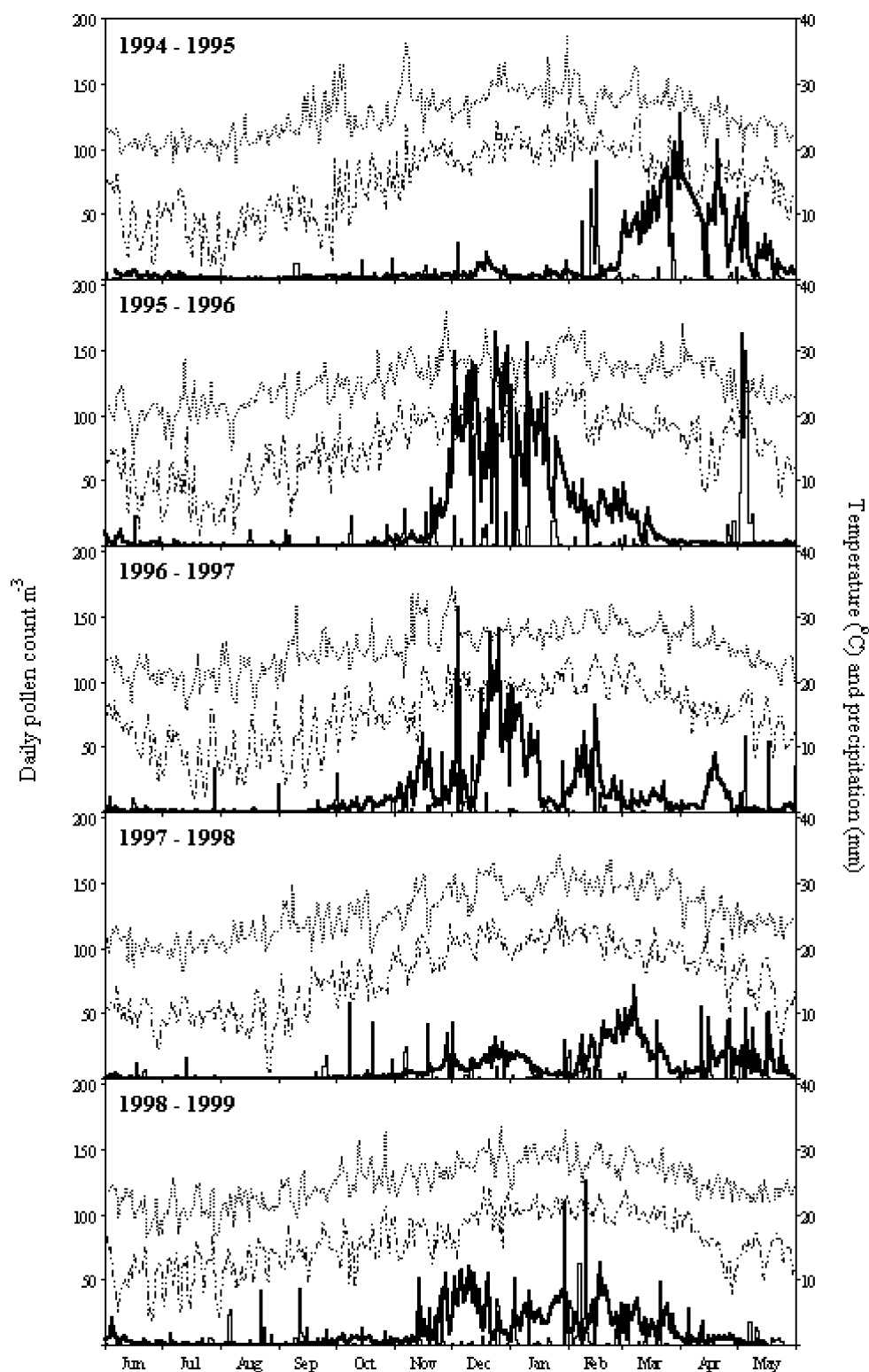
seasonal Poaceae pollen counts were not as consistent as those of temperature ($P < 0.05$, Table 4), particularly during the sampling years 1994–1995 and 1998–1999.

Discussion

Airborne Poaceae pollen is the most prevalent pollen type to occur in the atmosphere of Brisbane, with maximum

emissions restricted to the warmest and wettest periods of the year (October–May) (Green et al. 2002). The seasons are longer than at other temperate Australian locations. In Sydney, the main grass pollen season occurs during the months November–March (Bass and Morgan 1997), whereas further south, in Melbourne, 75% of flowering takes place during December and January (Ong et al. 1995). The Brisbane season is temporally comparable to those recorded in several other Southern Hemisphere locations, for example those for Pretoria, South Africa (Cadman 1990), and Santiago, Chile (Rojas Villegas and Roure Nolla 2001). By contrast in Europe, grass pollen seasons are much shorter particularly those recorded in London, England (65 days) (Emberlin et al. 1993), and in Bilbao, Spain (59 days) (Antepara et al. 1995). Such differences in the duration and annual abundance of Poaceae pollen types can be attributed to localized variations in climatic factors as well as differences in taxa represented in the different regions. Meteorological conditions, particularly temperature and light intensity, have been identified as critical components that are required for floral maturation and ear development (Emecz 1962), which determine the duration of the

Fig. 3 Seasonal distribution of (—) Poaceae pollen in the atmosphere of Brisbane, Australia during 5 individual years plotted with daily (...) maximum and (—) minimum temperatures (°C) and (—) total daily rainfall (mm)



Poaceae pollen season. However, studies conducted by Reddi et al. (Reddi 1988; Reddi et al. 1988) have demonstrated that anthesis periods can fluctuate by several months between genera, whereas, on a daily basis, the duration of pollen release may vary between

species by 2–13 h. In the present study, anthesis was not investigated; however, each season manifested multiple peaks. Numerous grass pollen varieties were observed in the daily counts but were unable to be identified to species level owing to the difficulties in taxonomically

differentiating Poaceae pollen, which are well documented throughout the literature and should be taken into account when evaluating these results.

Precipitation and wind, meanwhile, have deleterious effects on anthesis, which has been demonstrated by Emecz (Emecz 1962) in the case of *Festuca arundinaceae*, where the season was delayed by 69 days because of unfavourable weather conditions. Rainfall, has been established to inhibit anthesis particularly for *Lolium perenne* and *Monocymbium* spp., which in turn shortens the duration of pollen release (Reddi et al. 1988) in addition to washing pollen from the atmosphere (McDonald 1962). Alternatively other species, including *Dactylis* spp., *Phleum* spp., *Sehima nervosum* and *Alopecurus* spp., are adapted to releasing pollen even during periods of rainfall (Reddi et al. 1988). Decreases in daily pollen counts were observed after prolonged periods of rainfall, which is consistent with the aforementioned studies.

Weather conditions, including maximum and minimum temperature, were demonstrated in the statistical analyses to be significantly associated with daily Poaceae pollen counts during each sampling year. Analogous associations with temperature variables and daily Poaceae pollen counts have been established in the Northern Hemisphere (Davies and Smith 1974; Dvorin et al. 2001; Jato et al. 2002). Precipitation, however, had less consistent and weak correlations with daily Poaceae pollen counts across all of the sampling years. Previous studies conducted in Santiago de Compostela, Spain (Jato et al. 2002), and Montreal, Canada (Valencia-Barrera et al. 2001), have identified similar associations with precipitation; however, other meteorological parameters including wind speed, humidity, and hours of sunshine are also known to influence daily and seasonal Poaceae pollen counts (Emecz 1962; Davies and Smith 1974; Smart et al. 1979; Dvorin et al. 2001).

An anecdotal relationship between the average pre-seasonal maximum temperature and the start of pollen emission has been described. In Brisbane, later starting seasons occur when pre-seasonal maximum temperatures are higher, which contrasts with those demonstrated for temperate regions of Europe, where later starting seasons correlate with cooler temperatures (Emberlin et al. 1993; Antepara et al. 1995; Frei 1998; Gonzalez Minero et al. 1998). Studies of flowering phenology of some European grasses indicate that once light and temperature values are exceeded the required duration to initiate anthesis is reduced (Emecz 1962). Many of the grass species present in the environs of Brisbane are of subtropical origin and require specific temperature regimes for optimum growth. Under high ambient temperatures ($>35^{\circ}\text{C}$), net photosynthesis and the activation of Rubisco are inhibited in cotton and wheat leaf tissue (Feller et al. 1998; Crafts-Brandner and Law 2000; Law and Crafts-Brandner 2001) and reductions in the photoperiod have been shown to inhibit the winter growth of subtropical grasses (Sinclair et al. 2001). Start dates and yearly pollen frequencies are also influenced to a lesser extent by pre-seasonal precip-

itation, airflow patterns and grass development (Emberlin et al. 1993; Ong et al. 1995). Rainfall in the months preceding the pollen season initiates physiological growth, which results in a greater proportion of grass pollen produced for that season (Al-Doorey et al. 1982; Subiza et al. 1992; Ong et al. 1995). Similarly, rainfall coupled with warm temperatures stimulates the early germination of seeds and growth of annual species (Halwagy 1988; Gonzalez Minero et al. 1998). Although other studies have implicated pre-seasonal precipitation in the induction of earlier seasons, these relationships could not be confirmed by statistical analysis in this study and require further investigation.

Grass pollen is continuously represented in the atmosphere of Brisbane albeit in low frequencies during the period, May–October (Moss 1965; Green et al. 2002) and thus provides a continual exposure risk for allergic subjects. Pollen of the Poaceae has significant implications for asthma, allergy and mortality (Wright and Derrick 1975; Bass et al. 2000; Brunekreef et al. 2000; Marks et al. 2001) and Grote et al., have recently demonstrated (Grote et al. 2001) the release of subcellular allergen-containing particles from the cytoplasm of the grass pollen grain after periods of rainfall and hydration, which might explain why asthma attacks are observed after periods of rainfall during the grass pollen season. However, daily concentrations exceeding 30 grains m^{-3} are high enough to elicit respiratory symptoms (Davies and Smith 1974; Rantio-Lehtimäki et al. 1991). Counts within this range occur over a brief period (28–73 days) each season on days when the maximum temperature is high ($28.1^{\circ}\text{C} \pm 2.0$). Only trace amounts of pollen, however, are required for an allergic response and, if this were the case, exposure to lower concentrations of pollen would be prolonged in Brisbane (Smart et al. 1979).

In conclusion, this is the first study that gives an insight into the associations between meteorological parameters and grass pollen in Brisbane and provides a useful preliminary model for the prediction of Poaceae pollen seasons that could be applied in allergy prevention by allergists. Temperature, in particular maximum temperature, is an important factor that influences daily Poaceae pollen concentrations and start dates. Precipitation is considered to be less influential statistically, but it is still believed to be an important parameter in pre-seasonal physiological growth and pollen production. In a region such as Brisbane, where the prevalence of asthma and allergy is high, there is a need to assess further the anthesis periods of different grass species, to improve our understanding of the responses of individual taxa to meteorological parameters, to investigate associations between daily variations in Poaceae pollen counts and hospital admissions and to determine the extent to which grass pollen triggers particular respiratory diseases in Brisbane.

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