



Original Research Paper

Airborne *Pinus* pollen in the atmosphere of Brisbane, Australia and relationships with meteorological parameters

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Abstract

Relationships between weather parameters and airborne pollen loads of *Pinus* in Brisbane, Australia have been investigated over the five-year period, June 1994–May 1999. *Pinus* pollen accounts for 4.5% of the annual airborne pollen load in Brisbane where the *Pinus* season is confined to the winter months, July–early September. During the sampling period loads of 11–>100 grains m⁻³ were recorded on 24 days and 1–10 grains m⁻³ on 204 days. The onset and peak dates were consistent across each season, whereas the end dates varied. The onset of the *Pinus* pollen season coincided with the coolest average monthly temperatures (< 22 °C), lowest rainfall (< 7mm), and four weeks after daily minimum temperatures fell to 5–9 °C in late autumn. Correlations obtained between daily airborne *Pinus* pollen counts and temperature/rainfall parameters show that densities of airborne *Pinus* pollen are negatively correlated with maximum temperature ($p < 0.0001$), minimum temperature ($p < 0.0001$) and rainfall ($p < 0.05$) during the main pollination period. The mean duration of each pollen season was 52 days; longer seasons were shown to be directly related to lower average seasonal maximum temperatures ($r^2 = 0.85$, $p = 0.025$). These results signify that maximum and minimum temperatures are the major parameters that influence the onset and duration of the *Pinus* pollen season in the environs of Brisbane. Respiratory allergy is an important health issue in Brisbane, Australia, but it remains unknown whether or not airborne *Pinus* pollen is a contributing factor.

1. Introduction

Members of the Pinaceae (Coniferales) have anemophilous pollen that are characterized by air filled sacs (sacci), that assist in atmospheric floatation and dispersal (Niklas, 1985). The genus *Pinus* consists of more than 110 species, most of which occur throughout the Northern Hemisphere where they may form large forest stands. Although not native to Australia, *Pinus* has been introduced and mainly occurs as forest timber plantations in regional and urban environments. Species occurring in the Bris-

bane region include *Pinus radiata*, *P. patula*, *P. caribaea*, *P. elliottii* and *P. taeda* (Moss, 1965). *Pinus* pollen is an abundant pollen type in the aerospora of Brisbane during the winter months (Green et al., Grana 41(3), in press), but relationships between pollen loads, meteorological parameters and its role as a sensitising aeroallergen in the region remains unclear.

Allergy to *Pinus* has been documented in a number of studies (Antepara et al., 1994; Armentia et al., 1990; Cornford et al., 1990; Dvorin et al., 2001; Freeman, 1993; Harris and German, 1985; Marcos

et al., 2001; Senna et al., 2000), with an average of 1–13% of subjects displaying sensitisation. Characterization of *Pinus radiata* allergens by Fountain and Cornford (1991) and Cornford et al. (1990), detected specific IgE against five allergenic proteins. Partial cross reactivity of *Pinus* pollen allergens to *Lolium perenne* (Cornford et al., 1990; Fountain and Cornford, 1991), pine nuts (Jansen et al., 1996) and other conifer species (Pettyjohn and Levetin, 1997; Senna et al., 2000) have been established through RAST inhibition and immunoblotting experiments. The importance of *Pinus* pollen allergy in environments dominated by *Pinus* stands was established by Marcos (2001), who found that six out of 10 patients were mono-sensitised to *Pinus* pollen allergens. By contrast very few clinical and aerobiological studies have been conducted on Pinaceae pollen. Despite *Pinus*'s unclear clinical significance and its ability to produce large quantities of hydrophilic pollen, it is important to understand the daily and seasonal effects of meteorological parameters on the spatial distribution and airborne prevalence of *Pinus* pollen.

Pinus pollen is prevalent in the atmosphere of most environments, although at varying concentrations and durations. Pollen of the Pinaceae was determined to be the most abundant airborne pollen taxa during spring in Spain (Belmonte et al., 1998; Jato et al., 2000; Mendez et al., 2000), Portugal (Paiva et al., 1988; Silva, 1989), Poland (Kasprzyk, 1999), Finland (Kapyla and Koivikko, 1975), India (Singh, 1983) and China (Li and Yao, 1990). Less frequent occurrences of *Pinus* pollen have been documented in other countries including Australia (Bass and Morgan, 1997; Moss, 1965; Green et al., Grana 41(3), in press), New Zealand (Fountain and Cornford, 1991), Japan (Hakamada et al., 1979; Igarashi, 1987), Norway (Johansen and Hafsten, 1988), Switzerland (Wuthrich et al., 1983) and the United States of America (Dvorin et al., 2001). In Australia and New Zealand the *Pinus* pollen season occurs during the cooler months when airborne pollen of native species are low (Bass and Morgan, 1997; Moss, 1965; Green et al., Grana 41(3), in press).

The duration and intensity of the *Pinus* pollen season during and following anthesis often varies according to climatic parameters including maximum temperature, minimum temperature, rainfall and humidity (Ariano et al., 1994; Dvorin et al., 2001; Jato et al., 2000; Kapyla and Koivikko, 1975; Khanduri and Sharma, 2000; Mendez et al., 2000). The effect of meteorological parameters on *Pinus* pollen incid-

ence and duration is not well established in southern hemispheric regions. The aim of this paper is to extend the partial work already carried out in Brisbane (Moss, 1965; Rutherford et al., 1997; Green et al., Grana 41(3), in press) and to analyse the pollen season of *Pinus* spp., and in particular the role of meteorological parameters on the seasonal and daily prevalence of airborne *Pinus* pollen in the atmosphere of Brisbane, Australia.

2. Materials and methods

Airborne *Pinus* pollen was collected over a five-year period (June 1994–May 1999) in the city of Brisbane (27°29' S 153°8' E), south-eastern Queensland, Australia (Figure 1). The pollen was collected by a Burkard volumetric sampling trap (Burkard Manufacturing Co. Ltd., Rickmansworth, Hertfordshire, UK). The trapping site was located 2 meters above ground at an elevation of 12.5 meters above sea level, in the suburb of Rocklea, 7 km south east of the central business district on a Queensland Department of Primary Industries research farm. Brisbane experiences a subtropical climate (average yearly temperature 25.9 °C) with a summer rainfall regime (average yearly rainfall 1114.6 mm) (Bureau of Meteorology, 1983). The major vegetation formation of the trapping site is that of open *Eucalypt* woodland with an understorey of Poaceae species (including *Capillipedium* spp., *Chloris gayana*, *Cynodon dactylon*, *Eleusine tristachya*, *Lolium temulentum*, *Paspalum* spp., *Sorghum* spp. and *Cirsium vulgare*), as well as *Cyperus* spp. *Plantago* spp. and *Urtica* spp. Surrounding creeks and rivers are composed of riparian communities including *Casuarina cunninghamii*, *Melaleuca linariifolia*, *Eucalyptus tereticornis*, *Corymbia citriodora*, *Eucalyptus crebra*, *Acacia melanoxylon*, *Celtis sinence* and *Aegiceras corniculatum*. Urban and industrial areas are vegetated by both endemic and exotic species among the families Cupressaceae, Casuarinaceae, Sapindaceae, Myrtaceae, Proteaceae, Pinaceae, Araucariaceae and Mimosaceae. To the north of the city there are large plantations of *Pinus* spp.

Pollen trapped at this site was deposited onto tapes coated with a thin film of Dow Corning pressure-sensitive silicone adhesive (280A). The tapes were cut into seven daily lengths and mounted in Carberla's solution on glass microscope slides. *Pinus* pollen was counted at magnifications of x250 by scanning the entire surface area of the daily tapes using north south

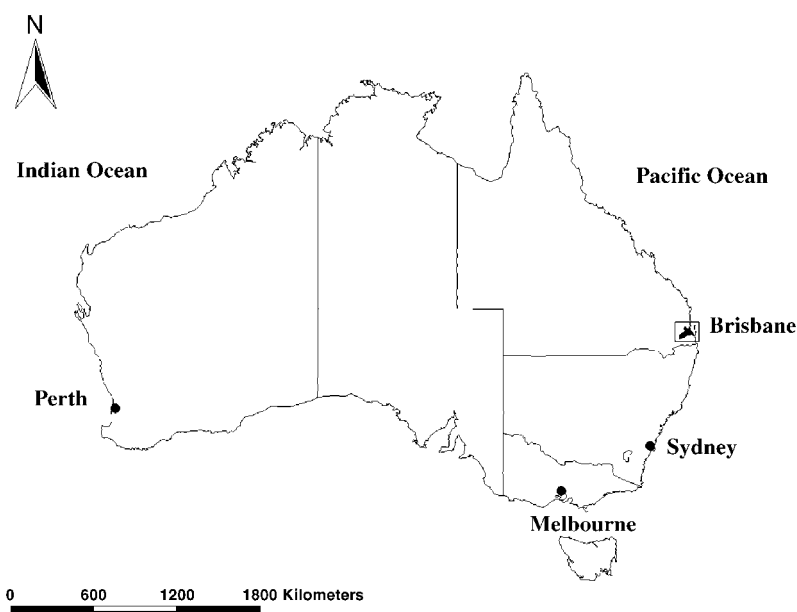


Figure 1. Map of Australia depicting the geographical position of Brisbane ($27^{\circ}29' \text{ S } 153^{\circ}8' \text{ E}$), south-eastern Queensland and the (□) sampling region.

traverses (Käpylä and Penttinen, 1981). The *Pinus* pollen counts were then converted to correspond to grains m^{-3} air as a daily mean value.

Maximum temperature, minimum temperature and rainfall data, measured at Brisbane airport, was obtained for the period (June 1994–May 1999) from the Department of Environment and the Australian Bureau of Meteorology (Queensland). The meteorological data was used for graphical and statistical analysis with *Pinus* pollen count data from the Rocklea site.

Pinus pollen count data was evaluated for each sampling year (June–May) over a five-year period (June 1994–May 1999). The characteristics of each pollen season were documented graphically and evaluated statistically. To calculate the period of the *Pinus* pollen season, the date when 5% of the total *Pinus* count for that year had accumulated corresponded to the beginning of the season, whereas 95% of the total accumulated *Pinus* pollen count corresponded to the end of the season. Daily counts were classified into three categories (1–10, 11–100 and > 100 grains m^{-3}), a standard which is used by the Palynological Laboratory, Swedish Museum of Natural History, Stockholm. Associations and relationships between meteorological parameters and *Pinus* pollen counts were calculated using Spearman's (non-parametric) correlation analysis and

linear regression for the entire study period and by season. All analyses were performed using STATA (Stata, 1999).

3. Results

3.1 *Pinus* pollen counts

Pinus pollen is present in the atmosphere of Brisbane between July and September, with peak average counts occurring in the month of July (Table 1, Figure 2) and total yearly counts of 136–404 grains m^{-3} (Green et al., Grana 41(3), in press; Figure 3). The duration of each season varied from 45 days in 1995–1996 to 61 days in 1994–1995, with a mean seasonal duration of 52 days. Start dates of the *Pinus* season over the five-year period occurred during the interval 13th–20th, July (Table 1); peak count date of each year occurred between 19th and 31st of July with the highest pollen count of 158 grains m^{-3} on the 27th July, 1998. End dates of the *Pinus* season were most variable ranging from 31st August (1995–1996) to 10th September (1996–1997). Daily counts exceeded 100 grains m^{-3} on only one day during the entire sampling period (June 1994–May 1999). Counts were within the range of 11–100 grains m^{-3} on 23 days and 1–10 grains m^{-3} on 204 days (Table 1).

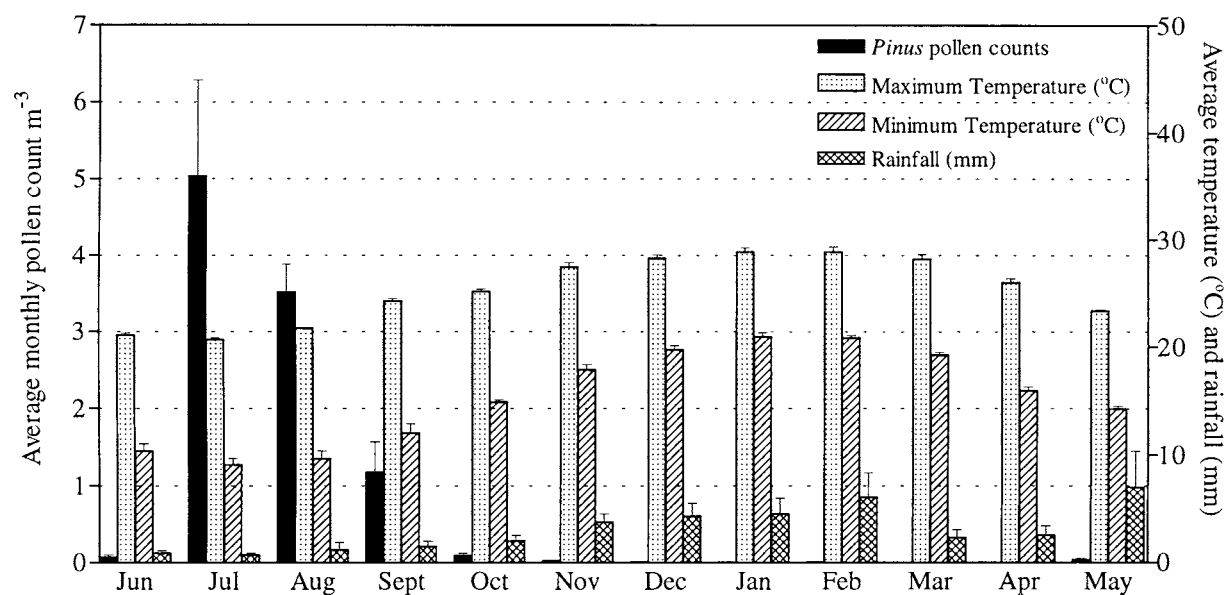


Figure 2. Average monthly *Pinus* pollen count based on five sampling years (June 1994–May 1999) of daily pollen counts (grains m^{-3}) plotted with maximum temperature ($^{\circ}\text{C}$), minimum temperature ($^{\circ}\text{C}$) and rainfall (mm).

Table 1. Seasonal distribution of *Pinus* pollen 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 spore count (grains m^{-3}) and date, seasonal duration and daily count categories is shown in each case

	1994– 1995	1995– 1996	1996– 1997	1997– 1998	1998– 1999
<i>Pinus</i>					
5%	13/7	18/7	14/7	18/7	20/7
Peak Day	30/7	31/7	19/7	27/7	27/7
Peak Count	81.9	55.2	11.5	50.8	158.9
95%	11/9	31/8	10/9	4/9	4/9
Season Duration	61	45	59	49	47
Days count > 100	0	0	0	0	1
Days count 11–100	8	6	1	7	1
Days count 1–10	57	36	40	29	42

3.2 Meteorology and *Pinus* pollen counts

The July–August *Pinus* pollen season in Brisbane (Figures 2 and 4) coincides with lowest average monthly temperatures ($< 22^{\circ}\text{C}$ maximum temperature and $< 10^{\circ}\text{C}$ minimum temperature) and rainfall ($< 1\text{ mm}$) recorded for the region. *Pinus* pollen counts were highest in 1994–1995 and 1998–1999 and lowest in 1996–1997, suggesting that highest emissions of *Pinus* pollen may occur every three years (Figure 3).

Significant negative associations ($p < 0.0001$) are evident between maximum temperature, minimum temperature and total *Pinus* pollen counts for the entire sampling period 1994–1999 (Table 2).

The individual yearly (June–May) *Pinus* pollen counts plotted against maximum temperature, minimum temperature and rainfall illustrate fluctuations from one year to the next (Figure 4). Four weeks prior to the *Pinus* season of each year minimum temperatures of $5\text{--}9^{\circ}\text{C}$ were recorded (Figure 4). Inter-seasonal variations in the amount of *Pinus* pollen may be attributed to daily rainfall, different *Pinus* species releasing their pollen at varying intervals, long distance pollen transport or post seasonal pollen refloating.

Non-parametric correlation analysis indicates strong negative associations ($p < 0.0001$) between daily *Pinus* seasonal counts and maximum and minimum temperature (Table 2), for each of the five years. Associations with rainfall were also negatively correlated with seasonal *Pinus* pollen counts, but this correlation is not as consistent compared to those of temperature (Table 2).

The duration of the *Pinus* pollen season plotted against maximum temperature (Figure 5) shows a trend towards a longer season (> 50 days) when seasonal maximum temperatures are $< 21.6^{\circ}\text{C}$, and shorter seasons (< 50 days) when seasonal maximum

temperatures are $> 21.6^{\circ}\text{C}$. Statistical analysis of this relationship supports that it is significant ($r^2 = 0.85$, $p = 0.0249$). Moreover, r^2 values for minimum temperature ($r^2 = 0.9$) and rainfall ($r^2 = 0.8$) were obtained, but these are not statistically significant ($p = 0.1$).

4. Discussion

Pinus pollen is the fourth most abundant pollen type to occur in the atmosphere of Brisbane contributing 4.5% to the annual pollen spectrum with maximum emissions restricted to the winter months of July and August, the coldest and driest months of the year (Green et al., Grana 41(3), in press). The season commences during the second week of July and extends to the first week of September, with a mean seasonal duration of 52 days. There is a strong relationship between the length of the season and maximum temperatures (Figure 5; $r^2 = 0.85$, $p = 0.0249$), with longer seasons occurring when maximum temperatures are less than 21.6°C . Similar relationships have been statistically demonstrated for *Pinus* pollen captured in Spain (Mendez et al., 2000; Jato, 2000) and Italy (Ariano et al., 1994), where statistically significant correlations were established between *Pinus* pollen counts, rainfall and maximum temperature during the main pollination period. The European studies provided positive correlations as the *Pinus* pollen season occurs during spring and summer, the warmest months, whereas in Brisbane, the season occurs during the coolest winter months and the correlations are negative. Nevertheless, these relationships support the hypothesis (Khanduri and Sharma, 2000; Sharma et al., 1998) that temperatures near 20°C combined with low rainfall are optimum requirements during anthesis of *Pinus*. For each year the onset of the season occurred four weeks after minimum temperatures drop to $5\text{--}9^{\circ}\text{C}$ in June; this chilling combined with low rainfall is suggested as requirements to overcome dormancy and to promote male strobili maturation as has been demonstrated for flowers of several dicotyledonous tree species including almond, apple, grape, peach, quince and oak (Faust, 1989; Garcia-Mozo et al., 2000; Richardson et al., 1974; Westwood, 1978).

The Brisbane *Pinus* pollen seasons follow a similar course with respect to the timing of onset and daily frequencies to those recorded for Sydney (Bass and Morgan, 1997) where the onset of the *Pinus* pollen season occurs in mid July as reported here. However,

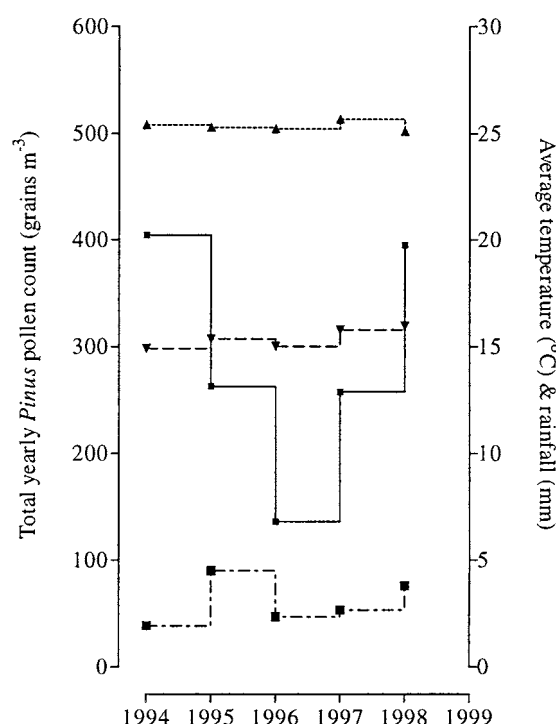


Figure 3. Comparison between (—■—) total *Pinus* pollen counts (grains m^{-3}) recorded for each individual sampling year (June 1994–May 1999) and the (···▲···) average yearly maximum temperature ($^{\circ}\text{C}$), (---▼---) minimum temperature ($^{\circ}\text{C}$), and (—■—) average rainfall (mm).

Table 2. Associations between meteorological variables and *Pinus* yearly and total pollen counts, calculated by Spearman's (non-parametric) correlational analysis

<i>Pinus</i>	Max. temp. $^{\circ}\text{C}$	Min. temp. $^{\circ}\text{C}$	Rainfall (mm)
1994–1995	–0.4489**	–0.6099**	–0.1532*
1995–1996	–0.4488**	–0.5551**	–0.1738*
1996–1997	–0.4507**	–0.5806**	–0.1979**
1997–1998	–0.4920**	–0.6088**	–0.1850**
1998–1999	–0.4655**	–0.4714**	–0.0679
1994–1999	–0.4559**	–0.5641**	–0.1591**

* $p < 0.05$.

** $p < 0.0001$ (p denotes level of significance).

in Sydney the mean seasonal duration is a month longer than in Brisbane (Bass and Morgan, 1997). Pollen monitoring of *Pinus* over 3 years at Palmerston North, New Zealand demonstrated that there was considerable variation in the onset and duration of the *Pinus* pollen season (Fountain and Cornford, 1991), but it is unknown whether or not these variations related to fluctuations in temperature/rainfall

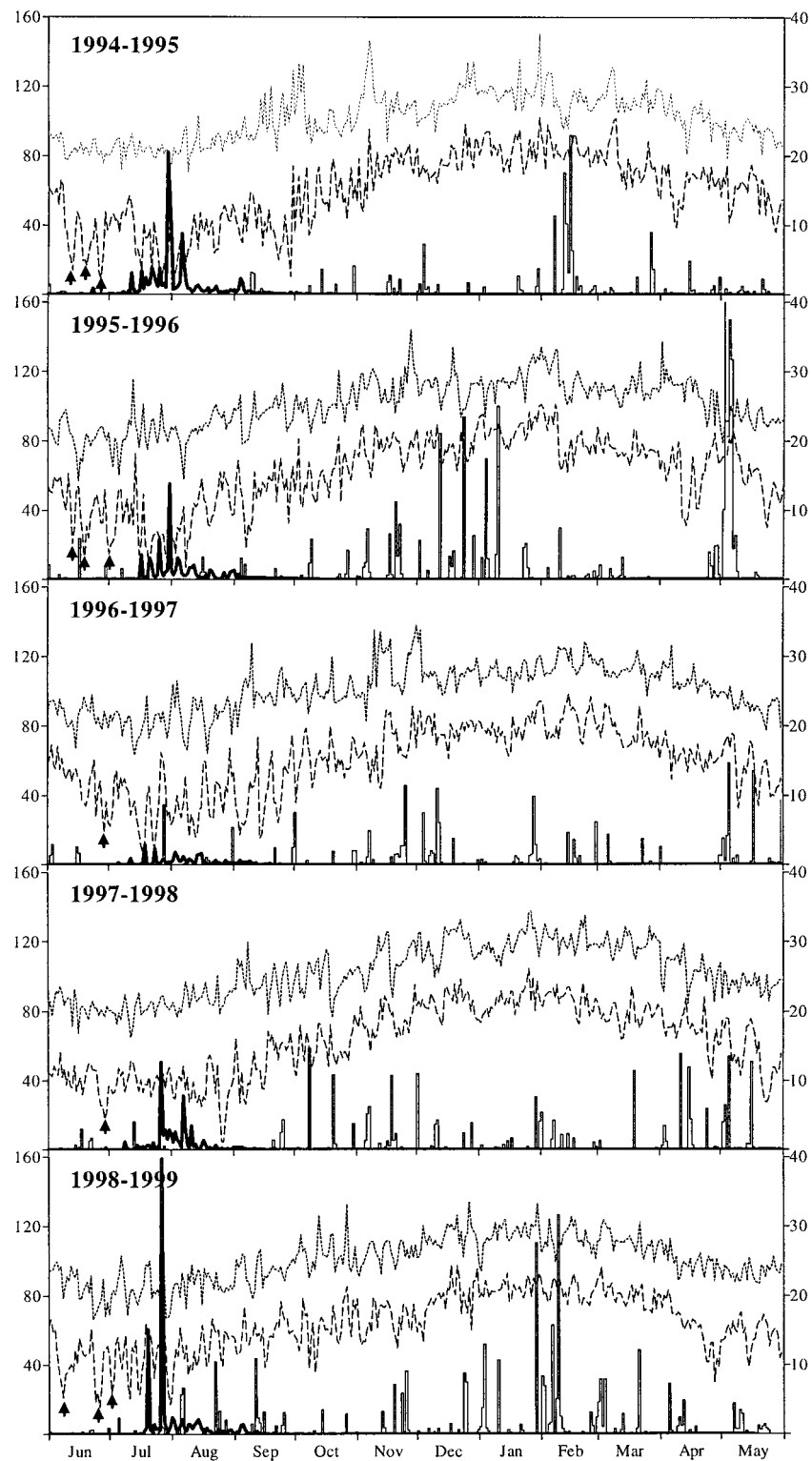


Figure 4. Seasonal distribution of (—) *Pinus* pollen in the atmosphere of Brisbane, Australia during five individual years plotted with daily (·····) maximum and (---) minimum temperature (°C) and (—) total daily rainfall (mm). Arrows (▲) indicate a fall of the daily minimum temperature below 9 °C during the month of June.

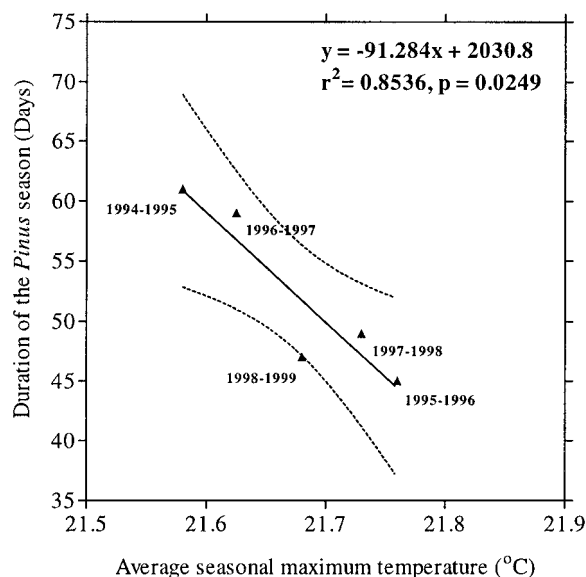


Figure 5. Duration of the *Pinus* season, established from the beginning of the season (accumulated sum 5%), to the end of the season (accumulated sum 95%) against the average seasonal maximum temperature (°C) for the duration of each individual season.

regimes during the trapping period. At Ourense, Spain (Mendez et al., 2000), and Rivera Ligure, Italy (Ariano et al., 1994), the *Pinus* pollen season is of similar duration to those of Sydney. In contrast, in higher latitudes in Finland the *Pinus* pollen season is brief (11 days), with the pollen derived solely from *P. sylvestris*. Moreover, there was a lag in the commencement of the *Pinus* pollen season along a 1000 kilometre north-south transect, with onset dates at more southerly locations up to 24 days earlier than at northern sites (Pessi and Pulkkinen, 1994).

Year to year fluctuations in the annual sums of the *Pinus* pollen captured in Brisbane indicate a cyclical trend of three years which corresponds to the three-year cycle established for loads of *Pinus* pollen in Stockholm, Sweden (Atkinson and Larsson, 1990).

Although rainfall did not prove to be statistically significant it was noted that when rainfall was recorded, minimal amounts of daily *Pinus* pollen were trapped suggesting washing out of pollen from the atmosphere (Hjelmroos, 1997; McDonald, 1962). Up to 81% of airborne pollen grains of *Pinus* are deposited within 700 metres of their source (Persson, 1954), under stable atmospheric conditions; of the pollen that are dispersed into the atmosphere, most will be removed by wind and precipitation. The deposited particles can be resuspended or refloated into the

atmosphere following turbulent climatic events, such as wind gusts. In central Hokkaido, Japan, refloated *Pinus* pollen comprised 0.5–22% of the total arboreal count (Igarashi, 1987). In this study refloating of *Pinus* pollen grains occurred beyond the *Pinus* season (data not shown) in very small concentration for short periods of time.

Long distance pollen transport can also influence the total yearly pollen count and seasonal duration. It is possible that under the right atmospheric conditions, *Pinus* pollen could be transported long distances from other sources. Long distance airborne pollen transport has been documented by Hjelmroos (1991, 1992, 1997) for *Betula* and Johansen and Hafsten (1988) for *Pinus* pollen grains in Europe. *Betula* pollen is often transported from central Europe to Sweden when the wind direction is favourable (Hjelmroos, 1992), while *Pinus* pollen is believed to travel from Finland to Ny-Alesund Svalbard, Norway (Johansen and Hafsten, 1988). Pollen of these species can travel thousands of kilometres from their point of origin, if they enter the upper atmospheric jet streams, and contribute to the aerobiological load of another geographical location.

Based on the five-year pollen monitoring program personal exposure in Brisbane to high volumes of *Pinus* pollen (11–100 grains m⁻³) would only occur for short time-periods each winter. This may explain why sensitivity to *Pinus* pollen in Brisbane is rare or remains undetected. Nevertheless, exposure to *Pinus* pollen may be of clinical importance due to the cross-reactive proteins it shares with *Lolium perenne* and other conifer species (Cornford et al., 1990; Fountain and Cornford, 1991; Pettyjohn and Levetin, 1997; Schwietz et al., 2000; Senna et al., 2000), and requires further investigation in Brisbane.

5. Conclusions

Results of this study demonstrate that over the period 1994–1999, the onset of the *Pinus* pollen season in Brisbane regularly occurred in mid-July each year, four weeks after minimum temperatures dropped to 5–9 °C. Moreover, a significant relationship has been identified between length of the season and maximum temperature, with the season of greater duration occurring when maximum temperatures were less than 21 °C than when temperatures were greater than 21 °C. Annual counts fluctuated markedly and demonstrate a tendency towards a three-year cycle. Variations in daily pollen loads may be attributable to meteor-

ological parameters, species diversity, long distance pollen transport and pollen refloating. A larger data set combined with a parallel phenological study may provide more insight into the effect of meteorological parameters on anthesis and the daily and seasonal pollen prevalence. Pollinosis is an important health issue in Brisbane, yet the clinical significance of exposure to *Pinus* pollen remains unclear and requires further investigation.

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