

Pollen in the atmosphere of Sydney, Australia, and relationships with meteorological parameters

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Pollen is significant from a human health perspective because it has been known to trigger allergic respiratory disease such as asthma and hay fever. The presence of pollen in the atmosphere has been related to meteorological parameters in past studies, but this has not been done previously in Sydney, Australia. This paper reports the results of a study on Poaceae, Plantaginaceae, Casuarinaceae, and total pollen in Sydney. Pollen concentration data for the period 19 August 1992 to 31 December 1995 was examined with meteorological data for the same period. The daily pollen concentration was compared to the meteorological data for the same day and for up to three days previously. The analysis methods were Spearman's rank correlation and multiple regression. Poaceae, Plantaginaceae, and total pollen appear to be positively correlated with temperature, dew point temperature, and wind speed, and negatively correlated with air pressure. Casuarinaceae pollen is also related to these meteorological parameters, but the sign of the correlations is the opposite. There is potential for the results of this study to be used by public health authorities in the prediction of pollen concentrations in Sydney.

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This study demonstrates a relationship between meteorological parameters and the concentration of pollen in the atmosphere of Sydney, Australia. Sydney is the largest city in Australia, both in population and physical size. It is located on the east coast at approximately 151° east and 34° south (Fig. 1). To the west of the Sydney region are the Blue Mountains, a part of the Great Dividing Range.

The population density is highest around the Sydney Harbour and along the Parramatta River and Georges River valleys and extends west to include the cities of Bankstown, Liverpool, Parramatta, and Blacktown. The north, south, and more distant western areas are less developed. The greater Sydney area contains many sparsely populated areas that are semi-rural, and other large areas that are set aside as parks and reserves.

Sydney has a temperate climate. Bankstown Airport is one of Sydney's major and most central climate stations. The station at this site has been in operation since it was opened in January 1968, and a summary of some data for this period is presented for comparison with that of the study period (Table I). The eastern Australian climate, especially rainfall, is influenced by the El Niño-Southern Oscillation which is a cause of drought and flood.

Because of its importance to human health, many studies have examined pollen and its relationships with meteorological parameters, including studies of individual species (e.g. Recio et al. 1996, Alba et al. 2000, Galán et al. 2001), individual genera (e.g. Laaidi 2001, Latałowa et al. 2002, Green et al. 2003), individual families (e.g. Diaz de la Guardia et al. 1998, Galán et al. 2000), and multiple genera and families, sometimes in conjunction with mould spores

(e.g. Rutherford et al. 1997, Jato et al. 2002, Porsbjerg et al. 2003, Ribeiro et al. 2003).

Previous studies carried out elsewhere have found relationships between pollen concentration and meteorological parameters including temperature, rainfall, relative humidity, wind speed and direction, and sunshine hours. The length of record and sampling interval examined in such studies have varied considerably, with studies ranging in length from days [e.g. Gassmann et al. (2002) used 41 days] to years [e.g. Galán et al. (2001) examined an 18 year record], and sampling intervals varying from hourly to daily, with daily being most common.

While many studies of pollen and meteorological parameters have been conducted outside Australia, and studies within Australia have been done in Perth and Brisbane, no studies have yet been published for Sydney. This study aims to examine the existing pollen data for Sydney, and explore relationships with meteorological parameters.

MATERIAL AND METHODS

The daily average concentration of pollen has been determined in the Sydney area at Campbelltown, on the campus of the University of Western Sydney, 19 August 1992 to 31 December 1995 (1230 days) (Bass & Morgan 1997). Air was continuously sampled using a Seven-day Recording Volumetric Spore Trap (Burkard Manufacturing Co. Ltd). Airborne particles were impacted on 'Melinex' tape coated with adhesive (50% saturated Dow Corning® high vacuum grease in solvent). The tape was sectioned into 24 hr segments using the supplied Perspex Cutting Block. These were stained and mounted on microscope slides to be examined under the microscope. The number of pollen grains in each of 27 families was

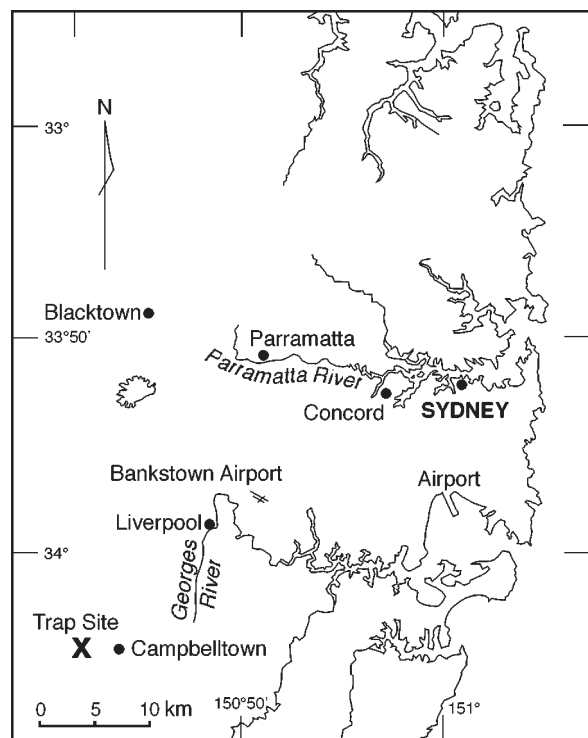


Fig. 1. The study area and meteorological and pollen sampling sites.

recorded. Of these, only three of the most prevalent and clinically significant, namely Poaceae, Plantaginaceae, and Casuarinaceae (representing the grass, weed and herb, and tree groups respectively), as well as total pollen, were examined here. Campbelltown is a satellite city on the south-western fringe of Sydney. It is located in an area of transition between the coastal plain and the foothills of the Blue Mountains (Fig. 1). The vegetation

around Campbelltown is dry grassland with small trees on the ridges.

Meteorological data was obtained from the Australian Bureau of Meteorology. The data used in this study are from Bankstown Airport (elevation 6.5 m, Site Number 66137), which is the closest station to the study area that has data that is both comprehensive and relatively complete for the entire study period. Bankstown Airport is located at a similar elevation and distance from the coast as Campbelltown, but about ten kilometres to the north. These data are from 3-hourly readings (midnight, 03:00, 06:00, etc.) except for rainfall, which is reported as a daily total from 09:00 on the previous day to 09:00 on the day of the report. They include temperature, relative humidity, dew point temperature, atmospheric pressure, wind speed and direction, and rainfall (Table I). Daily mean, minimum and maximum temperature, relative humidity, dew point temperature and atmospheric pressure were estimated from the data using all of the data available for the day. On days where it was recorded that a reading represented several days rainfall, each day's rainfall was estimated by dividing the accumulated rainfall by the number of days of accumulation.

Analysis

Analysis was performed using the Minitab Statistical Package (Minitab Inc. 1998 v.12). A frequency plot of the data was produced to determine the statistical distribution that might best describe them. As other authors have found (Munuera et al. 1999, Galán et al. 2000), the pollen data approximated an exponential distribution. The association between the daily average pollen concentrations and meteorological parameters was explored by Spearman's rank correlation, as has been done by a number of authors previously (e.g. Rutherford et al. 1997, Alba et al. 2000, Jato et al. 2000, Tormo et al. 2001, Green et al. 2003). Like Hobday & Stewart (1973), lags between meteorological parameters and pollen concentration of 1, 2 and 3 days were also examined.

Following the example of Ribeiro et al. (2003), stepwise regression was also performed using the pollen data as the dependent variable with all the meteorological data as independent variables, in order to determine which of these variables, if any, explain the variation in the concentration of pollen in the atmosphere. Like Galán et al. (2000), the daily averages in this study were logarithmically transformed to normalise the data. In order to eliminate zeros, 0.9 was added to each datum, as suggested by Strachan et al. (1990). Meteorological parameters are not normally distributed so they were also logarithmically transformed. Some data were no better when transformed and were used raw. These parameters were further scrutinised to determine if any could be removed without significantly reducing accuracy. This would simplify the model.

RESULTS

The data covers 1230 days, of which pollen was detected on all but two days, with the three families occurring from 43% to 68% of days (Table II). The mean, daily average concentration of total pollen was 163 grains m^{-3} , and for the individual families ranged from 10 grains m^{-3} for Plantaginaceae and Casuarinaceae to 26 grains m^{-3} for Poaceae (Table II). The minimum was zero grains m^{-3} for all groups. The maximum was 5178 grains m^{-3} for total pollen, and for the individual families ranged from just over 200 grains m^{-3} and 250 grains m^{-3} for Casuarinaceae and Plantaginaceae respectively, to just over 800 grains m^{-3} for Poaceae (Table II). Clear seasonality was exhibited, with

Table I. A summary of climate data at Bankstown Airport for the study period and long-term (28–33 years).

^aT – temperature; T_{min} – minimum temperature; T_{max} – maximum temperature; p_r – rainfall; RH_{3pm} – relative humidity at 3 p.m.; T_d – dew point temperature; u – wind speed; P – air pressure.

Parameter ^a	1992–1995		Long-term Mean
	Mean	Standard Deviation	
T (°C)	16.5	3.5	17.5
Average annual mean T_{min} (°C)	12.8	5.1	12.0
Average annual mean T_{max} (°C)	21.7	5.1	23.0
Average daily p_r (mm)	2.0	6.0	2.5
Average annual mean RH_{3pm} (%)	52.1	19.3	51.4
Average annual mean T_d (°C)	10.7	5.3	10.6 (3 p.m.)
u ($m s^{-1}$)	3.03	1.47	Not available
Average annual mean P (hPa)	1017.8	0.9	1015.7 (3 p.m.)

Table II. Numerical description of the pollen concentration data over the study period.

^aSp – spring; Su – summer; Au – autumn; Wi – winter.

	Poaceae	Plantaginaceae	Casuarinaceae	Total
Number of days with pollen	838	527	796	1228
Percentage of days with pollen	68	43	65	100
Mean conc. (grains m ⁻³)	26	10	10	163
Minimum conc. (grains m ⁻³)	0	0	0	0
Maximum conc. (grains m ⁻³)	825	265	218	5178
Total grains	32,336	12,175	11,888	200,898
Proportion	0.16	0.06	0.06	1
Pollen season ^a	Sp-Su-Au	Sp-Su	Au-Wi-Sp	

peaks tending to occur from spring through to autumn and lower concentrations during winter, except for Casuarinaceae which is more evenly distributed, with significant concentrations observed during winter (Fig. 2 A–D).

The results of the Spearman's rank correlation (Tables III–VI) show that mean, minimum and maximum temperature are consistently significantly correlated with the three families and total pollen, both on the same day and with lags of 1, 2 and 3 days. Correlations are positive except for Casuarinaceae, which is consistently negative.

Rainfall does not appear to be a major influence on pollen concentration, with relatively few significant results. Once again, the correlation results for Casuarinaceae differ from the other two families and total pollen, in that the sign of the correlations is negative rather than positive.

Similarly, the correlation results for relative humidity appear relatively weak, and are inconsistent. Exceptions to this are a positive correlation between Poaceae and minimum relative humidity with lags of 1, 2 and 3 days, a negative correlation between Plantaginaceae and mean relative humidity for both the same day and with lags, and a strong negative correlation between mean relative humidity (and minimum relative humidity) and total pollen on the same day. The results for dew point temperature mirror the results for temperature, with strong consistent positive correlations on the same day and with lags, with Casuarinaceae being the exception with consistently negative correlations.

Similarly, wind speed is consistently positively correlated with Poaceae and Plantaginaceae and negatively with Casuarinaceae. Less consistency is found in the correlations with total pollen, where strong positive correlations are found on the same day and with a 3-day lag, but weak or

non significant correlations occur with 1 and 2 day lags. Total pollen concentration plotted against wind direction at 9 a.m. and 3 p.m. is shown in Fig. 3 (A, B). At 9 a.m., winds from most directions except the east appear to be related to higher concentrations of total pollen. Winds at 3 p.m. appear less related to pollen concentrations on the same day, although the south-south-west to south-westerly winds appear to be associated with lower pollen concentrations.

Finally, air pressure is consistently strongly negatively correlated with Poaceae, Plantaginaceae and total pollen, but positively correlated with Casuarinaceae.

The regression results (Table VII) suggest a considerable amount of the variation in pollen concentration can be accounted for by meteorological parameters. The R^2 value ranges from 13% for Plantaginaceae to almost 30% for Poaceae. Five parameters appear regularly (three or more times) in the regression models. These are mean temperature, mean and maximum relative humidity, minimum dew point temperature, and minimum air pressure. All parameters except rainfall and mean dew point temperature appear at least once in a model.

DISCUSSION

The results of this study have revealed a number of significant associations between daily Poaceae, Plantaginaceae, Casuarinaceae, and total pollen concentrations and meteorological parameters in Sydney over the study period. Although a number of authors have examined Poaceae and total pollen, few have examined the other two families examined in this study. As such, direct comparison with previous studies is only possible for Poaceae and total pollen. The positive association between Poaceae and temperature in the current study is consistent with a number of previous studies (Rutherford et al. 1997, Jato et al. 2002, Bartková-Ščevková 2003). In particular, Rutherford et al. (1997) examined both minimum and maximum temperature and, like this study, found highly significant correlations. Although the results of the current study suggest little association between Poaceae pollen and rainfall in Sydney, the consistently positive correlation is similar to that found by Rutherford et al. (1997) in Brisbane. However, Jato et al. (2002) found a consistently negative correlation between Poaceae and precipitation.

Previous studies have had conflicting results regarding the association between Poaceae and relative humidity. Bartková-Ščevková (2003) found negative associations while Rutherford et al. (1997) found positive correlations. Rutherford et al. (1997) examined both a.m. and p.m. relative humidity and found the strongest associations with p.m. relative humidity. If it is assumed that minimum relative humidity will generally occur during the afternoon (i.e. p.m.) when temperatures are at their highest, then the positive and significant (with lags) correlations for minimum relative humidity in the current study are consistent with that of Rutherford et al. (1997).

Although few, if any, previous studies appear to have examined dew point temperature, the results of the current

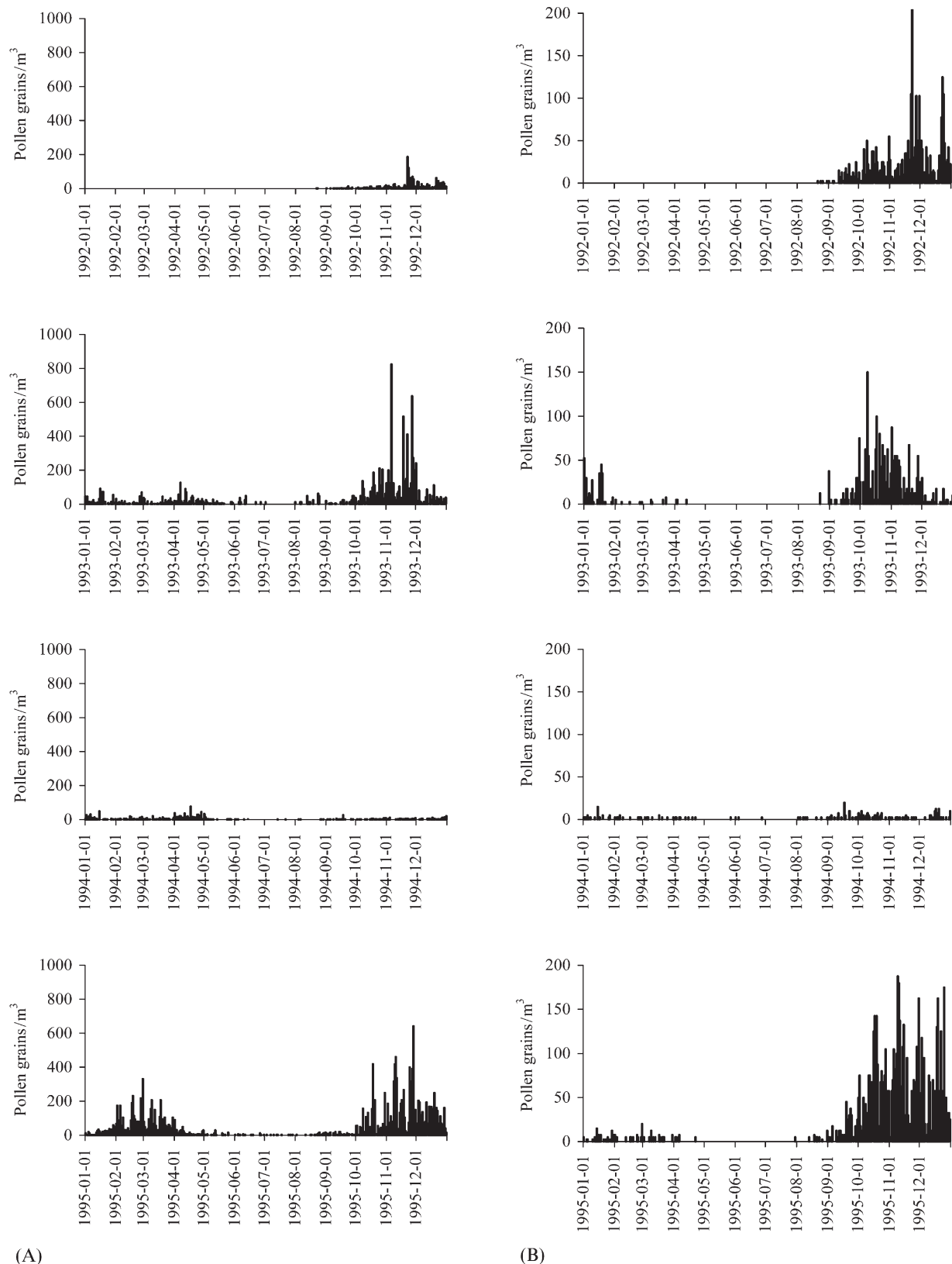
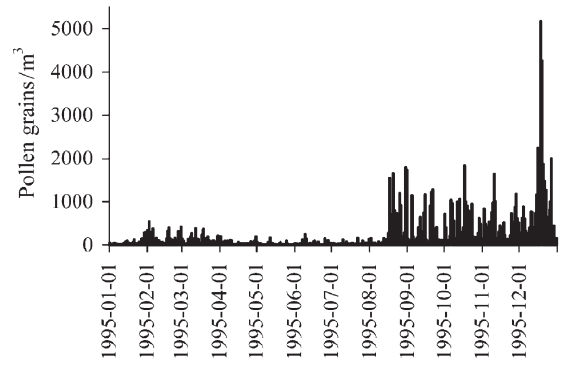
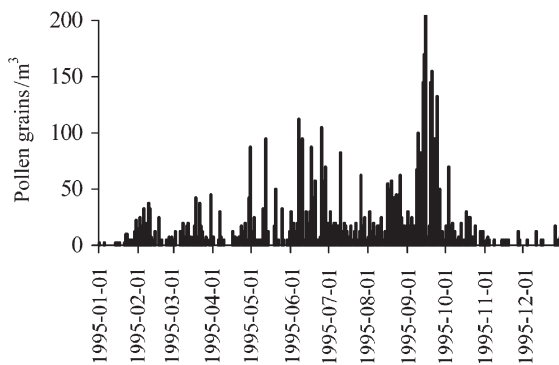
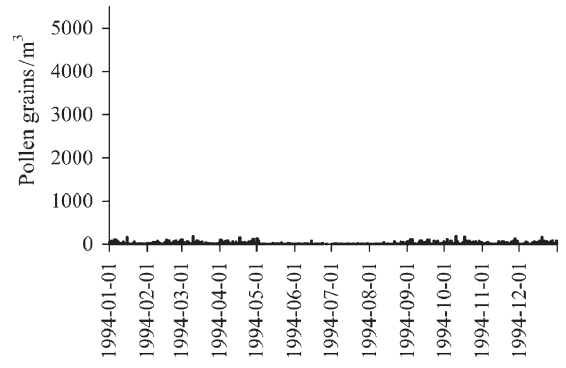
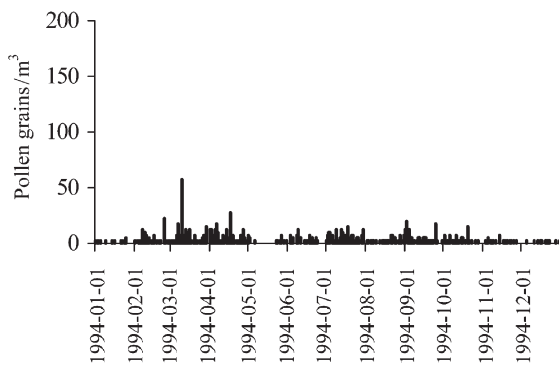
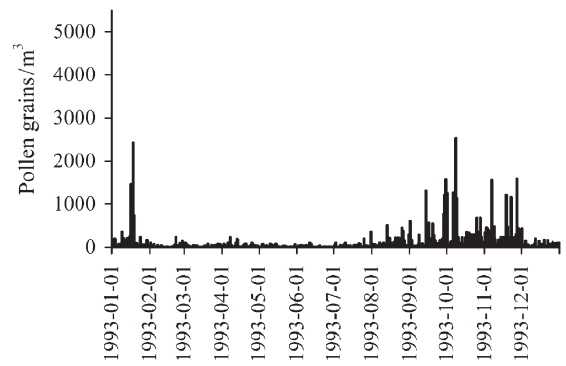
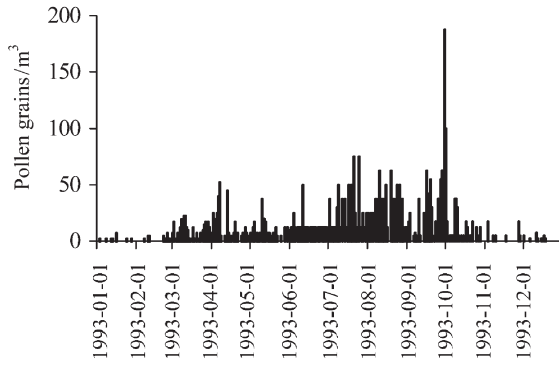
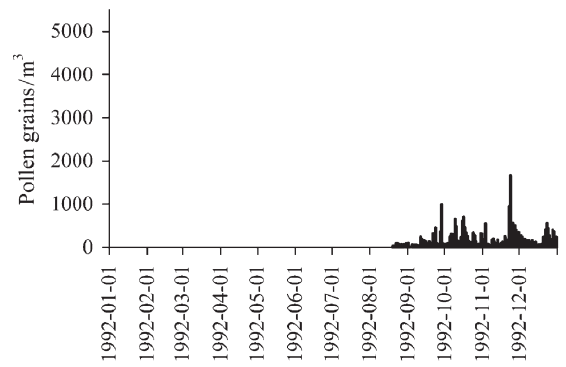
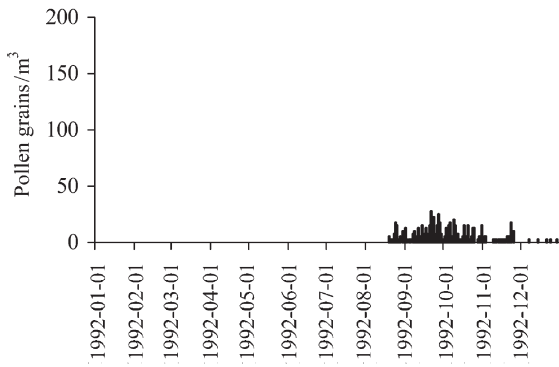


Fig. 2. Daily average (A) Poaceae, (B) Plantaginaceae, (C) Casuarinaceae, and (D) total pollen concentration—at Campbelltown 1992 to 1995. Pollen observations started on 19 August 1992. Date format is by year-month-day.



(C)

(D)

Table III. Spearman's rank correlation matrix for *Poaceae* pollen and meteorological parameters.

^aT – temperature; p_r – rainfall; RH – relative humidity; T_d – dew point temperature; u – wind speed; P – air pressure; P-value – * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Parameter ^a	Same day	Lag 1	Lag 2	Lag 3
T	0.540***	0.495***	0.458***	0.454***
T _{min}	0.388***	0.378***	0.369***	0.359***
T _{max}	0.516***	0.448***	0.385***	0.378***
p _r	0.016	0.069*	0.065*	0.053
RH	–0.033	0.011	0.016	–0.015
RH _{min}	0.026	0.093**	0.106***	0.079**
RH _{max}	–0.013	–0.022	–0.035	–0.050
T _d	0.408***	0.407***	0.401***	0.382***
T _{d min}	0.361***	0.380***	0.372***	0.358***
T _{d max}	0.436***	0.417***	0.411***	0.391***
u	0.123***	0.120***	0.142***	0.170***
u _{max}	0.145***	0.132***	0.136***	0.178***
P	–0.273***	–0.202***	–0.169***	–0.180***
P _{min}	–0.282***	–0.205***	–0.171***	–0.181***
P _{max}	–0.270***	–0.206***	–0.174***	–0.181***

study suggest it is a significant factor, which is worthy of further study. Similarly, few studies have examined air pressure.

The association between *Poaceae* and wind speed is similar with that found by Rutherford et al. (1997) at one of their two study sites, where a significant positive correlation with average wind speed was found.

A number of studies have examined *Plantago*, one of the three genera of Plantaginaceae. Rutherford et al. (1997) and Tormo et al. (2001) in particular have conducted similar analyses to the current study. The former examined just minimum and maximum temperature, and the latter examined mean, minimum and maximum temperature. Both found similar results to the current study, with

Table IV. Spearman's rank correlation matrix for *Plantaginaceae* pollen and meteorological parameters.

^aT – temperature; p_r – rainfall; RH – relative humidity; T_d – dew point temperature; u – wind speed; P – air pressure; P-value – * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Parameter ^a	Same day	Lag 1	Lag 2	Lag 3
T	0.304***	0.274***	0.248***	0.239***
T _{min}	0.208***	0.204***	0.192***	0.182***
T _{max}	0.288***	0.235***	0.204***	0.190***
p _r	0.043	0.074**	0.073*	0.063*
RH	–0.102***	–0.082**	–0.077**	–0.094**
RH _{min}	–0.010	0.022	0.034	0.017
RH _{max}	–0.038	–0.035	–0.054	–0.055
T _d	0.193***	0.185***	0.166***	0.145***
T _{d min}	0.169***	0.177***	0.161***	0.141***
T _{d max}	0.213***	0.192***	0.182***	0.159***
u	0.195***	0.215***	0.229***	0.227***
u _{max}	0.215***	0.231***	0.231***	0.234***
P	–0.290***	–0.257***	–0.222***	–0.216***
P _{min}	–0.296***	–0.258***	–0.223***	–0.223***
P _{max}	–0.280***	–0.251***	–0.222***	–0.204***

Table V. Spearman's rank correlation matrix for *Casuarinaceae* pollen and meteorological parameters.

^aT – temperature; p_r – rainfall; RH – relative humidity; T_d – dew point temperature; u – wind speed; P – air pressure; P-value – * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Parameter ^a	Same day	Lag 1	Lag 2	Lag 3
T	–0.263***	–0.305***	–0.339***	–0.344***
T _{min}	–0.251***	–0.268***	–0.265***	–0.272***
T _{max}	–0.156***	–0.208***	–0.282***	–0.302***
p _r	–0.065*	–0.058*	–0.031	–0.028
RH	–0.005	0.053	0.087**	0.061*
RH _{min}	–0.080**	–0.024	0.015	0.019
RH _{max}	0.064*	0.080**	0.026	0.020
T _d	–0.245***	–0.217***	–0.220***	–0.244***
T _{d min}	–0.233***	–0.186***	–0.184***	–0.202***
T _{d max}	–0.252***	–0.237***	–0.254***	–0.278***
u	–0.218***	–0.296***	–0.244***	–0.226***
u _{max}	–0.187***	–0.272***	–0.213***	–0.204***
P	0.079**	0.165***	0.230***	0.243***
P _{min}	0.060*	0.158***	0.227***	0.237***
P _{max}	0.100***	0.167***	0.231***	0.248***

positive correlations with maximum temperature being the strongest and most common. Although no previous studies appear to have examined lagged relationships between rainfall and *Plantago*, the insignificant result for the same day in the current study is consistent with the study by Rutherford et al. (1997), but is inconsistent with the study by Tormo et al. (2001) who found significant negative correlations.

Tormo et al. (2001) found similar results to the current study in their correlation between mean relative humidity and *Plantago* (significant negative correlation). Rutherford et al. (1997) found correlations with a.m. and p.m. relative humidity were either not significant or significantly negative, a result consistent with the current study.

Table VI. Spearman's rank correlation matrix for total pollen and meteorological parameters.

^aT – temperature; p_r – rainfall; RH – relative humidity; T_d – dew point temperature; u – wind speed; P – air pressure; P-value – * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Parameter ^a	Same day	Lag 1	Lag 2	Lag 3
T	0.308***	0.246***	0.197***	0.188***
T _{min}	0.168***	0.152***	0.137***	0.138***
T _{max}	0.369***	0.278***	0.184***	0.154***
p _r	0.001	0.035	0.035	0.053
RH	–0.132***	–0.023	–0.008	–0.027
RH _{min}	–0.098**	0.012	0.050	0.040
RH _{max}	0.011	0.031	–0.019	–0.029
T _d	0.167***	0.192***	0.176***	0.148***
T _{d min}	0.131***	0.182***	0.173***	0.154***
T _{d max}	0.204***	0.203***	0.173***	0.145***
u	0.105***	0.028	0.070*	0.103***
u _{max}	0.160***	0.047	0.086**	0.117***
P	–0.349***	–0.228***	–0.151***	–0.133***
P _{min}	–0.370***	–0.237***	–0.154***	–0.137***
P _{max}	–0.325***	–0.226***	–0.156***	–0.129***

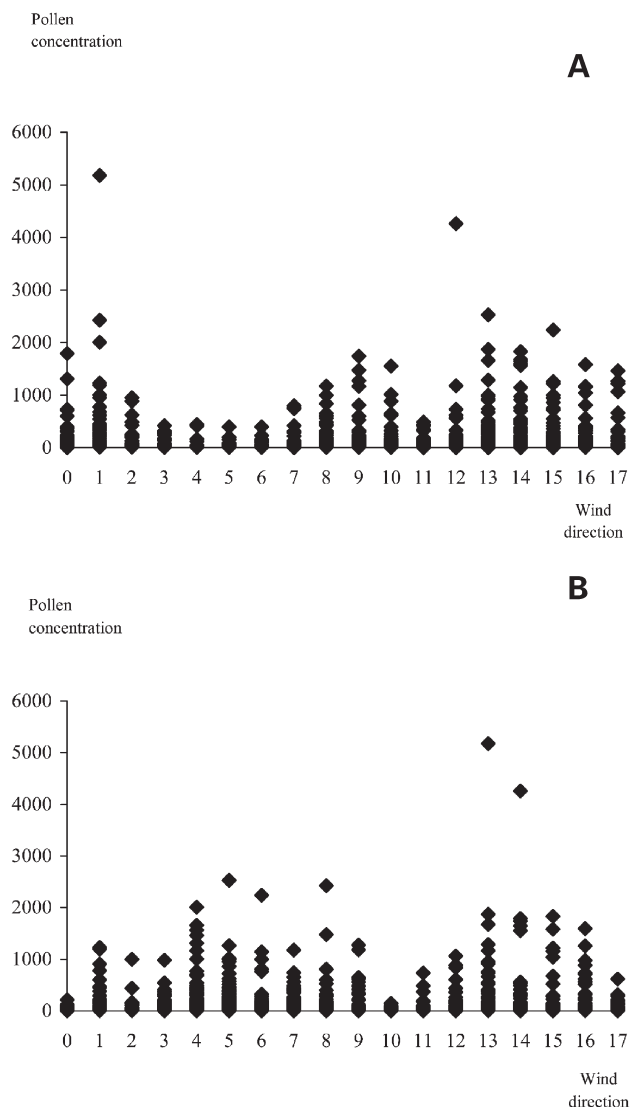


Fig. 3. Wind direction at 9 a.m. (A) and at 3 p.m. (B) plotted against total pollen concentration (grains m^{-3}) at Campbelltown for each day of the study period. 0 – calm; 1 – northerly; 2 – north-north-easterly; 3 – north-easterly; etc. 16 – north-north-westerly; 17 – missing data.

The strong positive correlation between wind speed and *Plantago* in the current study is inconsistent with previous studies, which have either found negative correlations (Tormo et al. 2001) or non-significant or weakly positive correlations (Rutherford et al. 1997).

Several studies (Hobday & Stewart 1973, Rutherford et al. 1997, Ribeiro et al. 2003) of total pollen have found, like this study, significant positive correlations with temperature. Although the positive and weak correlation with rainfall in this study was unexpected, this result is consistent to some extent with previous studies of total pollen that have found results of varying significance, though usually negative.

As with some previous studies (e.g. Hobday & Stewart 1973, Rutherford et al. 1997) the association between

relative humidity and total pollen appears relatively weak.

The wind speed results for total pollen are more variable than for the three families examined. It is likely that the interaction of wind speed and direction is of greater significance than either of these alone, and that the association between pollen concentration and these parameters is highly site-specific. Although the association between total pollen and wind direction does not appear very strong, the slightly lower concentration from the east is expected given the coastal nature of Sydney.

At least one previous study (Hobday & Stewart 1973) has found a significant association with air pressure and total pollen, interestingly a positive correlation with a 2-day lag (similar to the results for Casuarinaceae in this study).

Pollen concentrations throughout 1994, and particularly during the spring and early summer (December) of that year, appear to have been relatively low for all pollen types examined. An examination of meteorological parameters in that specific period reveals a number of anomalies that may be associated with the relatively low pollen concentrations. For example, the 3-month minimum temperature anomaly for the period July to September 1994, relative to the period January 1984 to December 2003, was 1.5 times lower (at -1.5°C) than at any other time during the 20-year period. The months preceding the spring and early summer of 1994 were also considerably drier than usual, with the 3 month anomaly rainfall totals for the period July to September 1994, relative to the period January 1984 to December 2003, amongst the lowest (at -140 mm) over the 20 year period.

Meteorological parameters do appear to affect the concentration of pollen in the atmosphere of Sydney. It may be necessary to consider large-scale weather patterns to detect possible remote sources of pollen so the regression models developed in this study can be refined. Nevertheless, there is potential for the results of this study to be used by public health authorities in the prediction of pollen levels in Sydney.

There is scope for further research on aeroallergens in the atmosphere of Sydney. If the data became available, it would be useful to look at the concentration of pollen in the atmosphere over a much longer time period. There is also scope to examine other plant families.

CONCLUSIONS

The results of this study suggest that daily Poaceae, Plantaginaceae, Casuarinaceae, and total pollen concentrations in Sydney are related to a number of meteorological parameters, such as temperature, dew point temperature, wind speed, and air pressure. Rainfall and relative humidity appear to be less-important parameters. The strength of the associations with meteorological parameters, both on the same day and with lags of 1, 2 and 3 days, suggests these meteorological parameters could be used in forecasts of pollen concentration, and therefore contribute to public health.

Table VII. Significant ($P < 0.05$) regression results for pollen and meteorological parameters.

^aT – temperature; p_r – rainfall; RH – relative humidity; T_d – dew point temperature; u – wind speed; P – air pressure.

Parameter ^a	Coefficients			
	Poaceae	Plantaginaceae	Casuarinaceae	Total
T	0.062	0.035	–0.026	–0.026
T _{min}		–0.020		
T _{max}			0.028	0.049
p _r				
RH	–0.013	–0.016	0.007	
RH _{min}		0.006		
RH _{max}	0.006	0.008	0.005	
T _d				
T _{d min}	0.021	0.014		0.007
T _{d max}			–0.042	
u			–0.014	
u _{max}	–0.006			
P		–0.016		
P _{min}	–0.009		–0.031	–0.020
P _{max}			0.028	

Parameter ^a	Analysis of variance			
	Poaceae	Plantaginaceae	Casuarinaceae	Total
F	0.609	0.585	0.526	0.540
R ²	29.22	13.37	15.40	18.88

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