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QUANTITATIVE TRENDS IN AIRBORNE LOADS OF *CELTIS SINENSIS* POLLEN AND ASSOCIATIONS WITH METEOROLOGICAL VARIABLES IN A SUBTROPICAL AUSTRALIAN ENVIRONMENT

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Abstract: *Celtis sinensis* is an introduced plant species to the southeastern region of Queensland that has had a destructive affect on indigenous plant communities and its pollen has been identified as an allergen source. Pollen belonging to *C. sinensis* was sampled during a 5-year (June 1994-May 1999) atmospheric pollen-monitoring programme in Brisbane, Australia, using a Burkard 7-day spore trap. The seasonal incidence of airborne *C. sinensis* pollen (C*s*P) in Brisbane occurred over a brief period each year during spring (August-September), while peak concentrations were restricted to the beginning of September. Individual C*s*P seasons were heterogeneous with daily counts within the range 1-10 grains m^{-3} on no more than 60 sampling days; however, smaller airborne concentrations of C*s*P were recorded out of each season. Correlation co-efficients were significant each year for temperature ($p<0.05$), but were less consistent for precipitation ($p>0.05$) and relative humidity ($p>0.05$). A significant relationship ($r^2=0.81$, $p=0.036$) was established between the total C*s*P count and pre-seasonal average maximum temperature; however, periods of precipitation (>2mm) were demonstrated to significantly lower the daily concentrations of C*s*P from the atmosphere. Given the environmental and clinical significance of C*s*P and its prevalence in the atmosphere of Brisbane, a clinical population-based study is required to further understand the pollen's importance as a seasonal sensitizing source in this region.

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Key words: atmosphere, Ulmaceae, *Celtis sinensis*, pollen, meteorology, temperature, precipitation, humidity, correlation.

INTRODUCTION

Plants belonging to the Ulmaceae family have a global distribution and are primarily localised to northern temperate regions. The family is composed of 18 genera and approximately 150 species with fossil evidence dating back to the Upper Cretaceous period; however, only 3 of these genera are most common and comprise *Ulmus*, *Celtis* and *Planera*. The defining morphological and physiological characteristics include tree or shrub habits; simple, stipulate and alternating leaves, nitrogen fixation by root nodules and C3 physiology. Several genera are economically utilized as sources of timber, cultivated as ornamentals or used for medicinal purposes. These economic applications have seen the rapid spread of northern temperate species to foreign environments, particularly in the case of *Celtis* spp., to Australia and the Southern Hemisphere.

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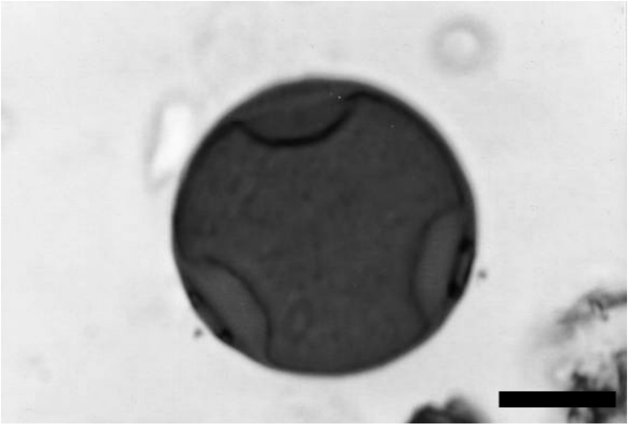

Figure 1. Photomicrograph of *Celtis sinensis* pollen. Scale bar = 15 µm.

Table 1. Seasonal distribution of *Celtis sinensis* pollen in Brisbane, June–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 (grains m^{-3}) and date, seasonal duration and daily count categories are shown in each case.

Parameter	1994-95	1995-96	1996-97	1997-98	1998-99
5%	3/9	19/8	28/8	25/8	22/8
Peak Day	5/9	3/9	4/9	1/9	4/9
Peak Count	9.02	2.92	3.68	3.12	16.87
95%	26/9	4/9	19/9	20/9	11/9
Season Duration	23	17	23	27	21
Days count 11-100	0	0	0	0	1
Days count 1-10	10	11	19	10	10

Celtis sinensis (Japanese Hackberry) is a deciduous tree species, native to eastern Asia and occupies riparian and disturbed habitats in concentrated pockets along the east coast of Australia. Originally introduced to the southeastern region of Queensland in the 1890's for ornamental and timber plantation purposes, *C. sinensis* has had a devastating affect on the indigenous flora and fauna of this region [2]. Its ability to tolerate different soil types, adapt to various climates, and displace native plant and animal species has led to the Queensland Government categorising *C. sinensis* as a Class 3 invasive declared species. This species can not only be classified as one of the 10 most highly ranked invasive species in Queensland, but it has also been acknowledged by Wodehouse [19] as being a suspected causal mechanism of seasonal allergic rhinitis and asthma.

Pollen belonging to *Celtis* spp. (Fig. 1) are typically anemophilous, shed large quantities of pollen, and are characterised by 3-10 pores with a thick undulating, granular sexine with sizes between 25-40 µm [18]. Airborne Ulmaceae pollen is prevalent in the atmosphere of Brisbane and other Southern Hemisphere cities [6, 12, 15]; however, its distribution and relationship with weather variables remains unclear. Given the ecological, environmental and clinical significance of *C. sinensis*, the aim of the study was to describe the quantitative and temporal distribution of C*s*P seasons with statistical reference to meteorological parameters based on 5 years (June 1994–May 1999) of environmental pollen monitoring. This is the first study to investigate the statistical associations between different aspects of *C. sinensis* aerobiology and weather parameters in a subtropical Southern Hemisphere environment, and follows Nitiu's [14] preliminary descriptive investigation of *Celtis* spp. pollen in the atmosphere of La Plata, Argentina.

MATERIALS AND METHODS

Airborne C*s*P was collected over a 5-year period (June 1994-May 1999) in the subtropical city of Brisbane (27º29'S 153º8'E), southeastern Queensland, Australia. The trapping site was located 7 km southeast of the central business district [6] on a Queensland Department of Primary Industries research farm. The climate of Brisbane is classified as subtropical with an average yearly mean temperature of 25.9ºC and an average yearly rainfall of 1,114.6 mm. The major vegetation formation of the trapping site is that of open *Eucalyptus* woodland with an understorey of grass and herbaceous species, and where surrounding creeks and rivers are vegetated by riparian communities [6]. Additionally, surrounding residential and industrial areas have numerous representatives of the exotic taxa *C. sinensis*.

Aerobiological data was 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–May 1999. The trap was calibrated to sample air at 10 litres per minute, and the atmospheric particulate matter was deposited onto tapes coated with a thin film of Dow Corning pressure-sensitive silicone adhesive (280A). The 7-day tapes were prepared and counted by the methods previously described [6]. The pollen data corresponded to the mean daily values expressed as the number of pollen grains m^{-3} of air. Meteorological data (maximum temperature, minimum temperature, average temperature, total rainfall and relative humidity) measured at Brisbane airport, which is situated 10 km northeast of the sampling site was obtained for the period, June 1994–May 1999, from the Australian Bureau of Meteorology.

Data corresponding to 5 years (June 1994–May 1999) of pollen monitoring and meteorological records were documented graphically and evaluated statistically. Each individual C*s*P season, was calculated using the criteria developed by Nilsson and Persson [13]. Daily counts were classified into 2 pollen count categories (1-10, 11-100 grains m^{-3}), a standard which is used by the Palynological Laboratory, Swedish Museum of Natural History, Stockholm. Associations between mean daily C*s*P counts and meteorological values were calculated using Spearman's (non-parametric) correlation analysis

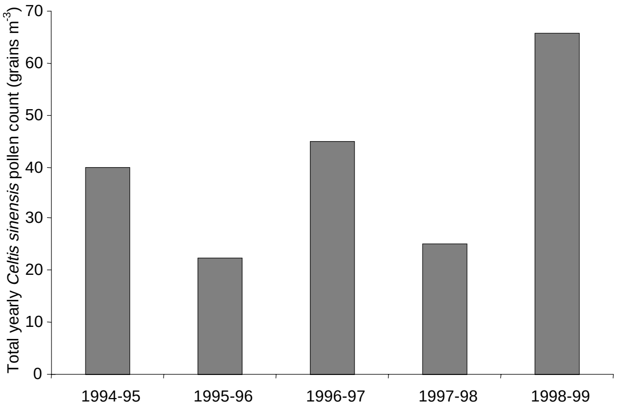

Figure 2. Total annual sum of *Celtis sinensis* pollen (grains m^{-3}) for June 1994–May 1999 in Brisbane, Australia.

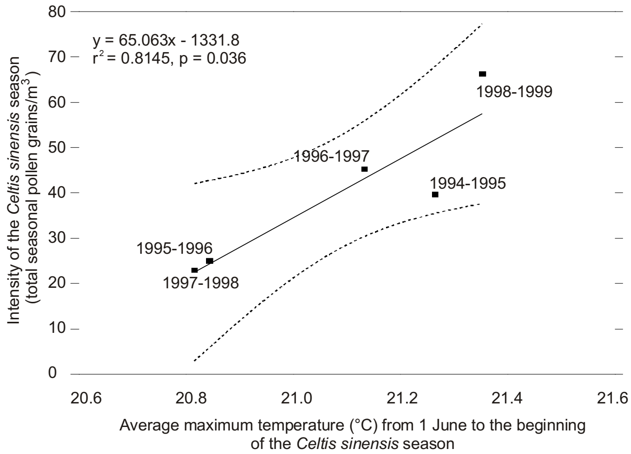

Figure 3. Intensity of the *Celtis sinensis* season, established from the average pre-seasonal maximum temperature from 1 June against the total seasonal *Celtis sinensis* pollen counts.

for the entire study period and by season. Statistical linear regressions relating meteorological parameters to various aspects of *C. sinensis* aerobiology (start, length and intensity of the pollen seasons) were performed using Stata [16].

RESULTS

In the atmosphere of Brisbane, C*s*P was restricted to spring (August-September) with total yearly counts ranging between 22-66 grains m^{-3} in 1995-96 and 1998-99, respectively (Tab. 1, Fig. 2). Homogeneous seasonal start and end dates characterized the C*s*P seasons, varying between 15 (season start)–23 days (season end). Peak pollen concentrations occurred between 1-5 September each year; however, the peak count of each season fluctuated between 2-16 grains m^{-3} (Tab. 1). In addition, the mean duration of the C*s*P season was 22 days and ranged between 17 days in 1995-96 to 27 days in 1997-98 (Tab. 1).

Individual sampling years (June-May) plotted against maximum temperature, minimum temperature and rainfall, illustrated inter- and intra seasonal variations in daily C*s*P counts (Fig. 4). Daily counts were within the range 11-100 grains m^{-3} on no more than 1 day (1998-99) and 1-10 grains m^{-3} on 60 days during the entire sampling period (Tab. 1). Periods of precipitation throughout each pollen season were shown to considerably lower the daily atmospheric concentrations of C*s*P (Fig. 5), whereas minimal quantities of daily pollen (0.06-0.1 grains m^{-3}) were recorded during a number of out-of-season sampling days (Fig. 4).

The highest incidence of daily C*s*P coincided with average monthly maximum temperatures of 21-24ºC, minimum temperatures of 8-12ºC, and the lowest yearly rainfall values ranging between 0.03-3 mm (Fig. 4). Non-parametric correlation analyses indicated weak significant negative associations ($p<0.0001$) between daily C*s*P counts and minimum temperature for each of the sampling years (Tab. 2). Associations with maximum and average temperature were less significant ($p<0.05$), compared to minimum temperature, particularly for the sampling year 1994-95. Other parameters studied, including relative humidity and precipitation, were not associated with daily C*s*P counts; however, a significant negative correlation was evident for precipitation in 1996-97 and for relative humidity in 1994-95.

The intensity of the C*s*P season plotted against the average maximum temperature from 1 June to the beginning of the pollen season (Fig. 3) demonstrated a statistically significant relationship (r^2=0.81, p=0.036). Lower average pre-seasonal maximum temperatures

Table 2. Spearman's correlation coefficients (r_s) between meteorological parameters and *Celtis sinensis* yearly (n = 365) and total pollen counts (n = 1826).

Celtis sinensis season	Spearman's correlation coefficients (r_s)					
	T_{max}	T_{min}	Precipitation	T_{ave}	$Rhum_{am}$	$Rhum_{pm}$
1994–95	0.0366	-0.2269**	-0.0428	-0.1419*	-0.1746*	-0.1701*
1995–96	-0.1169*	-0.1949*	-0.0837	-0.1697*	0.0919	-0.0033
1996–97	-0.1703*	-0.3332**	-0.1106*			
1997–98	-0.1169*	-0.2881**	-0.0886			
1998–99	-0.2778**	-0.2517**	-0.0090			
1994–99	-0.1304**	-0.2616**	-0.0660*			

significant r_s values * p<0.05 **p<0.0001

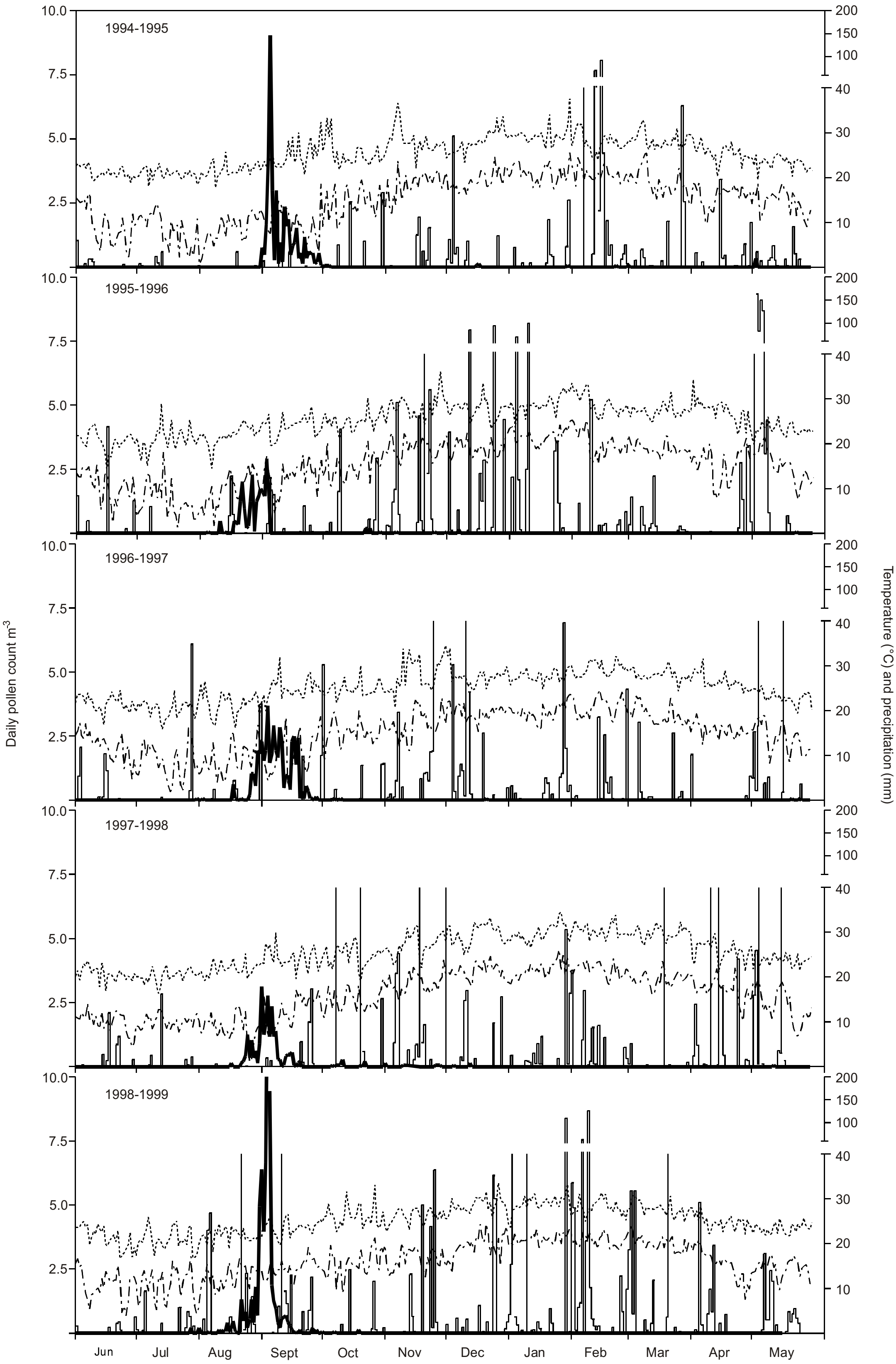

Figure 4. Yearly distribution of (▬) *Celtis sinensis* pollen (grains m^{-3}) in the atmosphere of Brisbane, Australia, during 5 individual sampling years (June-May) plotted with daily (· · · · ·) maximum and (–·–·–·–) minimum temperature (ºC) and (—) total daily precipitation (mm).

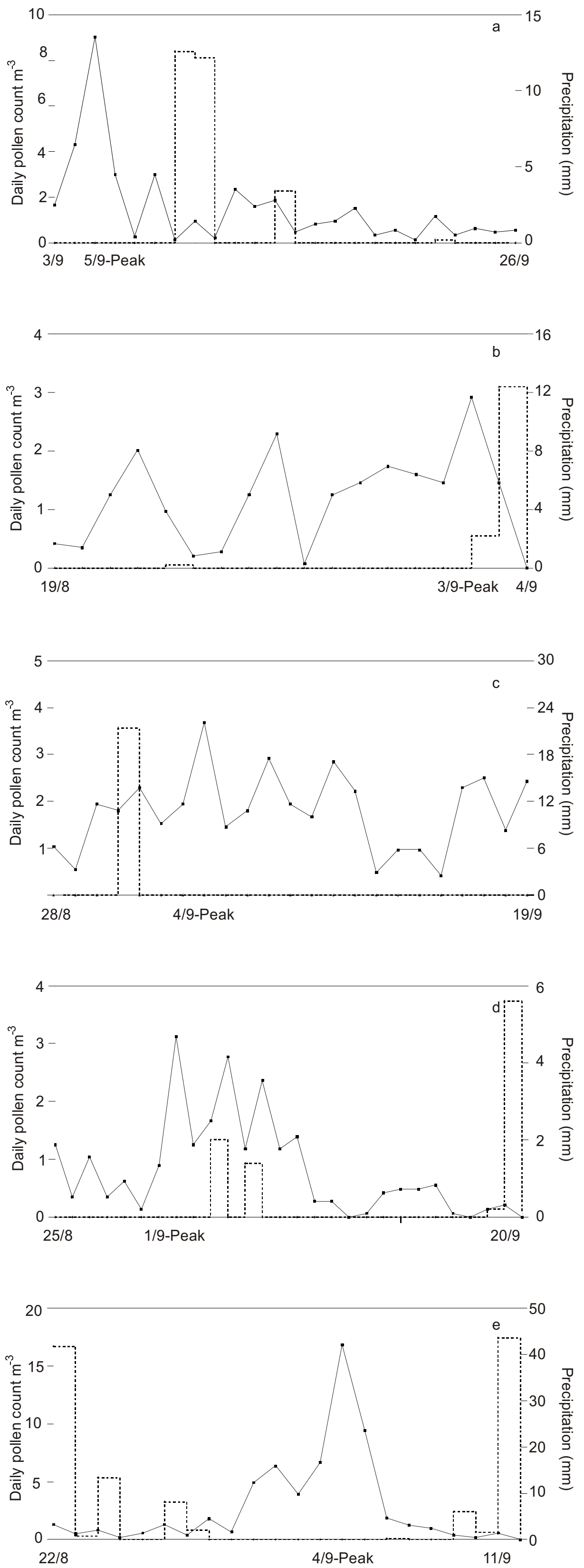

Figure 5. Distribution of daily (——) *Celtis sinensis* pollen (grains m^{-3}) and (-----) precipitation (mm) during each pollen season for 5 individual sampling years: a, 1994. b, 1995. c, 1996. d, 1997. e, 1998.

(1997-98) coincided with lower seasonal C*s*P counts (<25 grains m^{-3}), whereas higher C*s*P seasonal totals (1998-99) coincided with higher average pre-seasonal maximum temperatures (>21.3ºC). Trends with pre-seasonal minimum temperature and rainfall (data not shown) were not statistically significant (p>0.05). In addition, relationships between seasonal starting dates and seasonal duration with maximum temperature, minimum temperature and rainfall parameters, were investigated and found to not be statistically significant (p>0.05).

DISCUSSION

Airborne C*s*P is one of the 10 most prevalent pollen sources in the atmosphere of Brisbane, with maximum emissions restricted to the months August and September [6]. Since the original Brisbane pollen calendar study conducted by Moss in 1962-63 [12], the atmospheric composition, frequency and timing of peak emissions of airborne *C. sinensis* pollen has remained uniform. Previous studies from southern temperate regions of Australia have shown that pollen belonging to other ornamental Ulmaceae species, including *Ulmus minor*, *U. glabra* and *U. parvifolia*, are more common and represent a significant contribution to the pollen calendars of Sydney [1] and Melbourne [15]. In other Southern Hemisphere locations, including South Africa and Argentina, airborne pollen of indigenous *Celtis* species comprise the highest arboreal pollen frequencies and are comparably longer in seasonal duration than those of Brisbane [3, 14]. The annual abundance and duration of each season established in these studies varies from the reported Brisbane values due to variations in local weather parameters, as well as in taxa represented in the region.

Daily C*s*P counts were demonstrated in the correlation analysis to be associated with meteorological parameters, in particular temperature during each sampling year. Similar descriptive associations have been shown between *Celtis* pollen and temperature in La Plata, Argentina [14] and Modena, Italy [17]. Daily variations in *Celtis* pollen counts, however can be additionally attributed to the genera's multi-vector pollen dispersal strategy, as described by De Arrunda [4], who demonstrated that *Celtis iguanaea* pollen was not only disseminated by anemophilous vectors but that this species was also dispersed by the honeybee *Apis mellifera*. Furthermore, the total amount of C*s*P produced each season was shown for the first time to be statistically related to pre-seasonal maximum temperature. In Brisbane, temperature directly influenced the atmospheric C*s*P concentrations, which supports the findings from intra-diurnal studies that maximum temperature combined with optimum solar radiation was a prerequisite for anther ripening and anthesis [14].

Meanwhile, precipitation and relative humidity were shown not to be statistically associated with different aspects of C*s*P aerobiology. These parameters were suggested by Nitiu [14] to influence the start dates of *Celtis* pollen seasons by stimulating pollen production and anthesis. However, in Brisbane, precipitation was only established to significantly reduce and wash pollen from the atmosphere to levels lower than on the previous day, which has been demonstrated previously for a number of other pollen types [7, 11]. Other meteorological conditions, including wind speed and wind direction, have also been identified as important seasonal dispersal mechanisms for various anemophilous pollen types, including *Celtis*; however, in the present study small concentrations of C*s*P were detected during each season. Under the right atmospheric conditions, deposited particles may be disturbed and refloated into the atmosphere, as shown in the case of *Pinus* pollen in Hokkaido, Japan [8].

In the southeastern region of Queensland, *C. sinensis* occupies numerous environmental niches and has been classified by the Queensland government as a Class 3 invasive weed species [2]. Local authorities in Queensland regard this species as such an environmental hazard that there are current subsidised removal programmes in addition to legislation that outlaws its commercial distribution. In other areas of the world, *Celtis* is considered as an important timber resource, as an ornamental species, and has benefits extending into herbal medicine. Recent evidence has also suggested an etiological role for Ulmaceae pollen in the exacerbation of asthma and allergy [10, 19]. In New York City, the prevalence of hypersensitivity to Elm pollen was reported to be approximately 24% [10], whereas other studies conducted in Missouri [9] and Sweden [5] have shown that skin test reactions were often positive amongst the respective study populations to Ulmaceae pollen extracts. In Brisbane, personal exposure to C*s*P occurs over a short interval each year; however, the period during which peak seasonal counts are recorded may act as an additional seasonal source of environmental allergen.

CONCLUSIONS

Results of this study demonstrate that C*s*P seasons occurred at regular intervals between August and September each year; however, individual daily and seasonal C*s*P counts were heterogeneous. Meteorological parameters that influence daily and total seasonal C*s*P counts were identified in the statistical analyses to be maximum and minimum temperature. Precipitation and relative humidity were statistically less significant. It was demonstrated; however, that C*s*P was not only removed from the atmosphere during significant periods of rainfall, but precipitation may also be a prerequisite for pollen production and anthesis. Understanding the interactions between weather parameters and the dissemination and distribution of C*s*P is important in a region such as Brisbane, where the incidence of seasonal allergic rhinitis and asthma are high and the environmental impacts of *C. sinensis* are well documented. Previous studies have shown that Ulmaceae pollen types are important aeroallergen sources in the Northern Hemisphere; however, further clinical population-based studies are required in Brisbane to understand the role of C*s*P as a seasonal source of allergen, and whether it exacerbates seasonal rhinitis and asthma.

Acknowledgements

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REFERENCES

1. Bass D, Morgan G: A three year (1993-1995) calendar of pollen and *Alternaria* mould in the atmosphere of south western Sydney. *Grana* 1997, **36**, 293-300.
2. Batianoff GN, Butler DW: Assessment of invasive naturalised plants in south-east Queensland. *Plant Protection Quarterly* 2002, **17**, 27-35.
3. Cadman A, Dames JF: Airspora of Durban: a sub-tropical, coastal South African city. *Grana* 1993, **32**, 372-375.
4. De Arruda VLV, Sazima M: Pollination and reproduction of *Celtis iguanaea* Jacq. Sarg. Ulmaceae an anemophilous species. *Revista Brasileira de Botanica* 1988, **11**, 113-122.
5. Eriksson NE: Allergy to pollen from different deciduous trees in Sweden. An investigation with skin tests, provocation tests and the radioallergosorbent test (RAST) in springtime hay fever patients. *Allergy* 1978, **33**, 299-309.
6. Green BJ, Dettmann ME, Rutherford S, Simpson RW: Airborne pollen of Brisbane, Australia: A five-year record, 1994-1999. *Grana* 2002, **41**, 242-250.
7. Hjelmroos M: Washout of long-distance transported pollen grains by snow and rain. **In:** Robertsson AM, Hicks S, Risberg J, Akerlund A (Ed): *Landscapes and Life*. *PACT* 1997, **50**, 485-496.
8. Igarashi Y: Pollen incidence and wind transport in central Hokkaido. (II). *Research Bulletins of the College Experiment Forests Hokkaido University* 1987, **44**, 477-506.
9. Lewis WH, Imber WE: Allergy epidemiology in the St. Louis, Missouri, area. III. Trees. *Ann Allergy* 1975, **35**, 113-119.
10. Lin RY, Clauss AE, Bennett ES: Hypersensitivity to common tree pollens in New York City patients. *Allergy Asthma Proc* 2002, **23**, 253-258.
11. McDonald ME: Collection and washout of airborne pollens by raindrops. *Science* 1962, **135**, 435-437.
12. Moss JE: Airborne pollens of Brisbane. *Aust J Botany* 1965, **13**, 23-37.
13. Nilsson S, Persson S: Tree pollen spectra in the Stockholm region (Sweden), 1973-1980. *Grana* 1981, 20, 179-182.
14. Nitiu DS: Annual, daily and intradiurnal variation of *Celtis* pollen in the city of La Plata, Argentina. *Aerobiologia* 2003, **19**, 71-78.
15. Ong EK, Singh MB, Knox RB: Seasonal distribution of pollen in the atmsophere of Melbourne: an airborne pollen calendar. *Aerobiologia* 1995, **11**, 51-55.
16. Stata: *Stata 6.0*. Stata Corporation, College Station, Texas 1999.
17. Torri P, Accorsi C, Alberta, Mazzanti M, Bandini, Zagni A, Maria: A study of airborne Ulmaceae pollen in Modena (northern Italy). *J Environ Pathol Toxicol Oncol* 1997, **16**, 227-230.
18. Weber RW: Pollen identification. *Ann Allergy Asthma Immunol* 1998, **80**, 141-145.
19. Wodehouse RP: *Hayfever Plants*. 2nd ed. Hafner Publishing Company, New York 1971.