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Respiratory hospital admissions were associated with ambient airborne pollen in Darwin, Australia, 2004–2005

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Clinical and Experimental Allergy

Summary

Background Although the role of pollen and fungus in specific allergic disorders has been well established, the public health impacts of ambient concentrations of airborne pollen and fungal spores; the shapes of concentration–response relationships; and the relative effects of different taxa are gaps in current knowledge.

Objective To investigate associations between daily average ambient pollen and fungal spore concentrations with hospital admissions for total respiratory diseases; asthma; chronic obstructive pulmonary disease (COPD); and respiratory infections in Darwin, Australia, during the period from April 2004 to November 2005.

Methods We assessed these relationships in a two-stage modelling approach designed to quantify potential non-linear relationships. First, generalized additive models determined the shapes of concentration–response relationships. Second, linear associations were examined using generalized linear models. Non-linear relationships were analysed by categorizing pollen and fungal spore concentrations based on their distributions.

Results Positive linear associations were found between total pollen concentrations and hospital admissions for total respiratory diseases and COPD. While our exploratory first-stage analysis suggested non-linear relationships for total pollen with asthma and respiratory infections, no convincing evidence for these relationships was found in the second-stage analysis. When individual taxa were investigated, associations were the strongest in relation to Myrtaceae pollen (the dominant tree taxa in the region), while positive associations not attaining statistical significance were observed for Poaceae, Cyperaceae and Arecaceae. No associations were evident for any conditions with fungal spores.

Conclusions Our finding of an association between pollen count and respiratory hospital admissions that could not be explained by asthma admissions suggests that ambient airborne pollens might have a wider public health impact than previously recognized.

Keywords allergens, fungi, hospital, pollen, respiratory

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Introduction

In this study, aeroallergens are defined as airborne pollen grains and fungal spores that are associated with allergic disorders. While the role of these aerosols in the development and course of diseases such as asthma continues to be an area of extensive research [1, 2], the public health impact of daily fluctuations on population-level indicators such as hospital admissions has been less extensively researched. The main focus of population studies to date has been regarding asthma admissions or health service

attendances [3–13], with a few studies also examining rhinitis [14, 15].

Population health impacts of aeroallergens will vary from region to region due to variation in aerobiology, meteorology, air pollution and local characteristics of human exposure and susceptibility [16, 17]. Documenting these relationships is important for clinical practice and public health planning, particularly as the associated morbidity is likely to increase in association with global environmental and social changes. These include increasing pollen levels and allergenicity, altered seasonality and

interactions between aeroallergens, pollutants and more frequent weather extremes (such as heat waves) [13, 18].

Previous studies have generally assumed linear relationships, despite the fact that there is uncertainty regarding the shape of the concentration–response function and the possibility of threshold levels [3, 4, 19]. The development of rigorous methods for time-series analyses for air pollution studies over the last decade provides a useful approach for examining the contribution of aeroallergens [20, 21]. Recent studies using these approaches have documented associations between aeroallergens and asthma, and have highlighted the non-linear nature of some of these relationships [9, 11].

The aim of this study was to assess the public health implications of ambient concentrations of airborne pollen grains and fungal spores by comparing these with emergency hospital admissions for a variety of respiratory diseases in the city of Darwin, Australia. In other components of our research programme we are examining community-level indicators such as emergency department attendances, general practitioner visits and pharmacy sales.

Materials and methods

Ethical approval was gained from the Human Research Ethics Committees of the Northern Territory Government Department of Health and Community Services, the Menzies School of Health Research and the Charles Darwin University.

Setting

Darwin is a tropical city of approximately 110 000 residents. The vegetation of the city's hinterland is dominated by open woodlands and savannah. The urban environment is characterized by lush gardens and parkland. The climate alternates between wet and dry seasons, with the dry season extending from April to October and the wet season between November and March. The taxonomic groups Myrtaceae (*Eucalyptus* and *Melaleuca* trees), Arecaceae (palms), Poaceae (grasses), *Callitris* (cypress pine), Cyperaceae (sedges), *Casuarina* (sheoak) and *Acacia* (wattles) account for 90% of the pollen load, with the remaining 10% composed of around 30 different pollen types seen only occasionally and in low numbers [22]. The one major source of outdoor air pollution is vegetation fire smoke during the dry season [23].

Outcome measures

De-identified unit record data were obtained for all emergency admissions for respiratory diseases in the administrative database of the Royal Darwin Hospital between April 2004 and November 2005. This is the only major public hospital in the region.

Diagnoses and primary residence were recorded on discharge from the hospital. Patients whose primary residence was not in Darwin were excluded because many patients are transferred to Darwin hospital from regional centres each day. Data were extracted by their assigned diagnosis codes classified according to the International Classification of Diseases version 10. Time series of daily counts were constructed for total respiratory disease (codes J00–J99) and for three diagnostic subgroups: asthma (J45–J46); chronic obstructive pulmonary disease [COPD (J40–J44, J47 and J67)]; and respiratory infections (J00–J22). Together, these subgroups comprised 91% of the total respiratory admissions.

Exposure measures

Daily average airborne pollen grain and fungal spore concentrations (per m³) were measured during the period using a 7-day Burkard SporeWatch Electronic Spore Sampler (Burkard Scientific (Sales) Ltd, Uxbridge, Middlesex, UK) located on a rooftop approximately 14 m above the ground in the Darwin suburb of Casuarina, close to the main residential areas of the city [22].

Pollen were identified using an existing reference collection held in the Department of Archaeology and Natural History at the Australian National University, and by a pollen reference collection compiled specifically for this project by regularly collecting flowering material around the monitoring site. For technical reasons, the fungus *Alternaria* spp. were the only fungal spores we were able to identify. Although this species comprised a small proportion of the overall fungal load, we considered it worth reporting separately because *Alternaria* has been associated previously with allergic conditions [24].

There were 591 days in our time series. There were 58 days in the series that had no aeroallergen observations. Majority of the missing days were during the wet season and due to equipment failure, possibly caused by the increased air humidity. The values for these days were imputed by taking the average of the previous and subsequent days with observations. A secondary sampler located in a smaller population centre 20 km south of the city operated for the first half of the study period. This smaller dataset was used to validate the pollen counts measured at the primary sampler. This was the only period for which observations of ambient pollen and fungal spores were available.

Other explanatory variables

Particulate air pollution < 10 µm in aerodynamic diameter (PM₁₀) was included in all models. The majority of PM₁₀ is derived from vegetation fires in the surrounding savannah during the dry season. These observations were obtained using a sequential air sampler on the same rooftop

(Rupprecht and Patashnick Partisol plus, model 2025, East Greenbush, NY, USA), which provided 24-h gravimetric measures ($\mu\text{g}/\text{m}^3$). These data were validated by inter-laboratory comparison analyses conducted with the Marine and Atmospheric Research division of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Other explanatory variables such as weather, influenza epidemics and holidays were included in all models, as suggested in established protocols for air pollution health studies [25].

Meteorological data for average daily temperature, average daily relative humidity and rainfall were provided by the Australian Bureau of Meteorology.

Weekly influenza rates were provided by the Northern Territory Department of Health and Community Services from the Tropical Influenza Surveillance System, a network of sentinel general practitioners. An epidemic was defined as days with rates above the 90th centile.

Statistical modelling

We separately examined the association of same-day pollen or fungal spore concentrations (and lags up to 3 days) with admission counts for each diagnostic group. We used a two-stage approach to our analysis. Initially, we used generalized additive models (GAM) with penalized cubic regression splines to assess the shape of the concentration–response curves at each lag [26]. These results were used to determine whether linear or categorical modelling would be used in the second stage of the analysis. The smoothing parameters for the splines for exposure variables in the GAMs were selected using the unbiased risk estimation (UBRE) technique, a type of mean square error criterion [26]. The weather and temporal confounders were represented by splines with fixed degrees of freedom, selected from previous time-series regression studies [27, 28].

All models included the following explanatory variables: a smooth function of time in days (represented by a spline with 10 degrees of freedom); average same-day PM_{10} (a linear term); average daily temperature (with 6 degrees of freedom); rolling averages of daily average temperatures at lags 1, 2 and 3 days (with 6 degrees of freedom); relative humidity (with 3 degrees of freedom); rolling averages of relative humidity (with 3 degrees of freedom); and day of the week and public holidays.

School holidays were included as a dummy variable for all respiratory, asthma and respiratory infections because these conditions had a high proportion of young people aged less than 15 years (see Table 1). Additionally, a factor variable representing thunder heard in the 24 h from midnight to midnight (local time) was included in models examining asthma admissions as thunderstorms have been found to have associations with asthma admissions in some settings [7].

Table 1. Emergency hospital admissions for respiratory diseases (with proportion aged under 15 years) to Royal Darwin Hospital, April 2004 to November 2005

Diagnostic groups	Total	Mean daily admissions	Proportion <15 years (%)
Total respiratory admissions	1287	2.2	33
Asthma	184	0.3	60
COPD	334	0.6	1
Respiratory infections	657	1.1	46

COPD, chronic obstructive pulmonary disease.

We then used generalized linear models (GLMs) to quantify these effects. We adapted the method from the American Medicare Air Pollution Study (MCAPS) [29]. In this approach, over-dispersed Poisson models are used with parametric natural cubic splines for smoothed functions of time and meteorological data. We adapted Peng's MCAPS code [28] to suit our data as follows: we did not stratify by age and we included influenza epidemics and holidays as potential confounders.

For linear models, the effect estimates are represented as the percentage change in relative risk associated with an inter-quartile range (IQR) increase in aeroallergen concentration and 95% confidence intervals (CI) are included. The non-linear aeroallergen relationships were quantified using ordinal variables created from the distributions of each variable, so that the days with values between the minimum and the 50th centile were the reference category and were compared with those lying between the 50th and 75th centiles, the 75th and 90th centiles and the 90th to the maximum value [9, 11]. If the 50th centile was zero, then the second category included all values greater than zero but less than the 75th centile. *Alternaria* spp. fungal spores were coded as present or absent due to generally low levels of this aerosol, punctuated by a few spikes in concentration. We estimated the percentage change in hospital admissions for each category compared with its reference category.

In all GLMs, we used a sensitivity analysis similar to Dominici et al. [20] to select the optimal amount of temporal smoothing that minimized confounding bias. The sensitivity analysis was only conducted for the lag of each exposure variable that had the maximum absolute *t*-value to reduce excess computations, and then this optimal smoothing was applied to each of the other lags.

All analyses were conducted using the statistical software package R version 2.4.0 (R Development Core Team, Vienna, Austria) [30].

Results

There were 1287 admissions for respiratory diseases during the 20 months of the study period, an average of 2.2

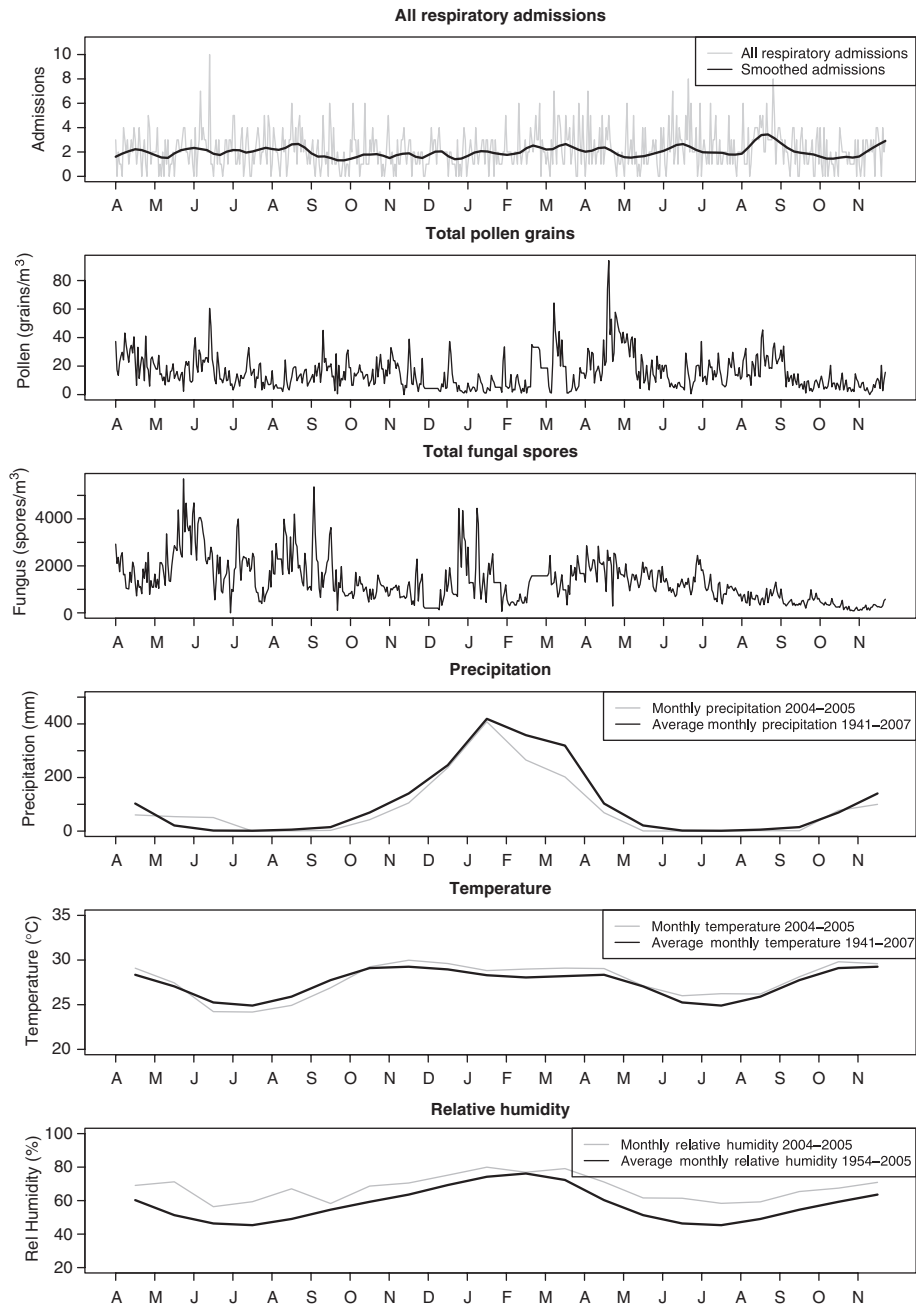


Fig. 1. Daily respiratory emergency admissions, pollen grains, fungal spores and monthly weather averages in Darwin, April 2004–November 2005.

admissions/day. The total number of admissions, daily mean and proportion less than 15 years of age for each group are given in Table 1. Figure 1 shows trends of the admissions, total pollen, fungal spores and the weather variables through the period. Summary statistics of all exposures and confounding variables are given in Table 2.

Weather

Our study period included data from two dry seasons but only one wet season. The temperature, precipitation and

relative humidity in our study period were similar to average weather conditions for Darwin, although the relative humidity levels were slightly higher than average (Fig. 1).

Aerobiology

Pollen and fungal spore loads from the primary monitor were validated against those from the secondary monitor. For the first 12 months of the study, these showed a generally similar distribution and loads of each taxa

Table 2. Summary statistics for exposure variables

Variables (common names)	Units	Relative proportions (%)	Daily mean	Standard deviation	50th centile	75th centile	90th centile	Maximum
Total pollen	grains/m ³	100.0	15.4	11.7	13.0	20.5	31.1	94.0
Myrtaceae (<i>Eucalyptus</i> and <i>Melaleuca</i>)	grains/m ³	31.9	4.9	7.3	2.7	5.9	11.9	78.9
Arecaceae (palms)	grains/m ³	25.2	3.9	4.0	2.7	5.9	9.2	27.0
Poaceae (grasses)	grains/m ³	17.8	2.7	4.4	0.5	3.1	9.2	24.3
<i>Callitris</i> (cypress pine)	grains/m ³	5.7	0.9	2.2	0.0	0.5	2.2	23.2
Cyperaceae (sedges)	grains/m ³	5.4	0.8	1.8	0.0	0.5	2.7	13.5
<i>Casuarina</i> (sheoak)	grains/m ³	3.1	0.5	2.0	0.0	0.5	0.8	32.7
<i>Acacia</i> (wattle)	grains/m ³	2.7	0.4	0.8	0.0	0.5	1.6	5.4
Total fungal spores	spores/m ³	100.0	1348.2	939.7	1158.0	1804.0	2488.9	5703.7
Fungus <i>Alternaria</i> spp.	spores/m ³	0.01	0.1	0.4	0.0	0.0	0.5	3.2
Influenza rates	per 1000 consults	–	13.3	11.4	10.5	18.3	25.7	61.9
Average daily temperature	°C	–	27.7	2.3	28.2	29.3	30.3	32.2
Average daily relative humidity	%	–	67.2	11.4	68.9	73.9	79.1	92.1
PM ₁₀	µg/m ³	–	17.5	7.3	16.7	22.0	27.6	68.7

PM₁₀, particulate air pollution <10 µm in aerodynamic diameter.

with the following exceptions: the primary sampler has a more urban location, and has the highest values of Arecaceae and *Casuarina* pollen, reflecting the proximity of the sampler location to suburban plantings and the coast, while the secondary site is in closer proximity to the regional savannah landscape and has higher values of Poaceae, Cyperaceae and *Callitris* [22]. We used the results from our primary sampler, because this provided the longest and more complete set of measurements.

The relative proportions for each taxonomic group measured by our primary monitor are given in Table 2. Myrtaceae, Arecaceae and Poaceae are the dominant pollen taxa, contributing 31.9%, 25.2% and 17.8% of the total pollen captured, respectively.

The seasonal patterns for each taxa are shown in Fig. 2. The levels of total pollen grains and total fungal spores are higher during the dry season months (April–November). In 2005, Myrtaceae appears to peak in both the early dry season (March and April) and late dry season, but only the later peak is seen in 2004. This may be due to the lack of data for months before April 2004. The late dry season peak was later in 2004 (October) than it was in 2005. Arecaceae shows a mid-dry season peak in both years (April–August) that lingered until the early wet season in 2004. Poaceae, Cyperaceae and *Acacia* all prominently peaked in the early dry season (April–June) in both years, whereas *Callitris* had higher levels in November (during the early wet season) in both years. *Casuarina* peaked late in the dry season, during September in 2004, and there was a hint of raised levels in the months of July and September 2005. The fungus *Alternaria* spp. peaked in May and June 2004, although the levels remained consistently low across the months in 2005.

Concentration–response relationships

The results of our statistical modelling for the same-day exposures only are presented here and the results for the other lags are available on request. No clear pattern of associations was observed for any clinical outcome for the analyses of lagged exposures. Figure 3 shows the concentration–response relationships estimated by our first-stage exploratory GAMs with same-day total pollen concentrations. The results of the second-stage GLMs are summarized in Table 3. We did not find evidence for relationships between daily average ambient fungal spores and any of the health outcomes.

Total respiratory admissions

We found a strong linear association between total respiratory admissions and same-day total pollen concentrations, with a 16.91% increase in admissions (95% CI: 8.93, 25.48) per IQR increase in pollen.

When individual taxa were assessed, this relationship was primarily explained by Myrtaceae pollen, which alone was associated with a 6.65% increase in admissions (95% CI: 3.27, 10.14) per IQR rise. Poaceae, Cyperaceae and Arecaceae also had positive associations that did not attain statistical significance. Other pollen taxa and fungal spores had no association with respiratory admissions.

Asthma

This was the smallest diagnostic subgroup with only 184 admissions during the study, an average of one admission every 3 days. Despite the exploratory GAM results suggesting that admissions for asthma had a non-linear relationship with same-day total pollen (Fig. 3), our GLM

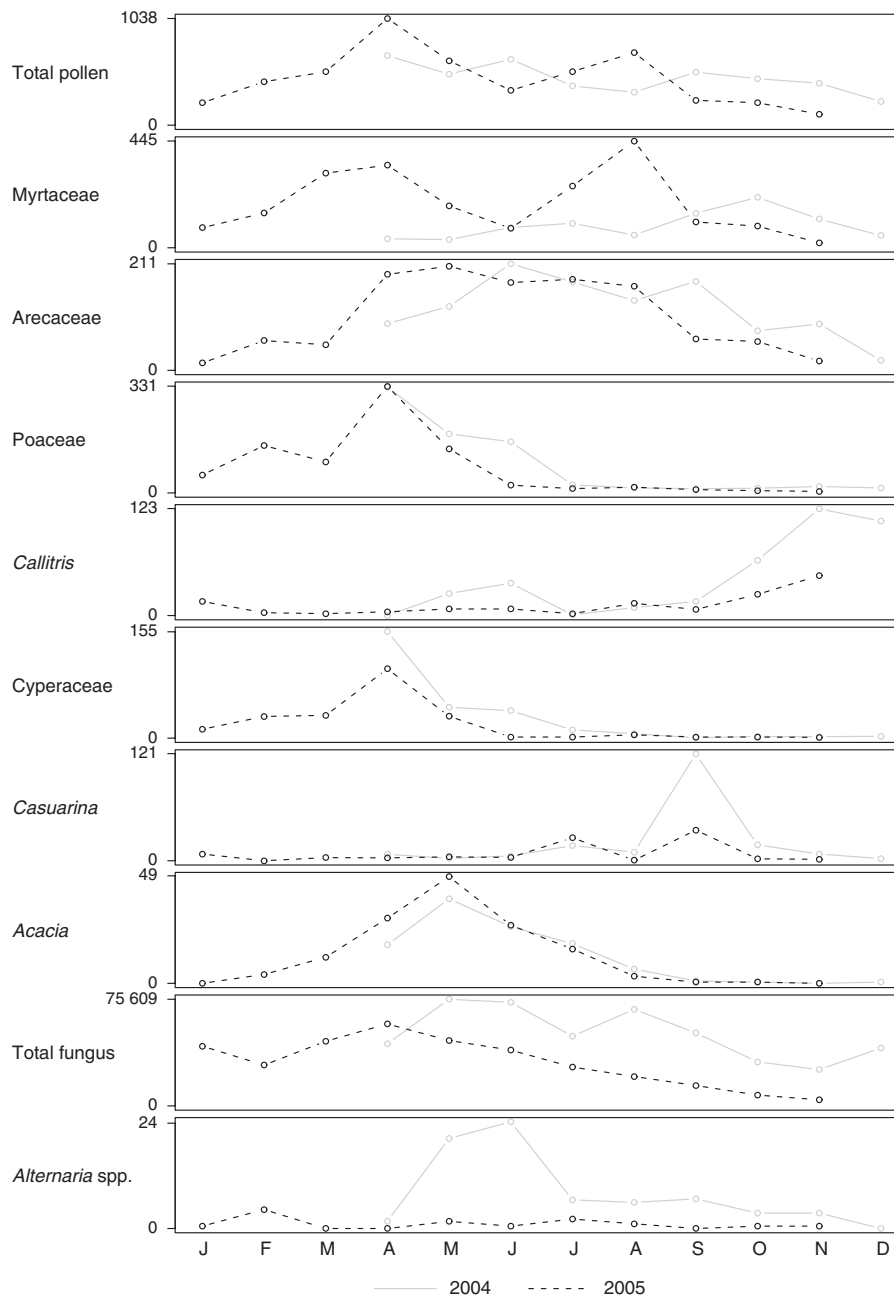


Fig. 2. Seasonal trends in pollen and fungal spore concentrations in Darwin, April 2004–November 2005.

results found that this relationship was unconvincing. Myrtaceae, *Acacia* and Arecaceae showed positive associations that did not attain statistical significance. Addition of thunder to these models did not substantially change the estimated associations or standard errors for asthma admissions.

Chronic obstructive pulmonary disease

A linear relationship was found between total pollen and COPD admissions with a 33.21% increase per IQR rise

(95% CI: 12.82, 57.3). The main individual pollen associated with COPD was Myrtaceae, and the estimated concentration–response relationship was also linear (14.32%, 95% CI: 5.83, 23.5).

Respiratory infections

No associations were observed with ambient aeroallergens in any models. The suggestion of a non-linear relationship between respiratory admissions with total pollen in our GAMs (Fig. 3) was not confirmed by second-stage GLM results.

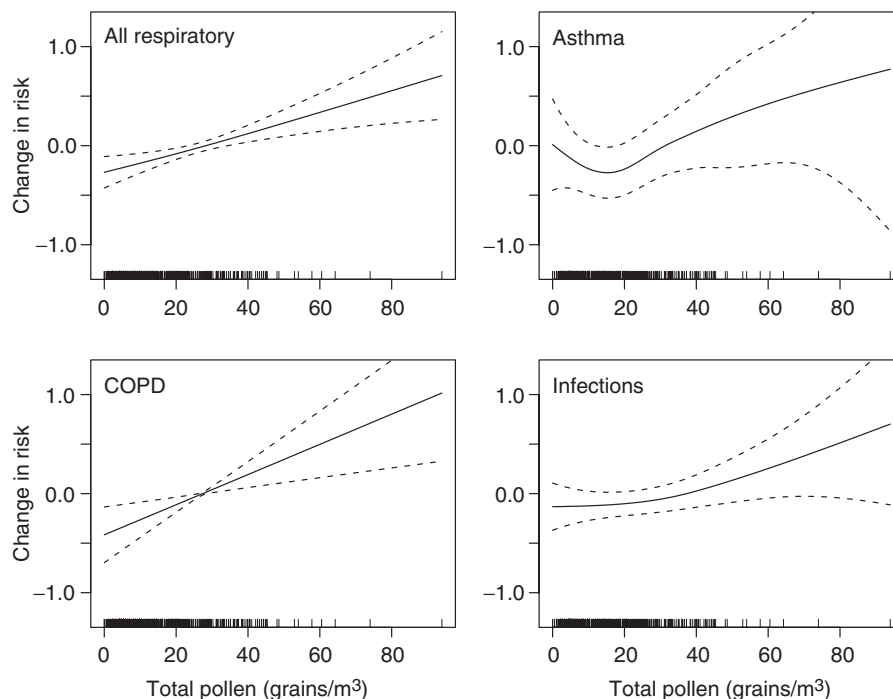


Fig. 3. Estimated concentration–response relationships from generalized additive models of admissions in each disease category with same-day total pollen (grains/m³) for Darwin during April 2004–November 2005. Tick marks on the *x*-axis represent the density of pollen data; dotted lines are 95% confidence intervals for model estimates. COPD, chronic obstructive pulmonary disease.

Discussion

We found that ambient concentrations of total pollen grains were associated with emergency hospital admissions for respiratory diseases. The lack of any associations with fungal spores was a surprising outcome as these exposures have been found to be associated with allergic conditions in other studies [11, 24].

As far as we are aware, this is the only study that has examined the outcome of total respiratory hospital admissions in relation to aeroallergens, as the majority to date have focused on specific diagnoses, particularly asthma. Surprisingly, our association could not be explained by variation in asthma admissions, the clinical group most clearly associated with allergic sensitization. This suggests that aeroallergens might have a wider public health impact than previously recognized [31]. Indeed, one population-based study has found positive associations with pollen concentrations and deaths from cardiovascular disorders, COPD and pneumonia [32]. However, here we are reporting a single small study and our findings require replication.

The lack of any associations with asthma admissions was a counterintuitive finding as this outcome has repeatedly been found to be associated with aeroallergen loads in other studies [9–11]. The most likely explanation for this was the small admission numbers in this group resulting in inadequate power to detect an association.

The association with COPD is consistent with existing evidence, as aeroallergens have previously been found to be associated with reduced peak expiratory flow rates, hospital admissions and mortality in people with COPD [3, 32, 33]. Additionally, there is a clinical overlap between COPD with asthma and an association with aeroallergens could therefore be expected in both groups [34, 35]. The lack of association with respiratory infections was less surprising, although a single study has found associations between pollen counts and deaths due to pneumonia [32].

On examination of different taxa in this study, Myrtaceae pollen (from *Eucalyptus* and *Melaleuca* trees) was the main aeroallergen associated with respiratory admissions in our study. Positive associations were also apparent for the other dominant taxa, particularly Poaceae (grasses), Arecaceae (palms) and Cyperaceae (sedges), although the pollen counts in these groups were smaller and the associations did not attain statistical significance. All the above taxa (except Cyperaceae) have been implicated in allergic disorders in other studies [10, 36–40]. However, our finding of a strong association with Myrtaceae species, which dominate the local floristic communities, supports the hypothesis that allergic reactions to particular types of pollen may be associated with prolonged exposure to the characteristic flora of the area in which the individual resides [14, 40]. Poaceae, although similarly represented in Darwin pollen loads, did not have such a clear association with respiratory admissions. This might

Table 3. Percentage change in relative risk and 95% confidence intervals (CIs) for emergency admissions for each respiratory condition for an inter-quartile range (IQR) change in aeroallergen load for linear responses, and compared with the reference category (0–50th centile) for the non-linear responses (apart from *Alternaria* spp. spores, which were analysed as present or absent)

Outcome	Relationship	Total pollen	Acacia	Areaceae	Callitris	Casuarina	Cyperaceae	Myrtaceae	Poaceae	Total fungal spores	<i>Alternaria</i> spp. spores
All respiratory	Linear	IQR rise 16.91 (8.93, 25.48)	-	-	0.03 (-1.86, 1.96)	-	1.94 (-0.48, 4.41)	6.65 (3.27, 10.14)	4.65 (-1.7, 11.41)	2.7 (-7.62, 14.18)	-
	Non-linear	50–75% -	9.77 (-29.36, 70.57)	13.58 (-3.89, 34.22)	-	-33.8 (-55.93, -0.55)	-	-	-	-	10.66 (-7, 31.68)
	(Reference: 0–50%)	75–90% -	10.3 (-6.4, 29.99)	19.74 (-1.44, 45.46)	-	-3.63 (-17.91, 13.12)	-	-	-	-	-
		90–100% -	8.63 (-13.49, 36.4)	0.5 (-19.8, 25.94)	-	6.64 (-13.43, 31.36)	-	-	-	-	-
Asthma	Linear	IQR rise -	4.16 (-7.73, 17.58)	-	-3.26 (-9.74, 3.68)	0.23 (-3.86, 4.5)	-	5.88 (-2.45, 14.91)	0.77 (-16.75, 21.97)	-	-
	Non-linear	50–75% -	-	-4.44 (-37.67, 46.5)	-	-	-55.73 (-94.7, 269.86)	-	-	-11.3 (-43.74, 39.85)	4.99 (-33.33, 65.32)
	(Reference: 0–50%)	75–90% -	9.35 (-32.21, 76.37)	51.75 (-4.93, 142.23)	-	-	-3.76 (-40.4, 55.39)	-	-	8.57 (-37.11, 87.44)	-
		90–100% -	41.42 (-20.94, 153)	26.53 (-25.96, 116.3)	-	-	-28.09 (-66.58, 54.7)	-	-	5.48 (-51.29, 128.4)	-
COPD	Linear	IQR rise 33.21 (12.82, 57.3)	0.62 (-8.58, 10.75)	-	1.43 (-2.39, 5.39)	-	-	14.32 (5.83, 23.5)	7.09 (-9.16, 26.25)	-	1.02 (-12.42, 16.52)
	Non-linear	50–75% -	-	14.11 (-17.41, 57.66)	-	-45.51 (-77.46, 31.77)	-35.4 (-77.3, 83.84)	-	-	-18.45 (-40.26, 11.32)	-
	(Reference: 0–50%)	75–90% -	-	27.43 (-12.8, 86.21)	-	9.92 (-19.28, 49.67)	26.32 (-8.01, 73.45)	-	-	-13.12 (-39.91, 25.6)	-
		90–100% -	-	22.8 (-19.82, 88.08)	-	-3.34 (-38.78, 52.61)	12.34 (-33.57, 89.96)	-	-	-7.12 (-39.78, 43.25)	-
Infections	Linear	IQR rise -	-	-	0.02 (-2.18, 2.27)	-	1.04 (-2.24, 4.42)	-	4.16 (-4.95, 14.15)	-1.98 (-15.73, 14)	-
	Non-linear	50–75% -	10.74 (-24.18, 21.74)	23.69 (-2.24, 56.51)	-	-26.84 (-57.45, 25.77)	-	-5.38 (-26.2, 21.31)	-	-	6.32 (-17.92, 37.72)
	(Reference: 0–50%)	75–90% -	17.56 (-30.66, 22.52)	5.79 (-20.42, 40.62)	-	-0.79 (-21.14, 24.81)	-	5.3 (-22.17, 42.45)	-	-	-
		90–100% -	11.54 (-28.35, 43.89)	-24.21 (-46.4, 7.18)	-	11.16 (-17.66, 50.08)	-	18.06 (-15.13, 64.24)	-	-	-

COPD, chronic obstructive pulmonary disease.

Bold significant *P*-values < 0.05.

be due to the different allergenicity and composition of species in the taxonomic groups. Additionally, Poaceae loads in our study (although locally abundant) were far lower than those reported in other studies and elsewhere in Australia [22].

The strengths of this study included the availability of hospital admissions data from the single hospital in the region that represent the admissions patterns of the entire population and the detailed aeroallergen data available for analysis. In addition, we were able to use well-established methods for time-series modelling to examine linear and non-linear relationships, and control for confounding by meteorological conditions, air pollution and respiratory viral epidemics.

The main limitation of this study was the small population of Darwin with low daily rates of hospital admissions, particularly for asthma. This led to wide CIs and limits the conclusions that can be drawn from the smaller subgroup analyses of individual taxa and health conditions. Another limitation was that exposure was based on data from a single pollen sampler. While comparison with the second sampler 20 km south indicated that exposure loads were broadly similar across the region, we had no information about how well this sampler reflected the exposure of individuals. Such unavoidable and non-differential misclassification would most likely have biased our results towards the null. Finally, as with many population-level time series studies, our analysis could not investigate the role of individual factors such as age, gender, ethnicity or smoking.

In conclusion, this study has contributed to the small body of literature examining the role of ambient airborne pollens and fungal spores in admissions to hospital for respiratory diseases. Although we found strong linear relationships for same-day total pollens with admissions for total respiratory conditions, and COPD in particular, the study was relatively small and these findings require replication. The public health implications of our findings are potentially large; if such relationships with hospital admissions are borne out, this would be important for clinical practice and public health planning, particularly as the associated morbidity is likely to increase in association with global environmental and social changes.

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