Exposure to bushfire smoke and asthma: an ecological study

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ABSTRACT

Objective: To examine the relationship between the mean daily concentration of respirable particles arising from bushfire smoke and hospital presentations for asthma.

Design and setting: An ecological study conducted in Darwin (Northern Territory, Australia) from 1 April – 31 October 2000, a period characterised by minimal rainfall and almost continuous bushfire activity in the proximate bushland. The exposure variable was the mean atmospheric concentration of particles of 10 microns or less in aerodynamic diameter (PM_{10}) per cubic metre per 24-hour period.

Outcome measure: The daily number of presentations for asthma to the Emergency Department of Royal Darwin Hospital.

Results: There was a significant increase in asthma presentations with each 10-μg/m^3 increase in PM_{10} concentration, even after adjusting for weekly rates of influenza and for weekend or weekday (adjusted rate ratio, 1.20; 95% CI, 1.09–1.34; $P < 0.001$). The strongest effect was seen on days when the PM_{10} was above 40 μg/m^3 (adjusted rate ratio, 2.39; 95% CI, 1.46–3.90), compared with days when PM_{10} levels were less than 10 μg/m^3.

Conclusion: Airborne particulates from bushfires should be considered as injurious to human health as those from other sources. Thus, the control of smoke pollution from bushfires in urban areas presents an additional challenge for managers of fireprone landscapes.

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CONSENSUS IS EMERGING about the adverse health effects of particulate air pollution. A recent report of the Australian National Environment Protection Council (NEPC) suggests that each increase of 10 μg/m^3 in the ambient concentration of respirable particulates is associated with a 3.0% increase in exacerbations of asthma.[1] This estimate was derived from published studies of the health effects of air pollution in large urban settings where particulate pollution originates from motor vehicles, and domestic and industrial sources.[2]

There have been very few studies on exposure to particulate pollution from bushfires. In the United States, after widespread forest fires, there was a 40% increase in patients presenting to hospital with asthma,[3] while, in Singapore, the pollution generated by forest fires in Kalimantan and Sumatra in 1997 was associated with a 19% increase in attendances for asthma.[4] However, in Australia, only one of three studies has supported a link between bushfire smoke and asthma,[5-7] and a further study did not find any clinically significant reduction in peak expiratory flow rates in children with wheeze during a severe bushfire episode.[8] A limitation of all these studies is that they are necessarily based on post-hoc comparisons of asthma presentation rates after an unexpected fire event compared with an "equivalent" historical period. They are thus vulnerable to errors caused by bias, including unmeasurable confounding factors.

The continuous monitoring of levels of airborne particles in Darwin (Northern Territory, Australia) during 2000 provided a unique opportunity to examine the association between airborne particulate concentration and hospital asthma presentations.

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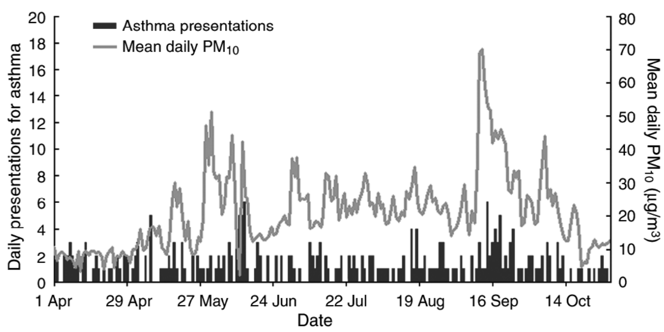
METHODS

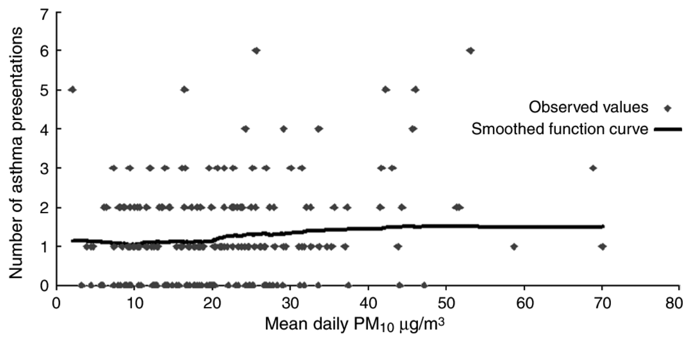
Asthma presentations

The study was conducted in Darwin during the "dry" season from 1 April to 31 October 2000, which is characterised by minimal rainfall and almost continuous bushfire activity in the proximate bushland. The outcome measure was the daily number of presentations for asthma to the Emergency Department of Royal Darwin Hospital (RDH), the main referral centre for the region. All Emergency Department clinical diagnoses are coded according to the classification system of the *International classification of diseases*, 9th revision, clinical modification (ICD-9-CM).[9] We extracted the daily number of cases assigned to codes 493.00 (childhood asthma) and 493.9 (asthma not elsewhere classified). The latter category is used by this database for all types of adult asthma.

1: Daily asthma presentations to the Emergency Department of Royal Darwin Hospital and 24-hour mean PM_{10} concentrations, Darwin, April – October 2000



2: Mean daily PM_{10} concentrations and same-day hospital attendances for asthma, Darwin, April – October 2000



Measurement of exposure variable

The exposure variable was the mean atmospheric concentration of particles of 10 microns or less in aerodynamic diameter per cubic meter (PM_{10}) per 24-hour period. These data were collected at two locations about 7 km apart in the Darwin suburbs of Berrimah and Nakara. At Berrimah the PM_{10} loadings were continuously measured using a tapered element oscillating mass balance, and at Nakara gravimetric mass and airborne PM_{10} lead loadings were determined by filter collections using a Microvol aerosol sampler (Ecotech Pty Ltd, Blackburn, Victoria) with a 10-µm-sized selective inlet. Details of the methods and results of the air quality sampling have been reported separately.[10]

We were confident that the reported particulate levels provided a good estimation of the exposure experienced by most residents of Darwin, as the geographic area is small and there is little spatial variation in air pollution levels. This assumption is supported by the high correlation between measurements of PM_{10} levels from the two sites ($r = 0.89$).[10]

Potential confounding variables

We controlled for the effects of two potential confounding variables.

■ *Acute respiratory infections.* These exacerbate asthma, and are associated with high PM_{10} concentrations[11] and with the winter months.[12] Sentinel general practitioners (GPs) in the Darwin region routinely report the proportion of their consultations meeting a standard clinical case definition of influenza, which, in aggregate, yields weekly presentation rates for influenza-like illness per 1000 general practice consultations.[12]

■ *Weekdays v weekends.* Nearly all fires near Darwin are ignited by people and occur much more frequently on weekends (Mr B Williams, Executive Officer, Bushfires Council of the Northern Territory, personal communication). In addition, presentations to the Emergency Department may be higher on weekends, when there are fewer general practice services available.[13] Thus, it was important to distinguish between weekdays and weekends to avoid overestimating the effect of PM_{10} on asthma presentations.

Statistical analysis

The analysis was conducted in STATA[14] using negative binomial regression, which provides estimates of the rate ratio. Negative binomial regression is used for count data when the counts are overdispersed, making a Poisson model inappropriate, as it would underestimate the variance.[15]

To examine the impact of PM_{10} concentrations on asthma presentations, we fitted PM_{10} as a continuous variable, divided by 10, to test for trend. We categorised PM_{10} as <10 µg/m^3, 10–<20 µg/m^3, 20–<30 µg/m^3, 30–<40 µg/m^3 and $\geqslant 40$ µg/m^3, and fitted additional models with lag times of one, three and five days. For this analysis, we assumed that the denominator (the population of Darwin) remained constant throughout the study period. We also plotted a non-weighted smoothing function of asthma presentations on same-day mean PM_{10} concentrations using the "ksm" command in STATA.[15] We tested for the significance of categorical variables with the likelihood ratio statistic and used the Wald statistic for analysing continuous variables.

RESULTS

Asthma presentations and mean daily PM_{10}

The total number of presentations with asthma during the seven-month study period was 265, with a mean of 1.2 presentations per day (range, 0–6), or 8.5 per week (range, 3–20). The mean daily PM_{10} and number of asthma attendances per day for the study period are shown in Box 1.

The mean daily PM_{10} for the entire study period was 20.84 µg/m^3 (95% CI, 20.30–21.38). The range was 2.0–70.0 µg/m^3. There were two peaks, the first in May and the second in September. The National Environment Protection Council target for maximum mean 24-hour PM_{10} of 50 µg/m^3 was exceeded on a total of six days (a single day in May and five consecutive days in September). The number of days on which the average PM_{10} concentrations were <10, 10–<20, 20–<30, 30–<40 and $\geqslant 40$ µg/m^3 was 39, 74, 65, 20 and 16, respectively.

We tested to see if the relationship between PM_{10} and asthma presentations was non-linear by fitting quadratic, natural logarithmic and square-

3: Rate ratio for asthma presentations, by exposure levels of PM_{10} (μg/m³)

PM_{10} category (μg/m³)	Adjusted rate ratio for asthma presentations* (95% CI)
Current day	
< 10	1.0
10– < 20	0.90 (0.60–1.35)
20– < 30	1.11 (0.74–1.69)
30– < 40	1.18 (0.72–1.97)
⩾ 40	2.39 (1.46–3.90)
Lag time 1 day	
< 10	1.0
10– < 20	0.84 (0.56–1.25)
20– < 30	0.97 (0.64–1.46)
30– < 40	1.03 (0.62–1.73)
⩾ 40	2.04 (1.25–3.34)
Lag time 3 days	
< 10	1.0
10– < 20	0.78 (0.52–1.15)
20– < 30	0.92 (0.61–1.39)
30– < 40	0.78 (0.45–1.33)
⩾ 40	1.92 (1.19–3.09)
Lag time 5 days	
< 10	1.0
10– < 20	1.13 (0.76–1.69)
20– < 30	1.06 (0.71–1.60)
30– < 40	1.60 (1.00–2.61)
⩾ 40	2.56 (1.60–4.09)

*Adjusted for the confounding effects of influenza-like illness (weekly rate) and day of the week (weekend v weekday).

root functions; however, the linear function fitted best with the data. Test for trend showed there was a significant increase in asthma presentations with each 10-μg/m³ increase in PM_{10} (rate ratio, 1.18; 95% CI, 1.08–1.31; $P < 0.001$), an effect that remained unchanged when we adjusted for weekly rates of influenza and for weekday versus weekend (rate ratio, 1.20; 95% CI, 1.09–1.34; $P < 0.001$).

Box 2 shows the scatter plot of mean daily PM_{10} concentrations and asthma presentations and a smoothed function curve. This suggests that the relationship between asthma and mean PM_{10} was flat until a PM_{10} of 20 μg/m³, when it started to increase in a linear fashion before flattening again at higher concentrations. More data are required to explore whether 20 μg/m³ represents a real threshold.

PM_{10} category and rate ratio for asthma presentations

Box 3 shows the results of the analysis of asthma presentations and particulate exposure levels for same-day PM_{10} concentrations, and after lag times of one, three and five days, by PM_{10} category. Only when the PM_{10} concentration was greater than or equal to 40 μg/m³ was there a statistically significant increase in the risk of asthma when compared with the baseline category of less than 10 μg/m³ (rate ratio, 2.21; 95% CI, 1.40–3.52) for same-day PM_{10} concentrations. This remained significant after adjusting for day of week and weekly rates of influenza (adjusted rate ratio, 2.39; 95% CI, 1.46–3.90).

We also fitted a model with six categories, including 40–<50 and ⩾50 μg/m³, but these did not improve the model fit and we found similar adjusted incidence rate ratios for the categories of >40–50 μg/m³ (incidence rate ratio, 2.32; 95% CI, 1.32–4.02) and ⩾50 μg/m³ (incidence rate ratio, 2.50; 95% CI, 1.28–4.91). The strongest effect for PM_{10} was found for analysis of PM_{10} concentrations ⩾40 μg/m³ after a lag time of five days. These were similar to the rate ratios for same-day exposures and asthma presentations, and slightly higher than the rate ratios associated with intervening lag times.

DISCUSSION

The positive association between PM_{10} and asthma presentations we demonstrated is supported by recent large reviews of both epidemiological and biological studies,[16-19] but the association between asthma and particulates we found was stronger than previously reported. We also observed a much greater association with presentations for asthma when the mean daily PM_{10} was above 40 μg/m³. Further studies are needed to determine whether a threshold is present at this or lower PM_{10} concentrations, as this has implications for setting air quality targets.

Measuring exposure to and outcomes of bushfire particulate pollution in Darwin provides a number of advantages.

- Darwin has no significant source of atmospheric air pollution other than bushfires.[10]
- The reliability of exposure measurement is enhanced by the region's highly predictable dry-season climate, characterised by steady south-easterly winds, negligible rainfall, low atmospheric humidity, and consistently high air temperatures.[20] Bushfires occur annually throughout the dry season, providing a continuous background of smoke pollution, with peaks and troughs over several months.
- Smoke particles are trapped by a temperature inversion at about 3000 m altitude, producing regionally widespread and persistent haze (Mr J Arthur, Chief Meteorologist, Darwin Bureau of Meteorology, personal communication).
- Darwin has a relatively small population, with a mid-year estimate of about 115 000 people (2000 mid-year estimate of the Epidemiology Branch, Northern Territory Department of Health and Community Services) served by a single major hospital (Royal Darwin Hospital) with systematic data collection systems.

We do not believe that our findings can readily be explained by bias or confounding effects, but recognise our study's limitations. Firstly, in keeping with an ecological study design, we did not have information about individual patients, such as duration of exposure, lifestyle factors, or age. Secondly, we were unable to adjust for pollen or mould levels, which are important environmental precipitants of asthma, as these are not routinely measured in Darwin. However, it is extremely unlikely that fires and atmospheric concentrations of these biological particles are systematically related to smoke levels. Nearly all the fires are, for a range of motives, started by people. Finally, the outcome data may have been biased by under-reporting and misclassification, but these errors would be independent of PM_{10} levels and the resulting bias would be in the direction of a null effect.

We conclude that airborne particulates from bushfires should be considered as equally injurious to human health as those from other sources. Thus, the control of smoke pollution from bushfires near urban areas presents an additional challenge for managers of fireprone landscapes.[21]

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COMPETING INTERESTS

None declared.

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