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Short Communications

Wildfire Smoke, Fire Management, and Human Health

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Abstract: Burning landscapes under controlled conditions to reduce the risk of wildfires is a controversial land management practice. The health risks of smoke generated from controlled burning relative to wildfire remain uncertain. Recent work in the Australian monsoon tropics provided a unique opportunity to study the health effects of smoke pollution at and well below national air quality standards. It found that for each increase in the atmospheric mass of particles 10 μg or less in aerodynamic diameter (PM_{10}) per cubic meter of air per 24-hour period, there was a 26% increase in daily asthma presentations to the emergency department of the Royal Darwin Hospital, with an apparent threshold at 40 $\mu g/m^3$ PM_{10} (lower than the Australian PM_{10} air quality standard of 50 $\mu g/m^3$). This finding was unaffected by adjusting for weekly rates of influenza, weekday vs. weekends, and school holiday periods. Although further research is being undertaken to substantiate these findings, the upshot of the study suggests that for airsheds containing large human populations, fire managers should strive to keep smoke pollution less than 40 $\mu g/m^3$ PM_{10}.

Key words: biomass burning, carbon particulates, epidemiology, fire management, human health, landscape ecology

Introduction

Wildfire management involves many ecologic and social trade-offs (Gonzalez-Caban, 1997). Burning landscapes under controlled conditions to reduce fuel loads and, thereby, to minimize the frequency and severity of wildfires is a controversial type of landscape management. A particularly problematic aspect of this land management intervention concerns the health effects of smoke pollution from frequent, controlled landscape fires vs. severe smoke pollution from infrequent, uncontrolled wildfires (Schwela, 2001; Lewis and Corbett, 2002; Sim, 2002). It has been recently suggested that particulates derived from wood smoke might be more injurious to human health (Boman et al., 2003) than particulates derived from other sources that are also known to cause ill health (Vedal and McClellan, 2002; Katsouyanni, 2003). Despite this knowledge base, there is a rudimentary understanding of the health effects of wildfire smoke on human health (Table 1). Consequently, land managers and health professionals are operating in a policy vacuum with little to guide them beyond existing national air quality standards. For example, the U.S. Environmental Protection Agency (1998) produced an interim policy for the management of wildfire management that promoted the "thoughtful use of fire by all wildland owners and managers while mitigating the impacts of emissions on air quality and visibility." In this

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Table 1. Summary of Previous Epidemiologic Studies of Wildfire Smoke and Human Health

Location and year	Finding	Reference
Darwin, Australia 2000	Increased hospital attendances for asthma (160%) when PM_{10} >40 μm/m^3	Johnston et al. (2002a)
California 1999	Increased clinic attendances (52%) and respiratory symptoms (63%) during haze episodes; greater in those with preexisting heart or lung conditions	Mott et al. (2002)
Florida 1998	Increased hospital attendances for asthma (91%), COPD (132%), and chest pain (37%) during days of smoke haze	Centers for Disease Control and Prevention (1999)
Sarawak, Malaysia 1997	Increased admissions for asthma and COPD (range, 20–80%) in 2-month period in which PM_{10} continuously exceeded 150 μg/m^3	Mott et al. (2003)
Malaysia 1997	Increased all-cause mortality of 7% with each 100-μg increase in PM_{10}; effect greater in ages <1 and >65 y	Sastry (2002)
Singapore 1997	Increased outpatient attendances for asthma (19%) and upper respiratory conditions (38%) with increase in PM_{10} from 50 to 150 μg/m^3; no effect on admissions or mortality	Emmanuel (2000)
Sydney, Australia 1994	No relationship identified between peak expiratory flow rates in children with wheeze and PM_{10}	Jalaludin et al. (2000)
Sydney, Australia 1994	No association between hospital attendances for asthma documented and days of smoke haze	Cooper (1994)
Sydney, Australia 1994	No association between hospital attendances for asthma and PM_{10}	Smith et al. (1996)
Sydney, Australia 1991	Increased hospital attendances for asthma during smoke haze period but no association between daily attendances and nephelometry	Churches and Corbett (1994)
California 1991	Many hospital attendances for respiratory conditions on the days of the fire; no comparison period reported	Schusterman et al. (1993)
California 1987	Increased hospital attendances for asthma (30%) and COPD (40%) on days of fire activity	Duclos et al. (1990)

COPD, chronic obstructive pulmonary disease.

context, the work of Johnston et al. (2002a) is very significant to the ongoing policy debate concerning fire management and air quality because, unlike all previous studies, they were able to study the effect of a wide range of smoke pollution levels at and well below national air quality standards.

Temporal Patterns in Asthma and Wildfire Smoke

Johnston et al. (2002a) undertook a correlative analysis of atmospheric pollution and asthma in the isolated coastal tropical city of Darwin, situated in the vast savannas of the Australian monsoon tropics (Fig. 1). The study was conducted during the 7-month rain-free dry season in 2000. There are a number of advantages for the study of human health effects of wildfire smoke in Darwin: 1) there is no significant source of atmospheric air pollution other than particulates derived from wildfires (CSIRO Atmospheric Research, 2001); 2) during the dry season, the lower atmosphere is stable, with little convective mixing and a persistent inversion at approximately 3000 m (Kondo et al., 2003), allowing reliability of exposure measurement within the geographic area (CSIRO Atmospheric Research, 2001); 3) there is a small population of approximately 115,000 and a single major hospital that has systematic data collection systems in place; and 4) wildfires occur in the Darwin re-

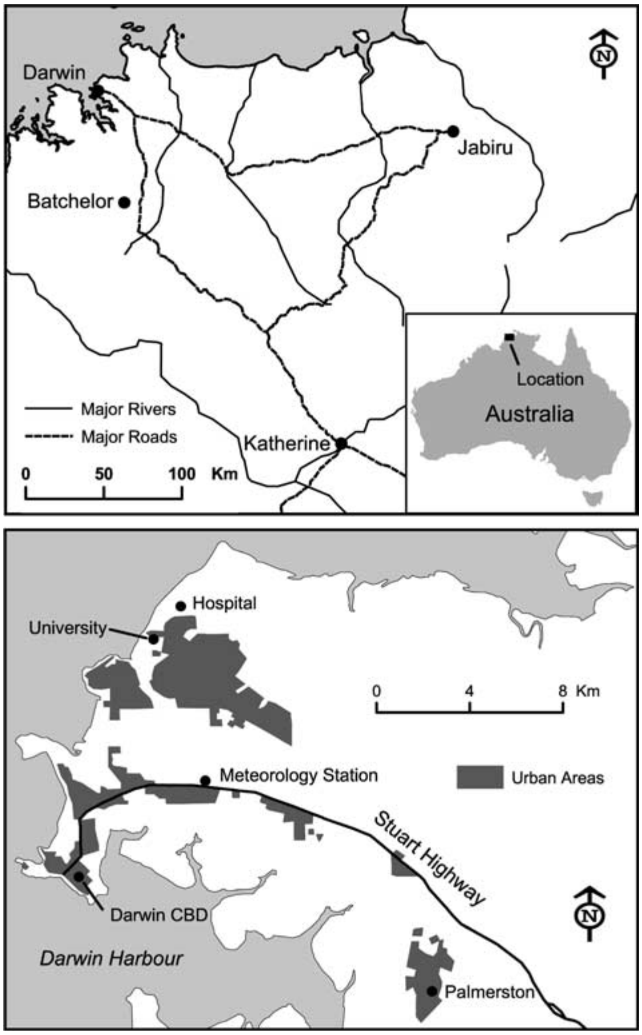

Figure 1. The location of the Australian city of Darwin and other regional population centers. Also shown is the extent of the urban area within Darwin and the location of the university and the meteorology station where PM_{10} (atmospheric mass of particles 10 μg or less in aerodynamic diameter per cubic meter of air) levels were measured. PM_{10} loadings were continuously measured by using a tapered element oscillating mass balance at the university, and gravimetric mass loadings were measured at the meteorology station. Determinations from the two sites were highly correlated ($r = 0.89$; CSIRO Atmospheric Research, 2001).

gion throughout every dry season (e.g., Edwards et al., 2001), thereby providing a continuous background of smoke pollution with peaks and troughs over several months.

Smoke pollution was measured as PM_{10} (atmospheric mass of particles 10 μg or less in aerodynamic diameter per cubic meter of air) averaged over a 24-hour period at two locations within the city of Darwin; this provided a reliable measure of exposure of the city's population (Fig. 1). For each day of the study, the number of asthma presentations to the emergency department of the Royal Darwin Hospital was determined by interrogating the electronic emergency department register, which was coded according to a subset of the *International Classification of Diseases*, version 9, codebook. The two codes used for asthma presentations were 493.00 (childhood asthma) and 493.9 (asthma not elsewhere classified), which was used to code all types of adult asthma.

Table 2. Rate Ratio and Confidence Intervals of Asthma Presentations and Exposure Levels of PM_{10} after a Negative Binomial Regression

PM_{10} category (μg/m^3)[a]	Rate ratio	95% CI
0 to <10	1.0	Reference category
10 to <20	0.84	0.43–1.63
20 to < 30	1.13	0.58–2.19
30 to <40	1.21	0.58–2.51
40 to <50	2.39	1.13–5.05
≥ 50	2.62	1.13–6.07

PM_{10}, atmospheric mass of particles 10 μg or less in aerodynamic diameter per cubic meter of air; CI, confidence interval.

[a]PM_{10} levels were classified into the following six categories: 1) <10 μg/m^3, 2) 10 to <20 μg/m^3, 3) 20 to <30 μg/m^3, 4) 30 to <40 μg/m^3, 5) 40 to <50 μg/m^3, and 6) ≥50 μg/m^3. The rate ratio was adjusted for the confounding effects of influenza-like illness (weekly rate), school holiday periods, and day of the week (weekend vs. weekday; likelihood ratio test, 16.32; $df = 4$; $P = 0.003$). By comparison, the linear model that assumes no threshold had an adjusted rate ratio of 1.26 for each increase in PM_{10} of 10 μg/m^3 (95% CI, 1.12–1.41; $P < 0.001$).

Johnston et al. (2002a, b) demonstrated a significant relationship of asthma presentations with increasing PM_{10} concentrations by using negative binomial regression and controlling for potential confounders known to be coincident with fire activity and potentially influencing asthma presentations to hospital, including weekend and holiday periods and the incidence of influenza-like illness, a well-known precipitant of asthma (Cohen and Castro, 2003). They showed that when the PM_{10} data were analyzed as a continuous variable, there was a significant increase in asthma presentations with each 10 μg/m^3 increase in PM_{10}. However, when the PM_{10} data were aggregated into 10 μg/m^3 PM_{10} classes, the modeling revealed a threshold at 40 μg/m^3, where the risk of asthma increased 2.6 times relative to the baseline category of less than 10 μg/m^3 (Table 2).

Time series has been the predominant and orthodox approach for longitudinal studies of air pollution at a number of urban loci and is used to overcome the effects of autocorrelation due to seasonality, weather fluctuations, and long-term trends or cycles (Jalaludin et al., 2002).

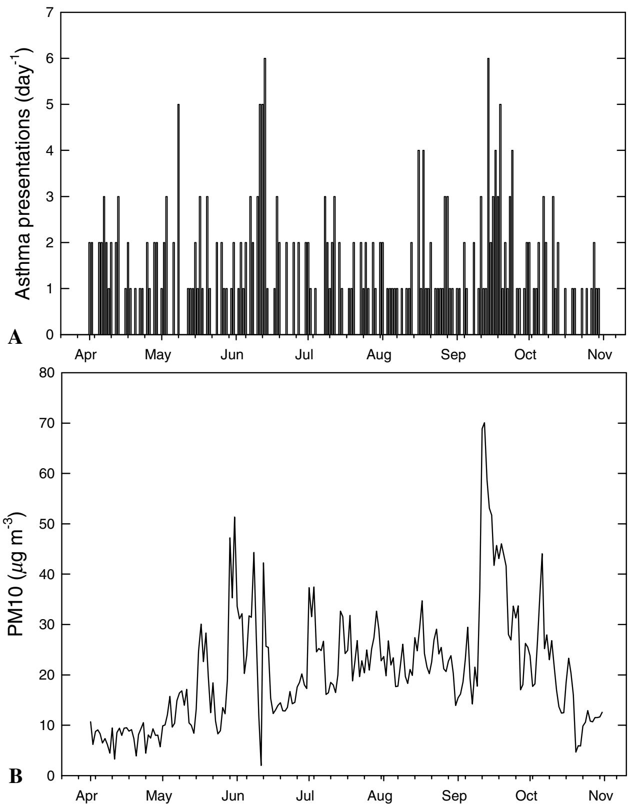

Figure 2. Daily asthma presentations to the emergency department of the Royal Darwin Hospital and 24-hour mean concentration of atmospheric particles (PM_{10}) measured at two locations in the city of Darwin from April 1 to October 31, 2000. With autoregressive integrated moving average (ARIMA) analysis, the highest partial autocorrelation coefficient for asthma presentations was 0.13 at 1 day, with no trends or cycles in the data. The mean daily PM_{10} for the entire study period was 20.84 μg/m^3, and it ranged from 2.0 to 70.0 μg/m^3. The observed PM_{10} levels are representative of the regional setting, because Vanderzalm et al. (2003) found similar levels of carbon particles at Jabiru (Fig. 1) in the dry season of 1996.

Reanalysis of Johnston and associates' original data to test for temporal autocorrelation (by using autoregressive integrated moving average autoregressive integrated moving average (ARIMA) modeling) indicated that their original analysis was robust: there was no evidence of temporal autocorrelation in asthma presentations or any obvious trend or cycle in the data (Fig. 2).

The Nexus between Human and Landscape Health

A manifestation of global environmental change is the worldwide increase in the severity and frequency of wildfires (Schwela, 2001). Because of the effects of wildfires on human populations, there is an increasing need to consider this problem in a holistic manner, including understanding the effect of both wildfires and prescribed fires on human health and landscape ecology. Demonstrating a health effect of wildfires presents numerous practical and technical challenges because of the infrequency of fire events and the large number of potential confounders that make it difficult to distinguish the epidemiologic "signal" from the background "noise."

The Johnston et al. (2002a) study represents an advance in this field because it examined temporal variation in smoke pollution over 7 months of continuous exposure rather than using a more usual retrospective design comparing an unexpected fire event with an "equivalent" period without wildfire (Table 1). The finding that asthma hospital presentation more than doubled at more than 40 μg/m^3 PM_{10} is potentially of great significance for fire management, because this is below currently accepted Australian air quality standards (i.e., <50 μg/m^3 PM_{10}). Furthermore, this threshold was rarely exceeded by fires in the early and mid dry season, most of which were deliberately lit to reduce fuel loads. This observation lends support to the idea that well-managed controlled burning programs may, for asthma, have negligible public health effects relative to uncontrolled fires that cause severe pollution (Table 1).

It must be stressed that the 40 μg/m^3 PM_{10} threshold detected by Johnston et al. (2002a) may be a statistical anomaly, given that it is inconsistent with previous studies of health effects of particulates. To resolve this question, we are exploiting the unique opportunity presented by Darwin to undertake a more comprehensive epidemiologic study of the associations between wildfire smoke and health. This study includes measures of particulate pollution measured as PM_{10} and $PM_{2.5}$, spores and pollens, meteorologic conditions, day of the week, and school holiday time periods. In contrast to previous study designs, we are examining multiple health outcomes, including tracking the response of a cohort of patients with asthma to varying levels of wildfire smoke exposure by recording their daily symptoms, medication use, and health service attendances for asthma. Additionally, for the city of Darwin, we are tracking hospital attendances for heart and lung diseases (including asthma, chronic obstructive pulmonary disease, and ischemic heart disease) and family physician presentations for rhinitis and flu-like illness. To understand the interactive effect of meteorologic conditions and the geographic location of fires on smoke pollution levels in Darwin, we are undertaking landscape ecology studies by using moderate resolution imaging spectroradiometer satellite imagery to locate active wildfires and by using a geographic information system and dynamic atmospheric modeling to map smoke dispersion from them (Draxler and Hess, 1998). Such ambitious joint landscape ecology and epidemiologic perspectives are crucial in the quest for sustainable fire management practices for a variety of reasons, including building a bridge between the presently segregated professions of fire management and public health; providing urban dwellers with a direct stake in fire management; and providing specific, evidence-based, and measurable air quality targets for fire managers.

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