IMPACT OF PRESCRIBED FIRE SMOKE ON DOWNWIND COMMUNITIES

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Abstract

Prescribed fires are conducted each year across Australia for fuel management and/or ecological reasons. In some regions, during the period of intensive prescribed burning, large quantities of hazardous air contaminants may be emitted and may exceed urban air quality guidelines. The impact on community health will depend on what hazardous pollutants the population is exposed to, the levels of exposures and the potential for such exposures to cause adverse health effects among the community.

The paper will discuss findings from a review of Australian and international literature regarding implications of exposure to bushfire smoke 'air toxics' on community health. Most studies have been on large fires, whether accidental or during forest clearing activities, with little to no research on community health and air toxics exposures downwind of prescribed fires. The review has shown that the primary pollutant consistently exceeding air quality guidelines downwind of large bushfires was particulate matter, but it also highlighted that there is clearly a need to further investigate the effects of bushfire on public health. Some of the issues to be addressed include

- Monitoring the seasonal exposure of communities to hazardous pollutants released during prescribed burning activities and determining major factors that influence exposure levels
- Assessing the health implications of such exposures, especially in relation to existing (urban) air quality measures or by developing a bushfire air quality index as a tool for better risk management.

Introduction

Bushfires, both accidental and planned, occur each year in many parts of the world. These bushfires can range from small-scale to large-scale, can burn for hours or weeks, and can release substantial quantities of hazardous air contaminants ('air toxics') into the air environments of communities. In Australia, the practice is to conduct fuel reduction burns during spring and autumn to remove fine, flammable fuels and thereby reduce the severity of unplanned fires. During the period of intensive burning activities, bushfire smoke can travel substantial distances to surrounding rural towns, resulting in regular annual exposures to rural communities. The impact on community health will depend on *what* hazardous pollutants the communities are exposed to, the *levels of exposure* to these pollutants, and whether *adverse health effects* are likely to occur in the *populations exposed*.

While much data are available on urban exposures to hazardous pollutants, there is currently a lack of measurements of these pollutants in rural areas. Rural communities undergo seasonal exposures to toxic air pollutants as a result of prescribed burns, but little is known of the levels of exposure that occur and potential adverse health impacts. This review will present findings on community exposures downwind from major bushfire events, and will consider exposure assessment, health impacts and exposure criteria.

Community Exposure Standards and Guidelines for Urban Air Pollutants

It is well known that urban communities are exposed to a range of air pollutants associated with urban activities, especially automobile exhausts. Regulations to control these exposures exist in Australia and most developed countries for what are termed 'criteria pollutants'. In Australia, these are applied as National Environmental Protection Measures (NEPMs) for ambient air quality, aimed at protecting the *health and well-being* of urban populations, as summarised in Table 1 (National Environmental Protection Council 2003). In Australia, the current ambient air NEPMs (24-hour) are 50 $\mu g/m^3$ for PM_{10} (particulate matter with aerodynamic diameter less than 10 μm) and 25 $\mu g/m^3$ for $PM_{2.5}$ (particulate matter with aerodynamic diameter less than 2.5 μm). It will be shown later in this review that such levels are often greatly exceeded for communities living downwind of large bushfires, though *it is unknown whether urban particles and bushfire smoke have equivalent health impacts at these exposures*.

Bushfire Emissions and Effects on Community Health

During bushfires, a wide range of air contaminants are released, which may cause adverse health effects if communities are exposed to elevated concentrations for extended periods. Air toxics in bushfire smoke are present in both the particle and gaseous phases, and include respirable particles, carbon monoxide (CO), carbon dioxide, nitrogen- and sulfur-based compounds, aldehydes, volatile and semi-volatile organic compounds (VOCs and SVOCs), polycyclic aromatic hydrocarbons (PAHs), dioxins, organic acids, free radicals and ozone (O_3) (Brauer 1999; Fujiwara *et al.* 1999; Malilay 1999; Ward 1999).

Table 1: National Environmental Protection Measures (NEPMs) for ambient air quality

Air contaminant	Average period	Maximum concentration	Maximum allowable exceedances
Carbon monoxide	8 hours	9.0 ppm	1 day per year
Nitrogen dioxide	1 hour	0.12 ppm	1 day per year
	1 year	0.03 ppm	None
Photochemical oxidant	1 hour	0.10 ppm	1 day per year
(as ozone)	4 hours	0.08 ppm	1 day per year
Sulfur dioxide	1 hour	0.2 ppm	1 day per year
	1 day	0.08 ppm	1 day per year
	1 year	0.02 ppm	None
Lead	1 year	0.5 $\mu g/m^3$	None
Particles as PM_{10}	1 day	50 $\mu g/m^3$	5 days per year
Particles as $PM_{2.5}$	1 day	25 $\mu g/m^3$	Gather sufficient data for review in 2005
	1 year	8 $\mu g/m^3$	
Benzene	1 year	0.003 ppm	Gather sufficient data to develop standard in 2009
Toluene	1 day	1.0 ppm	Gather sufficient data to develop standard in 2009
	1 year	0.10 ppm	
Xylenes	1 day	0.25 ppm	Gather sufficient data to develop standard in 2009
	1 year	0.20 ppm	
Formaldehyde	1 day	0.04 ppm	Gather sufficient data to develop standard in 2009
Benzo(a)pyrene	1 year	0.3 ng/m^3	Gather sufficient data to develop standard in 2009

Many studies have investigated the relationship between bushfire smoke exposure to downwind communities and a range of health outcomes such as mortality records, hospital admissions, emergency department visits for asthma or pulmonary disease, asthma exacerbation, change in lung function, increase of cardiopulmonary symptoms (coughing, wheezing, shortness of breath, angina), upper respiratory illness, as well as mucous membrane irritation. These studies relied primarily on hospital-based records (e.g. number of emergency department visits and hospital admissions during bushfire episodes), but very few community-based studies (e.g. epidemiological studies of communities) were conducted other than community surveys. Furthermore the majority of the studies focused on particulate matter, which was the primary pollutant that consistently exceeded air quality guidelines. This is a significant finding, since fine particles in urban air (not from bushfires) have been found to impact the health of urban communities. A summary of the reviewed studies is presented in Table 2.

The studies show several consistent findings:

- Bushfires generated large amounts of particulate matter, especially respirable particles, which greatly exceeded air quality standards. Maximum daily PM_{10} were recorded at approximately 200–1000 $\mu g/m^3$; any daily PM_{10} above 100–200 $\mu g/m^3$ was considered a high pollution episode.
- Other criteria pollutants (O_3, NO_x, SO_2 and CO) may have increased, but generally stayed within the health-based environmental standards. Elevated levels of CO and PAHs were observed in Indonesia during the 1997 fires (Kunii 1999; Aditama 2000; Kunii *et al.* 2002).
- Adverse health impacts were observed for all smoke exposures, except in two studies in suburban Sydney (Cooper *et al.* 1994; Smith *et al.* 1996). The health impacts were most severe for the Southeast Asian fires that involved the highest PM levels and the longest exposure periods.
- Adverse health impacts were found for: mortality rates in some studies; hospital and emergency department admissions for asthma or pulmonary disease; asthma exacerbation; reduced lung function; increase of cardiopulmonary symptoms (coughing, wheezing, shortness of breath, heart problems); upper respiratory illness; and mucous membrane irritation. Usually the observed health impacts were linked to PM levels on the basis of their high elevation compared to health-based environmental exposure standards.
- Within the significant limitations of different fire types, fire durations and PM measurements presented above, significant health effects were observed at levels that greatly exceed the current Australian one-day NEPMs for

PM_{10} and $PM_{2.5}$ of 50 and 25 μg/m^3, respectively. No data are available to confirm the adequacy of these standards for the protection of communities exposed to bushfire smoke.

- Indoor levels of fine particles varied little from outdoor levels downwind of the bushfires (Kunii *et al.* 2002; Radojevic 2003; Sapkota *et al.* 2005), indicating that deposition losses of smoke particles to building surfaces were small and resulted in little improvement of protection from bushfire smoke.

Table 2. Studies of PM exposures and health impacts on communities downwind of bushfires

	Air Toxics (Units PM [μg/m^3])	Increased health effects [A]	Reference
United States	Max. PM_{10} >150	A, COPD	Duclos *et al.* 1990
	Not measured	Bronchospastic and irritative reactions	Shusterman *et al.* 1993
	Not measured	A, B, chest pain	US Centers for Disease Control and Prevention 1999
	PM_{10} max. >1000, 16 day >150, 2 day >500	A, COPD and RD	Mott and Meyer 2000; Mott *et al.* 2002
	$PM_{2.5}$ max., ave. >65, no increases for PAHs and benzene; CO below std	RD, H	Ward and Smith 2001; Bible 2002
	$PM_{2.5}$ 63; CO 1 ppm	Worsening symptoms in 21 COPD	Sutherland *et al.* 2005
	$PM_{2.5}$ max. 90–200	Not measured	Sapkota *et al.* 2005
	PM_{10} max. 215; increases for CO and NO, but not for NO_2 and O_3	Not measured	Phuleria *et al.* 2005
Australia	Nephelometer readings	A	Churches 1991
	PM_{10} max. 250, median 18; no difference for O_3 and NO_2	No increase in A or RD	Cooper *et al.* 1994; Smith *et al.* 1996
	PM_{10} max. 210	Peak exp. flow rates in children (wheeze), no change	Jalaludin *et al.* 2000
	Max. $PM_{2.5}$ 70	A esp when $PM_{2.5}$ > 40	Johnston *et al.* 2002
Southeast Asia	PM_{10} max. 1800; CO very unhealthful; SO_2, NO_2 and O_3 good to moderate; increase in PAHs	A, RI, RD, pneumonia and worsening of respiratory symptoms, mortality (resp. failure)	Kunii 1999; Aditama 2000; Frankenberg *et al.* 2002; Kunii *et al.* 2002
	PM_{10} max. 930; High poll. day when PM_{10} >210	A, RI, RD, COPD (>65 yo); elderly and people with A had larger effect; mortality (>65 yo); decreased lung function among school children	Brauer and Hisham-Hashim 1998; Hisham-Hashim *et al.* 1998; WHO 1998; Awang *et al.* 2000; Sastry 2000; Mott *et al.* 2005
	PM_{10} range 44–60	A (<12 yo) correlated with PM_{10}; higher frequency of asthmatic attacks	Chew *et al.* 1995; Chia *et al.* 1995
	PM_{10} doubled to 60–100; slight increase for CO, NO_2 and O_3; no change for SO_2	A, R; mortality, no change	Emmanuel 2000
	Monthly PM_{10} increased from 48 to 69; max. daily 218; no change for NO_2 and SO_2	RD, B, COPD, A	Phonboon *et al.* 1999
	PM_{10} max. 1000; avg 110; no change for NO, NO_2 and O_3; SO_2, 4x increase; CO, 10x increase	Higher freq. of adverse health impacts for 1–5 yo, >60 yo and outdoor workers	Muraleedharan *et al.* 2000; Odihi 2001; Radojevic 2003

[A] Increased medical incidences of asthma (A), respiratory disease (RD), respiratory infection (RI), heart (H), chronic obstructive pulmonary disease (COPD), bronchitis (B) and rhinitis (R)

While many studies found that the levels of fine particulate matter were consistently and highly elevated downwind of bushfires, levels of other pollutants often varied little from baseline levels in urban areas, or showed increases that were much lower than health-based environmental standards. This difference is considered to reflect the different yields of pollutants, their dispersion in buoyant plumes and by meteorological effects over large distances, and the different environmental standards for pollutants. Smoke particles have a high yield in combustion and a (numerically) low environmental standard has been set to protect the general population from adverse health effects of urban particles. While bushfire smoke and urban particles have similar sizes, there may be significant differences in the constituents attached to the particles and their interaction with other pollutant species present in the smoke, and therefore they may affect community health differently. The studies reviewed above certainly identify similar morbidity impacts for urban particulates and bushfire smoke, and there is limited evidence for similar mortality effects, but *the exposure and health impacts are poorly quantified for bushfire smoke*. An environmental standard specific to bushfire smoke particles may be more appropriate.

Community Response to Bushfire Air Toxics

Communities can react in different ways to bushfire smoke to reduce their levels of exposure to air toxics. Government bodies may advise them to wear respiratory protection, to reduce physical exertion and to remain indoors. In response to fire danger, they may be advised (or required) to evacuate an area, though Australian fire agencies generally recommend home occupants remain under a 'stay or go' plan, where they either leave early or stay if well prepared to protect themselves and their homes. Assuming that home occupants stay in the bushfire smoke, their options to reduce air toxics exposures are:

- *Wear a respirator with a suitable protection factor* for the levels of air toxics, a strategy which was adopted in Malaysia (Hisham-Hashim *et al.* 1998). Assuming from this review that fine particle exposures are the primary concern, a particle respirator with a 10-fold protection factor would reduce exposure to one-tenth of the smoke levels. This level of protection has been selected since it is the maximum that can be provided by half-face respirators that are moderately comfortable to wear (Standards Australia and Standards New Zealand 1994)
- *Stay indoors with external doors and windows shut*. The basis for this recommendation is that short-term peak smoke levels will be avoided, and that particulate matter is partially deposited to surfaces as it enters a building with ventilation air (a loss we estimate to be ~20%). Note that recent research in Canadian communities downwind of bushfires determined a median indoor-to-outdoor pollutant concentration ratio of 0.91, indicating that staying indoors did not protect people from smoke exposure (Sapkota *et al.* 2005).

During the Southeast Asian fires, a Pollutant Standards Index (PSI) from the USA was used to characterize smoke haze events, which takes into account the five criteria pollutants (PM_{10}, CO, NO_2, SO_2 and O_3). PSI levels above 100 indicate that the ambient concentrations exceed at least one of the air quality standards and triggers preventative action by government, which could include health advice warnings. However the PSI ignores many of the air toxics of Table 1 that may be present in bushfire smoke, limiting the applicability of this index for bushfire haze episodes. A broader index may be appropriate for bushfire smoke.

Conclusions

More detail of each of these studies is presented elsewhere (Reisen and Brown 2006) but significant observations on further research needs are presented here. The studies in this review covered major bushfire events, predominantly overseas. They have shown that bushfire smoke consistently caused respirable particle levels in downwind communities to exceed ambient air quality standards, and that this was generally considered to be the primary factor in the adverse health effects observed in communities. However, assigning the health effects to particles assumes bushfire particles and urban air particles have similar health impacts and standards. Exposures to CO, NO_2, SO_2 or O_3 were increased in bushfire smoke, but not often above standards. Overall, little attention was given to the impact of PAHs, VOCs and aldehydes on community health and to the potential for interactive effects of pollutants.

Some studies observed increased mortality, but most observed increased morbidity, primarily among the susceptible population, which includes children, the elderly and people with asthma and pre-existing respiratory and/or cardiovascular disease. In general, healthy adults quickly recovered from short-term bushfire smoke exposures. An association between bushfire episodes and health impacts, measured by hospital visits for asthma and respiratory illnesses, were observed in South-East Asia and the USA. However, out of three Australian studies, only Johnston *et al*. (2002) reported an adverse health outcome as a result of bushfires around Darwin based on asthma attendances to major hospitals. No explanation is available for this significant difference in findings. There is clearly a need in Australia to further investigate the effects of bushfires on community health.

Even though the studies have all been related to accidental and forest clearing bushfires, it is possible that similar effects of bushfire smoke impact on community health will be observed during a season of intensive prescribed burn activities. In order to determine this potential, monitoring of the air toxics during prescribed burn seasons should be carried out for downwind communities so that the major factors that affect exposure levels are determined. Even in the reports of large fires reviewed in this paper, the determinants of exposure levels have not been sought and these studies have provided little to no information on the fuels combusted in the fires. This could be a key factor in the amount and nature of the pollutants formed, but is largely ignored in discussion. Other important details of the fires were also often lacking, e.g. fire conditions and proximity to communities, as well as meteorological conditions (wind speed, inversion).

Indoor measurements of bushfire air toxics have also been very limited, but generally indicate that staying indoors does not protect people from smoke exposure (other than short-term peaks). There is a need for research on how to protect indoor occupants from bushfire smoke.

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