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TECHNICAL PAPER

Impact of smoke from prescribed burning: Is it a public health concern?

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Given the increase in wildfire intensity and frequency worldwide, prescribed burning is becoming a more common and widespread practice. Prescribed burning is a fire management tool used to reduce fuel loads for wildfire suppression purposes and occurs on an annual basis in many parts of the world. Smoke from prescribed burning can have a substantial impact on air quality and the environment. Prescribed burning is a significant source of fine particulate matter ($PM_{2.5}$ aerodynamic diameter < 2.5μm) and these particulates are found to be consistently elevated during smoke events. Due to their fine nature $PM_{2.5}$ are particularly harmful to human health. Here we discuss the impact of prescribed burning on air quality particularly focussing on $PM_{2.5}$. We have summarised available case studies from Australia including a recent study we conducted in regional Victoria, Australia during the prescribed burning season in 2013. The studies reported very high short-term (hourly) concentrations of $PM_{2.5}$ during prescribed burning. Given the increase in $PM_{2.5}$ concentrations during smoke events, there is a need to understand the influence of prescribed burning smoke exposure on human health. This is important especially since adverse health impacts have been observed during wildfire events when $PM_{2.5}$ concentrations were similar to those observed during prescribed burning events. Robust research is required to quantify and determine health impacts from prescribed burning smoke exposure and derive evidence based interventions for managing the risk.

Implications: Given the increase in $PM_{2.5}$ concentrations during PB smoke events and its impact on the local air quality, the need to understand the influence of PB smoke exposure on human health is important. This knowledge will be important to inform policy and practice of the integrated, consistent, and adaptive approach to the appropriate planning and implementation of public health strategies during PB events. This will also have important implications for land management and public health organizations in developing evidence based objectives to minimize the risk of PB smoke exposure.

Introduction

With the advent of global warming, wildfires are set to increase in frequency and severity in the future (Keywood et al., 2013). Wildfires produce a large amount of smoke that disperses widely and affects population far from the fire source. Prescribed burning, also known as planned burning, is a purposeful application of fire under specified environmental conditions to a predetermined area to reduce fuel loads for wildfire suppression purposes (Penman et al., 2011). The available evidence is that the spatial area and intensity of wildfires will be reduced in proportion to the area of land burned by prescribed fires (Boer et al., 2009; Bradstock et al., 2012). Prescribed burning is also used for regenerating forests after timber harvesting (regeneration burning), and for protection and promotion of ecological assets (ecological burning) (Burrows, 2008; Wain et al., 2009). Prescribed burns are geographically widespread, and smoke production can have significant impacts on air quality (Naeher et al., 2007; Tian et al., 2008; Keywood et al., 2013).

Unlike wildfires that are of high intensity, prescribed fires are cool low-intensity burns and produce relatively short plumes (Williamson et al., 2013). While low-intensity prescribed burns (low heat, light emissions) cause minimal risk to life and property, they can however emit large amounts of smoke particulates (Wain et al., 2009; Bell et al., 2006). Furthermore, prescribed burns are conducted on a regular basis (annually) and impact communities each year. Wildfires, on the other hand, are unpredictable and episodic events. There may also be differences in the pattern of smoke exposure (such as duration and frequency) from prescribed fires compared to wildfires. Exposures to smoke plumes from prescribed fires are generally shorter in duration but occur more frequently than wildfire events, although studies are required to quantify the impacts from this. Prescribed burns are conducted under favorable meteorological conditions, for example, light winds and wind gusts, low temperature, and moderate humidity. These conditions limit the ventilation rate and smoke dispersion and

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thus promote the buildup of air pollution. As a result, smoke from prescribed burning can have a substantial impact on rural/regional areas, along with potential to impact urban airsheds due to long-range transport of smoke particles.

One of the important pollutants present in high concentrations in smoke from prescribed burns and wildfires is fine particulate matter ($PM_{2.5}$ with aerodynamic diameter <2.5 μm), and research studies have shown that $PM_{2.5}$ concentrations consistently exceed the air quality guidelines (Reisen and Brown, 2006; Naeher et al., 2007). Smaller particles are of greater public health concern than larger size fractions for two reasons: First, they remain in the atmosphere for longer periods of time, and second, they can penetrate further in the respiratory system, where they promote local and systemic inflammation.

The impacts of smoke production and other unwanted effects from prescribed burns need to be investigated in the context of the substantial public health impacts of wildfires. The latter include increases in mortality from extreme air pollution, injury, loss of assets, and degradation of water supplies (Johnston, 2009). As with any health intervention, the risks and benefits of preventive action must be balanced. If a system of elective burning operations with less extensive and more manageable fires is a practical and safer option than a regime of emergency responses to more severe and highly polluting wildfires, we need to know the safest ways of achieving this. This requires us to better characterize the impacts of prescribed fires on air quality and health, and to investigate interventions for reducing the community impacts of smoke and other risks associated with prescribed fires. In this short discussion paper we highlight (a) the impact of smoke from prescribed burning on air quality especially fine particulate matter and (b) the potential adverse impacts on health.

Prescribed Burning Practices

We restrict this discussion to the use of fire to manage fuel loads and mitigate wildfire risk in temperate climates. Tropical deforestation or savannah fires set for economic or agricultural activities are excluded, but we acknowledge that these contribute to the majority of vegetation fire emissions on a global scale.

Fuel reduction burns are carried out around the world in temperate climates. For example, in Australia around 100,000–200,000 hectares of land are burned annually for fuel reduction purposes (Wain et al., 2009). After the 2009 wildfires in Victoria, Australia, the Royal Commission inquiry into wildfires recommended expanding the prescribed burning program by burning at least 5% of the land each year, equating to 385,000 hectares, to reduce the risk of large and devastating wildfires (Teague et al., 2010). Before the 2009 fires the target area for prescribed burning in Victoria was only 130,000 hectares (2%). Another example is the fuel reduction burn activity in the southern United States (Georgia, Florida, Alabama, South Carolina), where as much as 3–4 million hectares of land are burned every year (Zeng et al., 2008).

Smoke Management

In many parts of the world smoke management programs and guidelines are being introduced to minimize smoke impacts on populations (Fernandez and Botelho, 2003; Wain et al., 2009; Sun and Tolver, 2012; Williamson et al., 2013; EPA-Tasmania, 2013). This has resulted in various air quality assessment tools being implemented and used to monitor smoke from prescribed burning, as well as smoke emissions from other sources. A good example of a smoke management program in Australia is Base Line Air Network (BLANkET) of Environment Protection Authority Tasmania (EPA-Tasmania, 2010), which is a statewide monitoring network. It consists of 19 monitors that are used to measure near real-time PM concentrations during smoke events from prescribed burning. It is also used to monitor smoke from domestic wood heaters and wildfires and generally used to provide a measure of air quality in rural areas of Tasmania. Another example from the United States is the Interagency Real Time Smoke Monitoring program (AIRSIS), which provides real-time PM concentrations from portable smoke monitors and is used during fuel reduction activities (U.S. Forest Service [USFS], 2013). Remote sensing and smoke forecasting using air quality models are also currently operational worldwide (Hu et al., 2008; Zeng et al., 2008; Johnston et al., 2010; Price et al., 2012; Johnston and Bowman, 2013; Williamson et al., 2013; Yao and Henderson, 2014; EPA, 2014). Nevertheless, there is considerable variation within and between countries, and while information describing impacts of prescribed burning (Pearce et al., 2012; Schweizer and Cisneros, 2014) on air quality is increasing, relatively little is known about the implications for human health. This is especially important in rural/regional areas where most of the prescribed burning is conducted, and where air quality can also be affected by smoke particulates from residential wood heaters, agricultural burning, and wildfires (Bell and Oliveras, 2006; Reisen et al., 2011), but where air quality monitoring is limited.

Fine Particulate Concentrations During Prescribed Burning Smoke Events

Table 1 summarizes available Australian data from internal reports and published papers that looked at impacts of prescribed burning on $PM_{2.5}$ concentrations. We only include studies from prescribed burns conducted for fuel reduction purposes and omit studies from regeneration burns. Table 1 highlights daily and hourly $PM_{2.5}$ concentrations measured over a prescribed burning season and/or during specific burn events. It includes our recent study where we investigated in 2013 the impact of prescribed burning smoke on $PM_{2.5}$ concentrations in the Yarra Valley, Victoria, a region that is regularly impacted by prescribed burns. The Yarra Valley is surrounded by mountains with steep slopes and dense forests with significant fuel loads. Monitoring was carried out at two sites approximately 9 km from each other during the autumn prescribed burning season in April. The E-sampler Aerosol

Table 1. $PM_{2.5}$ concentrations and duration of exposure during prescribed burning events

Location	Measurement period	Measurement method##	$PM_{2.5}$ max daily ($\mu g/m^3$)*	$PM_{2.5}$ maximum hourly ($\mu g/m^3$)	Duration of exposure (hr)###	Reference
Yarra Valley, VIC	April 2013	E-sampler aerosol monitor	56	222	9–15	
Manjimup, WA	October–December 2007	DustTrak	76	319	2–11	Reisen et al., 2011
Ovens, VIC	April–May 2007		151	377	16	
Sheffield, TAS	October 20–21, 2010	DustTrak	35	250	Several hours	BLANkET technical report 11#
George Town, TAS			26	80		
Carrick, TAS			23	150		
Lilydale, TAS	November 19, 2010	DustTrak	4	40	3	BLANkET technical report 12#.
Judbury, TAS	March 14, 2012	DustTrak	19	62	8	BLANkET technical report 20#
Huonville, TAS			12	48	5	
Geeveston, TAS			9	26	1	
Bryn Estyn, TAS	April 1–2, 2012	DustTrak	16	110	9	BLANkET technical report 21#
Hobart, TAS			11	40	4	
Gretna, TAS			9	70	1	
Hobart's Eastern shore regions, TAS	May 29, 2013	DustTrak	30–90	100	Several hours	BLANkET technical report 24#
	May 30, 2013		100–200	300		

Notes: #, BLANkET technical reports: http://epa.tas.gov.au/epa/blanket-report. ##, Continuous $PM_{2.5}$ data have been calibrated against gravimetric measurements. ###, Duration of exposure to smoke events when hourly concentrations of $PM_{2.5} > 25$ $\mu g/m^3$. *$PM_{2.5}$ maximum daily assumes a 24-hr average concentration. TAS: Tasmania; VIC: Victoria; WA: Western Australia.

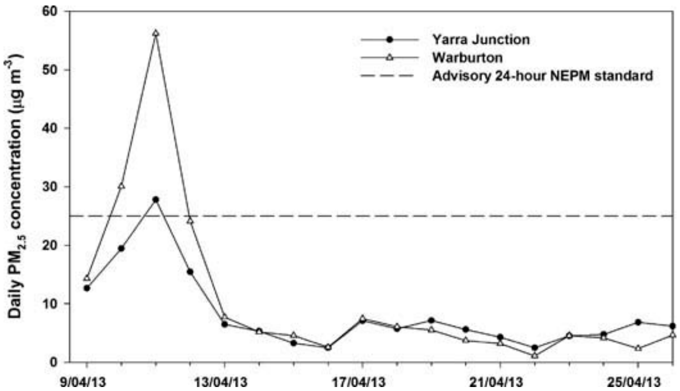

Figure 1. Yarra Valley (Warburton and Yarra Junction): daily concentrations of $PM_{2.5}$ during prescribed burning event (2013).

Monitor (E-sampler-9800, Met One Instruments, Inc., Oregon, USA) was used to measure concentrations of $PM_{2.5.}$ Figures 1 and 2 give an example of $PM_{2.5}$ concentrations measured during a prescribed burning event in the Yarra Valley in April 2013.

During prescribed burning events, air quality may also be impacted by smoke from domestic wood heaters; however, the elevated $PM_{2.5}$ concentrations depicted in Table 1 were mostly a consequence of smoke from prescribed burning conducted in the region. This is because most of the prescribed burning was conducted during relatively warmer months (March/April) when there is limited use of wood heaters. Second, the remote/regional areas selected for prescribed burns were generally located away from other potential sources of $PM_{2.5}$ air pollutant (e.g., traffic emissions, industrial emissions). Moreover, concentrations of levoglucosan, a biomass burning marker, also correlated well with increase in $PM_{2.5}$ concentrations during prescribed burning events, indicating smoke to be the primary contributor to $PM_{2.5}$ levels. However, it should be noted that smoke from domestic wood heaters could also lead to increase in levoglucason levels.

The data in Table 1 show that exposure to smoke from prescribed burning was usually of short duration, less than a day. The duration of exposure was based on the number of hours that $PM_{2.5}$ levels were above 25 μg/m^3. On several occasions, exceedances of the Australian Advisory Air Quality 24-hr standard of 25 μg/m^3 $PM_{2.5}$ were observed. The data also show that prescribed burning smoke can result in very high short-term (hourly) peak exposures, up to 15 times higher than the daily advisory standards (Figure 2 and Table 1).

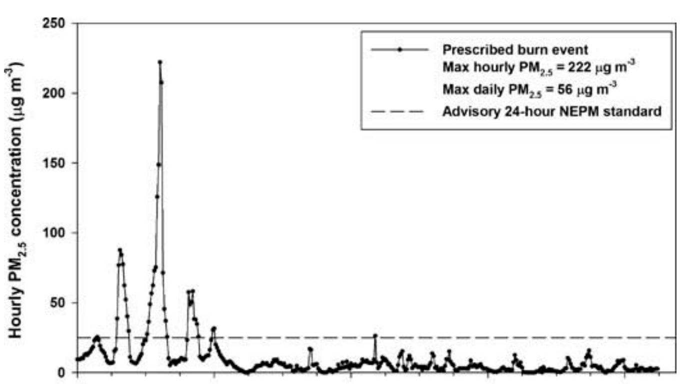

Figure 2. Yarra Valley (Warburton): hourly concentrations of $PM_{2.5}$ during prescribed burning event (2013).

Few overseas studies have also investigated the impact of prescribed burning smoke on air quality. For example, Tian et al. (2009) utilized air quality models to simulate the air quality impacts in Atlanta, GA (2002), and observed that prescribed burning was the largest source of $PM_{2.5}$ concentrations (50–80%). Another study by Zeng et al. (2008) used both model simulations and ground/satellite observation to investigate the impact of prescribed burning on air quality over the southeastern United States and showed daily and monthly mean enhancement of $PM_{2.5}$ levels of up to 8%. Hu et al. (2008) also used a forecasting system and modeling simulations to study smoke impacts from prescribed burning fires in Atlanta, GA (2007), and observed total daily (35 μg/m^3) and hourly (121 μg/m^3) simulated $PM_{2.5}$ concentrations.

Most studies have utilized different exposure assessment methods (e.g., air quality monitoring, model simulations) to measure $PM_{2.5}$ levels, and therefore the results are not comparable; however, the study findings indicate an increase in $PM_{2.5}$ concentrations during the prescribed burning period.

What Could be the Impact of Smoke From Prescribed Burning on Health?

Most research to date has focused on the health impacts of particulate matter exposure from wildfire smoke when it affects large population centers (Delfino et al., 2009; Morgan et al., 2010; Johnston et al., 2011; Henderson et al., 2012; Martin et al., 2013).

The most commonly investigated and established adverse health impact of $PM_{2.5}$ exposure from wildfire smoke exposure relates to pulmonary diseases (asthma, chronic obstructive pulmonary disease, infections) (Dennekamp and Abramson, 2011; Henderson and Johnston, 2012) and increase in clinical endpoints (hospital admissions, emergency department visits, increase in asthma symptoms and medication usage, decrease in pulmonary function) (Johnston et al., 2006; Delfino et al., 2009; Ignotti et al., 2010; Henderson et al., 2011; Do Carmo et al., 2013; Elliott et al., 2013; Martin et al., 2013). Evidence for adverse cardiovascular outcomes is also emerging, although the results have been null or inconclusive so far (Delfino et al., 2009; Johnston et al., 2007; Henderson et al., 2011; Rappold et al., 2011; Rappold et al., 2012; Martin et al., 2013; Youssouf et al., 2014; Liu et al., 2015). There is also strong evidence of the impact on nontraumatic mortality rates due to exposure to high concentrations of $PM_{2.5}$ during wildfires (Hanninen et al., 2009; Johnston et al., 2011; Kochi and Champ 2012; Youssouf et al., 2014; Liu et al., 2015). Most of the health impacts have been observed in vulnerable groups of people (especially the elderly and people with preexisting health conditions) (Delfino et al., 2009; Ignotti et al., 2010; Do Carmo et al., 2013; Rappold et al., 2011; Kochi and Champ, 2012; Rappold et al., 2012).

Indeed, the adverse health impacts due to PM related wildfire smoke exposure have been observed at comparatively low PM concentrations, well within current air quality standards (Chen et al., 2006; Johnston et al., 2006, Naeher et al., 2007; Morgan et al., 2010). Studies have also shown that slight increases of particulates from wildfire smoke were associated with increased incidence of hospital admissions for respiratory conditions especially asthma (Johnston et al., 2006; Chen et al., 2006). Given that prescribed fires cause more regular exposure to peak concentrations of particulate pollution, the impact on human health needs further investigation. Furthermore, due to the widespread nature of the smoke particles, numerous communities could be potentially impacted. This is especially important for at-risk groups of people exposed to smoke from prescribed burns on an annual basis.

Research Challenges

Given that wildfires are likely to increase in frequency and intensity in the context of warming climate (Bowman et al., 2009; Flannigan et al., 2009; Gill et al., 2013), prescribed burning is being used more frequently for wildfire suppression purposes (Bell and Adams, 2009; Teague et al., 2010; Penman et al., 2011). The increased $PM_{2.5}$ concentrations observed during prescribed burning events, their regular occurrence, and the likely adverse health impacts associated with these increases indicate the need for further research in this area. However, investigating the health impacts from exposure to smoke from prescribed burning presents a few challenges. Prescribed burning is conducted in rural/regional areas where the population size is small and sparsely located. This could significantly reduce the power of the study to detect any effect. Therefore, individual based studies are required to investigate the health impacts from prescribed burning smoke exposure. Conducting such studies is of logistic and financial concern, thereby limiting research in this area of need. The other challenges involved include:

- Very short window of opportunity present to investigate health parameters and conduct exposure assessment measurements. This is because the prescribed burning season is limited by the availability of suitable conditions, particularly dry fuel and stable weather patterns (light winds, low temperature, and moderate humidity) required to reduce fire intensity and rate of spread.
- Lack of easy accessibility to health care services (e.g., hospitals, health clinics, etc.) in regional areas could also impact on hospital service usage.
- Lack of exposure assessment due to limited air quality monitors in regional areas targeted for prescribed burning. The use of portable monitors can be expensive and data analysis can be time-consuming. However, the increased use of remote-sensing tools and satellite data and the increased development of low-cost particle sensors will assist in providing air quality data in areas with lack of monitoring facilities (Yao et al., 2013; Yao and Henderson, 2014).

Conclusion

Currently, smoke dispersion from prescribed burning is not required to be monitored and there is no known safe level of pollutant exposure below which adverse health impacts are not observed (Naeher et al., 2007; Craig et al., 2008). There is a need for the development of innovative methods for better prediction and effective exposure assessment in regional areas with a lack of air quality monitors. Air quality models are required to provide for accurate deterministic concentrations and predict spatial and temporal distribution of air pollution and smoke from prescribed burning. This information will be useful for communities living in and around the vicinity of the prescribed burns for advance warning, especially for at risk people with preexisting health conditions. Land managers would also benefit from such information to better manage the impacts of air pollution during prescribed burning. The challenge is for the land managers and scientists to work collaboratively to successfully integrate evidence-based knowledge, and experience contributing toward an adaptive management strategy. A recent study by Rappold et al. (2014) projected the mitigation of health impact of wildfire exposure based on forecasting the smoke plume and associated public health messaging that in theory would change behavior of the exposed population and limit exposure dose.

Prescribed burning is a valuable tool for managing fuels and in ultimately reducing the severity of high-intensity wildfires. As burns need to be conducted relatively close to communities to be effective (Gibbons et al., 2012), prescribed fires can be major contributors to local air pollution, despite being on much smaller scale than wildfires. Given the known adverse health impacts from wildfire smoke-sourced $PM_{2.5}$ exposure, prescribed burning smoke exposure is of public health concern. However, more research is required to quantify and determine health impacts, identify high-risk individuals, and derive evidence-based interventions for managing the risk.

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