

FIRE NOTE

ISSUE 30 MAY 2009

BUSHFIRE SMOKE RESEARCH: A PROGRESS REPORT PART 1 BUSHFIRE SMOKE: IMPACT ON FIREFIGHTERS

Bushfires can cause widespread air pollution through the emission of high levels of toxic air contaminants that may affect human health. Affected populations range from residents of rural towns and regional cities to firefighters at or near the fire front.

The Bushfire CRC project on 'Air Toxics Exposure and Measurement' assesses smoke exposure on the fire ground, focusing on key toxic air pollutants present at elevated levels in bushfire smoke and potentially impacting firefighter health if present at high levels (see *Fire Note Issue 12*, February 2007). These key pollutants include respirable particles, carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and aldehydes. Dioxins were initially considered

but concentrations measured in bushfire smoke were too low to determine a statistically significant difference between the firefighter group and the general population (Meyer *et al.* 2008).

RESEARCH BACKGROUND

Between 2004 and 2008, monitoring was conducted at prescribed burns and wildfires across Australia to assess firefighters' exposures to air toxics (Reisen & Brown 2009). Exposure levels and the ability to impair health and well-being were assessed in the first instance against established occupational exposure standards (OES). OES are used to assess the quality of the work environment and to identify situations when control strategies need to be implemented.

SUMMARY

This Fire Note summarises the research from two Bushfire CRC projects addressing the broad impacts of smoke. The project 'Smoke Composition and Impact on Human Health and Ecosystems' is aimed at understanding ecological aspects of smoke composition by characterising nutrient loss in smoke and how the composition of gaseous organic compounds varies with fuel composition and combustion conditions. The project 'Air Toxics Exposure and Management' addresses exposure and smoke-related health issues faced by firefighters on the fire ground and how to minimise the risks.



Smoke emitted from fires of all types is of concern to fire agencies and State and Federal departments because of its real and perceived impacts on health and amenity. Globally, biomass combustion is a prominent source of organic aerosols and greenhouse gases and a major cause of interannual variation in atmospheric carbon dioxide (CO₂) concentration (IPCC 2007). Impacts on agricultural industries, particularly viticulture, have recently emerged as a major risk to production, although the active compounds have not yet been unequivocally identified (Maleknia & Adams 2008). While there are some risks to firefighter health from exposure to high smoke concentrations, these are mostly mitigated through fire ground task management that minimises direct exposure.

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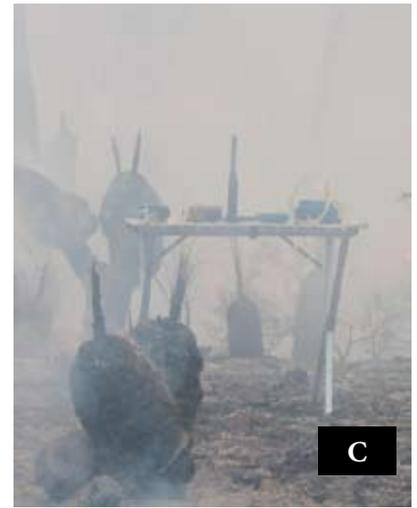
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A



B



C

▲ ABOVE: SAMPLING EQUIPMENT FOR (A) PERSONAL EXPOSURE MEASUREMENTS, (B) FIRE GROUND MEASUREMENTS ON SLIP-ON UNIT AND (C) STATIC AREA MEASUREMENTS.

BUSHFIRE CRC RESEARCH

THE APPROACH

Two sets of measurements were carried out: personal exposure measurements collected within the breathing zone of firefighters and fire ground measurements collected from fire vehicles (tankers and/or slip-on units) or static area samples.

Fire ground monitoring has shown that in less than 10% of cases, average and peak exposures to CO, respirable particles and formaldehyde exceeded OES during prescribed burns. A lower percentage of cases were found for tanker-based suppression activities during bushfires. Even though the percentage was quite small, attention should be given to all situations under which high exposure levels are measured. A range of factors have been found to affect exposure levels, including work activities, burn conditions and fuel characteristics.

WORK TASKS

During the monitoring program, sampling covered a range of work activities including ignition with drip torch, suppression with hose or rake-hoe, patrol on foot and in vehicles, fire ground supervision and mop-up. The lowest exposure levels were measured for lighting crews as they work primarily upwind of the smoke. Patrol and suppression crews showed the highest levels of exposure to bushfire air toxics with exposure frequently exceeding peak and average OES. Rotation of crews was shown to significantly reduce exposure levels.

BURN CONDITIONS

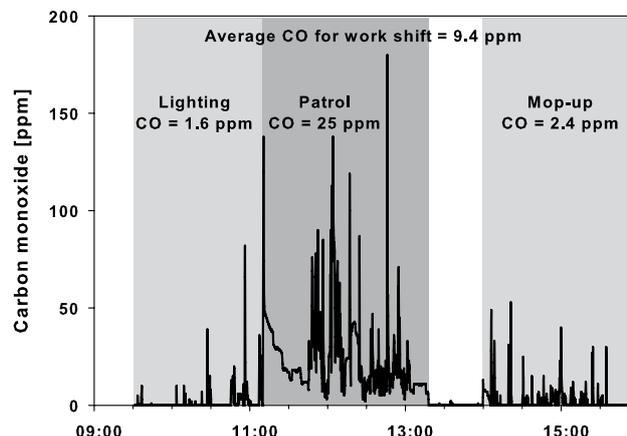
The terrain of the burn area as well as the lighting pattern was an important factor contributing to fire ground exposure. Suppression crews working in a flat burn area where smoke was drawn within the centre of the burn area had very low exposure to air toxics (see page 3, Site 1). In comparison, patrol crews working on the top of the ridge of a steep burn area were exposed to elevated levels of air toxics, largely exceeding OES (Site 2).



LIGHTING



PATROL



▲ ABOVE: CARBON MONOXIDE LEVELS DURING DIFFERENT WORK ACTIVITIES INCLUDING LIGHTING, PATROL AND MOP-UP.

ABOUT THIS FIRENOTE

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This Fire Note is an update of ongoing research by Bushfire CRC Program B, Fire in the Landscape, and Program D, Protection of People and Property.

FURTHER INFORMATION

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FUEL CHARACTERISTICS

Experimental burns of various vegetation types under three different fuel moisture contents have shown that fuel type and fuel moisture influences amount of particles and CO emitted. Further work is under way to assess the effect of other fuel characteristics on smoke emissions.

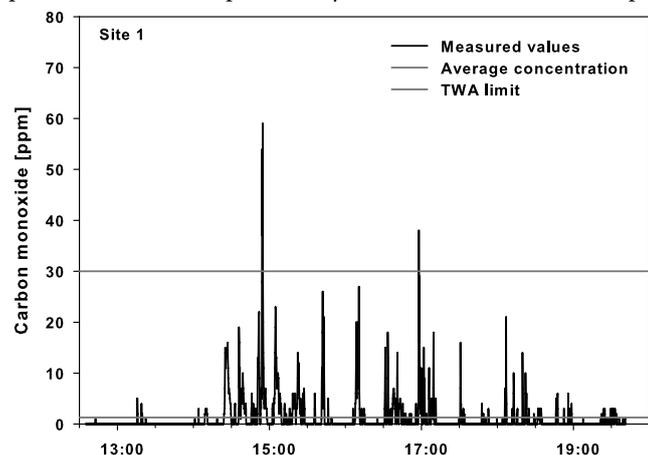
SMOKE PARTICLES

Particulates have emerged as an important pollutant of concern, particularly for

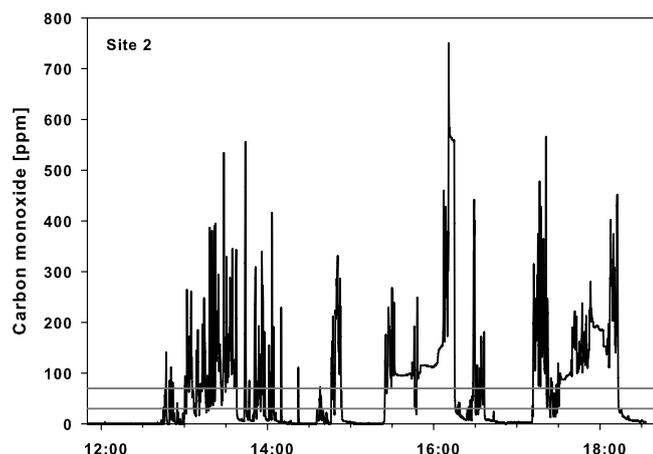
community exposure. During bushfire events, measurements of particles in the air were conducted to assess firefighters' exposure during their off-shift. Elevated levels of particulates were recorded. In response, a PhD project (Dane Hansen, RMIT) is now under way to better characterise the physical and chemical composition of smoke particles from bushfires and prescribed burning.

RESEARCH OUTCOMES

A reference guide and field guide with information and guidelines to assist fire and land management agencies in managing smoke exposure on the fire ground are currently being drafted and reviewed (see *Fire Update* 26, November 2008, Reisen & Meyer 2008). The documents are based on the data obtained from the environmental monitoring and experimental burns.



LEFT AND BELOW: CARBON MONOXIDE LEVELS RECORDED AT SITE 1 WHICH WAS RELATIVELY FLAT AND SITE 2 WHICH WAS ON A RIDGE TOP



PART 2 BUSHFIRE SMOKE: ECOLOGICAL ISSUES

The frequency and size of wildfires is predicted to increase in Australia with global warming (see *Fire Note Issue 4*, September 2006). Fire plays an important role in many Australian ecosystems but our knowledge of how these ecosystems will respond to changes in fire regimes is limited. Volatile organic compounds are released through burning of vegetation and are also produced naturally by many plants, with up to 10% of plant carbon devoted to the production of volatile secondary metabolites. Our current research explores the potential impact of increased fire frequency and size on the nature of emissions of plant-emitted VOCs to the atmosphere in Australia.

BACKGROUND

A number of features have defined this project. They were:

- A clear need to focus on the role of VOCs in smoke as this would be the most productive means of providing meaningful and practical information against a background of progressive worldwide research (Bell & Adams 2009).
- All plants continuously release a wide range of compounds to the atmosphere, even in the absence of fire. The compounds emitted and rates of emission depend upon the type of ecosystem and a range of environmental variables. There is little published data for speciated VOC emissions from vegetation in Australia

despite the potential significance of Eucalyptus dominated forests and plantations to be a substantial source of VOCs. We have therefore focused on identifying VOCs emitted from Australian plant species at temperatures ranging from ambient to combustion (Maleknia et al. 2007, 2009).

- The lack of a specific facility available in Australia for generation and analysis of combustion products at the scale and accuracy needed for this project. Analysis of smoke requires a range of analytical techniques which are generally labour intensive. Analyses in this project have been variously conducted using high-sensitivity proton-transfer reaction

mass spectrometry (PTR-MS) and gas chromatography mass spectrometry (GC-MS). A Mass-Loss Calorimeter is essential for gauging completeness of combustion. Dedicated CO and CO₂ analysers are used to measure fire emission factors by correlating concentrations of VOCs to CO and CO₂. Fire emissions are also being evaluated as a function of O₂ concentration to mimic various fire conditions (i.e. smouldering).

BUSHFIRE CRC RESEARCH

VOC EMISSIONS FROM VEGETATION

Using PTR-MS, an increase in temperature from 35 to 100°C resulted in emission of a greater diversity of VOCs (e.g. acetaldehyde, acetic acid, isoprene and furan) and greater amounts of several VOCs (e.g. some terpenes) when leaves of *Eucalyptus grandis* were heated (Maleknia et al. 2007). This type of information is important as heating of fuels (without burning) occurs in advance of the fire front and in the canopy beneath ground fires.

With systematic heating and combustion of a range of *Eucalyptus* species, three distinct groups of temperature-dependent VOCs have been identified (Maleknia 2008, Maleknia et al. 2009):

1. reactive organic compounds including a number of acids, aldehydes, alcohols and ketones
2. plant-specific isoprenoids including isoprene (C₅H₈), monoterpenes (C₁₀H₁₆) and sesquiterpenes (C₁₅H₂₄), and
3. pyrolysis products of plant-specific polymers such as cellulose and lignin.

Group (1) and Group (2) compounds are continually emitted from eucalypts under ambient conditions. In general, Group (1) compounds have low boiling temperatures and are released from plant material at relatively low temperatures (<100°C). Group (2) compounds (except isoprene) are released at higher temperatures (60 to ~200°C) and Group (3) compounds release a range of VOCs on pyrolysis (>250-300°C). 'Green fuels' (living plants) contain all three groups of compounds. 'Brown fuels' (aging plant material) generally do not contain substantial



▲ ABOVE: LOW PRODUCTIVITY STRINGYBARK WOODLAND NEAR CASTERTON, VICTORIA (LEFT), AND HIGH PRODUCTIVITY ALPINE ASH FOREST NEAR FALLS CREEK, VICTORIA (RIGHT).

amounts of Group (1) compounds. We are also correlating VOCs from pyrolysis to cellulose and lignin content of fuel (Maleknia & Adams 2008). This information will enable us to estimate both regional and global fire emissions based on temperatures of fires and the cellulose:lignin ratio of biomass.

NUTRIENT LOSS IN SMOKE

Losses of nutrients from fuels during fire are due to vaporisation of solutes as they reach boiling point (eg nitrate vaporises from living cells at 80°C) and oxidation of solid compounds to gaseous forms at higher temperatures (eg amino acids are oxidised at 200°C). This process is called volatilisation and results in considerable loss of some nutrients. The aim of this research was to determine potential nutrient loss from fuels during prescribed burning and wildfires.

Living (green leaves of *Eucalyptus* sp. and understory shrubs) and dead fuels (litter, bark, twigs, organic matter) were collected from a low productivity stringybark woodland growing on sandy soils and a highly productive alpine ash forest growing on deep loam. Fuels were systematically heated in an oven to 200°C or combusted in a muffle furnace to 800°C to determine loss of major nutrients (nitrogen, phosphorus, sulphur and potassium). This heating regime represents the temperature range that may occur during prescribed burning (lower temperatures) and wildfire (higher temperatures). Fuel loads of each ecosystem were measured in the field or determined from published literature to model potential loss of these nutrients.

RESEARCH OUTCOMES

A key outcome of this research is a better understanding of fuel management at the ecosystem scale.

We found that greater amounts of nutrients were volatilised from living fuels (green leaves) than dead fuels (twigs, bark, organic matter, soil) and nitrogen and sulphur loss was greatest from all fuel types. Little loss of phosphorus and potassium was recorded. Greater amount of nutrients, particularly nitrogen, were volatilised from fuels from the high productivity forest site. From a modelling exercise, it was calculated that potential losses of nitrogen from fuels during a high intensity wildfire (i.e. heating to 800°C) can be up to 376 t N 10 000 ha⁻¹ fire from low productivity woodlands and 551 t N 10 000 ha⁻¹ fire from highly productive forests.

FUTURE DIRECTIONS

The impact of smoke from prescribed burning and bushfires on air quality is becoming increasingly important for land managers as air quality guidelines become more stringent. There is a need for better operational tools for planning of prescribed burning strategies that incorporate aspects of smoke management such as forecasting of smoke plume dispersion. Current air quality models (e.g. Australian Air Quality Forecasting System) lack the high resolution needed for managing smoke over very short distances, such as near agricultural properties. A key requirement for both regional and close proximity models is the detailed quantification of emissions in smoke from planned and unplanned fires.

Fire Note is published jointly by the Bushfire Cooperative Research Centre (Bushfire CRC) and the Australasian Fire and Emergency Service Authorities Council (AFAC).

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Bushfire CRC is a national research centre in the Cooperative Research Centre (CRC) program, formed in partnership with fire and land management agencies in 2003 to undertake end-user focused research.
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AFAC is the peak representative body for fire, emergency services and land management agencies in the Australasia region. It was established in 1993 and has 26 full and 10 affiliate members.