Background briefings on emerging issues for fire managers from AFAC and Bushfire CRC.

FIRE NOTE

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SMOKE COMPOSITION AND THE FLAMMABILITY OF FORESTS AND GRASSLANDS

▲ This project is investigating the greenhouse gas emissions and flammability of three species of *Eucalyptus*, as well as a range of grasses. The knowledge developed will assist fire managers' understanding of the interaction between fuel type and burning conditions.

SUMMARY

This project has focused on the influence of the physical condition of different plant species from forests and grasslands in eastern and northern Australia. In two studies, the influence of fuel moisture on the combustion characteristics of leaves from three species of *Eucalyptus* was assessed in the laboratory. Generalised equations were developed to help improve estimates of carbon emissions during combustion for use in fire behaviour models and predictions of the impact of fire on air quality and climate. In a third experiment, a range of species of grasses was burnt in the laboratory and ranked according to flammability.

ABOUT THIS PROJECT

The *Greenhouse gas emissions from fire and their environmental effects* project is part of the Fire in the Landscape series of projects, within the Bushfire CRC *Managing the Threat* program.

AUTHORS

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CONTEXT

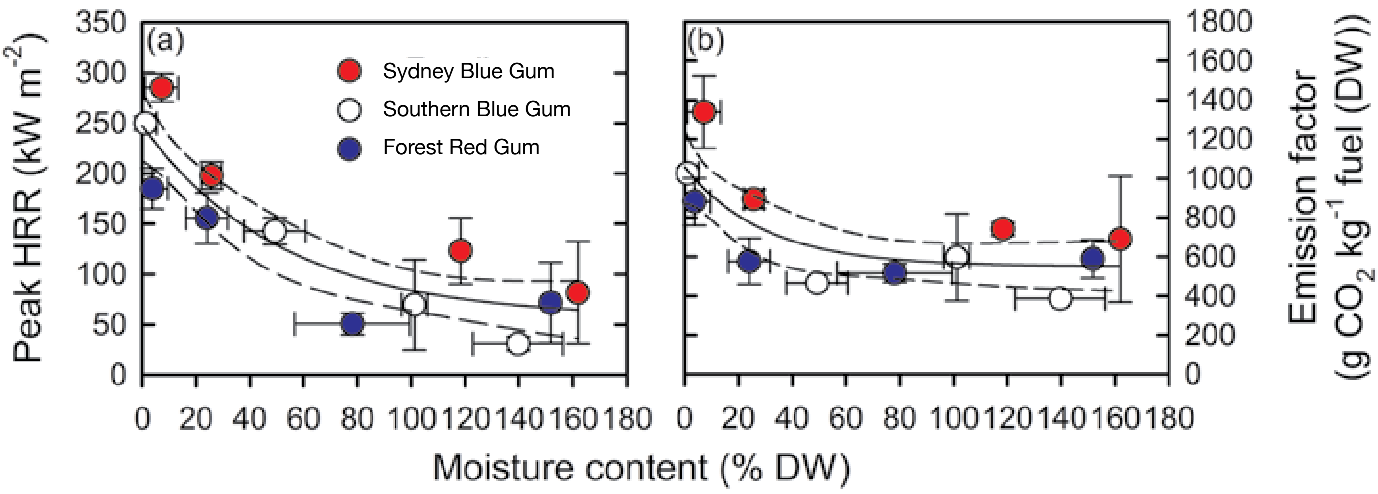
Fire directly impacts the carbon balance of forests and grasslands through emissions of carbon dioxide (CO_2), volatile organic compounds and other greenhouse gases formed during combustion of vegetation and leaf litter. This research aimed to develop knowledge of greenhouse gas emissions from fires by increasing the understanding of the interaction of fuel type and condition with burning conditions.

BACKGROUND

Fire behaviour is complex and depends primarily on the interactions between fuel, weather and topography. Understanding how these variables influence fire behaviour is essential for describing and predicting future fires and the consequences that fires may have. Fuel can vary by type (plant species, leaves, bark, ground litter), condition (moisture content and arrangement), and amount (fuel load), and has an integral role in fire behaviour. This is predominantly through determining rate of fire spread, fire intensity and flammability (ignitability, combustibility and sustainability).

Additionally, fuel is important in estimating emissions from fires. Variables such as fuel loading and emission factors, for both gaseous and particle emissions, along with knowledge of the area burnt and its vegetation type are used to estimate emissions.

There are many well-documented effects of fires on atmospheric chemistry through the production of trace gases such as ozone, methane, volatile organic compounds (VOCs) and aerosols, either directly or as precursors (Crutzen *et al*., 1979). CO_2 accounts for approximately 90% of the emissions (Andreae and Merlet, 2001), but the amount of CO_2 that vegetation fires contribute globally to the atmosphere every year is small (3-5% of the carbon exchanged between the land and the atmosphere). This is mainly because the carbon released is rapidly recaptured by growing vegetation. Trace gases and aerosols account for less than 10% of the total carbon emitted by fire (Andreae and Merlet, 2001); however, they have enormous consequences for regional air quality and pollution (Crutzen and Andreae, 1990). VOCs alter the oxidation capacity of the atmosphere and contribute to secondary organic aerosol formation (Crutzen



▲ **Figure 1:** The effect of fuel moisture content on (a) peak heat release rate and (b) the emission factors for CO_2 for three *Eucalyptus* species (Possell and Bell, 2012a).

and Andreae, 1990). Aerosols decrease visibility, modify cloud properties, affect human health and have uncertain impacts on climate.

The spatial impact of trace gas and aerosol formation from fires is mainly determined by the atmospheric lifetime of the species formed. For VOCs, this can extend beyond the fire region (and fire duration) owing to their subsequent reactions forming tropospheric ozone or aerosols that can travel across continents.

BUSHFIRE CRC RESEARCH

It is necessary to measure emissions from fires and apply our understanding of the control on these emissions into fire behaviour models. This allows us to couple fire behaviour models to atmospheric chemistry models, which in turn enables us to understand the formation of secondary VOCs and aerosols and predict the local to global effects of smoke.

Emission ratios and factors (see 'definitions', right) for aerosols and trace gases have been reported for fires in different ecosystems in many parts of the world. Despite the amount of information that has been amassed, data on emission factors for many compounds in smoke, and for many ecosystem types, are either still unavailable or have large uncertainties. This includes emissions from fire-prone ecosystems in Australia.

Studies on the composition of smoke have been conducted on a number of scales, ranging from airborne to ground collection of smoke, as well as in the laboratory. As the combustion of vegetation proceeds through several consecutive stages, from flaming to smouldering combustion, results from airborne and ground studies contain a mixture of gases and aerosols related to these stages, different fuel types and aging of the smoke plume. Laboratory studies allow the examination of the differences in emissions that occur between plant species

DEFINITIONS

Emission ratio: the ratio of the excess trace gas concentration measured in smoke relative to the excess concentration of a measured reference gas.

Emission factor: the mass of trace gas emitted per kilogram of fuel burned. An emission factor can also be expressed according to the carbon or nitrogen content of the fuel.

and at different stages of combustion within and among plant species (McMeeking *et al.*, 2009). However, these studies are limited by their size and complexity, restricting measurements to primary emissions and the determination of emission ratios or factors that may not be truly representative of the larger landscape. The major advantage of laboratory testing is that fires can be controlled. This allows for more detailed investigations on the mechanisms controlling emissions and simultaneous measurements of fire behaviour. As a result, laboratory testing provides an ideal starting point when determining emissions from, and the flammability of, specific fuels and ecosystems.

RESEARCH OUTCOMES

Experiment 1 – Effect of fuel moisture content on greenhouse gas emissions

Leaves from three species of *Eucalyptus* were combusted in the mass-loss calorimeter (see breakout box, next page) to characterise the effect of fuel moisture on energy release and combustion products. The species selected were Sydney Blue Gum (*Eucalyptus saligna*), Southern Blue Gum (*Eucalyptus bicostata*), and Forest Red Gum (*Eucalyptus tereticornis*). Species in this genus are common in south eastern Australian forests and woodlands; therefore the focus was to determine overall effects rather than to compare species. The data was then used to investigate whether relationships between leaf moisture content and the parameters measured can be described in a manner that can be used in fire behaviour or air quality models.

Findings showed that increasing moisture content reduced peak heat release and the effective heat of combustion (used in fireline intensity calculations) in a negative exponential pattern (Figure 1a), while simultaneously increasing time-to-ignition. Estimates of the probability of ignition, based upon time-to-ignition data, indicated that the critical fuel moisture content for a 50% probability of ignition ranged from 81% to 89% on a dry-weight basis.

As fuel moisture content increases, combustion efficiency reduces. This leads to an exponential increase to a maximum in CO emission factors across all three species (data not shown) relative to an exponential decline in the emission factors for CO_2 (Figure 1b). VOC emission factors were found to change with increasing fuel moisture content in a manner similar to that of the CO emission factor.

This study showed that fuel moisture was found to have an effect on the release of energy, ignitability and the production of combustion products from the three *Eucalyptus* species. The results presented in this study show that any values of heat of combustion used to estimate fireline intensity should not remain fixed and must be varied according to fuel moisture content. In light of this, the extent to which fuel moisture content changes fireline intensity through modification of the fuel consumption component of the equation needs further investigation.

The lack of significant differences among the responses of the three species supports the use of these data to identify general relationships among fuel moisture content and several related parameters that are used in

MASS-LOSS CALORIMETER

The mass-loss calorimeter is a device used for measuring the release of energy, in relation to the loss of product mass during combustion. Material is combusted by spark ignition under a fixed irradiance (10 to 100 kW m^{-2}) as set by a conical heater. Thermopiles in the chimney, calibrated to known energy outputs, measure the heat release while the balance measures the change in mass of the material over time. Gas concentrations in the smoke are measured by sampling air pumped into a sampling manifold through a heated sample line and sampling ring sited in the chimney.

fire behaviour or air quality models. Current emissions models do not take into account the effect of fuel moisture content.

Greater detail related to this research can be found in Possell and Bell (2013).

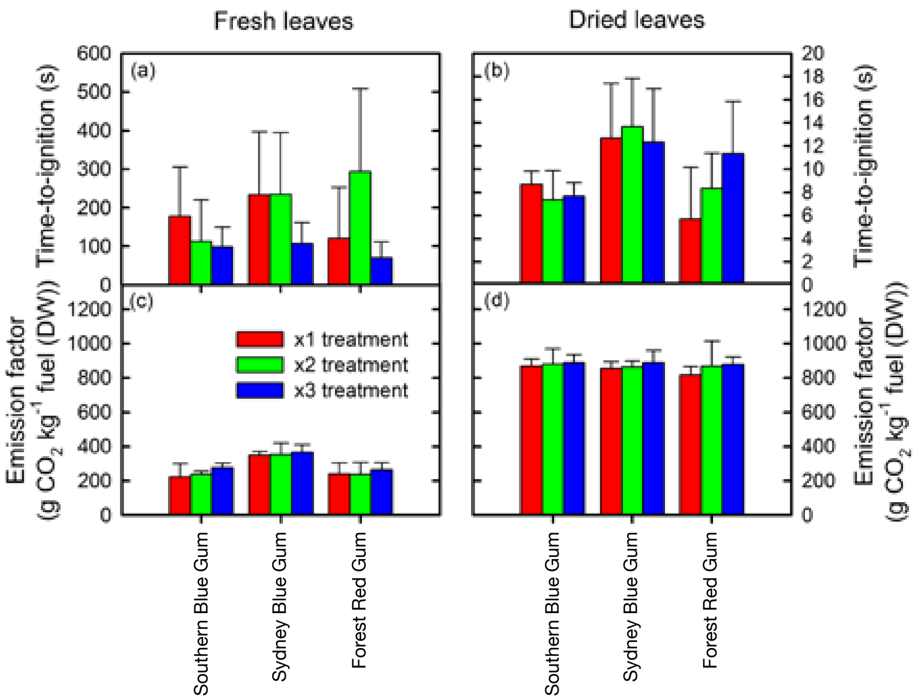
Experiment 2 – Effect of moisture availability on flammability and emissions

This study tested if plant water availability affected the fuel moisture content of live leaves, and therefore gaseous emissions in smoke. The same *Eucalyptus* species used in Experiment 1 were grown under three different watering regimes for 12 weeks to assess how different levels of water availability affects flammability and emissions.

At the time of harvest, all species had different soil moisture content, but this difference was not reflected in the moisture content of the leaves. Differences were measured in the flammability and emissions between fresh leaves and dried leaves (Figure 2), which is consistent with the findings from Experiment 1, but no differences were identified between the watering regimes. This lack of sensitivity to water availability in the eucalypts indicates strongly that leaf flammability and the formation of combustion products would be consistent over a range of climatic conditions. This hypothesis remains to be tested.

Once leaves are part of the leaf litter, their moisture content is a function of vapour pressure deficit, which itself is a function of the type of fuel, air temperature and humidity. Anecdotal evidence that vegetation in creeklines are not as flammable as surrounding vegetation and can act as fire breaks is therefore more likely due to the fuel moisture content of litter rather than living vegetation.

These results indicate that if forested landscapes have different water availability,



▲ **Figure 2:** Effect of three different watering treatments on the time-to-ignition (a, b) and CO_2 emission factors (c, d) of fresh and dried leaves from the three different species of *Eucalyptus*.

END USER STATEMENT

Estimating carbon emissions from bushfire is a difficult task. Research such as the *Greenhouse gas emissions from fire and their environmental effects* project will enable land managers to strengthen reporting on greenhouse gas emissions from bushfire. Data from the Bushfire CRC will enable land managers to improve their estimates of bushfire emissions. Additionally, science such as this will be of great value to those developing and applying national carbon accounting models to better include the effects of wildfire.

– Martin Moroni, Manager, Sustainability Branch, Forestry Tasmania

there is likely to be little influence on flammability and emissions of leaf material before they become part of the ground fuel layer.

Experiment 3 – A comparative study of smoke composition and flammability of sub-tropical and temperate grasses

Grassland occupies an area of approximately 440 million hectares in Australia and can be divided into two main regions: tropical/sub-tropical and temperate. Tropical and sub-tropical grassland covers large areas of northern Australia, extending from the Kimberley region in Western Australia, through much of the Northern Territory and into Queensland. Temperate grassland occupies a smaller north-south band across southern Queensland, New South Wales and Victoria between the arid interior and temperate forests along the east coast. Grass growth in recent years has increased due to heavy rains, influenced by the La Niña weather pattern following over a decade of drought. Consequently, there is value in knowing the composition of smoke that might be expected from fires in grassland.

Six grass species, comprising three species found in sub-tropical regions and three species found in temperate regions, were combusted in the mass-loss calorimeter to determine their flammability and combustion products. All species were selected as they are the most common to each sampling site within each region.

The sub-tropical grass species were Feathertop Wire Grass (*Aristida latifolia*), Barley Mitchell Grass (*Astrebla pectinata*) and Mitchell Grass (*Astrebla* species).

The temperate grass species were Kangaroo Grass (*Themeda triandra*), Phalaris grasses (*Phalaris* species) and African Lovegrass (*Eragrostis curvula*).

Results showed a number of differences in the components of flammability and gas-phase emission factors between grass species. Except for CO_2, there were no obvious patterns between the two grasslands (Figure 3a, next page). Emission factors for CO_2 were greater for grasses collected in the sub-tropical grasslands (Figure 3b, next page). This is the first time such comparison has been made with Australian grasses. Greater detail related to this research can be found in Possell and Bell (2012).

HOW IS THE RESEARCH BEING USED?

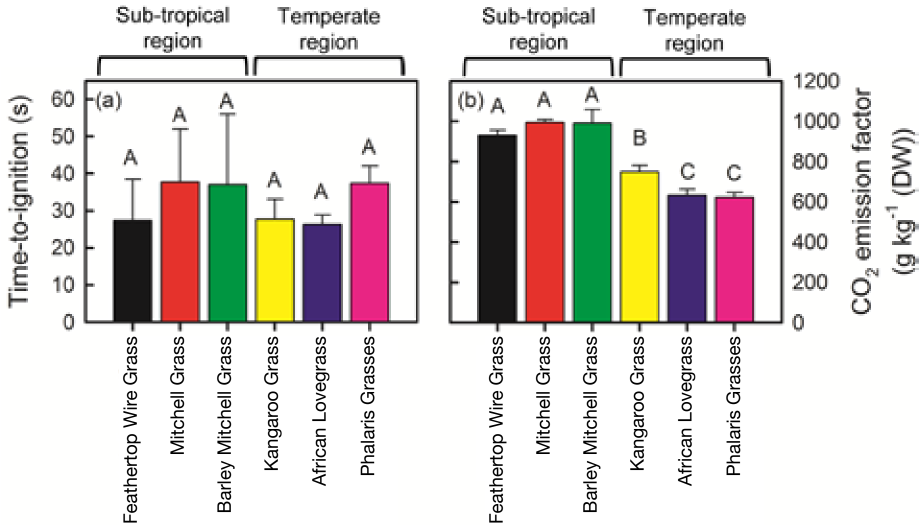
The results from this project are helping land managers assess, under different environmental conditions:

- The gaseous composition of smoke.
- How much carbon is potentially lost from the landscape because of fires.
- The flammability and potential fire behaviour from a range of fuel types.

These assessments will help land managers identify if a prescribed burn is likely to significantly affect air quality, as well as estimate with greater certainty the contribution of each prescribed burn to national carbon accounting. Additionally, the experimental data confirms that changes in fuel moisture content are critical for determining the release of energy and combustion products from the three *Eucalyptus* species, and that these effects can be readily estimated using empirical calculations. This enables a better understanding of fire behaviour, and subsequently, better assessment by fire managers for controlling a fire and selecting appropriate suppression actions.

It remains to be seen if the accuracy of fire behaviour or emissions models are improved with the inclusion of empirical relationships found among fuel moisture content, the release of energy, ignition timing, ignition probability and emission of combustion products. Continuing research is also required to determine how fuel moisture content relates to moisture gradients often found in the surface fuel layer *in situ* and whether the trends measured for the three *Eucalyptus* species used in this study are species specific or reflect a global pattern that could be applied to other regions or species.

The research has been informed by the requirements of end users, who requested additional samples on the effect of fuel moisture content on greenhouse gas emissions to include a more realistic range of fuel moisture content of the leaves tested. The study of smoke composition and flammability of sub-tropical and temperate grasses was instigated in response to the higher risk of grass fires from recent seasonal bushfire predictions.



▲ **Figure 3:** (a) Time-to-ignition and (b) emission factors for CO2 measured during the combustion of the six grass species collected from tropical and sub-tropical regions (Possell and Bell 2012).

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FUTURE DIRECTIONS

Research currently underway is exploring the combustion products and flammability of different types of fuel from a temperate *Eucalyptus* forest. Different fuel fractions (organic matter, leaf litter, elevated fuel) are being collected and combusted in the mass-loss calorimeter.

The sample material has different fuel moisture content representing conditions most likely found under bushfire and prescribed burn conditions.

By using these fuel fractions, the results will be useful in estimating carbon loss under high intensity (bushfire) and low intensity (prescribed burning) fire situations, as each situation will burn different amounts and types of fuel.

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