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OPTIMISATION OF FUEL REDUCTION BURNING REGIMES FOR FUEL REDUCTION, CARBON, WATER AND VEGETATION OUTCOMES

Annual project report 2015–2016

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Cover: Smoke from fuel reduction burn in ACT. Photo taken by Tina Bell.

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EXECUTIVE SUMMARY

This year we have made remarkable progress with collection and analysis of spatially explicit data in relation to fuel reduction burning. From this data, a number of reports have been produced. The intent has been to transform milestone reports into peer-reviewed publications to ensure that the research we are doing is robust enough to pass peer-review and that End Users can have confidence in our recommendations. In the past 12 months the research team has produced seven peer-reviewed publications and two final milestone reports and have presented at both international and national conferences.

The journals that we have published or intend to publish in have impact factors of 2.4 or greater and are rated in the top quartile for journals in the fields of Land Management, Forestry, Ecology, Fuels Technology or Chemistry.

Although we have had several successive End Users associated with the project we have worked hard to maintain contact with our industry partners and to keep them up to date with our research progress. The research team has established valuable links with operational staff, firstly, to access recently burnt sites and, secondly, to help End Users to understand how and why data is collected. A sampling protocol has been developed and the efficacy of our methods has been tested in the field.

Recent major fire events in Victoria, Tasmania and Western Australia and changes in government policy in Victoria related to risk-based fire management are creating need for new research into the effectiveness of fuel reduction burning. The expertise that we have in our project team and our knowledge of landscape-scale variation sees us well placed to embark upon new directions of research including the impact of risk-based fuel reduction strategies on vegetation, carbon pools and water resources.

END-USER STATEMENT

Naomi Stephens and Felipe Aires, *National Parks and Wildlife Service, Office of Environment and Heritage, NSW*

The use of prescribed burns to mitigate the impacts of bushfires is common practice across many fire management agencies in Australia and around the globe. Currently, there is a move towards changing bushfire management from a hectare-based performance target to a more risk-based approach. In most cases, the prioritisation of prescribed burning for environmental outputs roughly focus on soil erosion, protection of native vegetation and biodiversity though keeping fire intervals within acceptable thresholds for species preservation, retention of riparian zones and protection of aboriginal and cultural heritage sites.

This project will provide essential information for agencies to set up a framework capable of improving the effectiveness of prescribed burning by reducing the risk of loss of water yield and improving carbon sequestration. The ability to model the impact of fire on soil carbon storage capacity and water yield at a landscape scale, using a single model framework is still to be developed. The capacity of integrating common environmental variables into modelling will represent a step forward in reducing undesirable environmental impacts during prescribed fires.

Since last year, this research has advanced the knowledge of landscape variability improving the methodology to collect and analyse data. The four manuscripts in preparation for 2016 will represent an advance in many areas of science and will support new policies/operations in terms of optimisation of fuel reduction and risk reduction for environmental outcomes.

The 'Ember-SIM' bushfire simulator has great potential to be incorporated into agencies for educational purposes. The software could be used to enhance learning outcomes of staff undertaking fire training activities.

The Lead End User and the research team have had regular contact via e-mail. Felipe Aires led the initiative of creating a new communication tool between End Users, the project team and other cluster members. Researcher team member, Mana Gharun, wrote an End User update note that was distributed to the cluster network and received good feedback.

INTRODUCTION

A large proportion of the area of south eastern Australia is forested and most of this area is vital for water catchment – for recharge of the Murray Darling Basin, for potable water for capital cities (i.e. Melbourne, Canberra, Sydney) and water for a variety of uses in regional centres and their dependent agricultural communities. The annual and long-term water yield from these catchments, as well as their carbon storage potential, are amongst the most valuable of all natural assets of respective state governments and agencies, including power and water utilities in Victoria, NSW and the ACT.

The overall aim of this project is to improve the capability of land managers to use fuel reduction burning to manage land such that risks of loss of water yield and carbon sequestration capacity are mitigated. This project builds on our research in the Kiewa, Ovens, Mitta Mitta, Cotter and Corin catchments that has shown major differences between forest types in effects of fire intensity on subsequent stand and forest hydrology. These differences point to the capability of using different prescribed fire strategies in different parts of catchment landscapes. The project also draws on our research efforts in determining the effect of fuel reduction burning on carbon balances in forests in southern Victoria. In effect, this project will define and refine fire management of forests and forested catchments at an appropriate scale. This approach is akin to "precision land management" that has been developed and used in broadacre agriculture (both cropping and grazing). The key features of this concept are to quantify variability, understand the environment and make sound predictions to continually improve or adapt practices and become more efficient.

Land managers prioritise fuel reduction burning in a number of ways. The primary goal is for removal or reduction of fuel to minimise the risk of bushfire affecting life and property. The contribution of antecedent weather conditions to fuel moisture and current weather patterns to fire behaviour are used to govern the timing of fuel reduction burning. Fire management in Australian forests is also guided by good knowledge of the fire-response traits of key plant species. Similarly, landscape features are well understood in relation to fuel reduction burning – some landscape positions and aspects are more manageable than others are, and managers are able to prioritise burning on this basis as well. What has been lacking, but which has become increasingly important, is knowledge and projecting capacity of the effects of fuel reduction burning on carbon and water potential (e.g. capacity for carbon sequestration, water yield) of forests at a manageable spatial scale. This knowledge is required in a format that is readily useable by managers and, most commonly, is in the form of predictive models or tools. To address our current lack of understanding, this project will move research and management capabilities to its next logical focus – building a sensible framework and a predictive model combining and optimising the competing outcomes for fuel reduction burning.

PROJECT BACKGROUND

Two underlying problems have shaped the direction of our project:

1. Limited knowledge of the water storage capacity and dynamics of soil profiles (e.g. to a depth of at least 1 m) – this hinders both our ability to model water fluxes, especially the yield of water to streams and dams, and our ability to model whole stand and forest water use, before and after fires.
2. Limited knowledge of the effects of differing fire intensities on soil carbon. This requires, *a priori*, development of techniques to provide reliable and routine assessment of fire-related temperatures within soils at different depths.

These key issues can be tackled within an overall framework of developing models to facilitate optimisation of fuel reduction fire regimes. The use of spatially explicit models will take account changes in fuel loads and predict the likely effects of individual fuel reduction fires and collectively as prescribed burning regimes on carbon and water potentials and vegetation composition.

THE PROJECT

There is some argument that fuel reduction fires should be smaller rather than larger, often on the basis that this creates a mosaic of time-since-fire at the landscape scale. What is seldom considered is the heterogeneity within the boundaries of prescribed fires, which can include unburnt areas, partially burnt areas, areas burnt at moderate intensity or low intensity. This project is testing the effectiveness of fuel reduction fires of different size, as they are currently implemented, in terms of:

- fuel reduction
- carbon outcomes
- water outcomes
- vegetation outcomes

Our research is therefore framed with the null hypothesis that the size of prescribed fires (e.g. less than 100 ha, greater than 10^3 ha) has no effect on environmental variables or on their effectiveness in fuel reduction. Land managers in Victoria, NSW and the ACT currently implement a number prescribed fires in a typical year (e.g. 20–200 fires), with the size of fires spanning at least two orders of magnitude. These fires provide many opportunities to test this hypothesis.

WHAT HAS THE PROJECT BEEN UP TO?

DATA COLLECTION

One of the greatest achievements for the past 12 months is the field work and laboratory analysis that has been completed. This effort has been lead by Mana Gharun, assisted by our Forester, Ariana Iaconis and a team of field assistants including postgraduate, undergraduate and visiting students. On several occasions, additional help has been provided by operational staff from NSW and ACT state agencies.

Field protocols, described in our Sampling Schema (Gharun *et al*. 2015, see list of publications), were refined throughout the year. This was done to increase the efficiency of our sampling campaigns and to make the protocols clear for use in a training manual. The sampling scheme that we have adopted describes a 'burn unit' as a pair of sites that are measured and compared. The pair of sites can be in adjacent burnt and unburnt areas and are sampled at the same time (referred to as 'burnt' and 'unburnt' plots) or are the same site but sampled at different times (referred to as 'pre-fire' and 'post-fire' plots). Our fieldwork and sample analysis is well on-track with 39 burn units (burnt/unburnt pairs) from the ACT and NSW completed after two seasons of field campaigns (Table 1). In addition, we have resampled nine burn units (pre-fire/post-fire pairs) in Victoria.

State government agencies have played a major role in facilitating our fieldwork by providing us with essential information and access to sites. For example, to help decide where and when to sample, the NSW National Parks and Wildlife Service has provided us with weekly notifications about burning plans and operational schedules along with contact details for the relevant area mangers. End Users from ACT Parks and Conservation Services were invaluable for providing fire history information and site access for field work done in early 2015.

Once we are notified of recent or upcoming fuel reduction burns, maps of slope and aspect are overlain with the burnt areas to determine site suitability in terms of vegetation type, fire history, terrain and access. In the field, randomly located pairs of burnt/unburnt plots with similar vegetation, aspect and slope are established approximately 500 m apart. Depending on the extent of the planned burn, three to five burn units are established at each site to allow plot-, site- and landscape-level data collection. Figure 1 shows the spread of field sampling that has been achieved to date.

Each plot is circular in shape (22.5 m radius) with the centre point determining the orientation of the plot. Two transects (45 m in length) running north-south and east-west and crossing at the centre point are temporarily marked with star pickets at the centre point and at each end. Within each plot, four circular subplots of 5 m radius are set up at each of the N, S, E, and W terminal points such that the centre point of each subplot is at 5 m from edge of larger circular plot. Data collected and samples taken from plots and subplots include:

- Fuel load assessment according to Hines *et al*. (2010)
- Surface (litter) and near-surface (live) biomass sampling
- Estimates of near-surface fuel load using digital imagery (Macfarlane and Ogden 2012)
- Estimates of elevated fuel (understorey vegetation) using allometric relationships (Bi *et al*. 2004)
- Canopy and bark fuel (overstorey vegetation)
- Leaf Area Index (LAI) as a key indicator of energy and water flux (Yan *et al*. 2012)
- Estimates of water use of vegetation based on measurements of tree size (see Figure 2)
- Volume of coarse woody debris (CWD; >25 mm diameter) estimated by the line intersect method (Van Wagner 1968; Ilic *et al*. 2000)
- Soil carbon content (0–10 cm depth) (see Figure 2)

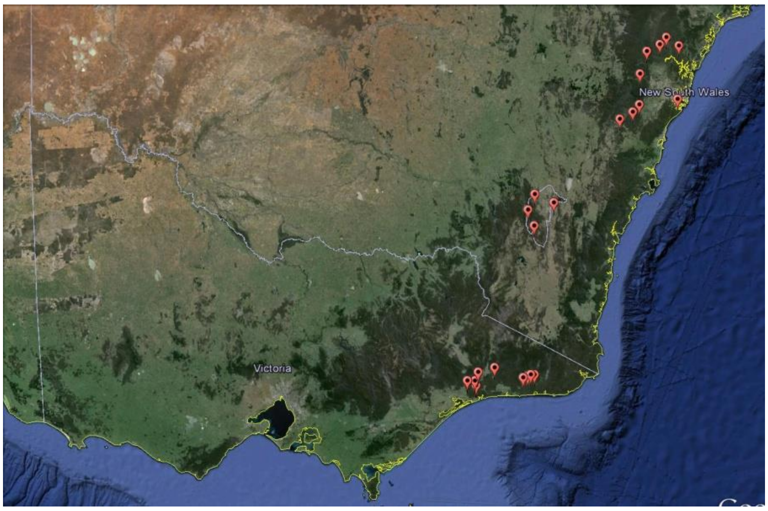

FIGURE 1. LOCATION OF FIELD SITES IN VICTORIA, THE ACT AND NSW

FIGURE 2. FIELD TECHNIQUES; MEASURING TREE HEIGHT (LEFT), INSERTING SOIL CORE (MIDDLE) COLLECTING SOIL FOR MEASUREMENT BULK DENSITY (RIGHT)

Our field data has been presented as a poster at the annual conference in 2015 and an update will be presented in 2016. It was also been reported by Malcolm Possell at a Research Advisory Forum in Brisbane in September 2015. Mana Gharun presented some of the data at the 6th International Wildland Fire Conference, Seoul, South Korea in October 2015.

TABLE 1. DETAILS OF FIELD AND LABOROATORY WORK COMPLETED IN 2015 AND 2016

Field trip number	Date	Location	State	Number of burn units	Laboratory analysis completed
1	April 2015	Namadgi National Park	ACT	4	Y
2	April 2015	Namadgi National Park	ACT	3	Y
3	April 2015	Namadgi National Park	ACT	5	Y
4	September 2015	Dharug National Park	NSW	3	Y
5	September 2015	Royal National Park	NSW	3	Y
6	September 2015	The Blue Mountains	NSW	3	Y
7	October 2015	The Blue Mountains	NSW	3	Y
8	October 2015	Nattai National Park	NSW	3	Y
9	April 2016	Nattai National Park	NSW	3	N
10	April 2016	Nattai National Park	NSW	3	N
11	May 2016	Parr State Conservation Area	NSW	4	N
12	May 2016	Parr State Conservation Area	NSW	2	N

LANDSCAPE VARIABILITY

A considerable amount of data analysis and writing has also been done throughout the past year. As a result, the research group has produced seven publications describing research relevant to this project (see publication list) including one publication involving student research (Wang *et al*. 2015). In addition, there have been two milestone report produced and four manuscripts are in preparation (see publication list). One of the themes explored in the manuscripts being prepared is landscape variability.

Fire plays a critical role in biodiversity, carbon balance, soil erosion and hydrological cycle outcomes. While empirical evidence shows that fuel reduction burning can reduce the incidence, severity and extent of unplanned fires in Australia, the integration of environmental values into fire management operations is not well-defined and requires further research and development. In practice, the priority for fuel reduction burning is for effective mitigation of risk to life and property. Environmental management objectives, including maintenance of high quality water, reduction of CO_2 emissions, and conservation of biodiversity, can be constrained by this priority. In Gharun *et al*. (2016a), we explore trade-offs in the literature between fuel reduction burning and environmental management objectives, and propose a framework for optimising fuel reduction burning for good environmental outcomes.

Many aspects of the environment, including soil and vegetation properties, are characterised by high spatial variation at multiple scales, ranging from point measurements (less than a meter) to landscape scales (tens of kilometres). This natural variation can hamper precise quantification of some variables and will affect scaling of the impact of prescribed burning to a resolution that is necessary for management purposes. We used data collected in the field describing vegetation and soil properties before and after fuel reduction burning to test the general assumption that the variability in these properties increases with spatial scales (Gharun *et al*. 2016b). We found that measurement variability does not always increase with increasing scale. While certain plant and environmental characteristics (e.g. leaf area index, tree basal area, litter carbon and nitrogen content) measured at a plot scale (i.e. ~500 m) are sufficiently indicative of these properties at the landscape scale, other properties that are affected by prescribed burning (e.g. litter biomass) are just as variable at the small scale (~30 m) as they are at larger scales (~50 km). This means that accounting for variation in both small and large spatial domains will be more challenging when small-scale properties are not indicative of properties at larger scales. With this in mind we discuss the implications of the sampling array used for landscape-scale modelling of the effect of prescribed burning with respect to time since fire, topography and climate variability.

SOIL CARBON

Another theme explored in our reports and manuscripts in preparation is the measurement of organic carbon in soil. A considerable fraction of soil carbon exists as living and dead plant or animal material (e.g. roots, insects and microbes) or as a result of biological activity (decomposition, comminution). This is often referred to as soil organic matter (SOM). Carbon may also exist in intractable forms such as charcoal or pyrogenic carbon (Jenkins *et al*. 2016).

Carbon in soil (<2 mm fraction) is normally measured by dry combustion elemental analysis after air drying, sieving and finely grinding the soil (to approximately 53 µm). This protocol follows standard soil preparation and analysis techniques. The 2–4 mm portion is not generally considered to be soil and is normally discarded but, after examining samples collected from the field, it was observed that a considerable amount of charred material and charcoal is in this coarser fraction. Clearly, disregarding this fraction would underestimate the contribution of prescribed burning to transformation of aboveground carbon. To determine the amount of carbon in the 2–4 mm fraction, an alternative method of analysis that does not require grinding and uses larger representative soil samples was trialled. This method is called the Soil Carbon Bench (Pallasser *et al*. 2014; 2015) and was a featured news story for the Faculty of Agriculture and Environment in 2013.

http://sydney.edu.au/news/84.html?newsstoryid=11723

Carbon in the coarse fraction associated with soil (2–4 mm) was indeed equal to or greater than the amount of carbon in soil but showed greater variability (i.e. bigger standard deviation), particularly for samples from burnt plots (Figure 3). This is not surprising as charred plant biomass and charcoal from the last fuel reduction fire and previous fires are likely to be represented by particles bigger than 2 mm diameter. Carbon in the fine soil fraction (<2 mm) is generally formed by decomposition and comminution of plant biomass and charred material from previous fires. Information about the amount of carbon in the soil matrix that is not traditionally recognised as soil has implications for determining changes in carbon pools after fire (see Jenkins *et al*. 2016).

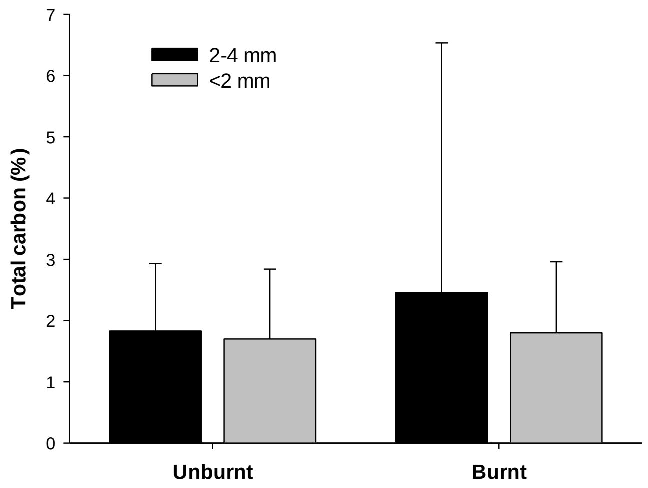

FIGURE 3. TOTAL CARBON (%; MEAN ± SD) IN TWO SOIL FRACTIONS FROM PLOTS WITHIN SITES BURNT BY FUEL REDUCTION FIRES AND NEARBY UNBURNT PLOTS IN THE ACT. THE SOIL DEPTH SAMPLED WAS 0–10 CM, N = 12

Characterisation of SOM is necessary to determine the mechanisms involved in erosion and soil stabilisation and to predict soil dynamics to provide recommendations for improving soil management. There are a number of analytical methods that have been used to determine the composition of SOM. These methods are used to examine the nature of chemical functions (e.g. nuclear magnetic resonance and Fourier transform infrared), for molecular identification of complex organic mixtures (e.g. Fourier transform ion cyclotron resonance mass spectrometry), spatial elemental and isotopic analysis (x-ray microscopy or secondary ion mass spectrometry), and degradation techniques that cleave the organic matter to provide molecular information (Derenne and Quenea 2015). An important thermal degradation technique is pyrolysis coupled to gas chromatography-mass spectrometry (pyr-GC-MS), which allows identification of the compounds that make up the pyrolysate.

At the University of Sydney, we have developed the capacity for high-end analysis and are currently using it to identify particular compounds that may be useful as marker compounds in assessing the impact of fire. As an enormous amount of data is generated using this technique, one of the most important steps is to develop a method that can sort through chromatograms quickly and efficiently but with high accuracy. Possell *et al*. (2016) uses an ensemble learning method to identify differences in the features of chromatograms that could be useful in classification of soil disturbance.

USE OF 'HISTORICAL' DATA

Two of the early publications for this project (Possell *et al*. 2015; Jenkins *et al*. 2016) used 'historical' data from forest sites in Victoria. The sites were established in 2013 and 2014 and were resampled for our project in early 2015 according to our sampling protocols to gain additional information about soil, tree water use and fuel loads.

This and other data was used to estimate carbon emissions from fuel reduction fires. Estimates of emissions were calculated using measurements of fuel load and carbon content of different fuel types, before and after burning and determination of fuel-specific emission factors (Possell *et al*. 2015). Median estimates of emissions for the four sites ranged from 20–139 Mg CO_2e ha^{-1}. Variability in estimates was a consequence of different burning efficiencies of each fuel type from the four sites. Higher emissions resulted from consumption of fine fuel (twigs, decomposing matter, near-surface live and leaf litter) or coarse woody debris (CWD; >25 mm diameter). The effect of declining information quantity and the inclusion of coarse woody debris in emission estimates was tested using Monte Carlo simulations to create seven scenarios where input parameters values were replaced by probability density functions. Simulations demonstrated that the probability of estimating true median emissions declined strongly as the amount of information available declined. Including CWD in scenarios increased uncertainty in calculations because CWD is one of the most variable contributors to fuel load.

Pyrogenic carbon (PyrC), a product of combustion during both planned and unplanned fires, plays a key role in global carbon stores and balances. Data from the nine sites in Victoria describing overstorey and understorey vegetation, coarse woody debris, fine litter, PyrC and soil was used to determine biomass consumption, PyrC production and changes in carbon pools during planned burning (Jenkins *et al*. 2016). Across all sites, PyrC was produced at a rate of approximately 5% of the biomass consumed. Fuel reduction burning had a short-term (<1 year) impact on forest carbon balance and on reduction risk of wildfire and associated losses of biomass carbon. From our studies, we concluded that there was no long-term impact of a single fuel reduction burn at the sites due to deposition of PyrC and recovery of biomass.

HYDROLOGIC RESPONSES TO BURNING

Fuel reduction burning impacts catchment water supply as it removes vegetation and modifies the amount of evapotranspiration (ET) that occurs. Evapotranspiration – the amount of water lost from forests due to surface evaporation plus plant transpiration – is the most important component of catchment water balance. It can be estimated either directly using a range of measurement techniques or indirectly using modelling efforts that require climatic and plant physiological inputs and parameters. Currently, there is no method that allows rapid estimation of vegetation water use in the field making post-fire assessments of water balance a challenging task for land managers.

Leaf area index (LAI), a variable which is directly proportional to foliage cover, is an important input for estimating ET. We used empirical relationships between tree size and tree water use to link vegetation foliage cover with vegetation water use to investigate the impact of prescribed burning on forest water use. Based on a preliminary assessment, we observed that removing understorey cover by 10% reduces understorey water use by up to 50% (Figure 4). This type of analysis allows for scaling up of hydrological impacts from fuel reduction burning from stand and plot to larger scales that are more appropriate for water management agencies.

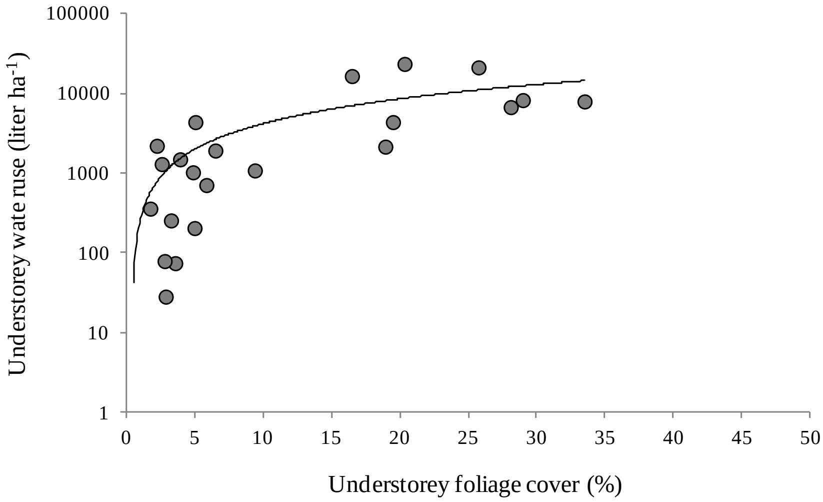

FIGURE 4. RELATIONSHIP BETWEEN UNDERSTOREY WATER USE AND UNDERSTOREY FOLIAGE COVER BASED ON MEASUREMENTS COLLECTED FROM 24 PLOTS IN THE ACT. WE WILL USE DATA COLLECTED FROM 54 PLOTS IN NSW TO SUPPLEMENT THIS ANALYSIS

Image analysis methods have recently been widely used to estimate LAI and foliage cover from digital images. The use of digital photography to estimate LAI can potentially be used by land managers and water supply agencies as a guide for assessing the impact of burning on catchment water balance. Compared to time- and labour-intensive biomass measurements, automated processing of digital images has lower risk of human error and makes the technique rapid and cost-efficient. Development and testing of this method is the subject of a renegotiated milestone.

EMBER-SIM – A WEB-BASED BUSHFIRE SIMULATOR

In 2015, Mana Gharun, Tina Bell and Mark Adams were awarded a Small Educational Innovation grant from the University of Sydney. The project proposal was titled "Burn and learn – an interactive online fire spread simulation for teaching purposes". A web-based bushfire simulator has been developed for teaching fire behaviour at the tertiary level. The aim of the learning tool is to improve student understanding of how research and technology is applied in real-world management of fires and to improve student knowledge of fire behaviour, Ember-sim is a bushfire simulator and can be used on laptop and desktop platforms:

http://ember-sim.s3-website-ap-southeast-2.amazonaws.com/#/

Students can manipulate a range of variables including wind speed and direction, humidity and temperature, fuel load and land management practices (e.g. grazing, fuel reduction burning) to investigate how fire moves through the landscape (Figure 5). They can also do sensitivity analyses to determine which the most important variables for modelling fire behaviour. The software was tested with a small group of students and a before-after survey showed that they enjoyed the exercise and thought that it had great potential. This tool was very successful in enhancing student learning outcomes and it has great potential for training new researchers and operational staff.

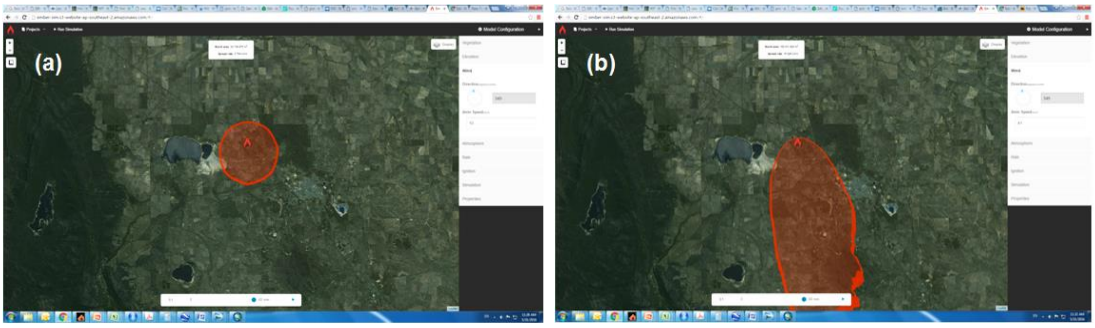

FIGURE 5. SCREEN IMAGES OF FIRE SIMULATIONS USING EMBER-SIM DEVELOPED TO TEACH STUDENTS ABOUT THE IMPACT OF A RANGE OF VARIABLES, IN THIS CASE, WIND SPEED, ON FIRE SPREAD.

WHAT IS THE RESEARCH PROJECT UP TO NEXT?

Field sampling and laboratory work will continue to achieve the milestone target of 20 burn units. Negotiations are underway to sample in Tasmania, South Australia and Queensland but this is contingent on suitable timing and weather conditions. Opportunistic sampling will continue in Victoria, NSW and ACT. A report detailing results from the first 40 burn units is being prepared. Models that are being developed to link water, carbon and vegetation outcomes with fuel reduction burning will be tested and refined using the additional data.

Work will continue on developing the alternative milestone (i.e. relationships among fuel moisture, water yield and mapped fire severity) that we negotiated in response to overlap with other BNH CRC project.

A new PhD candidate is due to commence in July 2016. This student's project has been developed to link fire intensity, severity and changes in soil in response to discussions with End Users (OEH and ACT Parks and Conservation).

Ongoing and significant changes in government policy in Victoria related to fire management and recent major fire events (e.g. Victoria, Tasmania, Western Australia) are creating the need for new research into the efficacy of fuel reduction burning. The new Code of Practice for 'Risk-based Bushfire Management' in Victoria is being implemented via introduction of Fire Management Zones with the treatment of fuel in each of four zones ranging from 'intensive' (i.e. cycles of 5–8 years fuel reduction burning) through to complete exclusion of fire. The rigidity of timing of fuel reduction burning in two of the four zones requires that there be greater focus on understanding the effects of prescribed fires at high frequencies, particularly in areas of land that are significant at regional scales.

POSTGRADUATE STUDENT RESEARCH

Student progress

Houzhi Wang – Initiation of biomass smouldering combustion
PhD commenced March 2014; enrolled at the University of Adelaide; scholarship funded by BNH CRC. Malcolm Possell is one of the members of Houzhi's supervisory panel.

In the past 12 months Houzhi's research activities have included:

1. A series of experiments to characterise the initiation of different combustion regimes in solid biomass. He wrote a conference paper and a journal paper based on this research
2. A presentation at the Australian Combustion Symposium
3. A second series of experiments to investigate the initiation of aided and self-sustained smouldering combustion in biomass fuel bed. He wrote a journal paper based on this research.
4. The design and construction of an isothermal reactor which can be used to determine the effects of fuel bed depth, fuel particle size on the air flow velocity.
5. The design and construction of a single-particle smouldering combustion reactor which will be used to investigate the smouldering combustion on a single fuel particle.

Mengran Yu – Modelling the effect of fire on the hydrological cycle
PhD commenced March 2015, enrolled at the University of Sydney; scholarship funded by BNH CRC.

Mengran commenced her PhD in March 2016 and has been funded by the BNH CRC since November 2015. Mengran has completed her research proposal and presented this to the Faculty in September 2015. She has also completed her first analysis of the effects of fire on water quality using linear mixed modelling and she presented this research at the 2015 Hydrology and Water Resources symposium in December 2015. Since the beginning of 2016, Mengran has further developed her research by focusing on the effects of fire on water quality after event flows. A manuscript detailing this work and her modelling efforts has been drafted with the aim to submit it for publication in July 2016.

As Mengran will be using data collected from our main project, she participated in a field trip to Nattai National Park to develop a better idea how the data is collected. She has started the second major chapter of her research which involves setting up the SWAT hydrological model to simulate the Effect of fire on water quality. Mengran's supervisory panel includes Tina Bell, Floris van Ogtrop and Thomas Bishop, all from the University of Sydney.

Gabriela Raducan – The impact of bushfires on water quality
PhD commenced March 2014; enrolled at RMIT; scholarship funded by BNH CRC

The impact of bushfires on water quality can be highly variable. This variability is caused by a number of landscape influences and climatic factors, most notably rainfall. High magnitude and intensity rainfall events soon after fire generate large impacts on water quality. However, because of the limited water quality data available, the evaluation of the model is still in progress. Gabriela's research is designed to develop a spatial approach to support the planning of the water quality in the areas subjected to bushfires. It is based on the implementation of a hydrological model in order to predict the river water quality. Gabriela is supervised by researchers at RMIT (Prof. Colin Arrowsmith and Dr David Silcock) and her End Users are Jacqueline Frizenschaf from SA Water Corporation and Craige Brown from Melbourne Water.

Angela Gormley – Effects of surface litter by forest classification on fuels and fire behaviour in the Sydney Basin
MSc commenced January 2016; enrolled at the University of Sydney; Associate Student of BNH CRC

Different vegetation classes have diverse fuel loads and structure and, therefore, different hazard ratings. Despite being residential many areas is the Sydney Basin are classified as being at an extreme risk for bushfires as the surface litter fuel arrangement in the nearby forests is completely connected and forms a continuous layer of fuel with few gaps. A good example is in and around the Shire of Hornsby, only 25 km from the central business district of Sydney.

Considerable work is required to provide empirical data to assist our understanding of how the differing classes of vegetation and conditions can affect fire behaviour. Angela's research project will characterise the flammability of fuels in urban areas of the Sydney Basin by incorporating fuel load, fuel moisture content and fire behaviour with combustion conditions.

Angela's research questions are:

1. What are the fuel loads in typical vegetation types in the Sydney Basin?
2. Do plants that are characteristic of different vegetation types in the Sydney Basin, such as Wet Sclerophyll forest, Dry Sclerophyll forest and Heath, differ in their leaf morphology and leaf flammability traits?
3. Can information about fuel loads and flammability be used to guide land managers in mitigation of risk from bushfires?

Our postgraduate students are shown 'in action' in Figure 6.

FIGURE 6. POSTGRADUATE STUDENT: HOUZHI WANG (TOP LEFT), MENGRAN YU (HOLDING PIPETTE, TOP RIGHT), GABRIELA RADUCAN (BOTTOM LEFT), ANGELA GORMLEY (BOTTOM RIGHT).

Completion of student projects associated with the Bushfire CRC

Felipe Aires – Fire ecology of woody weeds in Australian forests and woodlands (thesis passed March 2015)

Kerryn McTaggart – The effect of fire on soil microbial populations and processes (thesis passed March 2015)

Valerie Densmore – Fire-woody legume associations in south-eastern forests (thesis passed April 2015)

Cheryl Poon – Pyrogenic organic matter, soil carbon dynamics and prescribed fire in temperate forests of south-eastern Australia (thesis passed February 2016)

Undergraduate research

Bonnie Cannings was an undergraduate student whose Bachelor of Environmental Systems Honours project investigated the importance of volatile organic compounds (VOCs) as a loss of carbon in the decomposition of forest litter. Bonnie participated in fieldwork at Namadgi National Park, ACT and Cobbitty, NSW, where forest litter was collected for a series of laboratory measurements. She quantified the amount and type of VOCs emitted from the litter relative to the amount of carbon dioxide lost through respiration. Bonnie graduated in May 2016 with a First Class Honours degree.

Student internships

Erika De Almeida was part of the Study Abroad Internship Program for the University of Sydney from November 2015–January 2016. Erika's project aimed to validate a digital photography method for measurement of foliage cover to provide a non-destructive estimate of biomass and leaf area index of understorey vegetation. The methodology used images taken from above (nadir) and from the profile of seedlings (for leaf angle) before leaves were harvested, weighted and their leaf area was measured. We used more than 100 6 month-old *Eucalyptus* seedlings (kindly supplied by Dr Karanjeet Sandhu from the Plant Breeding Institute) to validate the digital photography technique. This research will help us to develop relationships between plant foliage cover, leaf area index and water use of understorey vegetation in dry sclerophyll forests across south-east Australia.

Katharina Leser was an undergraduate student visiting from University of Bielefeld, Germany as part of the DAAD Rise Internship from July–August 2015. Her project was titled "The breath of decay". The aim of her project was to investigate rates of respiration of course woody debris of different quality (sound or rotten, unburnt or burnt) under changing conditions as an indication of microbial communities present in the wood and the potential for decay.

FIGURE 7. MANA GHARUN TAKING DIGITAL IMAGES FOR MEASUREMENT OF LEAF COVER (LEFT) AND A REPRESENTATIVE IMAGE USED FOR ANALYSIS (MIDDLE TOP). AN INCUBATION CHAMBER (MIDDLE BOTTOM) AND EXAMPLES OF COARSE WOODY DEBRIS USED TO DETERMINE RATES OF RESPIRATION OF MICROBIAL INHABITANTS (RIGHT TOP AND BOTTOM).

END-USER INTERACTION

END-USER PARTNERSHIPS

We have worked determinedly to develop and maintain good relationships with our End Users in NSW, ACT and Victoria. Evidence of this engagement comes from recent successful sampling campaigns in NSW with crucial involvement of National Parks and Wildlife Service in the Office of Environment and Heritage. They have assisted our research by providing access to burn sites and valuable location information. Similarly, we have maintained a good working relationship with ACT Parks and Conservation Service who provided our group with fire ground training and supported fieldwork in 2015. Negotiations are currently being made with End Users in Queensland, South Australia and Tasmania for sampling campaigns later in 2016 and 2017.

Recent work with fire managers from Hornsby Shire Council in NSW has lead to a successful sampling campaign for a student research project.

COLLABORATIONS

During the past 12 months, Malcolm Possell has been invited to collaborate with End Users and other researchers by virtue of his expertise in measurement of flammability of fuels and analysis of combustion products. Prof. David Bowman from the University of Tasmania has provided plant material from a range of sites across eastern Australia for fuel flammability analysis and Prof. Ross Bradstock from the University of Wollongong has supplied soils exposed to fires of different intensities for potential characterisation. This follows earlier analyses of combustion and flammability of grasses from ACT in collaboration with Dr Adam Leavesley, ACT Parks and Conservation.

Tina Bell was requested to join a competitive grant proposal led by Dr Owen Price from the University of Wollongong along with researchers from Swansea University, United Kingdom. The decision for successful funding is still pending.

PUBLICATIONS LIST

PEER-REVIEWED PUBLICATIONS

Possell M, Jenkins ME, **Bell TL**, **Adams MA** (2015) Emissions from prescribed fire in temperate forest in south-east Australia: implications for carbon accounting. *Biogeosciences* 12, 257–3268.

Wang H, Medwell P, Birzer C, Van Eyk P, Tian Z, **Possell M** (2015) Investigation of smouldering combustion of biomass fuel. Proceedings of the Australian Combustion Symposium 2015, Melbourne, Victoria, The Combustion Institute Australia and New Zealand.

Gharun M, **Turnbull TL**, Pfautsch S, **Adams MA** (2015) Stomatal structure and physiology does not explain differences in water use among montane eucalypts. *Oecologia* 177, 1171–1181.

Dijkstra F, **Adams MA** (2015) Fire eases imbalances of nitrogen and phosphorus in woody plants. *Ecosystems* 18, 769–779.

Gharun M, Henry J, **Turnbull TL**, **Adams MA** (2015) Mapping spatial and temporal variation in tree water use with an elevation model and gridded temperature data. *Agricultural and Forest Meteorology* 200, 249–257.

Gharun M, Azmi M, **Adams MA** (2015) Short-term forecasting of water yield from forested catchments after bushfire: a case study from south-east Australia. *Water* 7, 599–614.

Jenkins ME, **Bell TL**, **Poon LF**, Aponte C, **Adams MA** (2016) Production of pyrogenic carbon during planned fires in forests of East Gippsland, Victoria. *Forest Ecology and Management* 373, 9–16.

MANUSCRIPTS SUBMITTED OR IN PREPARATION

Gharun M, **Possell M**, **Bell TL**, **Adams MA** (2016a) Optimisation of prescribed burning regimes for carbon, water and vegetation outcomes. *Forest Ecology and Management* (in final stages of review by authors prior to submission, approval to submit gained from BNH CRC)

Gharun M, **Possell M**, Jenkins ME, Poon LF, **Bell TL**, **Adams MA** (2016a) Variability in soil and fuel properties at different spatial scales after fuel reduction burning. *International Journal of Wildland Fire* (in final stages of review by authors prior to submission to BNH CRC for approval to submit)

Wang H, Medwell P, Birzer C, Van Eyk P, Tian Z, **Possell M** (2016) Identification and quantitative analysis of smouldering and flaming regimes in the combustion of biomass. *Energy and Fuels* (submitted May 2016)

Possell M, **Gharun M**, **Bell TL**, **Adams MA** (2016) Application of statistical techniques to pyrolysis-GC-MS data from soil to identify the impact of fire. *Journal of Analytical and Applied Pyrolyis* (in early stages of review by authors)

MILESTONE REPORTS

Finalised reports

(excluding annual and quarterly reports)

Gharun M, **Possell M**, **Bell T** (2015) Optimisation of prescribed burning regimes for carbon, water and vegetation outcomes – a review. (Y2Q1 milestone; Commonwealth milestone CM3.02.1)

Gharun M, **Possell M**, **Bell T** (2015) Sampling schema for measurement of the impact of prescribed burning on fuel load, carbon, water and vegetation. (Y2Q3 milestone; Commonwealth milestone CM3.02.2)

Gharun M, **Possell M**, **Bell T** (2015) Variability in soil and fuel properties at different spatial scales after prescribed burning. (Y2Q4 milestone; Commonwealth milestone CM3.03.3a)

Pending reports

Possell M, **Gharun M**, **Bell T** (2016) Application of statistical techniques to pyrolysis-GC-MS data from soil to identify features unique to fire impacts (draft report submitted; Y3Q3 milestone)

Gharun M, **Possell M**, **Bell T** (2016) Hydrologic responses to fuel reduction fires – calibration of field measurements for rapid assessment of hydrological impacts (in preparation; Y3Q4 milestone; CM 3.02.3b)

Gharun M, **Possell M**, **Bell T** (2016) Report on sampling and data analysis of 40 fuel reduction fires (in preparation; Y3Q4 milestone; CM 3.02.4)

CONFERENCE PRESENTATIONS

(excluding Annual BNH CRC/AFAC conferences and RAF meetings)

Gharun M, **Possell M**, **Bell T**, Spatial variability in the impact of prescribed burning on the environment in Australian eucalypt forests. Oral presentation at 6th International Wildland Fire Conference, Seoul, South Korea, October 2015

Wang H, Medwell PR, Birzer CH, van Eyk PJ, Tian ZF, **Possell M**, Investigation of smouldering combustion of biomass fuel. Oral presentation at Australian Combustion Symposium, Melbourne, Victoria, December 2015

OTHER PRESENTATIONS

This research project was showcased in a Hazard Note (February 2016) and updated in blogs by Mana Gharun and Tina Bell. End Users were recently updated by circulation of an update document written by Mana Gharun.

Mark Adams was interviewed for newspaper articles in The Age and radio interviews for ABC Radio 702 in Sydney and Radio National.

Tina Bell was interviewed for a newspaper article in The Land and radio interviews for Deutschlandfunk/German Public Broadcasting Corporation.

CURRENT TEAM MEMBERS

RESEARCHERS AND SUPPORT STAFF

Assoc. Prof. Tina Bell – Project Leader

Prof. Mark Adams

Dr Mana Gharun

Ms Ariana Iaconis

Dr Malcolm Possell

Dr Tarryn Turnbull

Assoc. Prof. Feike Dijkstra and Mr Michael Turner provided additional research and technical in-kind assistance

Dr Vicky Aerts, Dr Felipe Aires, Dr Marco Harbusch, Ms Helen Le and Dr Cheryl Poon provided additional assistance in the field

STUDENTS

Mr Houzhi Wang, PhD candidate, University of Adelaide

Ms Gabriella Raducan, PhD candidate, RMIT

Ms Mengran Yu, PhD candidate, University of Sydney

Ms Angela Gormley, MSc candidate, University of Sydney

Ms Bonnie Cannings, BEnvSys (Hons), University of Sydney

Ms Erika De Almeida, international student, Study Abroad Internship Program

Ms Katharina Leser, international student, University of Bielefeld, Germany

END-USERS

Naomi Stephens, Max Beukers and Felipe Aires, Office of Environment and Heritage, New South Wales

Mike Wouters, Department of Environment, Water and Natural Resources, South Australia

Liam Fogarty, Department of Environment and Primary Industries, Victoria

Neil Cooper and Adam Leavesley, ACT Parks and Conservation Services, Australian Capital Territory

Lachlan McCaw, Department of Parks and Wildlife, Western Australia

REFERENCES

1. Bi H, Turner J, Lambert MJ (2004) Additive biomass equations for native eucalypt forest trees of temperate Australia. Trees 18, 467–479.
2. Derenne S, Quenea K (2015) Analytical pyrolysis as a tool to probe soil organic matter. Journal of Analytical and Applied Pyrolysis 111, 108–120.
3. Hines F, Tolhurst KG, Wilson AAG, McCarthy GJ (2010) Overall Fuel Hazard Assessment Guide. Department of Sustainability and Environment, Fire Management Report No. 82. Victoria.
4. Ilic J, Boland D, McDonald M, Downes G, Blakemore P (2000) Woody Density Phase 1 – State of Knowledge. Canberra, Australian Greenhouse Office. Report No. 18.
5. Macfarlane C, Ogden GN (2012) Automated estimation of foliage cover in forest understorey from digital nadir images. Methods in Ecology and Evolution 3, 405–415.
6. Pallasser R, Minasny B, McBratney AB (2014) A novel method for measurement of carbon on whole soil cores. In: Soil Carbon, AE Hartemink, K McSweeney (Eds.), 69–76, New York, Springer.
7. Pallasser R, Minasny R, McBratney AB (2015) Carbon determination system for whole soil cores. Communications in Soil Science and Plant Analysis 46, 221–234.
8. Van Wagner CE (1968) The line intersect method in forest fuel sampling. Forest Science 10, 267–276.
9. Yan H, Wang SQ, Billesbach D, Oechel W, Zhang JH, Meyers T, Martin TA, Matamala R, Baldocchi D, Bohrer G, Dragoni D, Scott R (2012) Global estimation of evapotranspiration using a leaf area index-based surface energy and water balance model. Remote Sensing of Environment 124, 581–595.