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

Annual project report 2014–2015

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Cover: Smoke from prescribed burning in the ACT.

Photo by Tina Bell

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EXECUTIVE SUMMARY

Australian eucalypt forests are among the few forest types where prescribed burning—including fuel reduction fires, slash burning after forestry operations and ecological burning—has been practiced for many years. While empirical evidence shows that prescribed burning can reduce the incident 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 prescribed burning is for effective mitigation of risk to life and property while environmental management objectives including maintenance of high water yield and quality, reduction of CO_2 emissions, carbon sequestration and conservation of biodiversity may be reasonably constrained by this priority. Our research progress towards optimisation of fuel reduction burning with water, carbon and other environmental outcomes during the past 12 months is described. Highlights include the commencement of fieldwork in Victoria and the ACT, a review of current frameworks and decision systems for planning prescribed burning and ‘road testing’ of our Sampling Schema by End User agencies. A PhD student whose project will add value to our research was successful in gaining a BNHCRC top up scholarship.

END USER STATEMENT

Max Beukers, *Fire and Incident Management, Office of Environment and Heritage, NSW*

The application of conditions in prescribed burn programs is a well-established convention in Australia. These conditions seek to mitigate the negative impacts of planned burns on environmental values. This research will improve the efficacy of prescribed burning programs by providing more evidence on the impact of burning on three essential environmental services, surface and groundwater quality and quantity, and carbon sequestration.

Current extrapolations of the impact of fire soil capacity to store, clean and release water and carbon at a landscape level need review and testing. Burn program planners and managers are seeking predictive spatial models that provide greater surety on the impact burn programs have on a soils capacity to deliver the environmental services required.

The predictive model being developed by this project will quantify the optimisation of environmental service outcomes for water and carbon management against the effectiveness of the fuel reductions outputs. This will help fire management agencies because it gives them greater confidence on the forecast results for their actions.

The slow start in late 2014, while Postdoctoral Fellow and Research Assistant positions were filled, has passed and the project is now well underway. There was some delay in meeting early milestones but evidence now shows that outstanding milestones are well on the way to being completed. The consequences of these early delays to forecast program completion date is yet to be determined.

The sampling schema was presented to BNHCRC in May 2015 and is currently available through the BNHCRC website. Analysis from this work is being prepared for publication in the International Journal of Wildland Fire. Fieldwork in Victoria and the ACT has commenced and sampling in NSW will begin soon. Preliminary analysis of samples has begun.

A draft literature review that compared modelling frameworks for prescribed burning was sent to the BNHCRC in June 2015 and registered with the BNHCRC in August 2015. This will be released after it has been accepted for publication in a peer-reviewed journal.

INTRODUCTION

A large proportion of the area of south-eastern Australia is forested and most of this area is vital for water catchment – for the Murray Darling Basin, for capital cities (Melbourne, Canberra, Sydney) and for regional centres and dependent agricultural communities. The annual water yield from these catchments, and their annual carbon storage, as well as their long-term water yield and 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.

This project focuses on improving the capability of land managers to use prescribed fire to manage land such that risks of loss of water yield and carbon sequestration capacity are mitigated. This project builds on our recent work 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 prescribed fire on carbon sequestration capacity 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 broad-acre 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 prescribed 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 prescribed burning. Prescribed burning in Australian forests is also guided by good knowledge of the fire-response traits of key species. Similarly, landscape features are well understood in relation to prescribed 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 prescribed burning on fuel loads, broad vegetation types (in biomass terms) and 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. Most commonly, this lies 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 predictive model and framework for planning for prescribed 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 prescribed burning 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 prescribed 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 prescribed burns of different size, as they are currently implemented, in terms of:

- fuel reduction
- carbon outcomes
- water outcomes
- biodiversity outcomes

Our research is therefore framed with the null hypothesis that the size of prescribed fires (e.g. greater than 100 ha, less 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.

Reviewing current modelling frameworks

Gharun M, Possell M, Bell T (2015) Optimisation of prescribed burning regimes for carbon, water and vegetation outcomes – a review (Final report, draft manuscript intended for journal publication)

One of the first milestones for this project was to review current modelling frameworks that could be used to inform optimisation of prescribed fires for both risk mitigation with reduction of fuel loads and environmental outcomes.

Predictive models that can capture the impact of prescribed fire on carbon and nutrient stocks, water balance and vegetation diversity have generally been developed in isolation from one another. For example, models used to determine the impact of different fire regimes on soil carbon stocks either have been developed from field experimentation or are deterministic models that simulate the flow of nutrients and water through plant and soil compartments (e.g. CENTURY Soil Organic Matter Model[1]). In terms of vegetation diversity, species occupancy models are used to monitor trends in species occurrence in relation to prescribed burning[2]. A number of models have been developed to simulate changes in water balance after bushfire or changes in land cover (e.g. Macaque model[3]), but they are rarely used in combination with forest productivity or carbon accumulation models[4]. A great deal of benefit can be gained by linking seemingly disparate models through integration of common environmental variables. However, processes that are common drivers of carbon, nutrient and water cycling, including fine root production, plant productivity and formation of pyrogenic carbon, remain a large source of uncertainty in our current modelling approaches[5,6]. Studies that are designed to understand, quantify and manage current sources of uncertainty are greatly needed and combining statistically robust field sampling with remote sensing and spatial data may be an ideal way to achieve this.

To this end, we proposed a framework for development of a spatial decision support system for optimisation of prescribed burning. The framework has two main modules: one module is based on our current scientific knowledge and technical experience (e.g. knowledge of fire behaviour and the primary effects of fire on soil properties, biological diversity, nutrient cycling and atmospheric emissions) and the second fulfils knowledge gaps in operational and ecological issues. The second module requires collection of additional scientific knowledge about the 'flow-on' effects of fire on water, carbon and ecosystem recovery using field measurements, modelling and validation tasks. Both modules are added to a spatial decision support system[7,8] to provide land managers with a detailed cartographic product for exploring and optimising management outcomes.

Determining fire size

Bell, T, Kenny B (2014) Optimisation of fuel reduction burning regimes: determining fire size (Poster presentation)

Prescribed burns can vary in size across four orders of magnitude. Fuel reduction burning is often patchy as a result of fuel and climatic conditions and landscape features such as topography and soil type. A strong sampling design is required to capture this variation. In addition, it is becoming increasingly obvious that as bushfires become larger they become more intense and thus have greater influence on soils and vegetation. It is unknown if the same situation arises with prescribed burns. The relationships between burn size and soil, water, vegetation and fuel outcomes has yet to be quantified thus limiting our ability to predict the effects of prescribed fires across landscapes.

To design an *a priori* sampling scheme of prescribed fires with appropriate statistical power, it is important to define what a 'small' fire is compared to a 'big' fire. Logically, larger fires will need to be sampled at a different scale and frequency than smaller fires – but what range of burn area is most appropriate? Recognising patterns in fire size and timing will provide valuable information for determining our sampling design.

To establish historical fire size and timing, land and fire management agencies in NSW, Victoria, South Australia, Western Australia and Tasmania provided data relating to fire size, location and timing for the last 10 years (2003–2014). Some simple, preliminary analysis showed that mean fire size for NSW, Tasmania and the ACT was approximately 350 ha regardless of the total number of planned or completed burns. Mean fire size in Victoria was considerably smaller (approximately 70 ha) but the distribution of fire size was heavily skewed with 64% of prescribed fires being less than 10 ha in size. The opposite pattern was found for fire size in Western Australia with an average fire size of 1320 ha and with 66% of fires greater than 1000 ha. Fire size varied with location and purpose of the burn, generally increasing in size from asset protection to strategic land management burns.

Fuel reduction burning occurs in fewer months in the ACT and Tasmania compared to NSW and Victoria suggesting that the sampling period in each state needs to be taken into account. Such information has already been used to develop sampling schedules in the ACT and NSW.

Developing and testing our Sampling Schema

Gharun M, Possell M, Bell T (2015) Sampling schema for measurement of the impact of prescribed burning on fuel load, carbon, water and vegetation (Final report, training manual)

Fieldwork commenced in Victoria in early 2015. The sampling design that we have adopted is well established in the literature[9,10,11]. Our field sampling protocol ("Sampling Schema") was used as a training tool for two staff from ACT Parks and Conservation Services and staff and students from the University of Sydney. The Sampling Schema was circulated to participants prior to field work and protocols were demonstrated while in the field. The data collected has been analysed and found to be of very high quality. We plan to repeat this exercise to train staff from End User agencies for data collection in NSW.

Determining landscape variability

Gharun M, Possell M, Bell T (2015) Variability in soil and fuel properties at different spatial scales after prescribed burning (Draft manuscript intended for journal publication)

Empirical field measurements are commonly used to assess the effectiveness of prescribed burning. The general assumption is that variability increases from small (~1 m) to large spatial scales (~1 km). Based on our current sampling scheme (see above), we tested the following questions:

1. How much variability is captured in environmental measurements collected at different spatial scales?
2. What is the optimal number of samples required for burnt and unburnt areas?
3. How does fire size affect the accuracy of the measurements?

A total of 39 paired plots were sampled from nine 'landscape units' in Victoria (before/after prescribed burning configuration) and four the ACT (burnt/unburnt configuration). Each pair of plots (a "burn unit") was located at least 500 m from the nearest burn unit and included four circular subplots (~5 m radius) on N, E, S and W axes. Samples of litter, ground cover and soil and data for soil temperature, understorey vegetation and fuel load were collected from subplots (i.e. three plots with four subplots in each landscape unit). Data for coarse woody debris, bark fuel and overstorey biomass were collected from plots (the plots in each landscape unit). Soil analyses include determination of bulk density, moisture content, pH, electrical conductivity, total carbon and nitrogen, inorganic nitrogen and available phosphorus. Estimations of tree water use and leaf area index were calculated using current models.

Spearman's rank correlation between coefficients of variation (100 × standard deviation (SD)/mean) and Mantel tests were used to explore the association between measurements and sampling scale. We found that variation in biomass measures was less affected by the scale at which measurements were collected in burnt areas compared to unburnt areas (Table 1). We also found that sampling in spatially separate burnt and unburnt plots is comparable to sampling the same plot before and after a fire. Large prescribed burns (e.g. >2500 ha) generally require fewer samples to capture variability across the landscape than small prescribed burns (e.g. 500-1000 ha).

TABLE 1: THE NUMBER OF SAMPLES REQUIRED AT THE LANDSCAPE SCALE TO ESTIMATE THE MEAN TO WITHIN 10% OF ITS TRUE VALUE ($N_{0.10}$)[12] FOR DIFFERENT FUEL TYPES IN UNBURNT AND BURNT AREAS. 'SD' IS STANDARD DEVIATION.

Variable	Unburnt			Burnt		
	Mean	SD	$N_{0.10}$	Mean	SD	$N_{0.10}$
Litter (t ha^{-1})	14.5	8.2	125	2.0	2.9	826
Ground cover biomass (t ha^{-1})	1.5	1.7	481	0.03	0.05	1683
Understorey biomass (t ha^{-1})	11.1	6.8	156	7.82	6.0	249
Overstorey biomass (t ha^{-1})	367.1	164.2	85			
Coarse woody debris (t ha^{-1})	64.3	34.1	119	34.0	34.1	428

Estimation of changes in water balance after prescribed burning

Average water use for understorey shrubs and overstorey trees for the sites sampled in the ACT was inferred from individual tree size measurements, based on the observation that sapwood area is positively related to tree size[13,14]. We used empirical relationships previously developed for species of *Eucalyptus* and *Acacia* that related tree water use measurements to sapwood area to estimate water use from tree size[15,16]. In unburnt sites, the average water use of overstorey trees is 5145 l day^{-1} ha^{-1} and for the understorey is 7797 l day^{-1} ha^{-1}. Water use by the understorey vegetation was reduced by an average of 70% after prescribed burning (ranging from 0 to 100% reduction in water use depending on the patchiness of the fire).

WHAT HAS THE PROJECT BEEN UP TO?

During the past 12 months, we have:

- recruited and trained key research and technical staff
- commenced field work
- completed a literature review
- developed, refined and tested a field sampling protocol
- presented research to End Users
- added an important piece of equipment to increase our analytical capacity

Recruitment and training

Two of the positions associated with this project were filled in October 2015. Mana Gharun was appointed as the Postdoctoral Research Associate (Spatial Modelling – Biogeochemistry and Fire) and Ariana Iaconis was appointed as the Forester/Research Assistant. The third position, the part-time Postdoctoral Fellow (Data Management/Field Coordination) position has not been filled but essential analytical tasks have been done by Maggie Norton who was appointed as a Research Assistant (0.5 FTE, 12 months) on the project and with two casual appointments to provide assistance for fieldwork.

Field work in Victoria and NSW

Project fieldwork commenced in late 2014 with sampling from nine sites in mixed-species eucalypt forest. Sites were located near Orbost and Bemm River in south western Victoria. The aim of this work was to determine the effect of prescribed fire on carbon fractions in soil (i.e. plant roots, pyrogenic organic matter, soil organic matter).

Fieldwork in the ACT was developed in conjunction with ACT Parks and Wildlife Service. Members of the fire research group from the University of Sydney did mandatory fire ground training and staff from ACT Parks and Wildlife Service assisted with fieldwork. Four sites were sampled across the landscape in April 2015 and samples are currently being analysed in the laboratory.

The sampling scheme that we have adopted and subsequently tested describes a 'burn unit' as a pair of sites that have been measured and compared. The pair of sites can be (1) in nearby burnt and unburnt areas and are sampled at the same time or (2) are a single site sampled at different times before and after prescribed burning. This equates to sampling of 27 burn units in Victoria and 12 burn units in the ACT and effectively represents satisfaction of reporting requirements against milestones for 39 "Fuel Reduction Fires".

Literature review and field sampling protocol

See sections "Reviewing current modelling frameworks" and "Developing and testing a Sampling Schema", respectively, for details.

Presentation to End Users

Formal and informal presentations to End Users have included discussions and meetings throughout the year with appropriate End Users, a poster at the BNHCRC/AFAC annual meeting in Wellington in September 2014 and presentation of a research update at the Research Advisory Forum in December 2014. Two blogs were written for the BNHCRC website describing fieldwork in the ACT and interaction between the Rural Fire Service and undergraduate students from the University of Sydney.

Adding to our analytic capacity

Indices of burn severity that are currently available are based solely on visual characteristics (Table 2). As with all guides of this nature, scoring is open to interpretation. We are developing an empirical method for determining burn severity using our strong analytical capacity.

A pyrolysis unit was installed onto our existing gas-chromatography mass-spectrometer. Upon pyrolysis, chemical bonds in the soil organic matter are broken, producing a wide variety of volatile compounds. The volatile compounds are then separated through gas chromatography prior to their identification by mass spectrometry. The identification of these molecules provides a unique chemical fingerprint that can be used to improve our understanding of how fires affect the make-up of soil carbon and its likely fate after prescribed burning. This information, in conjunction with measurements of soil temperature and indices of fire intensity and severity, can be used to calibrate a quantitative algorithm of intensity or severity. This algorithm can then be used in the broader aim of the project to develop models to facilitate optimised burning regimes in terms of carbon and water potentials and vegetation composition. Appropriate analytical methods and statistical analyses are being developed and tested. Soil collected from two high intensity fires in Victoria are being used to test methodologies and will be compared with soil already collected from the ACT and to be collected in NSW during our next field campaign.

TABLE 2: AN EXAMPLE OF A VISUAL BURN SEVERITY INDEX FOR SOIL[17].

Level of soil burn severity	Indicator characteristic 1	Indicator characteristic 2	Indicator characteristic 3
0	Unburned	No evidence of recent fire	-
1	>40% litter cover	Charred and unburnt litter present	Mineral soil with black char; litter fall since fire
2	2 – 39% litter cover	Mineral soil with black char	Grey char from burnt logs; litter fall since fire
3		Mineral soil with black or grey char	Lines of orange under logs; litter fall since fire
4	<1% litter cover	Mineral soil with black char	Grey and orange-coloured soil under logs; litter fall since fire
5		Mineral soil with black or grey char	Orange-coloured soil under logs; litter fall since fire
6		Mineral soil with orange char	Black ash line present below soil surface

PUBLICATIONS LIST

Bell, T, Kenny B (2014) Optimisation of fuel reduction burning regimes: determining fire size (Poster presentation)

Gharun M, Possell M, Bell T (2015) Optimisation of prescribed burning regimes for carbon, water and vegetation outcomes – a review (Final report)

Gharun M, Possell M, Bell T (2015) Sampling schema for measurement of the impact of prescribed burning on fuel load, carbon, water and vegetation (Final report)

FIGURE 1: IMAGES FROM OUR RESEARCH – PYROGENIC CARBON IN THE 2–4 MM FRACTION OF SOIL CAN MAKE UP TO AS MUCH AS 40% BY WEIGHT (TOP LEFT); STUDNETS FROM THE UNIVERSITY OF SYDNEY VISITING THE RURAL FIRE SERVICE AS PART OF THEIR STUDIES (TOP RIGHT); THE FIELD CREW FROM ACT PARKS AND WILDLFIE SERVICE AND THE UNIVERSITY OF SYDNEY (BOTTOM LEFT); PHD CANDIDATE, HOUZHI WANG INVESTIGATING SMOULDERING COMBUSTION (BOTTOM RIGHT).

CURRENT TEAM MEMBERS

Team members include:

Prof. Mark Adams – Researcher

Tina Bell – Project Leader and Researcher

Tom Buckley – Researcher

Mana Gharun – Postdoctoral Research Associate in Spatial Modelling – Biogeochemistry and Fire (since October 2014, BNHCRC funded)

Ariana Iaconis – Forester/Research Assistant (since November 2014, BNHCRC funded)

Maggie Norton – Research Assistant (since March 2015, BNHCRC funded)

Malcolm Possell – Researcher

Tarryn Turnbull – Researcher

Feike Dijkstra and Michael Turner provided additional research and technical in-kind assistance. Vicky Aerts, Felipe Aires, Helen Liang and Marco Harbusch provided casual assistance in the field and laboratory.

International visitors:

Dr Maryna Zharikova, Kherson National Technical University, Ukraine

Dr Tim Curran, Lincoln University, New Zealand

End Users include:

Naomi Stephens and Belinda Kenny, 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

Lachlan McCaw, Department of Parks and Wildlife, Western Australia

Students include:

Houzhi Wang, PhD candidate, University of Adelaide

Bonnie Cannings, Honours student, FAE, University of Sydney

Amanda Josefsson, international student, University of Gothenburg, Sweden

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