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

Annual project report 2016-2017

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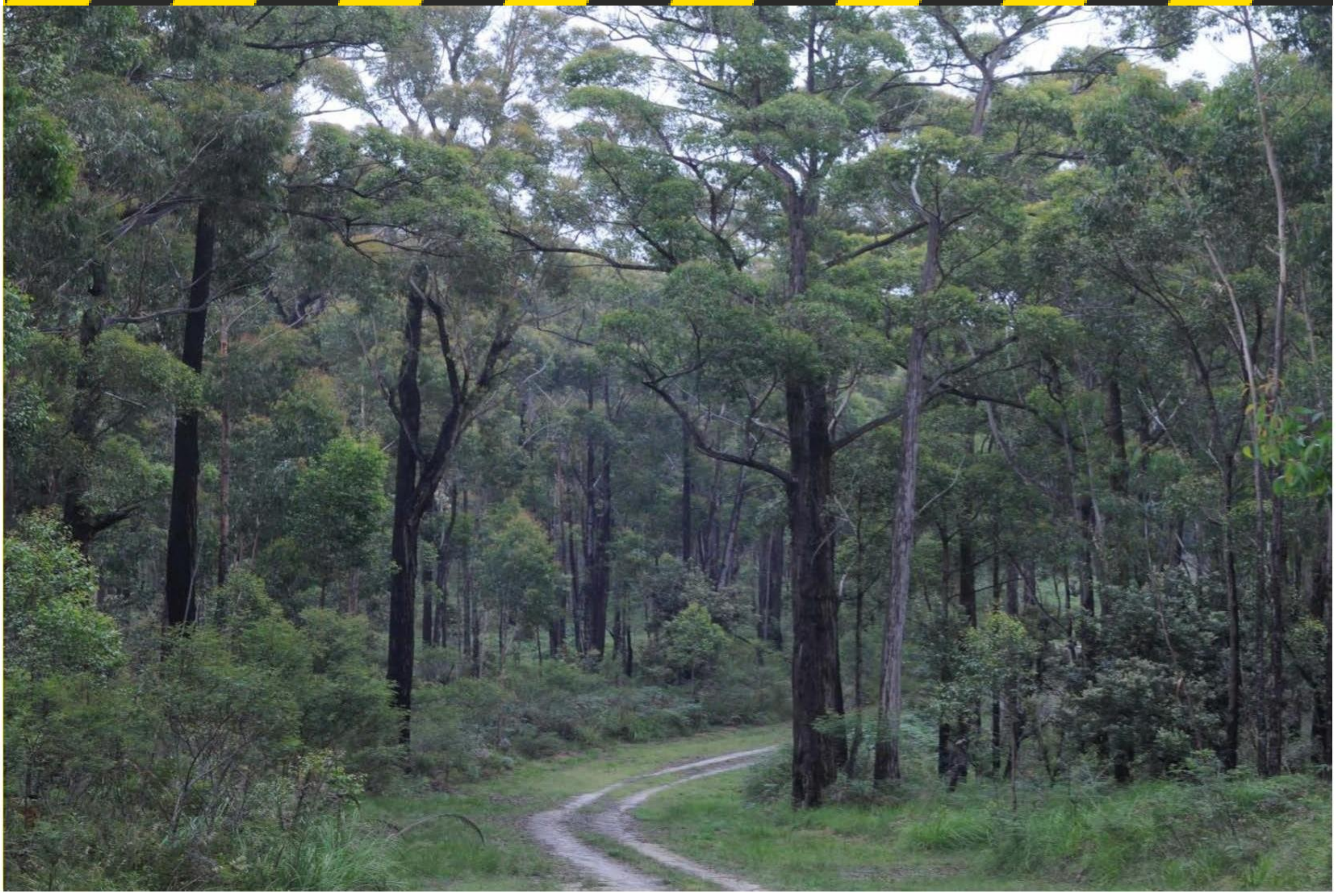

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Cover: Bush track through mixed-species forest within the Cotter Water Catchment to the west of Canberra, Mana Gharun

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SUMMARY

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

Tina Bell, *Faculty of Science, University of Sydney, NSW*

During the year the focus has been on consolidation of our landscape-scale empirical dataset, development and validation of models of carbon, water and vegetation, and conversion of research reports into peer-reviewed publications. The journals that we have published in have impact factors of 2.2 or greater and are rated in the top quartile for journals in the fields of Land Management, Forestry, Ecology, Fuels Technology or Chemistry. In addition, members of the research team and postgraduate students have presented their work at a number of international and national conferences.

We have exceeded the requirements for field work with a total of 83 plots sampled during the life of the project with 29 plots (equivalent to 58 burn units) sampled in the current financial year. The sample sites have spanned Victoria, the ACT and NSW and have involved interaction with local land management agencies for access, sharing of site information (e.g. burning prescriptions and history) and assistance with sample collection. A highlight of our more recent sampling efforts has been part of the Mechanical Fuel Load Reduction Trial project overseen by Forestry Corporation NSW. For our part, we will model the impact of mechanical thinning versus fuel reduction burning on forest carbon and water balance.

We have endeavoured to maintain good communication with our End Users – earlier in the year to develop a Research Utilisation Roadmap for the 'Prescribed Burning and Catchment Management' Cluster and a Project Plan for continuation of our research from 2017–2020. Later in the year we worked closely with End Users as they developed a presentation for the 'Research Driving Change Showcase'. We have also had a number of multi-agency meetings to keep our End Users up to date with our research progress.

As we move into our second phase of research we will continue to aim to increase the capacity of fire and land management agencies to enhance their planning capabilities for fuel reduction burning (FRB). This will lead to better outcomes related to provision of high quality water, carbon sequestration and maintenance of vegetation diversity while reducing fuel loads for protection of life and property.

END USER STATEMENT

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

In Australia, prescribed burning is one of the most important tools available to land managers to mitigate bushfire risk. While planning of burning will always be prioritised for protection of life and assets, the incorporation of prescribed fires for environmental protection is the main focus for agencies like NSW National Parks and Wildlife Service. This project is addressing the gaps in knowledge of the extent of the effect of fire in the landscape – be it planned or from wildfires. The ability to explore options for prescribed burning to fulfil multiple purposes is an important step forward for our agency and other land management agencies in Australia.

The aim of the project is not to create new models, particularly for predicting the effect of fire on carbon and water, but to examine existing models and test them for the capacity to reflect the real world. The models used are process-based (e.g. incorporating biological processes such as decomposition and tree growth and physical processes such as the relative humidity and vapour the water potential of water). Models like these have far greater predictive power than those dependent on correlations where a change in one variable promotes a relative but not necessarily mechanistic change in another.

During the year this project has identified and tested several carbon and water models and researchers have found great potential in the WAVES model to test the sensitivity of hydrological and ecological effects of fuel management. This model has been tested using data collected from several plots from south-east Australia. Preliminary fuel management scenarios have been tested including the two extremes of no fuel-reduction treatment or fuel reduction fires where all of the litter and 100% of understorey is vegetation removed. This research was presented to an international audience and has been documented in a recently submitted manuscript.

Moving forward, this project will look into validating the model using all of the fuel reduction fires sampled to date. This will encompass a range of fire sizes, topographies, weather conditions, overstorey tree and understorey vegetation density and soil types. There are also several assumptions that need to be tested to investigate the robustness of modelling efforts. The capacity of integrating common environmental variables into modelling will represent a step forward in reducing undesirable environmental impacts during prescribed fires.

The research team and End User agencies have kept a high level of engagement throughout the year. This culminated in the Research Driving Change Showcase with the roles reversed as the End Users of the research described the research products.

INTRODUCTION

The overall aim of this project is to improve the capability of land managers to use fuel reduction burning (FRB) to manage land such that risks of loss of water yield, carbon sequestration capacity and vegetation diversity are mitigated. This project builds on previous research in forested catchments in NSW, the ACT and Victoria 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 FRB strategies in different parts of catchment landscapes. The project also draws on our research efforts in determining the effect of FRB 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 to become more efficient.

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.

Land managers prioritise FRB 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 primarily used to govern the timing of FRB. 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, and managers are also able to prioritise FRB on this basis. What has been lacking, but which has become increasingly important, is knowledge and projecting capacity of the effects of FRB 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 FRB.

BACKGROUND

Three underlying problems continue to shape the direction of our project:

1. Limited knowledge of the nature and water storage capacity 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 capacity to incorporate the dynamics of whole forest growth (i.e. maturity) and tree regrowth after disturbance into relevant models.
3. 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 FRB regimes. The use of spatially explicit models will take into account changes in fuel loads and predict the likely effects of individual 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:

- reduction of fuel loads
- 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 HAVE WE BEEN UP TO?

Field work and laboratory analysis

During the past 12 months data and samples have been collected from additional sites in NSW (29 plots equivalent to 58 burn units). The total number of sites and equivalent burn units sampled throughout the project to date are presented in Table 1 and the scale of measurements made for each burn unit is provided in Table 2.

A number of analyses have been done using samples collected from these sites including:

1. Characterisation of soil properties (i.e. particle size analysis, total carbon, nitrogen and phosphorus content, organic carbon content)
2. Composition and characterisation of live and litter fuel. This involved sorting samples into the main fractions (live fuel; leaves; twigs (<6 mm diameter); decomposed (<2 mm fraction); other components such as fruit and bark) to determine the variation in proportions across all sites. Each fraction was characterised chemically (I.e. total carbon and nitrogen content).
3. Data sets of actual fuel load measurements are being compiled for comparison with visual fuel load assessments following Volkova et al. (2016).

Using the data collected, several models were developed or applied including:

1. An estimation of burn severity for the measurement sites using the Differenced Normalized Burn Ratio (dNBR) derived from Landsat 8 data.
2. A model of green biomass from Landsat 8-derived Normalized Difference Vegetation Index based on our field measurements. The model of green biomass was used to improve sampling strategies for assessing the fuel reduction burns. The results were used to substantially revise and improve our manuscript.
3. Information about the landscape (slope, aspect, radiation, TWI), soil (depth to rock, rooting depth, organic carbon, pH, $CaCl_2$, clay, silt, sand, electrical conductivity, available water capacity, total phosphorus, total nitrogen and bulk density), and bioclimatic attributes (e.g. annual mean temperature, annual precipitation) were compiled over the study areas from multiple sources for modelling and validation purposes.
4. Vegetation and climate input data were assembled and the WAVES model was parameterised for a number of plots (testing different scenarios) to model vegetation carbon state and hydrological impacts from fuel-reduction burning. Soil hydraulic properties were used for modelling soil water flux with a soil-vegetation-atmosphere model (WAVES, Slavich et al. 1998).
5. Carbon and nitrogen content of live and litter fuel was used to validate a predictive carbon model developed from a subset of sites in the ACT and Victoria.

6. Dead fuel moisture content at the time of measurement was modelled using MODIS land surface temperature satellite data and following the method of Nolan et al. (2016). Modelled fuel moisture content was compared with actual measurements to test the suitability of this model for further application.

TABLE 1. DETAILS OF NAME, LOCATION AND SAMPLING DATE OF SAMPLING SITES IN VICTORIA, THE ACT AND NEW SOUTH WALES.

Plot number	Burn/site name	Latitude	Longitude	Sampling/ resampling date
Victoria (pre-/post-fire sampling)				
1–3	Frogs Hollow	-37.65	148.05	March 2011/January 2015
4–6	Upper Tambo	-37.76	147.88	February 2011/January 2015
7–9	Poddy	-37.68	148.96	March 2011/January 2015
10–12	South Boundary	-37.82	148.02	March 2011/January 2015
13–15	Sandy Point	-37.60	148.31	February 2011/January 2015
16–18	Oliver	-37.70	148.85	April 2012/January 2015
19–21	Gravel	-37.72	148.78	March 2012/January 2015
22–24	Patrol	-37.68	148.90	April 2013/January 2015
25–27	Pettmans	-37.76	148.01	March 2013/January 2015
ACT (burnt/unburnt)				
28–30	Googong	-35.51	149.28	April 2015
31–33	Tidbinbilla	-35.46	148.90	April 2015
34–36	Wrights Hill	-35.87	148.93	April 2015
37–39	Cotter	-35.61	148.82	May 2015
NSW (burnt/unburnt)				
40–42	Haycock Trig	-33.45	151.09	September 2015
43–45	Helicopter Spur	-33.80	150.51	September 2015
46–48	Spring Gully	-34.09	151.15	September 2015
49–51	Paterson	-33.53	150.58	October 2015
52–54	Lakesland	-34.16	150.49	October 2105
55–57	Martins Creek	-34.30	150.44	April 2016
58–60	Joadja	-34.37	150.21	April 2016
61–63	Kief Trig	-33.29	150.94	May 2016
64–66	Left Arm	-33.36	150.80	May 2016
NSW; Mechanical Fuel Load Reduction Trials (burnt/unburnt; thinned/unthinned)				
67–69	Wauchope T3	-31.54	152.75	April 2017
70–72	Wauchope T4	-31.54	152.75	April 2017
73–75	Wauchope T6	-31.53	152.74	April 2017
76–80	Wauchope T7	-31.53	152.74	April 2017
81–83	Wauchope T10	-31.53	152.73	April 2017

TABLE 2. THE NATURE AND SCALE OF SAMPLING USED IN THIS PROJECT.

Variable	Scale
Overstorey biomass	Plot
Understorey biomass	Subplot
Ground cover biomass	Subplot
Litter biomass	Subplot
Soil pH and EC	Plot
Soil carbon and nitrogen content	Plot
Overstorey leaf area index	Plot
Understorey leaf area index	Plot
Visual fuel hazard assessment	Plot
Litter fuel moisture content	Subplot
Soil bulk density	Plot
Litter carbon and nitrogen content	Subplot

At the request of Forestry Corporation NSW, a research proposal to model the impact of mechanical thinning versus fuel reduction burning on forest carbon and water balance was developed to value-add to the Mechanical Fuel Load Reduction Trial project. This project is part of the Australian Government's National Bushfire Mitigation Programme and partners are Forestry Corporation NSW, VicForests and several universities in Queensland and Western Australia. Initial (pre-thinning and pre-fire) field work was completed for sites located in Wauchope, NSW (17 plots). For our contribution, pre-treatment measurements of leaf area index (overstorey and understorey) were collected and analysed and data were sent to the research partners. In addition, soil samples collected by Forestry Corporation NSW were sent to the University of Sydney and analysed for total carbon and nitrogen content. We will use biomass and fuel assessment data collected by partner agencies. Sites will be resampled after prescribed fire and thinning treatments have been completed.

Historical prescribed fire data held by the Forestry Corporation of NSW was assessed for usefulness in additional testing spatial and temporal variability of forest carbon pools. A preliminary investigation of the types of data available indicate that fine fuel load, understorey vegetation and coarse woody debris has been measured in a way that can be matched to measurements made in our contemporary studies. For example, litter (surface fuel) and ground cover (near surface fuel) has been collected before and fuel reduction burning and sorted into fractions using methods similar to what we are currently using.

PUBLICATIONS AND RESEARCH REPORTS

During the past 12 months we have concentrated our efforts in completing research reports and converting them to peer-reviewed publications where possible. We completed three research reports and had two manuscripts accepted for publication. A third manuscript was recently submitted and we are awaiting the outcome. An abstract was submitted and accepted for presentation at the AFAC/BNH CRC Conference in Sydney in September 2017.

Gharun M, Possell M, Jenkins M, Poon LF, Bell T, Adams MA (2017) Improving forest sampling strategies for assessment of fuel reduction burning. *Forest Ecology and Management* 392, 78–89.

Land managers typically make post hoc assessments of the effectiveness of fuel reduction burning (FRB), but often lack a rigorous sampling framework. A general, but untested, assumption is that variability in soil and fuel properties increases from small (~1 m) to large spatial scales (~10–100 km). Based on a recently published field-based sampling scheme, we addressed the following questions: (i) How much variability is captured in measurements collected at different spatial scales? (ii) What is the optimal number of sampling plots required for statistically robust characterisation of burnt areas? (iii) How can land managers improve their assessment of the effectiveness of FRB? We found that measurement variability does not increase with scale for all fuel components. Results showed that coarse woody debris is as variable at the small scale (plot, m) as it is at the landscape scale (km). For certain fuel components, such as litter biomass (in unburnt areas), overstorey biomass and leaf area, and soil properties such as total carbon and total nitrogen, samples taken at the small (plot) scale were indicative of variation at the larger scale of an individual FRB and more broadly across the landscape.

We then tested the hypothesis that site stratification can reduce variability between sampling plots and as a consequence will reduce the required number of sampling plots. To test this hypothesis we used Landsat Normalized Difference Vegetation Index (NDVI) across areas treated with FRB and compared the number of sampling plots required to estimate mean fuel biomass with and without stratification. Stratification of burnt areas using remotely sensed vegetation indices reduced the number of sampling plots required. We provide a model of green biomass from Landsat NDVI and make recommendations on how sampling schemes can be improved for assessment of fuel reduction burning.

Gharun M, Possell M, Bell TL, Adams MA (2017) Optimisation of fuel reduction burning regimes for carbon, water and vegetation outcomes. *Journal of Environmental Management*, accepted for publication.

Fire plays a critical role in biodiversity, carbon balance, soil erosion and nutrient and hydrological cycles. While empirical evidence shows that fuel reduction burning can reduce the incidence, severity and extent of unplanned fires in Australia and elsewhere, 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 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. We explore trade-offs between fuel reduction burning and environmental management objectives, and propose a framework for optimising fuel reduction burning for environmental outcomes.

For optimisation purposes, we propose a framework that incorporates a combination of surveying and modelling approaches as summarised in Figure 1. The framework prescribes a burning regime based on the key components of every FRB: defined objectives, a specified area of application, a particular timeframe for execution (to be optimised), and specific environmental and fire conditions (i.e. behaviour, spread and intensity). The framework has two main modules. One is based on current scientific knowledge and technical experience (information for this module is marked with solid lines in Figure 1), and the other fulfils knowledge gaps both on the operational and ecological issues that are currently not included (marked with dashed lines in Figure 1).

The framework requires collection of additional scientific knowledge using field measurements (e.g. functional and empirical relationships), modelling and validation tasks. Both modules are added to a spatial decision support systems (SDSS) software that provides land managers with a detailed cartographic product for exploring and optimising management outcomes and reducing undesirable impacts on the environment. Within this system, prescriptions are modified according to management objectives (e.g. risk of soil erosion within water catchments, smoke exposure in urban areas, and protection of a particular species). Suitability of the prescription is then evaluated categorically (e.g. high, medium, low), or quantitatively (e.g. using a relative value) (Rigolot et al. 1996; Power 2006; Craig et al. 2012).

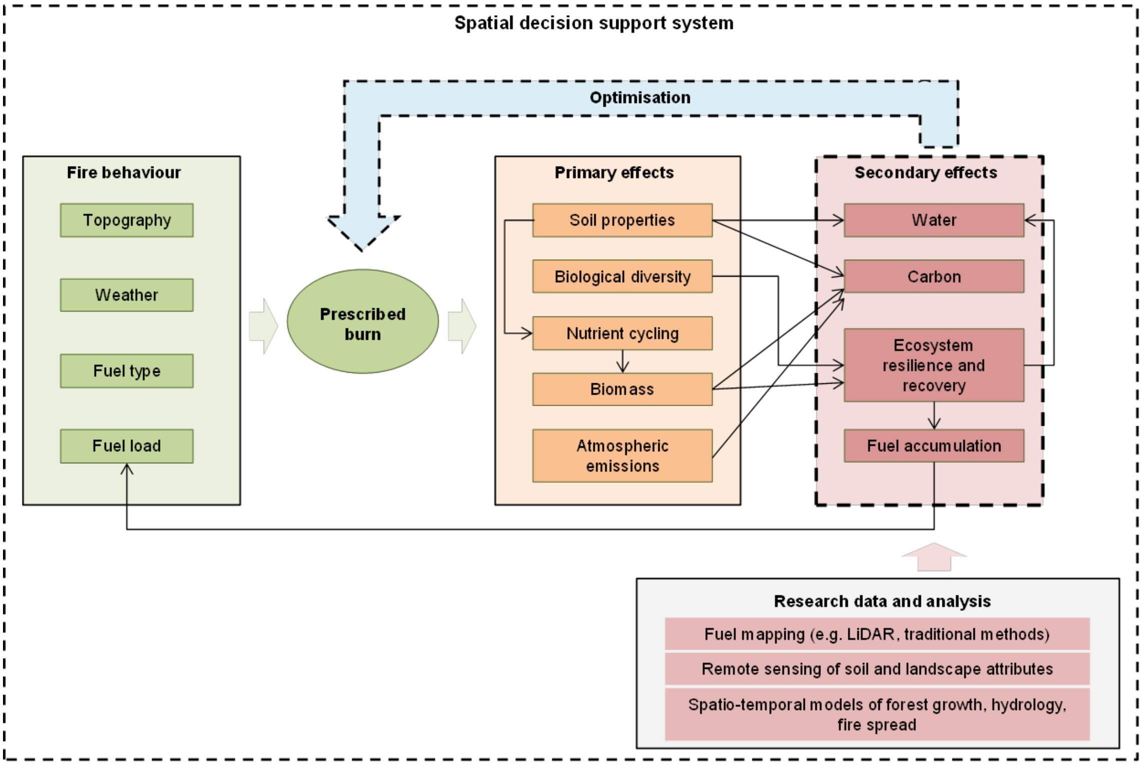

FIGURE 1. CONCEPTUAL FRAMEWORK FOR OPTIMISING FUEL REDUCTION BURNING FOR CARBON, WATER AND VEGETATION OUTCOMES. SOLID LINES MARK CURRENTLY USED INFORMATION AND DASHED LINES SHOW ADDITIONAL INFORMATION AND TASKS REQUIRED.

Gharun M, Possell M, Vervoort W, Bell TL, Adams MA (2017) Can a growth model be used to describe forest carbon and water balance after fuel reduction burning in Australian eucalypt forests? Submitted to *Science of the Total Environment*.

Empirical evidence from Australia shows that fuel reduction burning significantly reduces the incidence and extent of unplanned fires. However, the integration of environmental values into fire management operations is not yet well-defined and requires further research and development. While carbon and water processes in forested ecosystems are coupled, effects of fire on these processes are often studied in isolation. Models that simulate the dynamic interactions and feedbacks between these processes are needed for investigations of the effects of fuel management in the field.

WAVES, a plant growth model that incorporates soil-vegetation-atmosphere transfer, was used to simulate the hydrological and ecological effects of four fuel management scenarios on a forest ecosystem. WAVES was applied using inputs from a set of forest plots across south-east Australia for a period of one year after four potential scenarios: (1) no fuel-reduction treatment (unburnt), (2) all litter removed, (3) all litter and 50% of the understorey vegetation removed, (4) all litter and all of the understorey vegetation removed.

The key change between unburnt and fuel reduced forests was a significant increase in soil moisture after fire. Predictions of the recovery of aboveground carbon as plant biomass were driven by model structure and thus variability in available light and soil moisture at a local scale. Similarly, effects of fuel-reduction burning on water processes were mainly due to changes in vegetation interception capacity (i.e. regrowth) and soil evaporation. Predicted effects of fuel-reduction burning on total evapotranspiration (ET) – the major component of water balance – were marginal and not significant, even though a considerable proportion of ET had effectively been transferred from understorey to overstorey. In common with many plant growth models, outputs from WAVES are dictated by the assumption that overstorey trees continue to grow irrespective of their age or stage of maturity. Very large areas of eucalypt forests and woodlands in SE Australia are well beyond their aggrading phase and are instead over-mature. The ability of these forests to rapidly respond to greater availability of water remains uncertain.

Gharun M, Possell M, Bell TL (2016) Calibration of water balance using digital photography. BNH CRC Report, 20 p.

In this study we used relationships between tree size and tree water use and leaf area index (LAI) and forest water use to investigate the impact of fuel-reduction burning (FRB) on water availability. Leaf area index is an important input for estimating ET and measurement techniques such as digital photography can potentially be used by land managers as a means of rapidly quantifying the impact of FRB on water balance at both the plot- and catchment-scale. Understorey LAI measured with digital photography correlated strongly with LAI measured for seedlings of *Eucalyptus globulus* (R^2 = 0.92; Figure 2). Validation of digital photography indicated that a methodology developed for measuring the LAI of the overstorey can also be used to estimate LAI of the understorey by replacing parameters relevant to the understorey (i.e. crown porosity and light extinction coefficient in the LAI). The results will enable land managers to identify hydrologically sensitive areas in accordance with their management objectives.

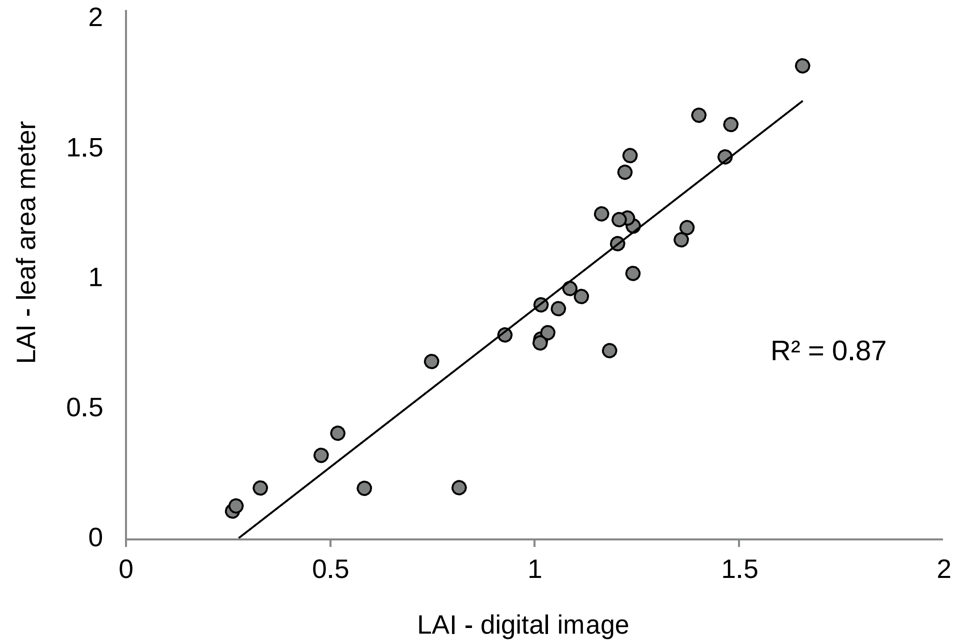

FIGURE 2. RELATIONSHIP BETWEEN LEAF AREA INDEX (LAI) MEASURED FROM DIGITAL IMAGES (LAI – DIGITAL IMAGE; X-AXIS) WITH LAI MEASURED FROM GLASSHOUSE-GROWN SEEDLINGS OF *EUCALYPTUS GLOBULUS* (LAI – LEAF AREA METER; Y-AXIS).

Possell M, Gharun M, Bell T (2016) Application of statistical techniques to pyrolysis-GC-MS data from soil to identify the impact of fire. BNH CRC Report, 21 p.

Soil organic matter has strong effects on many soil properties such as water holding capacity, soil structure and stability, nutrient availability and cation exchange capacity. Therefore, characterising soil organic matter is necessary to improve soil management. Pyrolysis coupled to gas chromatography-mass spectrometry (pyr-GC-MS) is one of many techniques that have been successfully used in this characterisation (Figure 3). However, a major limitation of pyr-GC-MS is that generates large amounts of mass-spectrometry data preventing fast, high throughput data analysis. This hinders our ability to identify compounds in complex matrices such as SOM that could be useful for predicting their characteristics. In this study, we aimed to investigate whether it was possible to rapidly identify significant differences among pyr-GC-MS data from soil from burnt and unburnt areas using an unsupervised statistical approach and identify the specific features that cause them. Of nearly 400 useful compounds extracted from the pyr-GC-MS data, only 15 were found to be necessary to classify between burnt and unburnt soil. We discuss how these features could be useful in the classification of soil disturbance such as fire or, potentially, as a quantitative measure of fire impact (intensity or severity).

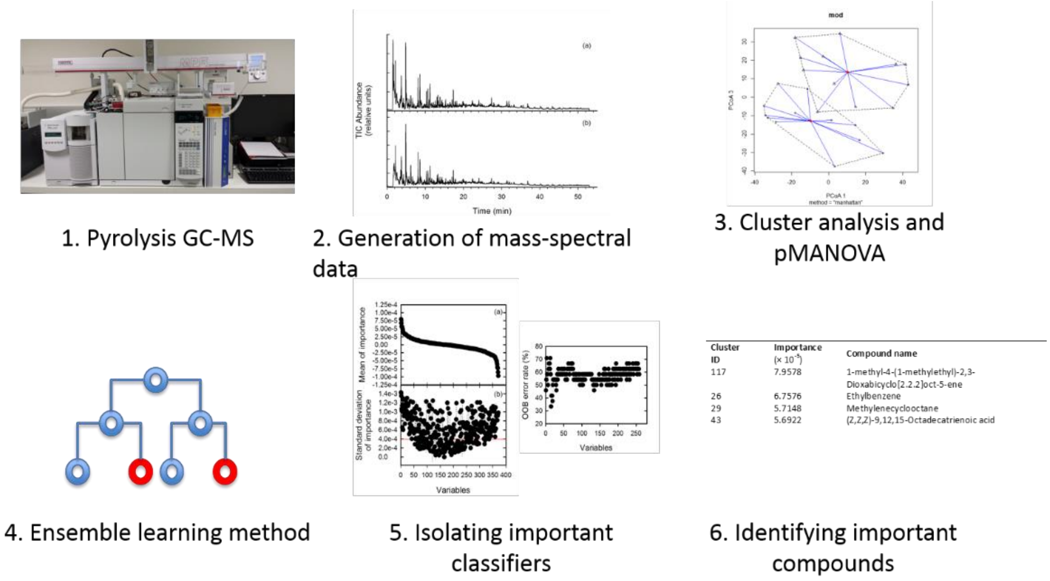

FIGURE 3. A SCHEMATIC OF ANALYSIS OF SOIL FROM BURNT AND UNBURNT PLOTS: 1. PYROLYSIS-GC-MS; 2. CHROMATOGRAMS CONTAINING UP TO 388 PEAKS; 3. MULTIVARIATE ANALYSIS OF VARIANCE OF DATA; 4. THE ENSEMBLE MACHINE LEARNING METHOD (RANDOM FORESTS); 5. IDENTIFICATION OF CANDIDATE COMPOUNDS THAT CAN DISTINGUISH BETWEEN SOIL FROM BURNT AND UNBURNT PLOTS; 6. CANDIDATE COMPOUNDS IDENTIFIED USING A MASS-SPECTRAL DATABASE.

COMMUNICATION WITH END USERS

We presented our project formally to End Users on a number of occasions including:

1. End users from ACT Parks and Conservation Service and NSW Office of Environment and Heritage in August 2016. At this meeting we provided an overview of the project and reported on progress for improving our sampling strategies and data utilisation, and methods of soil spectra for identifying the impact of fire. We discussed future directions of our project. This discussion was continued with a broader group of End Users at a Cluster Group meeting that coincided with the AFAC 2016 conference.

2. Research Advisory Forum in Canberra in October 2016. Breakout sessions were used to discuss project plans and we were supplied with valuable feedback from End Users. With this and other feedback from End Users, our Project Plan for 2017–2020 and our Research Utilisation Roadmap were completed and submitted in 2016.

3. Rural and Land Management Group meeting in Melbourne in May 2017. This presentation described outputs, including methods and a description of field work, accounting for all of the research objectives for the project and a description of our future research directions.

4. End Users from ACT Parks and Conservation Service in Canberra in May 2017. Our presentations included an account of the research objectives for the project and a description of our future research directions. We also provided an introduction to Ember-sim and there were excellent discussions around how this product might be enhanced for fireground training and as an example of an interface for End Users using carbon and water models for predictive scenarios.

We also presented our research in a number of other forums:

1. Tina Bell was an invited speaker at the annual conference of the Ecological Consultants Association of NSW held in Bowral, NSW in July 2016. In this presentation she described current field and sampling protocols used in the project.
2. Mana Gharun and Tina Bell gave oral presentations at the Environment, Sustainable Agriculture and Forest Management Conference held in Padova, Italy in September 2016. Mana's presentation ("Application of computer simulations in Forestry Education") described a fire behaviour simulation exercise and discussed how inquiry-based exploration of forest, climate and landscape attributes can help the students understand the scientific concepts and observe the effect of their management strategies on the environment. Tina's presentations ("Advances in forest fire research in Australia") described our current research including forest carbon and water balances.
3. Tina Bell (Invited Keynote Speaker), Malcolm Possell, Mana Gharun and Houzhi Wang all gave oral presentations at the International Congress on Prescribed Fires in Barcelona in February 2017. The titles of the four presentations were:
    a. Filter bubbles, wishful thinking and prescribed fires; Bell
    b. Optimisation of prescribed burning for carbon and water outcomes – an Australian perspective; Gharun, Possell, Bell
    c. Measurement of the combustion properties of selected grasses from central Australia; Possell, Bell
    d. Analyses of permeability and pressure-drop in south eastern Australian woody debris fuel bed; Wang, Possell et al.

Filter bubbles, wishful thinking and prescribed fires

Tina Bell
Invited Speaker, International Congress on Prescribed Fires, Barcelona, February 2017

The concept of a filter bubble comes from the social media where algorithms are used to personalise information presented to the user based on their past interactions with the internet. The information offered is according to a set of preferences and is thought to reinforce particular beliefs through confirmation bias. This presentation will examine community perceptions about prescribed burning in light of such psychology. People living in fire-prone areas of Australia are well aware of the dangers of uncontrollable bushfires yet they have conflicting insights about the effects of prescribed fires. This is despite prescribed burning being used extensively in Australia for the past 50 years for fuel reduction and environmental management on public land. People living in forested areas have the feeling that the amount of prescribed burning done in the forest is adequate for protection of life and property, a perception that may affect their preparedness in the event of an uncontrollable bushfire. In addition to this critical conflict in awareness, many people are still suspicious of prescribed burning being a suitable management practice for maintaining forest health and diversity. Even with the growing concern about an increase in frequency and severity of bushfires with climate change, the general public are not overtly changing their attitudes towards fire. Ecological, health and social research associated with fires has flourished in recent years and we have the opportunity to learn more with every new planned and unplanned fire event. This new knowledge must be used more effectively in educating the populace to break any filter bubbles that have been created.

From an educational perspective, Mark Adams and Tina Bell delivered an MSc course titled 'Forest Ecology and Management in Mediterranean Climates' in December 2016 in Padova, Italy. Our fire behaviour simulation teaching tool, BurnSim, was used as an assessment and to help students understand the scientific concepts and observe the effect of their management strategies on the environment.

Tina Bell invited a series of guest presenters to talk to undergraduate students doing a senior year unit of study called Fire in Australian Ecosystems. Presenters included Matt Hunter from Transport NSW, Felipe Aires from NP&WS NSW, Amelia Jones and Michelle Brown from Hornsby Shire Council and Stuart Matthews from Rural Fire Service. Mana Gharun and Malcolm Possell also taught into this unit.

Earlier this year, our group at the University of Sydney hosted Assoc. Prof. Emanuele Lingua from the Department of Land, Environment, Agriculture and Forestry (TESAF), University of Padova, Italy. We discussed further collaboration which is likely to result in a MSc student exchange in late 2017.

Staff and students attended and presented at the Nature Conservation Council NSW Bushfire Conference in May 2017 in Sydney.

WHAT ARE WE UP TO NEXT?

In Phase 2 of the research (July 2017–June 2020) we will build on our previous research to achieve the following objectives:

1. Completion of sampling and analysis of 100 burn units
2. Developing modelling frameworks for water, carbon and vegetation potentials (see definitions below)
3. Integrating water, carbon and vegetation potentials
4. Exploring temporal and spatial variation in fuel condition after disturbance
5. Continued development of measures of effects of fire intensity on soil carbon
6. Modelling and data synthesis
7. Translating our research for End User agencies and providing training for model use

Carbon potential – long term storage of carbon in forests and forest soils; reduced greenhouse gas emissions from FRB; maintenance of rates of forest carbon turnover by balancing practices such as fuel reduction and timber harvesting and facilitating processes such as vegetation growth and decomposition.
Water potential – effective management of water yield from forested catchments; limiting erosion and nutrient loss; protection of catchments for provision of potable water to cities and towns.
Vegetation potential – managing fuel loads to mitigate the risk of bushfires; retaining diversity of species and functional groups of plants, animals and microorganisms; promoting regeneration of vegetation and forest health.

Field work and laboratory analysis

During the next 12 months we will complete our 100 burn unit target by resampling sites from Wauchope (see Table 1) and incorporating sites selected for a new PhD project. Analysis of all samples collected to date are complete and data sets are being finalised.

We will enter a new phase of research with an important change to our research and technical staff. One of the features of the Phase 2 of this project will be to actively translate our research to make it accessible to End Users. To this end we will be recruiting a Research Assistant dedicated to translation of our research for End User agencies. Tasks for this person will be in the form of organisation of face-to-face seminars, meetings and workshops with End User agencies, particularly in regional centres; production user-friendly guides and reports, and provision of support to researchers for more efficient preparation of manuscripts. To facilitate ongoing research, the Research Assistant will also provide support for data collection and analysis as required by researchers and postgraduate students associated with ongoing projects.

As part of normal staff turnover we will also be recruiting for two new Postdoctoral Researchers to the project.

Modelling efforts

In Phase 2 we will revise and adjust existing carbon, water and vegetation models (e.g. WAVES) that have been applied to quantify fuel, carbon and water potentials to better reflect the effects of FRB on soil carbon and to test likely effects of soil water dynamics on stand and catchment hydrology. For example, in the model we use at present, the soil is assumed to be similar through the profile, forests are assumed to grow at the same rate regardless of age and crucial biological processes such as photosynthesis and respiration of vegetation are not accounted for. Research over the next 3-year period will explore these assumptions and determine how much of an effect they have.

All models need calibrating and recalibrating. While we have already used a subset of empirical data collected in Phase 1 of this research project to build and test models, we need to refine these models with our remaining data. Further adjustment requires establishment of a series of 'calibration sites' of known fire history, including both FRBs and bushfires. Calibration sites will span time-since- fire to enable us to assess the effects of fires on carbon sequestration and water yield for the 10–20 year period post-fire. Calibration sites will include forests that will not be treated with FRB but are known to burn at high intensity (e.g. ash-type forests), and those that are treated with FRB (mostly foothill and mixed-species forests). This will potentially allow us to interrogate the effect of multiple fires on carbon, water and vegetation potentials. Most importantly, by working closely with End User agencies, some calibration sites will already have existing data sets that can be used.

POSTGRADUATE STUDENT RESEARCH

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:

- Completion of experimental work to investigate the effect of oxygen concentration and heating time on the initiation of aided and self-sustained smouldering. He has written a manuscript based on this topic.
- Completion of experimental work to investigate the effect of particle size, fuel type and fuel bed depth on the permeability of fuel beds. The experimental results have been used to validate a computational fluid dynamic model.
- The design and development of a single-particle smouldering combustion reactor.
- The design and testing of a two-axis traverse system which was then used to accurately position the thermal anemometer probe. This work is part of experimental work investigating the effects of particle size, fuel type and fuel bed depth on the air permeability of fuel beds. A manuscript is being prepared on this work.
- Collected and prepared field samples and started analysis of different types of fuel from four common species of *Eucalyptus* (*E. camaldulensis*,

E. fasciculosa, *E. baxteri* and *E. obliqua*) for his fourth research paper on the effects of species and fuel type on smouldering combustion.

Houzhi has presented his work at the:

- International Combustion Symposium in Seoul, South Korea
- Chemeca 2016 Conference in Adelaide, South Australia
- International Congress on Prescribed Fires in Barcelona, Spain
- AFAC/BNH CRC 16 Brisbane, Queensland
- Annual School Seminar Series for the University of Adelaide, South Australia

We are very proud that Houzhi has published two research papers:

Wang H, Van Eyk PJ, Medwell PR, Birzer CH, Tian ZF, Possell M (2016) Identification and quantitative analysis of smoldering and flaming combustion of radiata pine. *Energy & Fuels* 30, 7666-7677.

Wang H, van Eyk PJ, Medwell PR, Birzer CH, Tian ZF, Possell M (2017) Effects of oxygen concentration on radiation-aided and self-sustained smoldering combustion of radiata pine. *Energy & Fuels*, doi:10.1021/acs.energyfuels.7b00646

Mengran Yu – Modelling the effect of fire on hydrological cycles

PhD commenced March 2015, enrolled at the University of Sydney; scholarship funded by BNH CRC. Tina Bell is one of the members of Mengran's supervisory panel.

In the past 12 months Mengran has completed the following research:

- Built and calibrated SWAT models for five separate catchments in NSW. She has used the calibrated models to predict catchment behaviour with and without the effect of fire.
- Calculated burn severity for each catchment using pre-fire and post-fire Landsat images.
- After completing particle size analysis and organic carbon analyses for 92 soil samples from burnt and unburnt sites in NSW and the ACT she investigated the change in soil carbon content and developed a predictive model using regression.

Mengran has presented or will present her work at the:

- AFAC/BNH CRC 16 Conference held in September 2016 in Brisbane
- American Geoscience Union Fall meeting held in December 2016 in San Francisco
- 22nd International Congress on Modelling and Simulation (MODSIM) to be held in December 2017 in Hobart, Tasmania.

Gabriela Raducan – The impact of bushfires on water quality

PhD commenced March 2014; enrolled at RMIT; scholarship funded by BNH CRC.

In the past 12 months Gabriela's research and writing activities have included:

- A literature review about evaluation and validation of hydrological models.
- Continuation of use of the eWater hydrological model in the La Trobe catchment by creating new scenarios and changing the parameterisation to improve model outputs. She has also created a hydrological model using ArcHydro (based on ArcGIS) and has compared the outputs of both models.
- Writing seven of nine chapters of her thesis and has begun preparation of two manuscripts related to her work. She has also completed her final PhD presentation.

Gabriela has presented her research in the following forums:

- Poster presentation at the AFAC/BNH CRC 16 Conference held in September 2016 in Brisbane.
- Oral presentation (3M thesis format) at the Forest Fire Managers Group meeting held in September 2016 in Melbourne.
- Oral presentation at the BNH CRC Research Advisory Forum held in October 2016 in Canberra.
- Oral presentation at the 29th Victorian Universities Earth and Environmental Sciences Conference held at Monash University, School of Earth, Atmosphere and Environment in November 2016 in Melbourne.

Angela Gormley – Effects of surface litter by forest classification on fuels and fire behaviour in the Sydney Basin

MSc commenced January 2016; enrolled part-time at the University of Sydney; Associate Student of BNH CRC, co-supervised by Tina Bell and Malcolm Possell

In the past 12 months Angela has undertaken the following research and writing tasks:

- Completed data processing associated with fieldwork (i.e. site features, canopy species and tree density, visual assessment, pin transect, litter volume and bulk density, coarse woody debris).
- Collected and sorted additional litter samples from field sites and is now working on creating mixtures for burning experiments.
- Developed a draft of her literature review and site description as the first and second chapters of her thesis.

Angela has presented her research at the following fora:

- Project proposal as a major milestone for her candidacy at the University of Sydney
- Poster presentation at the Nature Conservation Council of NSW Bushfire Conference in May 2017 in Sydney.

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 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

End Users

Naomi Stephens and Felipe Aires, Office of Environment and Heritage, NSW
Neil Cooper and Adam Leavesley, ACT Parks and Conservation Services, ACT
Tim McGuffog, Forestry Corporation of NSW
Jacqueline Frizenschaf, SA Water
Melissa O'Halloran, NSW Rural Fire Service

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