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SAMPLING AND DATA ANALYSIS OF FIELD SITES OF 40 PRESCRIBED BURNS

Milestone 2.4.2

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Cover: Typical vegetation in the Nattai National Park, New South Wales. Source: Veronica Quintanilla-Berjon.

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SUMMARY

This report provides a summary of the main features of the sites sampled as burn units in the Blue Mountains, NSW to characterise the biomass, carbon and nitrogen held in vegetation/fuel in unburnt and burnt sites. Sites sampled in Victoria and NSW for refinement and testing of current surface fuel models is also provided. Details of how empirical data collected from the field has been used in our modelling efforts and in student projects has been provided.

INTRODUCTION

The underlying emphasis of our research being done in the project titled '*Optimisation of fuel reduction burning regimes for fuel reduction, carbon, water and vegetation outcomes*' has always been to increase our knowledge about three important environmental elements – vegetation, water and carbon. Using the lens of prescribed burning across the landscape, understanding vegetation dynamics is critical for managing fuel loads to mitigate the risk of bushfires while retaining diversity of plants, animals and microorganisms for overall promotion of forest health and regeneration of vegetation after disturbance (Gharun et al. 2017a). Adding low intensity fire into forested catchments can be used for protection of potable water supplies to cities and towns and effective management of water yield by limiting erosion and nutrient loss. Awareness of the transformation of carbon during fire is essential for managing the long term storage of carbon in forests and forest soils, facilitating processes such as vegetation growth and decomposition and to reduce greenhouse gas emissions from prescribed burning. In Australia, it has been estimated that fires contribute 127 Tg C to the atmosphere each year (Haverd *et al*. 2013).

As planning by fire agencies becomes more sophisticated and accountable, environmental management objectives for fuel reduction burns (FRB) need to consider maintenance of high-quality water sources, reduction of carbon dioxide (CO_2) emissions and conservation of biodiversity.

As a consequence of these drivers, the main aim of our research is to develop a spatially explicit model combining existing and new models of fuel dynamics, carbon balance, catchment hydrology, nutrient cycling and vegetation change for effective planning of prescribed burning. To achieve this, the project had the ambitious goal of sampling and analysing 100 burn units to provide empirical data to build and test the old and new models used. We describe a 'burn unit' as a pair of burnt/unburnt plots. This has now been accomplished and the details of the remaining 40 sites sampled are presented in this milestone report.

Sites sampled in Victoria, New South Wales and the Australian Capital Territory were done during the first phase of our research July 2014-June 2017) and were initially used to explore temporal and spatial variation in fuel/vegetation after disturbance. This work resulted in a number of milestone reports and publications (Gharun *et al*. 2017b; 2018). Existing models, such as WAVES (Water Atmosphere Vegetation Energy and Solutes), was used with data collected from field sites to investigate forest hydrological and ecological responses to fuel management and climate variations. Another existing model, FullCAM, has been tested using empirical data we have collected from field sites to determine the sensitivity of this widely available modelling tool to changes in carbon pools due to prescribed burning (see Milestones 1.3.2, 1.4.3 and 2.2.3). In addition, using a combination of field data and satellite data, one of our recent milestones (Milestone 2.3.3) investigated the effect of prescribed fire on evapotranspiration as a means to determine change in tree water use.

In Phase 2 of our research (July 2017-June 2020) we have completed sampling another 40+ burn units which are described in this report. We refocussed our sampling efforts and sites selected were in consultation with fire agencies. Two important questions asked by collaborators included:

1. What is the likely effect of the Blue Mountains Branch 2018/19 prescribed burning program on carbon and water content within each burn block over the short to medium term?
2. What if we didn't burn? How would the carbon and water content change over time if the burn blocks were left in their unburned state? By leaving the blocks unburned we also run the risk that they might be burned by a high intensity wildfire. What would be the likely effect of this wildfire on water and carbon content?

Moreover, some of the sites were specifically selected to test a new model developed for predicting changes in biomass and carbon with presccibed burning without having to undertake laborious sampling and analysis (see Milestones 2.1.3, 2.2.2, 2.3.2, 2.4.3 and 3.1.3). More recently we have used samples from field sites described in this report to explore the potential for determining fire intensity using near infra-red spectroscopy to indicate completeness of combustion of surface fuels. Current methods for this are rudimentary and rely on non-objective assessment (e.g. ash colour).

BURN UNITS: BIOMASS AND SOIL SAMPLING FOR CARBON AND WATER MODELLING

STUDY AREA

Four sites located in the Blue Moutnains, New South Wales (Rocky Waterholes, Lawsons Ridge, Belmore Crossing and Oak Ridge) were sampled to determine aboveground biomass, quantify carbon pools and to describe soil characteristics. Details and distribution of these sites are presented in Table 1 and shown in Figure 1. The types of data collected from replicate burn units (paired unburnt/burnt circular plots) are listed in Table 2 and methods for data collection are described in detail in Gharun *et al*. (2015).

Selection of the study sites required close collaboration with fire planners from the Blue Mountains Branch of NSW National Parks and Wildlife Service. This was done with consultation about their priority burn schedule for 2019, to gain access to the sites, and to be provided with relevant information about location, vegetation type and timing of ignition. More importantly, sites were chosen to answer questions such as those posed in the Introduction. Study areas were also chosen to complement the sites we had sampled in previous years in NSW, the ACT and Victoria (see Gharun et al. 2017b; 2018) and to match the broad vegetation type of 'dry sclerophyll forest'. Factors such as spatial proximity of replicate burn units, dominant canopy species, tree size and density distribution, slope and aspect were considering before selecting adjacent burnt and unburnt plots to ensure that differences in plot characteristics were minimised.

The sites were sampled in May-July 2019, approximately 1-4 weeks after prescribed burning events took place (Table 1). The sampling design, data collection and sample analysis followed protocols described in Gharun et al. (2015). Long-term rainfall and temperature conditions taken from the nearest weather stations are presented in Figure 2.

Vegetation at the four burn unit sites (Rocky Waterholes, Lawsons Ridge, Belmore Crossing and Oak Ridge) are broadly classified as dry sclerophyll forest with a shrubby understorey (1-3 m). Specific vegetation type ranged from Sydney Coastal Dry Sclerophyll Forest at elevations less than 700 m to Sydney Montane Dry Sclerophyll Forest at elevations from 750-1200 m (Keith 2004). Vegetation at the site with the highest elevation, Oak Ridge, is described as tall open forest dominated by Brown Barrel (Eucalyptus fastigata) with Mountain Gum (E. dalrympleana), Narrow-leaved Peppermint (E. radiata), Messmate Stringybark (E. obliqua) and Blackwood (Acacia melanoxylon). Slopes and ridges in the area are dry sclerophyll open forest dominated by Brittle Gum (E. mannifera), Broad-leaved Peppermint (E. dives), Red Stringybark (E. macrorhyncha) and Scribbly Gum (E. rossi).

Plot number	Burn/site name	Latitude	Longitude	Elevation (m asl)	Ignition date	Sampling date
67-69	Rocky Waterholes	-34.32	150.47	613	12-14 April	14-16 May
70-72	Lawsons Ridge	-33.69	150.44	676	19 May	6 and 12 June

73-75	Belmore Crossing	-34.51	150.57	627	10 April	23 May
76-78	Oak Ridge	-34.27	149.93	944	30 May	27 June

TABLE 1 DESCRIPTION OF SAMPLING SITES IN THE BLUE MOUNTAIN, NEW SOUTH WALES. ALL SITES WERE SAMPLED IN 2019 USING THREE REPLICATE PLOTS IN NEARBY UNBURNT AND BURNT AREAS. ASL – ABOVE SEA LEVEL

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

TABLE 2 THE NATURE AND SCALE OF SAMPLING USED IN STUDY SITES.

FIGURE 1 DISTRIBUTION OF FOUR STUDY SITES (12 BURN UNITS) IN NEW SOUTH WALES SAMPLED IN 2019 AS PART OF THE JURISDICTION OF THE BLUE MOUNTAINS NATIONAL PARKS AND WILDLIFE SERVICE.

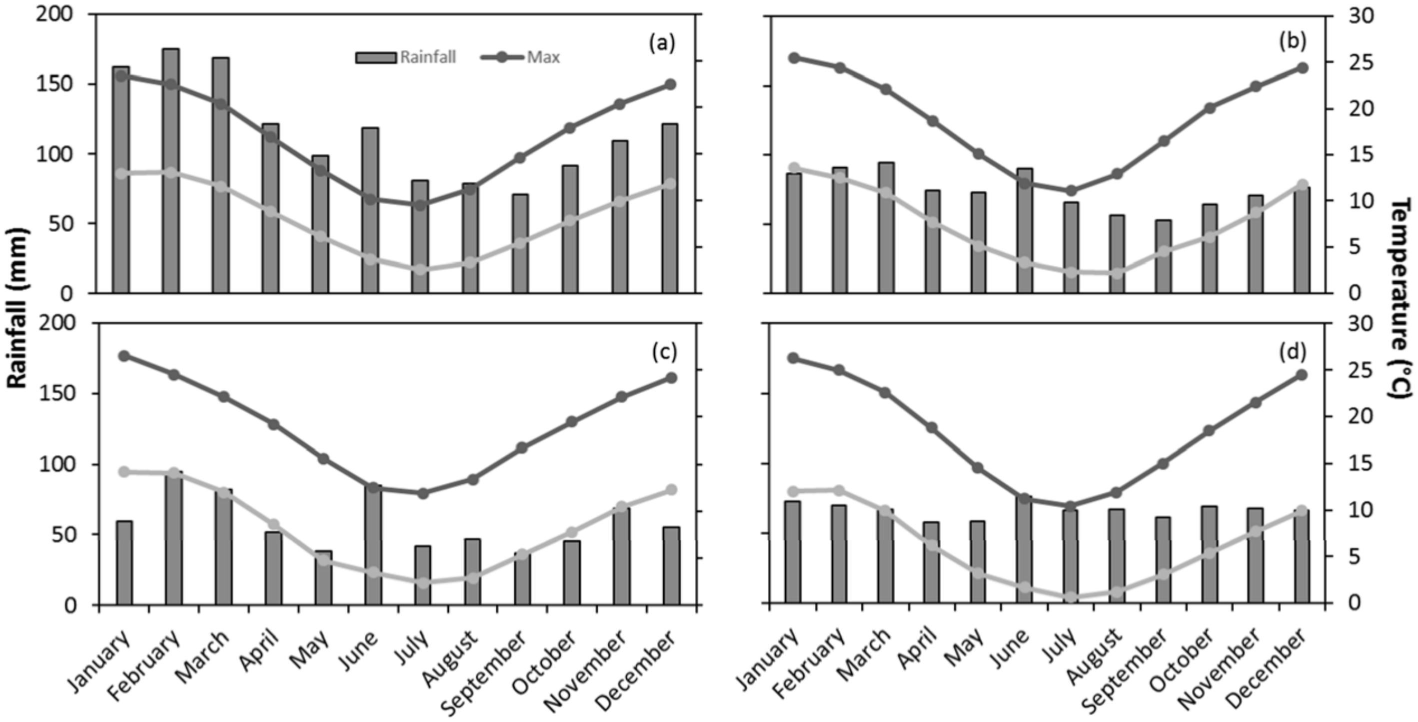

FIGURE 2 LONG TERM RAINFALL (BARS) AND MAXIMUM (BLACK LINE) AND MINIMUM (GREY LINE) TEMPERATURES RECORDED AT THE CLOSEST WEATHER STATION FOR (A) LAWSONS RIDGE (KATOOMBA WEATHER STATION), (B) ROCKY WATERHOLES (MITTAGONG WEATHER STATION), (C) BELLMORE CROSSING (MOSS VALE WEATHER STATION) AND (D) OAK RIDGE (TARALGA WEATHER STATION).

VEGETATION

Details of average tree size in the overstorey and understorey in unburnt and burnt plots are provided in Table 3. Overstorey trees from plots measured at the Oak Ridge site were bigger (greater diameter at breast height (DBH) and height) compared to other sites (Table 3a). As an indication of variability of the overstorey, the biggest tree measured at Oak Ridge had a DBH of 139.5 cm (three times bigger than the average DHB of trees in the area) and was approximately 32 m tall. The tallest tree measured was 41 m tall. Overstorey trees at the remaining three sites were of a similar size ranging from 22 to 30 cm DBH. Trees measured in paired unburnt/burnt plots were generally similar in size except at Belmore Crossing where mean tree DBH differed between paired plots by 10 cm. Individual tree sizes varied considerably in the burnt plots (12.5-94.0 cm) at this site.

The understorey vegetation in plots at Belmore Crossing and the unburnt plots at Rocky Waterholes was composed of small shrubs with heights of up to 1.5-2.0 m (Table 3b). At the other sites, trees and shrubs were bigger but never very tall (up to 5.0 m) but had considerably greater DBH.

Plot number	Burn/site name	Overstorey		Understorey	
		Unburnt	Burnt	Unburnt	Burnt
(a) DBH (cm)					
67-69	Rocky Waterholes	26.2 ± 13.5	22.8 ± 9.2	5.4 ± 7.6	12.6 ± 11.0

70-72	Lawsnos Ridge	28.5 ± 19.0	28.3 ± 13.3	15.7 ± 11.5	20.5 ± 16.8
73-75	Belmore Crossing	35.4 ± 2.5	25.9 ± 16.8	2.3 ± 2.2	1.5 ± 0.4
76-78	Oak Ridge	45.5 ± 23.8	48.8 ± 29.5	12.6 ± 10.7	17.3 ± 18.5
(b) Tree/shrub height (m)					
67-69	Rocky Waterholes	13.3 ± 5.4	13.1 ± 3.6	2.2 ± 0.7	2.0 ± 0.5
70-72	Lawsnos Ridge	13.2 ± 5.1	15.2 ± 4.4	2.0 ± 1.0	2.3 ± 1.1
73-75	Belmore Crossing	15.6 ± 7.4	12.0 ± 4.8	1.7 ± 0.5	1.4 ± 0.3
76-78	Oak Ridge	27.0 ± 9.5	25.4 ± 8.0	1.2 ± 1.5	0.9 ± 1.0

TABLE 3 SIZE (MEAN ± STANDARD DEVIATION) OF OVERSTOREY AND UNDERSTOREY TREES/SHRUBS IN PAIRED UNBURNT/BURNT PLOTS IN FOUR SITES IN THE BLUE MOUNTAINS, NEW SOUTH WALES; (A) DIAMETER AT BREAST HEIGHT (DBH) AND (B) HEIGHT.

NEAR-SURFACE AND SURFACE FUEL

The near-surface fuel layer was particularly sparse in the most recently sampled sites in NSW (Table 4a) with many instances of no sample of live fuels being taken from subplots. Despite this, plots in Belmore Crossing and Lawsons Ridge had on average, more near-surface fuel than sites sampled in earlier field campaigns. Prescribed burning resulted in 50% (Oak Ridge) or more reduction in fuel (Table 4b).

With prescribed burning the surface fuel layer had a mean reduction of 67% across all sites (Table 4), with the greatest reduction occurring at Oak Ridge (78%) and the smallest reduction (59%) at Lawsons Ridge. When data from the four sites sampled in 2019 were compared with pooled data from all sites sampled in NSW previously, mean values for surface fuels in unburnt plots were 20-50% greater for three of the sites (Table 3).

Burn/site name	Near-sruface (live) (tha^{-1})		Sruface (litter) (tha^{-1})		Coarse woody debris (tha^{-1})	
	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
(a) Sites sampled in NSW in 2019						
Rocky Waterholes	0.5 ± 0.4	<0.1	22.9 ± 7.0	14.1 ± 6.6	79.2 ± 39.7	47.3 ± 38.3
Lawsnos Ridge	1.9 ± 0.8	<0.1	19.0 ± 7.6	11.2 ± 3.5	6.3 ± 3.6	26.5 ± 11.2
Belmore Crossing	1.4 ± 0.9	<0.1	18.6 ± 6.1	13.1 ± 6.0	7.0 ± 4.7	33.8 ± 20.8
Oak Ridge	0.7 ± 0.5	0.4 ± 0.3	9.3 ± 9.6	7.3 ± 7.0	100.0 ± 43.4	91.6 ± 27.3
(b) Sites sampled in NSW in 2015/2016						
	0.5 ± 0.3	<0.1	14.0 ± 6.0	5.9 ± 4.5	46.5 ± 26.3	27.8 ± 26.8

TABLE 4 TOTAL BIOMASS ((MEAN ± STANDARD DEVIATION) OF NEAR-SURFACE AND SURFACE FUEL LAYERS (A) AT FOUR SITES SAMPLED IN NEW SOUTH WALES (NSW) IN 2019; (B) COMPARED TO SITES SAMPLED IN 2015 AND 2016.

COARSE WOODY DEBRIS

The mean volume of coarse woody debris (CWD) varied considerably among sites and in both unburnt and burnt plots (Table 4). Mean values for the four sites varied from 6.2 to 100.0 t ha-1 and individual plots ranged from having no CWD (three plots) to over 200 t ha-1 (three plots). The greatest amount of CWD was found at Oak Ridge which also corresponded with the biggest trees but not the greatest amount of near-surface or surface fuel load. A single prescribed burn did not appear to have any effect on reduction of the volume of CWD. The average amount of CWD in sites sampled elsewhere in NSW were within the range of CWD measured in the four sites in the Blue Mountains (Table 4b).

SURFACE FUEL STUDIES

SAMPLING SITES, VEGETATION AND FUEL LOADS

To supplement our studies for development of the fuel condition/vegetation model (see Possell *et al*. 2019), some of our sampling efforts (plots 79-105; Table 5) concentrated on collection of surface fuel samples from dry sclerophyll forests to fulfil data requirements for the model (i.e. low and high productivity sites from low and high rainfall areas, respectively). In all cases, recently burnt counterpart sites could not be found. Some sites (Wombat, Orbost, Halls Creek, Rofe Park) have been fully characterised (i.e. according to variables in Table 2) as part of either PhD or MPhil research projects, but other sites (Booker Road, Whitecross Road, Stringybark Woodland, Grassy Box Woodland) have only been partially characterised.

Plot number	Burn/site name	Latitude	Longitude	Elevation (m asl)	Ignition date	Sampling date
79-83	Wombat	-37.49	144.19	718	December 2017	79-83
84-87	Orbost	-37.59	148.76	371	February 2018	84-87
88-90	Halls Creek	-33.40	184.53	142	May 2016	88-90
91-93	Rofe Park	-33.36	184.55	206	May 2016	91-93
94-96	Brooker Road	-33.65	150.64	264	May 2018	94-96
97-99	Whitecross Road	-33.66	150.61	336	May 2018	97-99
100-102	Stringybark Woodland	-34.56	150.00	625	September 2018	100-102
103-105	Grassy Box Woodland	-34.56	150.00	625	September 2018	103-105

TABLE 5 DESCRIPTION OF SAMPLING SITES IN VICTORIA (PLOTS 79-87) AND NEW SOUTH WALES (PLOTS 88-105) SAMPLED FOR SURFACE FUEL STUDIES. ALL SITES WERE SAMPLED USING THREE REPLICATE PLOTS APART FROM WOMBAT (N = 5 PLOTS) AND ORBOST (N = 4 PLOTS). ASL – ABOVE SEA LEVEL.

At all sites, circular plots (22.5 m radius) with a centre point marking the halfway point of two transects (45 m) from north-south and east-west were used (see Gharun *et al*. 2015). Four circular subplots (5 m radius) were established at N, E, S and W directions.

As described in Gharun *et al*. (2017b), the overstorey and understorey biomass was calculated from the DBH using allometric equations based on similar species. Samples of litter and live ground material were collected using a circular sampling ring (0.1 m^2 area) placed randomly in each subplot. The samples were oven-dried at 70°C for at least 48 h and weighed. Plot biomass (n = 3 (sites in NSW), n = 4 (sites in Orbost) or n = 5 (sites in Wombat); t ha-1) was calculated as the mean biomass for each subplot. Coarse woody debris (>25 mm diameter) was estimated at one set of sites in the same way as described in Gharun *et al*. (2015), with CWD being classified according to its state of decay (sound = solid or only partially decayed internally; rotten = crumbly and unstable).

For several sites, visual assessment of fuel structure was made using the method described in Hines *et al*. (2010) and Gould *et al*. (2011). At 10 m intervals along a 50 m transect (i.e. 5, 15, 25, 35, 45 m), a hazard rating guide was used to estimate fuel hazard score (FHS) and percentage cover score (PCS) in a circle of 5 m radius around the sampling point. Litter depth was measured, and height of near surface and elevated fuel layers were estimated to the nearest 0.5 m.

WOMBAT AND ORBOST

Plots from sites in Victoria, referred to as Wombat and Orbost (Table 5), were sampled as part of an ongoing PhD project (Veronica Quintanilla-Berjon). Plots at both sites were located in unburnt state forest along transects (100-200 m) spanning ridge, mid-slope and valley bottom positions. Plots were characterised in the same way as other burn units (Gharun *et al*. 2015). Plots in Wombat State Forest were first sampled in December 2017 (litterfall) and had been characterised by mid-2018. Plots in Orbost State Forest were first sampled in February 2018 (litterfall) and had been characterised by December 2018. Both sties had not been burnt for at least 15 years.

The main overstorey tree species in Wombat State Forest are Messmate Stringybark (*Eucalyptus obliqua*), Candlebark (*E. rubida*) and Narrow-leaved Peppermint (*E. radiata*) (Figure 3a). The understorey is commonly composed of scattered acacias, bracken, small shrubs and grasses (Department of Sustainability and Environment 2003). Mean annual rainfall in the study area is about 900 mm. Elevation of the area ranges between 550 and 730 m above sea level (asl). Ground slopes are generally less than 15°. Soils are yellow podzols derived from Ordovician sedimentary rock.

The main overstorey trees in Orbost State Forest included Red Stringybark (*E. macrorhyncha*), Yerchuck (*E. consideniana*), Yellow Stringybark (*E. muelleriana*), Red Ironbark (*E. tricarpa*), Mountain Grey Gum (*E. cypellocarpa*), White Stringybark (*E. globoidea*) and Silvertop Ash (*E. sieberi*) depending on elevation and aspect (Figure 3b). The understorey vegetation is dominated by acacias and other small myrtaceous shrubs with Bracken (*Pteridium esculentum*) as the most common groundcover species. Elevation of the sites sampled range between 250 and 500 m asl. The average annual precipitation in the general area is 850 mm but also depends on elevation and aspect. Soils were formed on Pliocene sands and gravels (Hendrickx *et al*. 1996; Vandenberg *et al*. 1996).

Overstorey trees were similar in size at both sites with DBH ranging from approximately 20-50 cm and tree heights of 20-35 m (Table 6). Surface fuel biomass was also similar amongst plots at Orbost and Wombat.

Additional surface fuel studies at these two sites include bimonthly collection of litterfall. Five to six litterfall traps (1 m^2, 0.10-0.60 cm aboveground depending on slope) have been installed at each plot (Finotti *et al*. 2003). Following Wilm's (1946) sampling design, two traps are fixed (static) and three to four traps (roving) are moved to a different location every time litterfall is collected. This data will be presented elsewhere.

FIGURE 3 TYPICAL SITE SAMPLED IN (A) WOMBAT STATE FOREST (MID-SLOPE) AND (B) ORBOST STATE FOREST (RIDGE TOP) IN VICTORIA. IMAGES FROM VERONICA QUINTANILLA-BERJON.

Plot number	Breplicate plots	Aspect	Elevation (m asl)	Ignition date	Sampling date
(a) Wombat					
79	4	South	37.6 ± 5.9	32.5 ± 0.7	18.5 ± 4.0
80	3	West	38.2 ± 5.1	24.6 ± 3.4	14.6 ± 2.4
81	4	South	35.4 ± 4.8	27.1 ± 2.7	18.4 ± 3.3
82	4	West	42.9 ± 3.5	34.4 ± 1.4	17.5 ± 1.4
83	2	South-east	41.5 ± 12.0	34.0 ± 3.5	16.9 ± 0.9
(b) Orbost					
84	3	North	46.4 ± 13.6	25.8 ± 9.2	18.1 ± 1.2
85	3	West	29.2 ± 5.0	22.6 ± 2.3	19.8 ± 4.9
86	3	North	29.2 ± 1.3	31.0 ± 6.3	23.6 ± 3.0
87	3	West	59.3 ± 28.7	23.8	19.7 ± 3.1

TABLE 6 VEGETATION AND SURFACE FUEL CHARACTERISTICS OF SITES FROM VICTORIA SAMPLED FOR SURFACE FUELS. SITES WERE SAMPLED IN (A) WOMBAT STATE FOREST (N = 5 REPLICATE PLOTS) AND (B) ORBOST STATE FOREST (N=4 REPLICATE PLOTS). UNPUBLISHED DATA FROM VERONICA QUINTANILLA-BERJON.

ROFE PARK AND HALLS CREEK

These two sites were located in Rofe Park, Hornsby (hereafter referred to as 'Rofe Park') and near Bay Road, Arcadia (hereafter referred to as 'Halls Creek') in NSW and were sampled as part of a recently completed MPhil research project (Angela Gormley). Both sites were located on public land managed by the Hornsby Shire Council. The elevation of the two study sites ranges from approximately 140-210 m above sea level (Table 5). According to data from the Bureau of Meteorology from Dural, the closest weather station to both sites, long-term maximum monthly temperatures over 30°C are recorded in summer months (December and January) and minimum monthly temperatures of 4-5°C are recorded in winter months (July and August). The general study area has a mean average annual precipitation of 1078 mm. One plot in the study site at Halls

Creek was last burnt with a prescribed fire in 1990 and one plot at Rofe Park was burnt in 1996 (Gormley 2019).

At Rofe Park, dominant overstorey and midstorey tree species included Scribbly Gum (*Eucalyptus haemastoma*), Sydney Peppermint (*E. piperita*), Red Bloodwood (*Corymbia gummifera*), Sydney Red Gum (*Angophora costata*), Saw Banksia (*Banksia serrata*), Black Sheoak (*Allocasuarina littoralis*) and New South Wales Christmas Bush (*Ceratopetalum gummiferum*) (Figure 4a). Dominant canopy and midstorey species at the site in Halls Creek included *E. haemastoma*, Yellow Bloodwood (*Corymbia eximia*), *B. serrata*, Paperbark Teatree (*Leptospermum trinervium*) and *Cerapetalum gummifera* (Fairley and Moore 2010) (Figure 4b). The vegetation type at both sites is classified as Sydney Coastal Dry Sclerophyll forest (Keith 2004).

Average tree densities, biomass of surface fuel and CWD at Rofe Park and Halls Creek were similar and equally variable. However, bulk density of surface fuels and live biomass differed considerably, with mean values being higher for plots from Rofe Park compared to Halls Creek (Table 7). Similarly, litter depth was greater in plots measured at Rofe Park. As a result, the overall fuel hazard score was higher for Rofe Park, but fuel heights and individual fuel hazard and percent cover scores were similar (Table 7).

FIGURE 4 TYPICAL SITE SAMPLED IN (A) ROFE PARK WITH A THICK UNDERSTOREY OF SHEOAK (CASUARINA LITTORALIS) AND (B) HALLS CREEK WITH A PROMINENT UNDERSTOREY OF SAW BANKSIA (BANKSIA SERRATA) IN HORNSBY SHIRE COUNCIL, NEW SOUTH WALES. IMAGES FROM TINA BELL.

In the study that this information was gathered, differences in the amounts, arrangement and flammability of components of litter were determined. Data describing fuel load, structure and condition of surface litter were measured using semi-quantitative (e.g. fuel hazard score, percent cover score, pin transect) and quantitative methods (e.g. surface litter depth, bulk density). Surface litter was sorted into fractions (whole leaves and twigs, partially and fully decomposed organic material) and used to determine which component or mixture of components were the most flammable. The Simplex Centroid Design method was used to determine optimum mixtures of fuel fractions and a General Blending Model was used to determine the best statistical model fit for flammability metrics (ignitability, combustability, consumability, sustainability). Flammability measures included time to ignition, burn to completion, vertical fuel height, rate of spread, volume consumed, duration of vertical flame and residual mass fraction (Gormley 2019).

Site descriptor	Rofe Park (Plots 88-90)	Halls Creek (Plots 91-93)
(a) Fuel (vegetation) characteristics		
Overstorey tree density (trees ha^{-1})	1198 ± 400	1358 ± 811
Near surface (live) biomass (t ha^{-1})	35.2 ± 17.1	22.3 ± 6.1
Surface fuel (litter) biomass (t ha^{-1})	8.6 ± 4.7	7.2 ± 2.9
Surface fuel (litter) bulk density (kg m^{-3})	25.7 ± 10.3	20.0 ± 5.3
Surface fuel (litter) depth (mm)	75 ± 31	46 ± 17
Coarse woody debris (sound) (t ha^{-1})	0.42 ± 0.35	0.97 ± 0.74
Coarse woody debris (rotten) (t ha^{-1})	0.32 ± 0.27	0.39 ± 0.30
(b) Fuel hazard characteristics		
Near surface fuel height (m)	1.0 ± 0.2	0.4 ± 0.1
Elevated fuel height (m)	2.4 ± 0.7	2.9 ± 0.3
Overall FHS	3.7 ± 0.5	3.3 ± 0.5
Elevated FHS	1.5 ± 0.6	1.4 ± 0.2
Bark FHS	2.4 ± 0.2	2.3 ± 0.6
Near surface FHS	2.6 ± 0.7	2.6 ± 0.3
Surface FHS	3.4 ± 0.2	3.3 ± 0.5
Elevated PCS	1.8 ± 0.2	1.8 ± 0.2
Canopy PCS	2.4 ± 0.2	1.6 ± 0.2
Near surface PCS	2.0 ± 0.7	2.0 ± 0.7
Surface PCS	3.1 ± 0.4	3.1 ± 0.5

TABLE 7 CHARACTERISTICS OF (A) FUEL (VEGETATION) AND (B) FUEL HAZARD (MEAN ± STANDARD DEVIATION) OF TWO SITES IN THE HORNSBY SHIRE COUNCIL AREA SAMPLED FOR SURFACE FUELS. BOTH SITES WERE REPRESENTED BY THREE REPLICATE PLOTS. DATA FROM GORMLEY (2019). SHS – FUEL HAZARD SCORE; PCS – PERCENT COVER SCORE.

Surface fuels from Rofe Park proved to be more flammable than those from Halls Creek; visual flame heights were twice as high, and rate of spreads were twice as rapid. Fuel from both sites had rapid time to ignition although 60% of surface fuel mixtures from Halls Creek failed to burn compared to 35% of the mixtures from Rofe Park. Litter (cladodes) from *Allocasuarina littoralis* provided a non-additive effect by driving flammability of litter mixtures from Rofe Park. Surface fuel mixtures from Halls Creek had negative and positive non-additive effects for three flammability metrics; bulk density, residual mass fraction and rate of spread. Surface fuel mixtures from Rofe Park had strong positive but non-additive effects of six flammability metrics: burn to completion, residual mass fraction, rate of spread, volume consumed, vertical fuel height and flame duration (Gormley 2019). Knowledge about flammability of surface fuel will help inform management decisions about prioritising prescribed burning to mitigate the risk of fire.

BROOKER ROAD AND WHITECROSS ROAD

Both sites were located in the Blue Mountains National Park, NSW and were sampled in 2018 as part of an internship research project done towards completion of a MSc in Forests and their Environment (Sophie Van Meteren). The sites have also been sampled every year as part of field work for a senior level undergraduate course called Fire in the Australian Environment. The site near Winmalee (Whitecross Road) was burnt in September 2013 by a bushfire, the other site near Hawkesbury Heights (Brooker Road), has remained unburnt for more than 20 years. Various fuel and vegetation measures have been recorded for both sites since 2013.

The elevation of the area is approximately 310 m above sea level (Table 5) and has a mean temperature of 18°C and 1175 mm annual precipitation (long-term data from the Bureau of Meteorology, 2018). The field sites were located in narrow valleys associated with Springwood Ridge and Chapman Ridge. The ridges are composed of Hawkesbury Sandstone and the bottom of the valleys are mainly alluvium washed down by Shaws Creek.

At both sites, the overstorey vegetation is dominated by Deane's Gum (*E. deanei*) and the understorey is composed of Dorothy's Wattle (*Acacia dorothea*), Sunshine Wattle (*A. terminalis*), Broome Spurge (*Amperea xiphoclada* var. *xiphoclada*) and Silvertop Wallaby Grass (*Joycea pallida*) (Keith 2004) (Figure 5).

FIGURE 5 SITES SAMPLED IN THE BLUE MOUNTAINS NATIONAL PARK, NEW SOUTH WALES. (A) THE SITE NEAR WINMALEE (WHITECROSS ROAD) WAS BURNT IN SEPTEMBER 2013 BY A BUSHFIRE, PICTURED WITH ONE YEAR OF REGROWTH, AND (B) THE SITE NEAR HAWKESBURY HEIGHTS (BROOKER ROAD) WHICH HAS REMAINED UNBURNT FOR AT LEAST 20 YEARS. IMAGES FROM TINA BELL.

Sites have been sampled annually since 2013 but the data presented here is for sampling done in September 2018. Overstorey trees were at a higher density at Whitecross Road (burnt in 2013) than at Brooker Road (long unburnt), most likely because of landscape position (i.e. higher elevation) (Table 8). Not surprisingly, surface fuel biomass from plots at Brooker Road (long unburnt) was more than twice that for plots at Whitecross Road. Conversely, biomass represented by the near surface (live) layer was greater in plots from Whitecross Road (Table 8).

Surface litter was sorted after oven-drying for 48 h at 65°C then passing through a sieve to separate different fractions. Larger material (>6 mm) was separated into leaf, twig and 'other' (bark, fruits) fractions. Material less than 6 mm diameter was classified as the 'fine fraction' and included fragments of plant material in various stages of decomposition, small seeds and fruits.

The greatest fraction of surface fuel from both sites was the fine fuel (decomposed) fraction with more than two times by weight in samples from the unburnt site compared to the burnt site. There were similar proportions of leaves and twigs at both sites but again, with two to three times greater biomass in samples from the unburnt site (Table 8).

Fuel hazard measurements or scores were similar for canopy or elevated fuels but, as expected, were higher for the long unburnt site for near surface (FHS) and surface (FHS and PCS) fuel layers.

Site descriptor	Brooker Road – Unburnt (Plots 94-96)	Whitecross Road – Burnt (Plots 97-99)
(a) Fuel (vegetation) characteristics		
Overstorey tree density (trees ha^{-1})	759 ± 286	966 ± 134
Near surface (live) biomass (t ha^{-1})	0.2 ± 0.1	0.4 ± 0.3
(b) Surface fuel		
Litter depth (mm)	36.8 ± 22.0	17.1 ±13.4
Litter biomass (t ha^{-1})	22.8 ± 11.9	8.9 ± 2.9
Leaves (t ha^{-1})	5.4 ± 4.2	2.6 ± 1.3
Twigs (>6 mm diameter) (t ha^{-1})	6.0 ± 5.5	2.2 ± 1.6
Other (t ha^{-1})	1.9 ± 1.2	1.2 ± 0.8
Fine fraction (<6 mm diameter) (t ha^{-1})	8.9 ± 4.2	3.5 ± 2.0
(c) Fuel hazard characterstics		
Near surface fuel height (m)	0.8 ± 0.4	0.8 ± 0.4
Elevated fuel height (m)	2.6 ± 1.1	2.7 ± 1.0
Overall FHS	2.4 ± 0.3	1.7 ± 0.3
Elevated FHS	1.9 ± 0.3	1.9 ± 0.5
Near surface FHS	2.3 ± 0.5	1.9 ± 0.5
Surface FHS	3.3 ± 0.6	1.7 ± 0.6
Elevated PCS	2.1 ± 0.5	2.1 ± 0.8
Near surface PCS	2.1 ± 0.6	2.2 ± 0.8
Surface PCS	3.1 ± 0.6	1.4 ± 0.6

TABLE 8 CHARACTERISTICS OF (A) FUEL (VEGETATION), (B) SURFACE FUEL (LITTER), AND (C) FUEL HAZARD (MEAN ± STANDARD DEVIATION) OF TWO SITES FROM THE BLUE MOUNTAINS NATIONAL PARK SAMPLED FOR SURFACE FUELS. BOTH SITES WERE REPRESENTED BY THREE REPLICATE PLOTS. UNPUBLISHED DATA FROM SOPHIE VAN METEREN. FHS – FUEL HAZARD SCORE; PCS – PERCENT COVER SCORE.

Vegetation cover (using cover estimation classes; Class 1 = 1-5% cover, Class 2 = 6-25%, Class 3 = 25-50%, Class 4 = 51-75%, Class 5 = 76-95%, Class 6 = 96-100%;

Daubenmire (1959)) was assessed using 1 × 1 m quadrats positioned regularly along a 50 m transect and vegetation structure was assessed at the same points using a cover board divided into the three heights (0-20, 20-50 and 50-100 cm). In 2018, six years after bushfire, there was still more bare ground in plots at Brooker Road compared to plots at Whitecross Road, the unburnt site (data not shown). Cover of grasses, lichens/moss and forbs were similar at both sites but shrub cover in plots at Brooker Road was greater compared to the long unburnt site. The vertical structure of the vegetation indicated similar patterns (Table 9). The vertical distribution of CWD suggested that heavy fuel was elevated above the ground as broken branches rather than as fallen trees in direct contact with the ground.

The visual assessment data collected from these two sites were combined with similar data collected from burn units sampled in NSW and the ACT for carbon and water modelling (see Gharun *et al*. 2105; 2017b). Visual assessment guides are commonly used for assessing fuel loads in eucalypt forests and are increasingly being used for conversion to indicative fuel loads, saving time required for destructive sampling. Empirical measurements of fuel load from sites in NSW and the ACT did not match well with indicative fuel loads, even when a single assessor provided visual assessment scores. Fuel loads were highly underestimated at low hazard ratings and overestimated at high hazard ratings. It was concluded that visual assessment guides should not be used to estimate fuel loads as this practice could lead to poor management decisions. However, such guides can be used to describe fuel arrangement and fuel accumulation after fire.

Height interval	Grasses/forbs	ShrUbs	CWD
0-20 cm			
Burnt	3.4 ± 0.9	2.3 ± 1.7	0.6 ± 0.4
Unburnt	2.2 ± 0.9	3.1 ± 1.2	2.6 ± 0.6
20-50 cm			
Burnt	2.3 ± 0.9	2.1 ± 1.4	0.1 ± 0.1
Unburnt	0.9 ± 0.4	3.1 ± 1.1	1.8 ± 0.4
50-100 cm			
Burnt	0.5 ± 0.6	1.8 ± 1.1	0.3 ± 0.3
Unburnt	0.1 ± 0.1	3.2 ± 0.7	0.7 ± 0.3

TABLE 9 COVER CLASSES (MEAN ± STANDARD DEVIATION; N = 3) OF VEGETATION STRUCTURE AND COARSE WOODY DEBRIS (CWD) IN HEIGHT INTERVALS (0-20, 20-50 AND 50-100 CM) AS AN INDICATOR OF VEGETATION DENSITY AT SITES ON BROOKER ROAD (UNBURNT) AND WHITECROSS ROAD (BURNT) IN THE BLUE MOUNTAINS NATIONAL PARK, NEW SOUTH WALES MEASURED IN 2018. COVER ESTIMATION CLASSES: CLASS 1 = 1-5% COVER, CLASS 2 = 6-25%, CLASS 3 = 25-50%, CLASS 4 = 51-75%, CLASS 5 = 76-95%, CLASS 6 = 96-100%; FROM DAUBENMIRE (1959).

STRINGYBARK FOREST AND GRASSY BOX WOODLAND

The final two sites described in this report are Stringybark Forest and Grassy Box Woodland (Table 5). These sites were sampled in September 2018 to collect information for two low productivity forest types to test the model developed for estimating carbon stocks and biomass in surface fuel layers. Development and testing of the model have been detailed in Parnell *et al*. (2018; Milestone 2.1.3), Parnell *et al*. (2019a; Milestone 2.2.2), Parnell *et al*. (2019b; Milestone 2.3.2) and Parnell *et al*. (2019c; Milestone 2.4.3). The descriptive information for these field sites is presented here and the final reiteration of the surface fuels model using this data will be presented in Milestone 3.1.3.

The two sites were located on Arthursleigh Farm, a property owned by the University of Sydney, approximately 15 km of Marulan in the Southern Tablelands of NSW. The property covers a total area of 6,377 ha and carries approximately 15,000 head of sheep and 1000 head of cattle. Much of the natural vegetation has been cleared apart from fenced remnant patches of Grassy Box Woodland and a large contiguous stand of Stringybark Forest (Figure 6).

Grassy Box Woodland was once widespread on lower slopes on the tablelands and western slopes of NSW. As a result of Grassy Box Woodland being associated with relatively fertile soils, this vegetation type has been drastically reduced in area and is now highly fragmented due to clearing for cropping and pasture (Stol and Prober 2015). The overstorey trees are characterised by a range of species including White Box (*E. albens*), Yellow Box (*E. melliodora*) and Blakely's Red Gum (*E. blakelyi*). The ground layer is composed of grasses, lichens and mosses, while shrubs are generally sparse or absent (Figure 7a). Grassy Box Woodland is listed as an Endangered Ecological Community in NSW under the *Threatened Species Conservation Act 1995* (now *Biodiversity Conservation Act 2016*) and as a Critically Endangered Ecological Community nationally under the *Environment Protection and Biodiversity Conservation Act 1999*.

Stringybark Forest is in the general class of ‘Dry Sclerophyll Forest’ and is associated with soil of low fertility (Commonwealth of Australia 2017). Stringybark Forests are characterised by a reasonably dense overstorey of trees from the genus *Eucalyptus* that are 15-20 m tall. The shrub layer (understorey) is usually sparse with a patchy groundcover of tussock grasses. Stringybark Forests tend to be stunted on exposed stony hills and taller on deeper soils in undulating terrain. There are some large pockets of Stringybark Forest remaining in NSW as low fertility soils are undesirable for agriculture and these areas have not been cleared (Commonwealth of Australia 2017). Red Stringybark (*E. macrorhyncha*) was abundant at the sites sampled (Figure 7b).

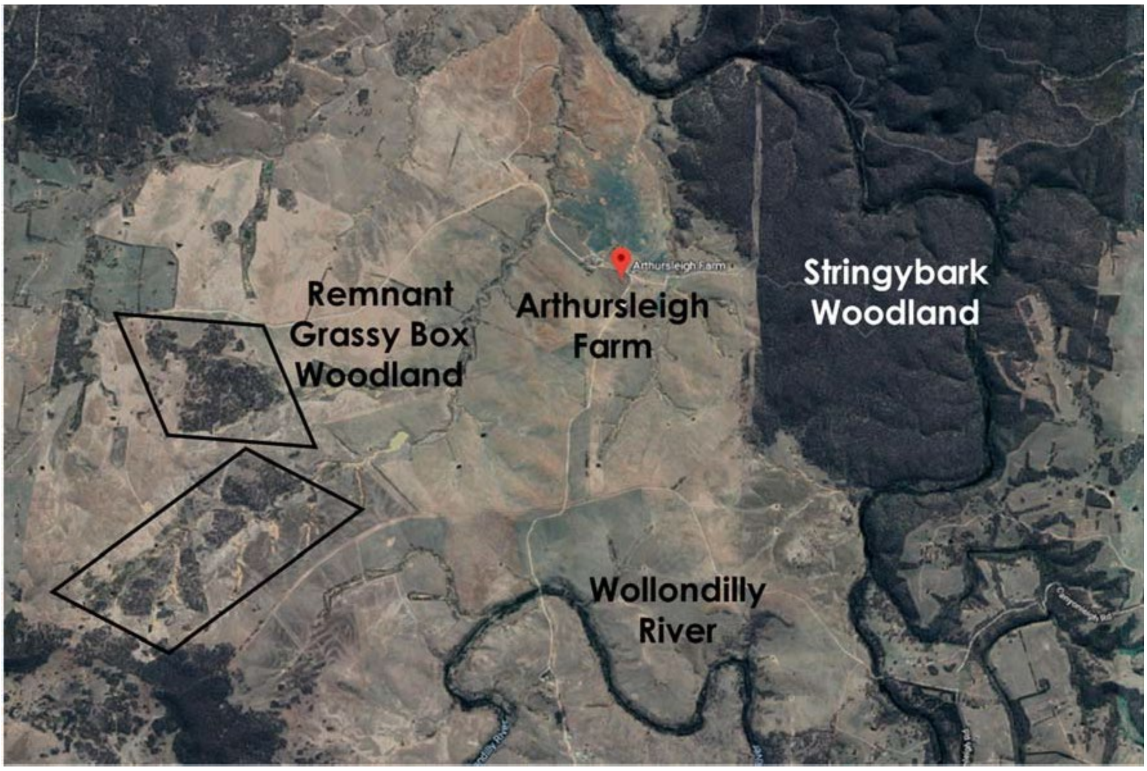

FIGURE 6 ARRANGEMENT OF TWO VEGETATION TYPES ON ARTHURSLEIGH FARM IN THE SOUTHERN TABLELANDS, NEW SOUTH WALES. PATCHES OF REMNANT GRASSY BOX WOODLAND AND A CONTIGUOUS STRINGYBARK FOREST WAS SAMPLED FOR SURFACE FUELS IN SEPTEMBER 2018. IMAGE FROM GOOGLE EARTH.

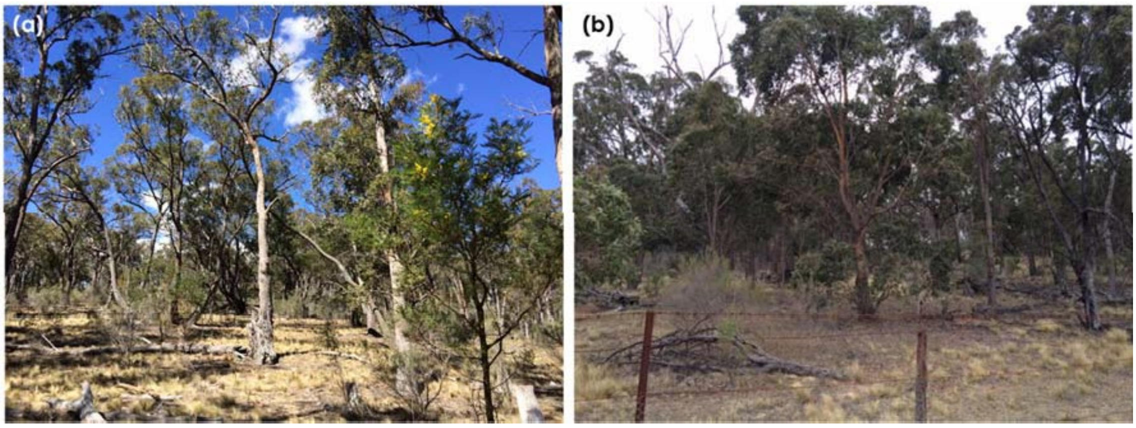

FIGURE 7 TYPICAL VEGETATION AT TWO SITES SAMPLED ON ARTHURSLEIGH FARM, NEW SOUTH WALES: (A) GRASSY BOX WOODLAND, AND (B) STRINGYBARK FOREST. IMAGES FROM TINA BELL.

Descriptive features measured for Stringybark Forest and Grassy Box Woodland are presented in Table 10. Tree density in Stringybark Forest was double that in Grassy Box Woodland but, for both vegetation types, was 10-fold lower compared to other sites described in this report. This is likely to reflect the poor soils associated with Stringybark Forest (Commonwealth of Australia 2017) and describes the open woodland nature of Grassy Box Woodland (Stol and Prober 2015). Trees were generally larger (i.e. DBH and height) in Stringybark Forest compared to Grassy Box Woodland and this equated to greater aboveground biomass. Surface fuel fractions were generally similar but with greater biomass as the fine fuel fraction in Stringybark Forest.

Site descriptor	Stringybark Forest (Plots 100-102)	Grassy Box Woodland (Plots 103-105)
(a) Fuel (overstorey vegetation)		
Tree density (trees ha^{-1})	56.8 ± 16.2	25.3 ± 11.2
DBH (cm)	45.4 ± 26.5	35.6 ± 16.6
Height (m)	19.6 ± 11.1	18.1 ± 4.5
Biomass (t ha^{-1})	70.9 ± 11.2	31.4 ± 5.0
(b) Surface fuel (litter)		
Litter depth (mm)	17.3 ± 15.4	18.6 ± 9.8
Litter biomass (t ha^{-1})	14.58 ± 3.51	9.16 ± 1.87
Leaves (t ha^{-1})	1.4 ± 0.8	0.9 ± 0.8
Twigs (>6 mm diameter) (t ha^{-1})	4.2 ± 2.5	2.5 ± 3.2
Other (t ha^{-1})	0.6 ± 0.4	0.8 ± 0.7
Fine fraction (<6 mm diameter) (t ha^{-1})	8.4 ± 3.9	4.2 ± 4.0

TABLE 10 CHARACTERISTICS OF (A) FUEL (OVERSTOREY VEGETATION) AND (B) SURFACE FUEL (LITTER) (MEAN ± STANDARD DEVIATION) OF STRINGYBARK FOREST (N = 4 REPLICATE PLOTS) AND GRASSY BOX WOODLAND (N = 7 REPLICATE PLOTS) SAMPLED ON ARTHURSLEIGH FARM, NEW SOUTH WALES. DBH – DIAMETER AT BREAST HEIGHT.

APPLICATION OF DATA

In 2018 and 2019, a range of field campaigns were successfully completed in Victoria and NSW. The empirical data is currently being used to test models to estimate the movement and transformation of carbon in forest ecosystems including a detailed model to estimate of the amount of carbon in surface fuels and improve predictions of carbon loss during prescribed fires. In addition, spatial modelling approaches have used the data to upscale point observations for estimates of carbon pools across the landscape. These efforts will assist End Users with their need for carbon accounting of land management practices.

Data from the field sites reported here have been or will be used for the following milestones:

- Model predictions for fuel reduction burning (Milestones 3.2.2 and 3.3.1)
- Fuel condition/vegetation model (Milestones 2.4.3 and 3.1.3)
- Calibration of water and carbon model using field/existing data (Milestone 2.3.3)
- Soil carbon fingerprinting and fire severity (Milestones 2.3.4, 3.1.4 and 3.3.2)

In addition, data collected has been used in the following student projects:

- Angela Gormley, MPhil University of Sydney (completed 2019) Effects of Sydney Coastal Dry Sclerophyll Forest litter on fuels and fire behaviour in Hormsby Shire
- Veronica Quintanilla Berjon, PhD University of Sydney (commenced 2017) Dynamics of litterfall and fine fuels after fire in sclerophyll forests and woodlands
- Michelle Wang, Honours University of Sydney (completed 2019), Ashes to ashes – the nature of ash produced from wildfire
- Matthias Gesing, DAAD Internship from Bielefeld University, Germany (completed 2019) Ashes to ashes – the nature of ash produced from wildfire
- Marisa Estefania González Pérez, International Exchange from the Universidad Nacional Autónoma de México, Mexico (commenced 2019) Flammability of dry sclerophyll forest litter

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