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SAMPLING AND DATA ANALYSIS OF FIELD SITES IN NSW

Milestone 1.4.4

Tina Bell ^{1,2}, **Danica Parnell** ¹, **Malcolm Possell** ^{1,2}

University of Sydney, NSW ¹

Bushfire and Natural Hazards CRC ²





Version	Release history	Date
1.0	Initial release of document	31/10/2018



Australian Government
**Department of Industry,
 Innovation and Science**

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Publisher:

Bushfire and Natural Hazards CRC

ISBN:

October 2018

Cover: Canopy of long unburnt forest in the Blue Mountains, New South Wales.
 Photo: Tina Bell.



TABLE OF CONTENTS

SUMMARY	4
END-USER STATEMENT	ERROR! BOOKMARK NOT DEFINED.
INTRODUCTION	5
METHODS	6
Study area	6
Fuel and soil sampling	9
Sample analysis	11
RESULTS AND DISCUSSION	14
Fuel biomass	14
Carbon content of surface fuel	18
Soil characterisation	18
What next?	21
REFERENCES	22



SUMMARY

This report provides a summary of the main features of the sites sampled in NSW and characterises the biomass, carbon and nitrogen held in vegetation/fuel and soil in unburnt and burnt (with fuel reduction burning; FRB) condition. Data collected from the field has already been used in our modelling efforts (Gharun *et al.* 2017b; 2018) and will be used again in future efforts.



INTRODUCTION

Fuel reduction burning (FRB) is used as a risk mitigation strategy for unplanned fires by altering fuel loads and changing fire behaviour. This involves temporary removal of accumulated fuels of the near-surface and surface fuel layers (Fernandes and Herminio 2003). As the main intention of FRB is to reduce the risk to life and property, associated environmental impacts are often overlooked (Sohngen and Haynes 1997; Gharun *et al.* 2017a). Fire has a major role in altering biodiversity, carbon and hydrological balances, and can be the cause of soil erosion. As such, changes due to disturbance caused by FRB need to be investigated, and, where practical, integrated into management operations (Gharun *et al.* 2017a). As planning by fire agencies becomes more sophisticated and accountable, environmental management objectives for FRB need to consider maintenance of high-quality water sources, reduction of carbon dioxide (CO₂) emissions and conservation of biodiversity.

Carbon (C) stocks, often referred to as 'pools', are held in the atmosphere, vegetation, soils and oceans. C movement in between these pools contributes to climate regulation. Fires contribute significant amount of carbon to the atmosphere each year (as CO₂ and other greenhouse gases) during combustion of vegetation, litter and soil biomass. In Australia, fires contribute 127 Tg C or 6% of continental net primary production (NPP) to the atmosphere each year (Haverd *et al.* 2013). Understanding the effects of FRB on carbon stocks in soil and vegetation and on the release into (as CO₂ and greenhouse gases) and recovery from the atmosphere (via photosynthesis and plant growth) in relation to the dynamics of fuel loads is important for any form of carbon accounting or tracking. Quantifying pools of carbon in different fuel strata in forests with empirical data is a critical step for any subsequent modelling efforts.



METHODS

STUDY AREA

The study area included nine sites in New South Wales, five from the Hawkesbury region (upper box; Figure 1, Table 1) and four in the Nattai region (lower box). Each site included three pairs of circular burnt/unburnt plots (each pair as a 'burn unit') located at least 500 m apart. Four sites located in the ACT region (Figure 1) were reported in Gharun *et al.* (2015; 2017b) and a subset of three unburnt plots (one from each burn unit) from the sites in NSW (Helicopter Spur, Haycock Trig and Spring Gully) were reported in Gharun *et al.* (2018).



Figure 1. Distribution of study sites selected in NSW (nine sites, 27 burn units). The sites in NSW (highlighted in red boxes) have been grouped based on their spatial proximity to local management regions. Five sites in the Hawkesbury region are in the upper box and four sites in the Nattai region are in the lower box. The four sites in the ACT have been reported in Gharun *et al.* (2015; 2017b).

For the NSW sites, adjacent unburnt and burnt plots were sampled consecutively within a few days after FRB. Factors such as spatial proximity, dominant canopy species, tree size and density distribution, slope and aspect were considered before selecting the adjacent burn and unburnt plots to ensure that visual differences in plot characteristics were minimised. Each site corresponded to one FRB and had a variety of sampling activities done at each site (see Table 2).

**Table 1.** Description of sampling sites in New South Wales. asl – above sea level.

Burn unit number	Burn/site name	Latitude	Longitude	Mean elevation (m asl)	Mean tree diameter (cm)
40–42	Haycock Trig (HT)	-33.45	151.09	230	21.8
43–45	Helicopter Spur (HES)	-33.80	150.51	450	19.6
46–48	Spring Gully (SG)	-34.09	151.15	41	17.4
49–51	Paterson (PTS)	-33.53	150.58	468	18.4
52–54	Lakesland LAK)	-34.16	150.49	465	23.0
55–57	Martins Creek (MTC)	-34.30	150.44	552	21.8
58–60	Joadja (JOD)	-34.37	150.21	713	22.7
61–63	Kief Trig (KIF)	-33.29	150.94	200	27.5
64–66	Left Arm (LEF)	-33.36	150.80	259	21.9

Table 2. The nature and scale of sampling used in study sites.

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

Vegetation

The research sites were in mixed-species dry sclerophyll forests in NSW, south-eastern Australia. The five sites sampled in the Hawkesbury region (Figure 1), were classified according to Keith (2004) as a Sydney Hinterland Dry Sclerophyll forest, dominated by Beyer's Ironbark (*Eucalyptus beyeriana*), Red Bloodwood (*Corymbia gummifera*), Narrow-leaved Stringybark (*E. sparsifolia*) and Grey Gum (*E. punctata*) trees on ridges, exposed slopes and plateaux. The main species of understorey shrubs are Mountain Devil (*Lambertia formosa*), Prickly Shaggy Pea (*Persoonia oblongata*), *Phyllanthus hirtellus* and *Podolobium ilicifolium*, along with the Common Ground Fern (*Calochlaena dubia*) and Oat Speargrass (*Anisopogon avenaceus*).

The four sites sampled in the Nattai region (Figure 1) were categorised according to Keith (2004) as a combination of Sydney Coastal Dry Sclerophyll forest and Sydney Montane Dry Sclerophyll forest. These forests were dominated mainly by Sydney Red Gum (*Angophora costata*), Blue Mountain Ash (*E. oreades*), Brown Stringybark (*E. blaxlandii*) and Broad- and Narrow-leaved Scribbly Gum (*E. haemastoma*, *E. racemosa*). In the understorey, this area was dominated by a mixture of shrubs (*Banksia serrata*, *B. spinulosa* var. *spinulosa*, *Persoonia pinifolia*, *Acacia dorothea*, *A. terminalis*), herbs and ferns (*Cassytha pubescens*, *Damperia stricta*, *Patersonia glabrata*) and grasses (*Anisopogon avenaceus*, *Joycea pallida*), sedges (*Caustis flexuosa*), and rushes (*Schoenus ericetorum*).

Weather

Long-term data from the weather stations closest to the study sites were used to determine the mean monthly rainfall, minimum temperature and maximum temperature (Oakdale and Cooyong Park were used for sites in the Nattai Region and Wanganderry for sites in the Hawkesbury Region; Figure 2). Mean annual rainfall (1961–1990) for the general area of study is 1195 mm (data from Bureau of Meteorology 2018).

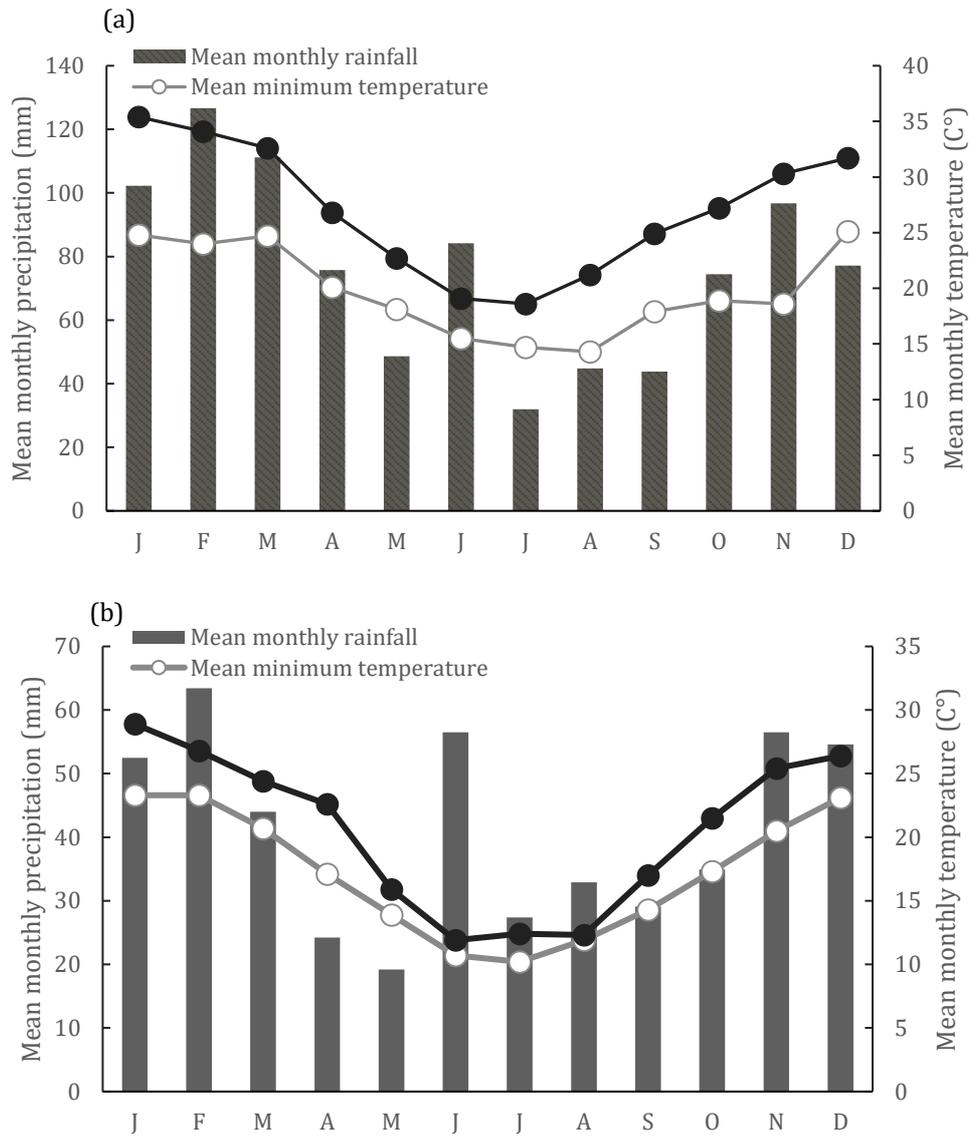


Figure 2. Mean monthly rainfall and mean maximum and minimum temperatures from the nearest weather stations to sites sampled: (a) Nattai region and (b) Hawkesbury region (see Figure 1).



FUEL AND SOIL SAMPLING

For each of the nine sites (27 burn units), three circular measurement plots with 22.5 m radius (Figure 3) were selected, at least 500 m from the nearest plot. Plots were set up within 20–50 m from the road to minimise any edge effects and to ensure they were burned during FRB. Each circular plot was paired with a second circular plot in a nearby unburnt area (no more than 50 m apart) to form a 'burn unit'. There were three burn units established at each site.

In each plot, four circular subplots (5 m radius) were selected at N, E, S and W directions from the centre of the plot for the collection of measurements at the subplot level (Table 2). See Gharun *et al.* (2015; 2017b) for a detailed description of the sampling schema.

In each of the circular measurement plots, a variety of measurements were taken in each of the different fuel layers – canopy (overstorey), elevated (understorey), near surface (shrubs and grasses) and surface (litter).

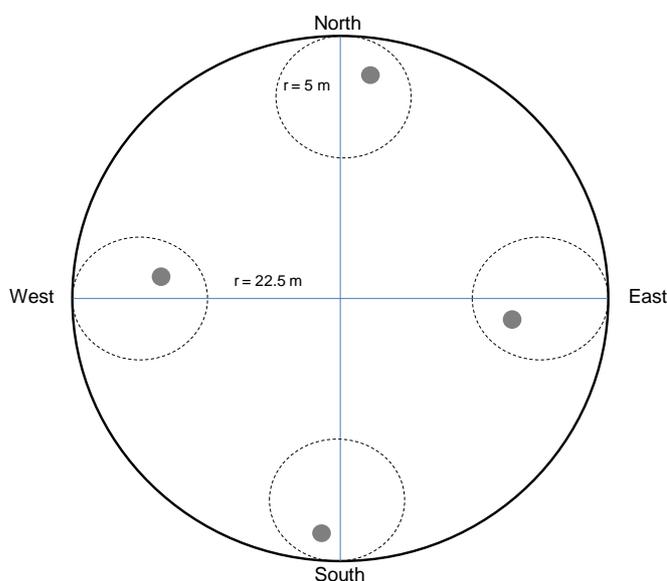


Figure 3. Schematic view of a circular measurement plot. Dashed circles mark the subplots and filled circles mark the random sampling location inside the subplots.

Canopy (overstorey) fuel

Within each plot, diameter at breast height (DBH) of all trees >10 cm was measured, and dead/alive status was recorded. Plot basal area ($\text{m}^2 \text{ha}^{-1}$) was determined from the sum of basal areas for individual trees. Allometric equations for calculation of aboveground tree biomass were applied to the data using equations developed for this type of forest (Bi *et al.* 2004).

Leaf Area Index (LAI), a key indicator of energy and water flux (Yan *et al.* 2012), was measured using digital cover photography following the method of Macfarlane *et al.* (2007). Measures of tree density and size and LAI were used to calculate tree water use. Empirical water use relationships previously developed for species of *Eucalyptus* and *Acacia*, which were based on actual tree water



use measurements, were used to estimate sapwood area and derive water use from tree size (Pfautsch *et al.* 2010; Mitchell *et al.* 2012). The data relating to tree water use is not presented in this report but has been reported in part in Gharun *et al.* (2018).

Elevated (understorey) fuel

Density of understorey vegetation was recorded using 5 m diameter subplots established at N, E, S, W points of each circular plot. Diameter at breast height was recorded for all trees with combined DBH <10 cm and height >50 cm (Volkova and Weston 2013; Possell *et al.* 2015; Gharun *et al.* 2017b). Empirical models based on similar species were used to estimate understorey biomass (Bi *et al.* 2004; Jenkins *et al.* unpublished data) as plots were located within National Parks destructive sampling for allometric measurements was not possible.

Near-surface (ground) and surface (litter) fuel

The biomass of near-surface and surface fuel layers was measured using a circular sampling ring (0.1 m² area) placed randomly within each subplot. Live/dead material was clipped at ground level and stored separately from surface fuels. Care was taken to avoid collecting the mineral soil along with the fine organic material but, on some occasions, this was unavoidable, and samples needed to be adjusted for soil content (see below).

Near-surface and surface fuel samples were oven-dried for 48 h at 60°C. Once dried, surface fuels were passed through a 9 mm sieve to separate different fractions. Larger material (>9 mm) was separated into leaf, twig and 'other' fractions. The 'other' fraction included seeds, small fruits and bark fragments. Material less than 9 mm in diameter was classified as the 'fine fraction' and included fragments of organic material in various stages of decomposition and sand. Samples from plots located in burnt sites may have contained large (>9 mm) fragments of charred leaves, twigs and bark and there may have been ash and charred organic matter in the fine (<9 mm) fraction.

Dry weights of the near-surface samples and each of the surface fuel fractions were recorded and, where necessary, the weight of the fine fraction was adjusted to take into account the weight of non-organic material.

Coarse woody debris

Two transects (45 m in length) running north-south and east-west and crossing at the centre point were marked in each plot and all coarse woody debris (CWD) >25 mm diameter that intersected with the two transects were recorded for diameter, length and state of decay (rotten or solid). Representative subsamples of CWD were used to determine density using the volume and weight of fresh samples and the dry weight of the same samples once they had been oven dried at 105 °C for at least 48 h. The volume of coarse woody debris for each plot was calculated following the method described by van Wagner (1968) and converted to weight using density measurements.



Soil

Soil samples were collected from four randomly located points in each of the 5 m radius subplots (N, E, S, W). The surface litter was cleared from a small area until mineral earth was exposed, and samples (0–10 cm depth) were taken using a soil core of known volume (5 cm diameter, 10 cm depth, 196.35 cm³). A second sample, used for determination of bulk density, was collected in the same way from the N subplot only. Samples were stored separately in zip lock bags and kept cool (<5°C) until transferred to the laboratory for further processing (see below).

SAMPLE ANALYSIS

Carbon and nitrogen content

Subsamples of soil and surface fuel fractions (leaf, twig, 'other' and fine fraction (<9 mm)) were finely ground (53 µm) and carbon (C) and nitrogen (N) content (% dry weight) was measured by combustion analysis (Elementar Vario Max CNS, Analysensysteme GmbH, Hanau, Germany).

Adjustment of the C content of the fine fraction of the surface fuel layer was required if it contained clay, sand or small stones (i.e. non-organic or non-combustible material). Collection of non-organic material was often impossible to avoid, particularly at sites with sandy soils, as the surface fuel was intermingled with the underlying mineral soil layer. The ashing method (ASTM-E1755-01, ASTM International, West Conshohocken, PA, United States) was used to determine the proportion of the sample that should not be included as being combustible.

Samples (approximately 1.0 ± 0.5 g) were weighed into a ceramic crucible and heated in a muffle furnace at 105°C for 1 h to remove moisture. Samples were allowed to cool and reweighed. The temperature of the muffle furnace was increased to 250°C to avoid flaming before heating to 600°C for a further 3–4 h. Samples were allowed to cool in a desiccator and reweighed. The sand content (%) was calculated as:

$$\% \text{ sand} = \left(\frac{(\alpha - \beta)}{(\gamma - \beta)} \right) \times 100$$

Where α is equal to the weight of the crucible and sample after heating at 600°C, β is equal to the original weight of the crucible without sample and γ is equal to the weight of the crucible and sample after heating at 105°C. The percent sand was used to create a correction factor for each sample which was calculated as:

$$\text{correction factor} = 1 - \left(\frac{\% \text{ sand}}{100} \right)$$



The adjusted C numbers were calculated as:

$$\text{adjusted } C = \left(\frac{\alpha}{\beta} \right)$$

Where α is equal to the original C values for the fine fuel layer and β is equal to the correction factor for the sample.

The adjusted biomass numbers were calculated as:

$$\text{adjusted biomass} = (\gamma \times \beta)$$

Where γ is equal to the original biomass values for the fine fuel layer and β is equal to the correction factor for the sample.

Soil bulk density and moisture content

Bulk density is a useful indication of the physical condition of soil and, together with soil moisture content, is needed for calculation of nutrient concentrations in soil. The total volume of soil is the volume of solids and pores which contain air and/or water.

The dry weight of soil samples collected for bulk density was measured after oven-drying at 105°C for 48 h. Soil bulk density was calculated by dividing the weight of dry soil by the volume of the soil core.

Gravimetric soil moisture content was measured using subsamples (10–15 g) of fresh soil sieved to 2 mm and oven-dried for 24 h at 105 °C. The weight of soil was recorded before and after drying. Gravimetric moisture content was calculated as:

$$\text{Gravimetric moisture content} = \left(\frac{\text{soil wet weight (g)} - \text{soil dry weight (g)}}{\text{soil dry weight (g)}} \right)$$

Soil acidity and electrical conductivity

Fresh soil samples were sieved to 2 mm and analysed for soil acidity (pH) and electrical conductivity (EC). For these analyses, approximately 5 g soil was mixed with 25 mL deionised water (1:5 ratio) and shaken on wheel rotator for 15 min. Samples were allowed to settle for 15 min before measurement. Values for pH and EC in the water suspension were measured using a pH meter (PHM210, MeterLab™) and EC meter (CDM210, MeterLab™), respectively).



Particle size analysis

To determine the proportion of each particle size fraction, the hydrometer method was used for particle size analysis (PSA). After determining the presence of soil C through carbon analysis, samples with high C values were adjusted using a hydrogen peroxide 'pre-treatment' to remove organic matter presence (see Standards Association of Australia, AS 1289.C6.2-1976 for full method).

Soil samples (50 g) were weighed into a 600 ml shaking bottle and 50 ml of sodium hexametaphosphate was added. Deionised water was added to each bottle until three quarters full and shaken on a wheel rotator for 24 h. Samples were transferred to a 1 L measuring cylinder and deionised water used to fill to the 1 L mark. The soil suspension was agitated with a stirrer and hydrometer readings were recorded at 5 min and again after 8 h. Sand content was analysed by separating the sand into a beaker and decanted until the supernatant was clear. The residue was oven dried at 105°C overnight, passed through a 0.2 mm sieve and weighed (Standards Association of Australia, AS 1289.C6.2-1976).



RESULTS AND DISCUSSION

FUEL BIOMASS

Canopy and elevated fuel layers

For all fuel layers (canopy, elevated, near-surface and surface), there was a change in biomass after FRB (Figure 4). In the field, it was noted that the canopy (overstorey) and elevated (understorey) fuel layers were generally unaffected by FRB and this was supported with mean differences between burnt and unburnt plots being less than 1% for canopy fuel and less than 14% for elevated fuel (Figure 4a, b). However, for individual sites, the greatest difference in canopy fuel between burnt and unburnt plots was 13% for Martins Creek (MTC), and the smallest difference was found for Kief Trig (KIF) with a 16% difference (Figure 4a). For the elevated fuel layer, the greatest difference between burnt and unburnt sites was 56% for Helicopter Spur (HES), and the smallest, 48%, was again for Kief Spur (KIF; Figure 4b).

This variation reflects site differences rather than a reduction in biomass due to FRB. This is not surprising as it was calculated that for similar forests in the ACT measured using the same sampling methods, to capture the variability in overstorey and understorey biomass within 15% of the mean and 95% confidence, would require a minimum of 30 sampling points (plots) to be measured for canopy biomass and nearly 200 sampling points for the elevated fuel layer (Gharun *et al.* 2015). To capture the variability within 5% of the mean and 95% confidence, the number of sampling points needed increases 10-fold for elevated fuel and 100-fold for canopy fuel (Gharun *et al.* 2015). This level of sampling is clearly not possible given time and economic constraints. Similar site patchiness has been recorded in other studies in dry sclerophyll forest (e.g. Penman *et al.* 2007). Site variability need to be taken into account when interpreting data collected from the field.

Near-surface and surface fuel layers

The near-surface fuel layer was the most affected by FRB, with an average reduction in biomass of 88% for all sites (Figure 4c). The greatest decrease occurred at Lakesland (LAK) as no near-surface fuel remained at the points sampled within the burnt subplots (100% reduction in fuel). The smallest reduction in the near-surface fuel layer occurred at Joadja (JOD; 28%; Figure 4c).

The surface fuel layer had a mean reduction with FRB of 45% across all sites (Figure 4d; Table 3), with the greatest reduction occurring at Helicopter Spur (HES; 83%) and the smallest reduction (4%) occurring at Haycock Trig (HT; Figure 4d).

The number of samples required to capture the variability of biomass of near-surface fuel within 15% of the mean and 95% confidence was estimated to be more than 450 for unburnt sites and more than 1550 in unburnt sites, while for surface (litter) samples, this was estimated to be 53 and 256 sampling points, respectively (Gharun *et al.* 2015). Despite this, when data from subplots for these



two fuel types were pooled across all sites sampled in NSW, mean values were similar for samples from Victoria and the ACT (0.5–1.0 t ha⁻¹; Table 3).

Table 3. Total biomass (t ha⁻¹; mean ± standard deviation) of fuel layers at sites nine sites sampled in New South Wales compared to sites sampled in Victoria and the Australian Capital Territory (ACT).

Site condition	Canopy (overstorey) (t ha ⁻¹)	Elevated (understorey) (t ha ⁻¹)	Near-surface (ground) (t ha ⁻¹)	Surface (litter) (t ha ⁻¹)	Coarse woody debris (t ha ⁻¹)
<i>New South Wales (n = 9)</i>					
Unburnt	172.7 ± 53.2	30.5 ± 14.2	0.5 ± 0.3	14.0 ± 6.0	10.1 ± 7.6
Burnt	167.5 ± 37.1	22.0 ± 6.9	0.03 ± 0.04	5.9 ± 4.5	9.5 ± 7.4
<i>Victoria and ACT (n = 12)</i>					
Unburnt	296.6 ± 122.2	17.9 ± 20.1	1.0 ± 1.4	13.6 ± 7.4	46.5 ± 26.3
Burnt	335.2 ± 269.8	12.7 ± 20.9	0.04 ± 0.10	3.6 ± 3.8	27.8 ± 26.8

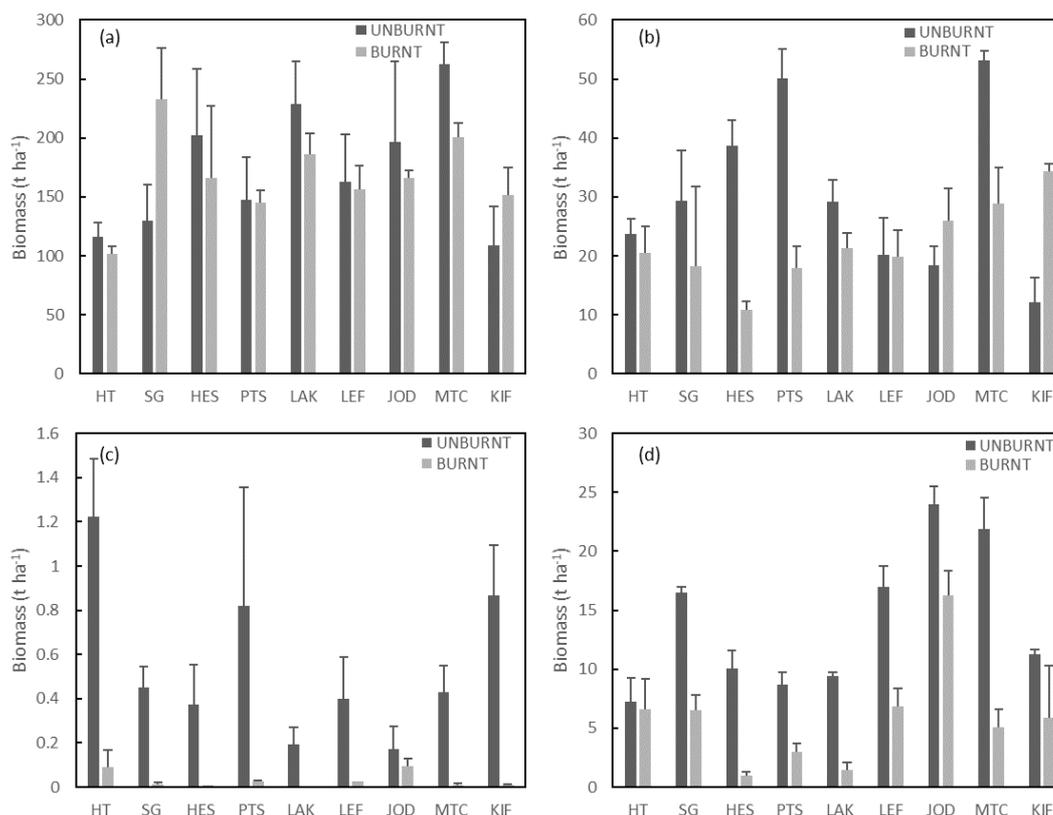


Figure 4. Total biomass (t ha⁻¹; mean ± standard deviation) for each of the nine sites in NSW with and without fuel reduction burning: (a) canopy (overstorey), (b) elevated (understorey), (c) near-surface, and (d) surface (litter). See Table 1 for abbreviations of site names.



Surface fuel layer fractions

The biomass of all fractions of surface fuel was reduced by FRB (Figure 5, Table 4). After adjusting weights of fine fuel biomass for sand content, the mean decrease in the fine fuel fraction with FRB was 32%, with the greatest reduction (91%) at Helicopter Spur (HES; Figure 5a). There was little change in fine fuel biomass at Haycock Trig (HT), Spring Gully (SG), Kief Trig (KIF) and Joadja (JOD; Figure 5a). This may be because the surface fuel layer was too moist to burn, particularly at Joadja (JOD) where there was up to 10 t ha⁻¹ fine fuel, or at other sites was discontinuous in horizontal distribution. The condition of the fine fuel layer, including moisture content, depth and proportion of mineral soil exposed to fuel thickness, determines how readily this fuel type can burn (Sandberg 1980; Graham *et al.* 2000; Chen *et al.* 2013). In contrast, at HES and Lakesland (LAK), where the greatest reduction of surface fuel occurred, the fine fuel layer in particular, was completely or almost completely combusted and the remaining biomass is likely to be ash and charcoal derived from combustion of other fractions (leaves, twigs or other) in the surface fuel and the near-surface fuel layers (Latham and Williams 2001; Miyanishi 2001).

The leaf, twig and other fractions of the surface fuel showed more consistent reduction in biomass after FRB, ranging from 52–57% for all sites (Figure 5b, c and d). For the leaf fraction, the greatest biomass reduction occurred at Kief Trig (KIF; 73%) and the smallest reduction occurred at Paterson (PTS; 22%; Figure 5b). The greatest reduction in the 'other' fraction was at Lakesland (LAK; 90%; Figure 5c). The greatest decrease in biomass for the twig fraction was at Helicopter Spur (HES; 97%) and the smallest decrease occurred at Kief Trig (KIF; 9%; Figure 5d).

Table 4. Biomass (mean \pm standard deviation) of fractions of the surface fuel from nine sites sampled in New South Wales.

Site condition	Fine fuel (t ha ⁻¹)	Leaf (t ha ⁻¹)	Twigs (t ha ⁻¹)	Other (t ha ⁻¹)
Unburnt	7.0 \pm 4.3	2.9 \pm 0.8	2.9 \pm 1.2	2.4 \pm 1.3
Burnt	4.1 \pm 4.1	0.9 \pm 0.3	0.7 \pm 0.4	0.8 \pm 0.5

Coarse woody debris

The mean volume of CWD was similar in unburnt and burnt plots (Table 3) with site means varying from 2.1 to 27 t ha⁻¹ (Table 4) and individual plots ranging from less than 1 t ha⁻¹ (two plots) to over 80 t ha⁻¹. According to Gharun *et al.* (2105), it would require a minimum of 71 plots to capture variability in CWD within 15% of the mean with 95% confidence and more than 1600 plots within 5% of the mean.

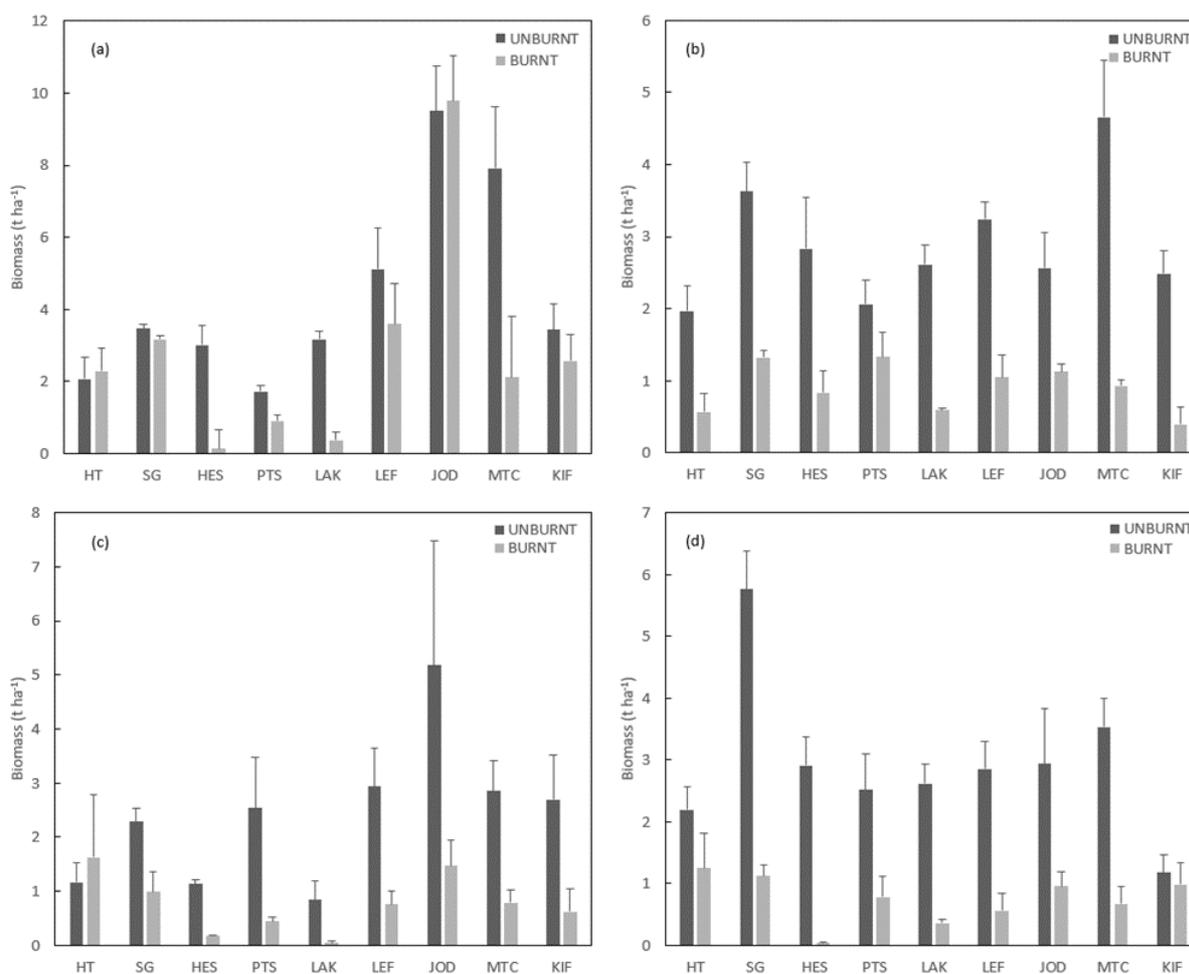


Figure 5. Biomass of surface fuel fractions (t ha⁻¹; mean ± standard deviation) for each of the nine sites in NSW, with and without fuel reduction burning: (a) fine fuel (<9 mm), (b) leaf, (c) other (seeds, small fruits and bark fragments) and (d) twigs. See Table 1 for abbreviations of site names.

Table 5. Biomass (t ha⁻¹; mean ± standard deviation) of coarse woody debris from nine sites sampled in New South Wales.

Site	Unburnt (t ha ⁻¹)	Burnt (t ha ⁻¹)
Haycock Trig	5.4 ± 4.1	3.0 ± 2.0
Spring Gully	2.1 ± 1.2	27.6 ± 45.9
Helicopter Spur	11.1 ± 10.0	8.4 ± 6.1
Paterson	6.6 ± 4.7	6.8 ± 5.1
Lakesland	5.6 ± 2.5	9.0 ± 7.7
Left Arm	9.9 ± 10.6	6.1 ± 3.7
Joadja	26.8 ± 15.6	16.4 ± 8.4
Martins Creek	13.6 ± 5.7	9.9 ± 10.2
Kief Trig	4.3 ± 4.5	3.8 ± 2.1



CARBON CONTENT OF SURFACE FUEL

Analysis of the surface (litter) fuel layer was done to determine the carbon (C) content of different fractions (fine fuel, leaves, other and twigs) to understand how much C is lost from the surface fuel layer during FRB. Currently, the default value of 47% is used in carbon accounting schemes (e.g. IPCC 2004) and we wanted to test how this varied in different fractions of surface fuel, particularly when the amounts of each fraction were considered. The C content of the fine fraction was adjusted for sand content.

The proportion of C in the fine fraction ranged considerably from 35–51 %C (Figure 6a). For most sites there was a greater proportion of C in the fine fraction collected from burnt sites compared to unburnt sites (i.e. HES: 6.5% difference, LAK: 6.3% difference, KIF: 2.2% difference), which is expected as ash and charred material has a higher C content than the plant material it is derived from (Jenkins *et al.* 2104, 2016).

Leaf and twig fractions were far less variable with C content ranging from 48–53 %C and 44–50 %C, respectively (Figure 6b and d). The proportion of C in the 'other' fraction varied much more widely from 26–51 %C (Figure 6c). Again, differences in C in leaf (0.2–1.6%), twig (1.6–2.9%), and other (3.8–12.0%) samples collected from burnt sites was evident and can be attributed to an increase in C content due to combustion. Lower values for C content in leaves and twigs from some of the burnt sites compared to samples from paired unburnt sites could be due to a number of reasons including differences in completeness of combustion and species composition.

Variability in carbon content of different tissues of trees is well documented (see review by Gifford 2000). The range of values found in this study for the different fractions of surface fuel (26–53 %C) is greater than for leaf litter reported by Gifford (2000) (51.5–55.6 %C), but the latter range only included litter from eucalypts.

SOIL CHARACTERISATION

Soil acidity and electrical conductivity

Soil acidity (pH) was generally higher for sites unburnt by FRB compared to their burnt counterparts (Figure 7a). The greatest change in soil pH occurred at Spring Gully (SG), where the pH for samples from the burnt sites were considerably higher than samples from unburnt sites (Figure 7a). It is likely that ash residues from FRB decreased soil acidity (Ohno and Erich 1990; Pitman 2006; Augusto *et al.* 2008; Karlton *et al.* 2008; Jenkins *et al.* 2014). A similar pattern was found for EC with samples from most of the burnt sites being greater than samples from unburnt sites (Figure 7b). Ash residues from forest fires have been found to increase soil EC (Ohno and Erich 1990; Clapham and Zibilske 2008).



Total carbon and nitrogen

Carbon and N in soil varied across sites but levels were generally higher in samples from burnt plots compared to paired unburnt plots (Figure 7c and d). At Kief Trig (KIF) there was a 17% difference in C and a 14% difference in N in soil from burnt plots compared to unburnt plots (Figure 7c and d). At Lakesland (LAK), there were similarly-sized differences in soil C (14%) and N (18%). It should be noted that both of these sites also had the greatest loss of surface and near-surface fuel. Differences in soil C and N were smaller for all other sites.

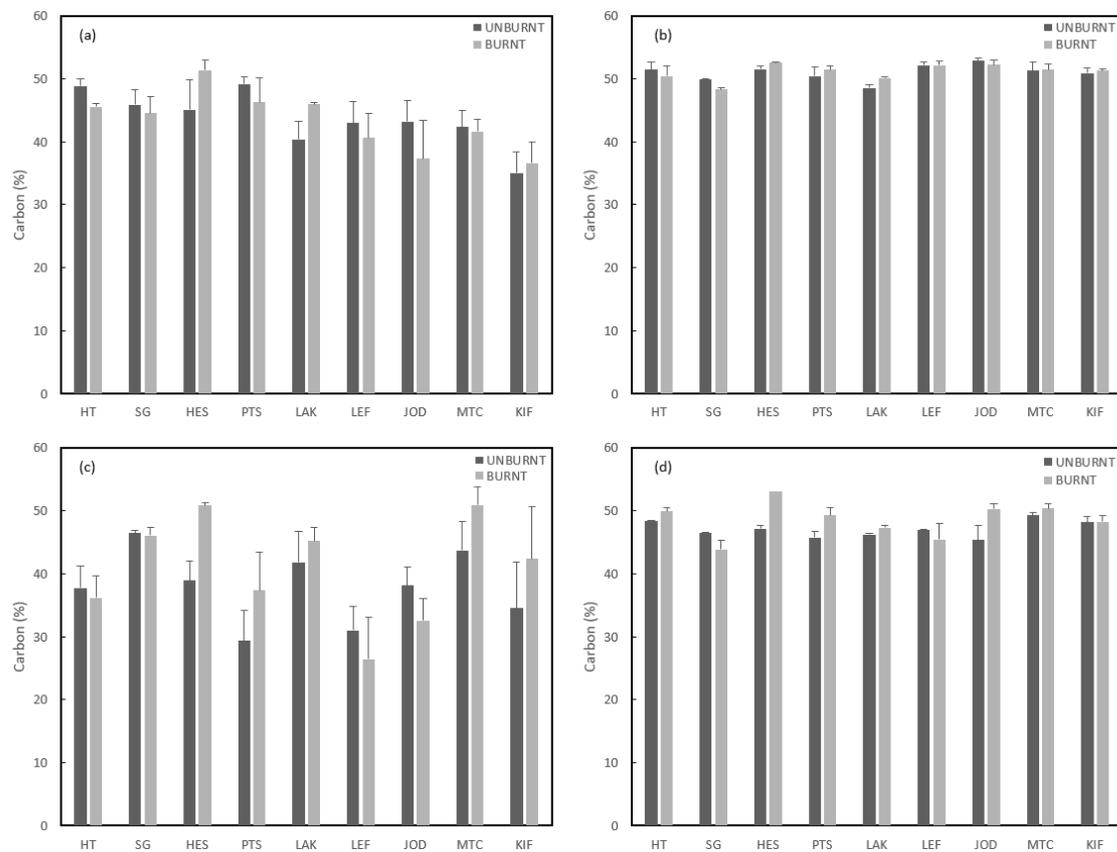


Figure 6. Proportion of carbon in surface fuel fractions (%; mean \pm standard deviation) for each of the nine sites in New South Wales, with and without fuel reduction burning: (a) fine fuel fraction (<9 mm), (b) leaf, (c) other (seeds, small fruits and bark fragments) and (d) twigs. See Table 1 for abbreviations of site names.

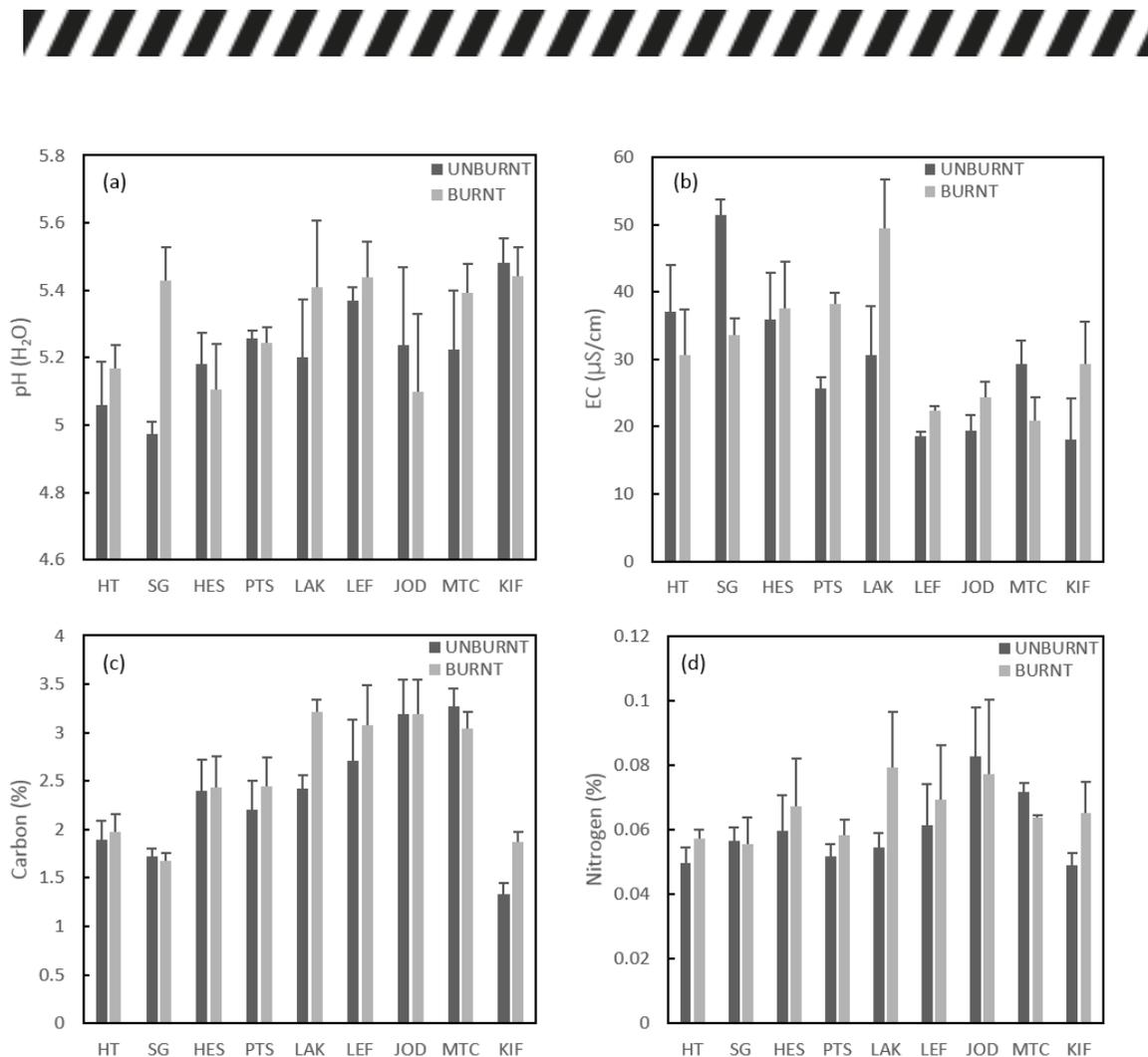


FIGURE 7. Characterisation of soil (mean \pm standard deviation) for each of the nine sites in New South Wales, with and without fuel reduction burning: (a) pH, (b) electrical conductivity (EC), (c) total carbon and (d) total nitrogen. See Table 1 for abbreviations of site names.

Particle size analysis

Soil samples for particle size analysis (PSA) taken from the northern subplot in each plot were combined by treatment (unburnt or burnt) for each site to determine the proportion of each soil fraction (sand, silt and clay). This information was used to determine the texture class for each site (Table 6). Soil texture ranged from sand to loamy sand.

**Table 6.** Particle size analysis for soil from both burnt and unburnt sites in New South Wales.

Site	Site condition	% Clay	% Silt	% Sand	Texture Class
Haycock Trig	Unburnt	6.9	3.9	89.2	Sand
	Burnt	5.9	2.3	91.8	Sand
Spring Gully	Unburnt	2.3	0.6	97.1	Sand
	Burnt	4.0	1.0	95.0	Sand
Helicopter Spur	Unburnt	12.1	6.2	81.7	Sandy loam
	Burnt	11.0	3.8	85.3	Sandy loam
Paterson	Unburnt	13.1	3.9	83.0	Loamy sand
	Burnt	11.8	4.6	83.7	Loamy sand
Lakesland	Unburnt	10.1	4.1	85.7	Sandy loam
	Burnt	9.7	2.8	87.4	Loamy sand
Left Arm	Unburnt	11.5	7.3	81.2	Loamy sand
	Burnt	13.7	10.9	75.4	Sandy loam
Joadja	Unburnt	12.0	8.6	79.3	Sandy loam
	Burnt	13.9	7.0	79.0	Sandy loam
Martins Creek	Unburnt	16.1	9.0	74.8	Sandy loam
	Burnt	16.1	9.9	74.0	Sandy loam
Kief Trig	Unburnt	9.1	4.0	87.0	Loamy sand
	Burnt	7.6	4.78	87.6	Loamy sand

WHAT NEXT?

With the completion of 13 successful field campaigns measuring a (total of 63 burn units) across Victoria, ACT and NSW and recent discussions with End Users, the empirical data that has been collected is currently being used to develop models to estimate the movement and transformation of C. Our modelling efforts include better estimations of the amount of C in surface fuels and predictions of loss of C during FRB. In addition, spatial modelling approaches will be used to upscale point observations for estimates of C pools in fuel across the landscape. By combining models for estimating C in fuel with spatial modelling of changes in C pools due to FRB, particularly loss of C as emissions, we will be able to assist End Users with their need for carbon accounting of land management practices.



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